SCALING LAND-BASED MITIGATION SOLUTIONS IN INDONESIA

NEGATIVE EMISSIONS NARRATIVE AND SCENARIOS

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2. Introduction

This report describes a generic nation-wide transition scenario for implementing land-based mitigation technologies and practices for the AFOLU sector (agriculture, forestry, and other land use sectors) in Indonesia. The report shows the outcomes of a series of research steps that have been conducted in this country since the start of the project in July 2020 until the end of 2022:

First, we performed an initial scoping of key LMTs in the case study country. The scoping assessment resulted in a long list of broad portfolios of different LMTs that could be viable within the various case study countries.

Second, following this long list, we developed a short-list LMT portfolio containing key LMTs that would be the most relevant for a given country context. All case study country partners were asked to propose and validate their LMT portfolio through complementary (policy) literature review and with the help of stakeholder interviews (i.e. external validation by relevant country experts and stakeholders). Ex-ante, no specific guidance of criteria for LMT portfolio short-listing was provided to allow for a free and open co-design process with stakeholders. The scoping process and results are presented in section 3 of this report (steps 1 & 2). The main outcomes of stakeholder engagement activities for the Indonesia case study in the past 30 months were a validated LMT portfolio, modelling scenario, and case study collaboration and dissemination. The stakeholder engagement contributed significantly to developing LMTs scoping for the Indonesian LMT portfolio through interviews, meetings, surveys, workshops, and discussions.

Third, after the short-listed LMT portfolios were validated, the LANDMARC case study country partners were asked to develop national scaling narratives or storylines for each LMT included in their portfolio. The assessments focus on climate risks, vulnerabilities, socio-economic co-benefits, and trade-offs associated with upscaling LMTs in the case study countries. The analysis is based on a broad range of information/literature sources and stakeholder consultations conducted. This process is supported through a risk and impact assessment (i.e. an online survey, workshops, focus group discussion, meetings, and policy dialogue. The engagement activities also explored the stakeholders' capacity gap in LMT implementation (task 6.5). As a result of our stakeholder engagement, we have several options and enough resources for data collection, project dissemination, case study scenarios, and a national LMT portfolio. The stakeholder engagement improves modelling data collection, project dissemination, land use and carbon research.) conducted through the LANDMARC tasks 4.1, 4.2 and 5.2. The results of this analysis are a set of LMT narratives presented in section 4 of this report.

The research steps are designed to enable an **analysis of the risks and (climate) impacts of scaling up land-based mitigation and negative emission solutions**. This report mainly contributes to objectives 2, 3 and 4 of the six LANDMARC key objectives (see Table 1).

Table 1: LANDMARC project objectives.

	Project key objectives
1	Determine the potential and effectiveness of LMTs in GHGs mitigation using Earth Observation (EO)

2	Improve climate resilience of LMT solutions at the local level for large-scale implementation
3	Assess the risks, co-benefits, and trade-offs of scaling up local LMTs nationally
4	Scaling up LMT solutions to the continental and global level to assess the effectiveness
5	Improve current methodologies to estimate emissions and removals for LMTs
6	LMT capacity building and develop new tools and services for decision making

While the results in this report represent a mostly qualitative storyline describing the context and impact of scaling up LMTs in a country context, they also enable project partners to proceed with the translation of the outcomes in a manner so that they can serve as direct model input.

Furthermore, these national-level assessments provide a testing ground and empirical basis for the continental and global assessment of the realistic scaling potential of land-based mitigation and negative emission solutions implemented in Work Packages 6 and 7 of the LANDMARC project (***Objective 4***).

3. Scoping of land-based mitigation solutions

3.1 Overview of the potential of LMTs in Indonesia

3.1.1 Introduction

Since forests cover 65% of Indonesia's total area, forestry and land use are the main contributors to Indonesia's greenhouse gas (GHG) emissions (Ministry of Environment and Forestry, 2016). Peatland Restoration Agency was established in 2016 and engaged all stakeholders and actors (private, local governments, students, and communities) in a national program to control climate change in forests and peatlands.

The Paris Agreement set targets to increase carbon dioxide removal technologies and practices for the countries. These technologies will remove and sequester carbon dioxide (Levin, 2017). Various land-based mitigation technologies (LMTs) exist to capture CO_2 and achieve carbon-neutrality, i.e. afforestation and reforestation, biochar and soil carbon sequestration (SCS), ocean fertilisation, bioenergy with carbon capture and storage (BECCS) and utilisation (BECCU), enhanced weathering, and direct air capture (DAC) (Minx et al., 2017). Aside from the technologies, land-based mitigation technologies from the land-use change are divided into land-use types, such as forest, agriculture, wetland, grassland, and other lands. Some technologies and practices are implemented in Indonesia, while others are still at the research stage. In Indonesia, these technologies and practices are planned under The Ministry of National Development Planning (BAPPENAS), in collaboration with Ministry of Energy and Mineral Resources (MEMR), the Ministry of Environment and Forestry (MoEF), and the Ministry of Agriculture (MoA).

BAPPENAS has two reports addressing climate change mitigation and adaptation, RAN-API (National Action Plan for Climate Adaptation) and RAN-GRK (National Action Plan for Reducing Greenhouse Gas Emissions). These reports are known as NAMA (Nationally Appropriate Mitigation Action) and NAPA (National Adaptation Programme of Action) of Indonesia. Emissions by sector in Indonesia are divided into six categories: land-use (Land-use Change and Forestry), non-combustion, buildings, transport, industry, and power and heat (Dunne, 2019). Based on the RAN-GRK report, the implementation analysis of LMTs is described in some points, i.e. contribution, implementation target, potential technologies, and emission reduction in Indonesia.

A. Contribution to emission reduction

The main contributor to emission reduction in 2019 was the forestry and peatland sector. More than 80% of emission reductions are achieved through afforestation, forestation, and restoration of forest and peatland.

Table 2 Contribution of LMT to Emission Reduction in Indonesia (2019)

LMT	Contribution to Emission Reduction (%)
BECCS	14.14%
Green Chemistry	
Gasification	
Construction	
Concrete	
Afforestation	81.70%
Forestation	
Restoration	
Land-use (mix of measures)	3.04%
Compost	1.12%

Source: Adapted from (BAPPENAS, 2020).

B. Implementation Target of LMTs in Indonesia

Based on the Medium-Term National Development Plan (RPJMN) 2020-2024 of the Ministry of National Development Planning (BAPPENAS), each LMT has specific targets between 2020 and 2024. LMT focuses on BECCS and gasification. LMT targets afforestation, restoration, sustainable agriculture, and organic waste management.

Table 3 Implementation Target of LMTs in 2020-2024

LMT Category	LMT	Targets	2020	2024
Land-based Mitigation Technologies	BECCS	- Final Energy Intensity (BOE/IDR billion - Primer Energy Intensity (BOE/IDR billion)	0.9 139.5	0.8 133.8
	Gasification			
	Green Chemistry			
Land-based Mitigation Practices	Afforestation	National land cover (ha)	366,000	2,143,000
	Restoration	Peatland restoration (ha)	301,800	1,600,000

	Land-use (mix of measures)	Sustainable farm area/farmland requirement (%)	60	100
	Compost	Organic waste management (million tons)	64.8	69.8

Source: Adapted from (BAPPENAS, 2020).

C. Potential LMT in Indonesia in 2030

MEMR has forecasted potential BECCS and Gasification production (PJ) per year and the substitution cost from both business and government perspectives in 2030. Potential gasification production is higher than BECCS since the gasification technology targets the industrial sector. The substitution cost is calculated from the investment cost and energy substituted (IRENA, 2017).

Table 4 Potential LMT in Indonesia by 2030

LMT	**Technical Potential (PJ/year)**	**Substitution Cost - Business Perspective (USD/GJ)**	**Substitution Cost - Government Perspective (USD/GJ)**
BECCS	30	-26.1	-24.5
Gasification	71.1	24.5	23.5

Source: Adapted from (IRENA, 2017).

D. Emission Reduction of LMTs in 2015-2019

Based on the RAN-GRK report, the annual emission reductions are recorded for the last ten years. The primary contributor to annual emission reductions is from LMTs. Those practices include afforestation, restoration, and sustainable farm and organic waste management.

Table 5 Emission Reduction from LMTs in Indonesia from 2015 to 2019

Year	BAU Baseline	land-based mitigation technologies	land-based mitigation practices	Total	Cumulative Baseline	Emission Reduction (per year)	Emission Intensity
	(1000-ton CO_2e)					%	(1000-ton CO_2e/IDR billion)
2015	1,703,000	40,129.9	100,782.36	140,912.26	9,046,000	8.27	0.516
2016	1,764,000	51,122.2	561,235.40	612,357.64	11,170,000	34.71	0.358
2017	1,860,000	64,833.7	345,091.35	410,053.25	13,030,000	22.05	0.424
2018	1,953,000	81,378.8	829,799.09	911,647.48	14,983,000	46.48	0.295
2019	1,959,000	86,577.3	315,245.21	401,822.53	16,942,000	20.51	0.420

Source: Adapted from (BAPPENAS, 2020).

The data recorded has some assumptions. Specific assumptions are required for each data. However, in general, the following assumptions are used for the data above (table 1-4):

a. Emission reduction in Indonesia is divided into seven contributing sectors (forestry, energy, transportation, industry, coastal & ocean, agriculture, and waste) (Low Carbon Development Indonesia (LCDI), 2020).
b. Indonesia aims to reduce emissions by 29% (baseline) and 41% (with international support) by 2030.
c. The target of renewable energy and BECCS is 23% of the energy mix by 2025.
d. Coal and gas are still the primary energy sources in the industry, as it is projected to be until 2050.

3.1.2 Technologies dependent on biomass/photosynthesis

BECCS

Indonesia is a coal- and carbon-intensive region. Consequently, low-carbon technologies to reduce and store carbon is needed. BECCS can be an LMT solution to reduce Indonesia's fossil fuel dependency. Besides, BECCS can contribute to waste management since 60% of the waste production in Indonesia is biomass (Tahar, 2018). Biomass is organic material-based fuel, including firewood (wood waste, charcoal, wood) and waste (agriculture, urban solid, and industrial). It converts biomass to energy, storing it in either underground or long-lived products (i.e. concrete) and capturing the embodied carbon (Mulligan, 2018). The energy produced from BECCS can be used for the industrial, power, and transportation sectors. This technology can be a net carbon removal when more carbon is stored and more biomass grows.

In Indonesia, bioenergy without carbon capture storage is implemented through anaerobic digestion (biogas), fermentation (ethanol production), thermal biomethane, hydrogen/ammonia production, top-gas recycling (blast furnaces), industrial processes with high amounts of waste heat, mineral process (cement kilns), bio-CNG (Compressed Natural Gas), co-firing, and power production in CHP mode. However, some technologies cannot be implemented largely due to the high cost and insufficient technological experience (Grönkvist, 2012). The mainstream first pathway to implement BECCS technologies in Indonesia is through biomass, biogas, biofuel, thermal biomethane and co-firing for coal power plants (DEN, 2019). Furthermore, Indonesia is developing bio-CNG to utilise biomass. Some quality standards depend on RDF (Refuse-derived fuel) heating value, especially for biomass fuel.

The Government of Indonesia (GoI) has specific bioenergy targets set to meet the energy mix's target in 2025: 5.5 GW of bioenergy, 13.8 M kL of biofuel, 8.4 M tonnes of biomass and 489.9 million m^3 of biogas. By 2050, the target is 54.2 million kL and 30% of the blending target in biodiesel (CIFOR et al., 2018). MEMR initiates some strategies for developing bioenergy, such as implementing waste-to-energy and co-firing, developing biofuel, small-scale biogas, biomass stove, and bio-CNG. Biogas is an energy source which can be utilised for household, Bio-CNG, and power generation. Other co-products from biogas are biomethane from the fuel and gas grid, fertiliser, soil amendments, and livestock bedding. Bio-CNG can be applied to compressors, vehicles, and households (Dilisusendi, 2020).

The Ministry of Energy and Mineral Resources (MEMR) published press release No 092.Pers/04/SJI/2020 about implementing the co-firing method from biomass as the coal substitution for the coal power plantation. Potential raw materials for the co-firing method are organic waste (agriculture, forestry, and industrial), with the percentage of biomass being 1 - 5%. As one of the potential feedstocks, forestry waste has 20,925 tons/day collected from 15 waste management sites in Java. Also, Indonesia's biomass from potential wood (wood pellets) can generate 1,335 MWe. The State Electricity Company (PLN) initiated corporate action through co-firing. To meet the needs of 1% co-firing for coal power plants in Indonesia, Indonesia needs 17,470 tonnes/day of biomass or 5 million tonnes/year of wood pellets. PLN has implemented co-firing technology in five coal power plants (EBTKE ESDM, 2020). Accordingly, BECCS has not been implemented in Indonesia. Biomass co-firing in the coal-power plant is the first step to initiating BECCS implementation.

BIOCHAR

Biochar is a potential alternative to improve soil quality and restore degraded land. Other advantages include a slower decomposition process and resistance to microorganisms. In agriculture, biochar has functions to reduce soil acidity, increase nutrient availability, and bind nutrients. For example, biochar can be applied on land with high acidity (around 3-5) to increase the pH. Also, biochar can be used for the areas with less water to bind this little water. The Agency for Agricultural Research and Development (Balitbangtan), MoA, introduced the manufacture and application of biochar through technical guidance in several locations. Introducing the technique of making biochar to farmers is easy and inexpensive, particularly when using the Kon tiki model. This model has a cone-shaped hole with an upper diameter of 150 cm and a height of 75 cm. It is simple and suitable for farmers (Bardono, 2018).

In Lampung (a province on Sumatera Island, Indonesia), biochar from rice husks and cocoa pod skins (5-10 tonnes/hectare) is applied to acidic, dry land. After using this technology, stable harvest results for up to three consecutive growing seasons are achieved. In another location of similar conditions, 5-10 tonnes/ha of biochar were used in Kupang, East Nusa Tenggara (eastern region of Indonesia). Results showed increased water availability in the soil, increasing the planting intensity from once to twice per year.

There is an annual trend of gradual drying out during the dry season and long-term flooding during the rainy season in the riparian wetlands. Due to this unpredictable and uncontrollable flooding, the growing season typically occurs only once a year (Kartika et al., 2018). The farmers are used to planting rice seedlings in the anaerobic conditions of floodwater and harvesting in the aerobic conditions of dried-out land. Biochar is applied in transitional anaerobic-aerobic conditions on riparian wetlands to increase yield production and improve grain quality (Lakitan et al., 2018).

The Agency for Agricultural Research and Development (Balitbangtan) suggested giving biochar gradually every season by utilising agricultural waste as the raw materials in the field (Bardono, 2018). Agricultural Research and Development (Balitbangtan) has classified BIOCHAR SP 50, a simple technology from agricultural waste, as an agricultural product (Balitbangtan, 2019). However, this potential LMT is not included yet in the government priority. Hence, biochar implementation in Indonesia is still in the pilot stage.

3.1.3 Land management practices

Based on SNI 7645-2010, the Indonesian government classified land-use types into 22 classes of land cover: 7 classes for forest cover and 15 classes for non-forest cover (Ministry of Environment and Forestry (KLHK), 2017). Then, BAPPENAS grouped the land use into nine categories: forestland, rice field, cropland, coastal and ocean (mangrove), settlements, plantation, grassland, and other lands. Based on RAN-GRK (NAMA) report, the negative emission solution in land use management would refer to group differentiation from BAPPENAS.

REFORESTATION/AFFORESTATION

The government of Indonesia relies on reforestation and afforestation to counterbalance deforestation rates, along with other measures such as fire prevention and the halting of new permit issuance. During one year in both 2017-2018 and 2018-2019, 53.9 thousand ha and 31 thousand ha of forest were recovered due to these reforestation efforts (BAPPENAS, 2020). These have successfully reduced net deforestation (gross deforestation – reforestation) in the last few years (KLHK, 2020).

In the National Forestry Plan 2011-2030, KLHK pledged to rehabilitate 11.55 million ha of degraded forest and land by 2030. The government employs two strategies to achieve this target: intensive and incentive rehabilitation. While intensive rehabilitation is centred on priority areas and relies entirely on government funding (APBN), its counterpart focuses on involving local communities in reward-based rehabilitation activities. The idea of incentive rehabilitation is to provide financial incentives for local communities that promote their commitment to maintaining and rehabilitating adjacent forestlands near their residence. Within 2015-2019, intensive and incentive methods have contributed to forest and land rehabilitation as vast as 308 thousand ha and 873 thousand ha, respectively (KLHK, 2020).

RESTORATION

Indonesian peatland covering approximately 14.3 million ha has been an enormous GHG emissions source (Ritung et al., 2011). The Ministry of Environment and Forestry (KLHK) data reported soaring figures in carbon emissions from peat fires and peat decomposition. Data peaked in 2015 due to extreme warming effects attributed to *El Niño,* wherein Peatland fires and decomposition contributed to 802.87 million TCO_2e and 359.52 million TCO_2e, respectively (KLHK, 2020). Aside from natural phenomena such as *El Niño* that frequently trigger fires and decomposition, human activities such as peatland clearings and conversion contribute to peatland's increased vulnerability. Those activities make forests and peatlands more prone to fires and decomposition. In the last decades, 6 out of 14.4 million ha of peatland has been converted from natural peat forests into agricultural land and industrial plantation (Masripatin et al., 2017).

To address this problem, KLHK established the Peatland Restoration Agency (Badan Restorasi Gambut/BRG) in 2016 to manage and facilitate peatland restoration in seven priority provinces: Riau, Jambi, South Sumatra, West Kalimantan, Central Kalimantan, South Kalimantan, and Papua. According to the Strategic Plan of BRG 2016-2020 (BRG, 2016), BRG mainly relies on three strategic action plans to restore Indonesian peatland: i) rewetting, ii) revegetation, and ii) peatland-based socioeconomic revitalisation for the locals.

2.5 million ha of peatland will be subjected to rewetting by 2020 to restore its hydrologic characteristics by maintaining peatland surface water level and groundwater table, especially during drought. Also, rewetting could minimise the risk of peat fires and restore peatland to its original condition. While rewetting is designed to restore drained peatland, revegetation is designed for degraded peatland (peatland that has lost its full or partial vegetation). The purpose of revegetation is to restore the peatland ecosystem and improve land coverage by planting trees that are endemic to the land. The target of revegetation by 2020 covers 670,000 ha of peatland. The last focused restoration program is a peatland-based socioeconomic revitalisation that aims at encouraging people living in the proximity of the peatland area to participate in taking care of the degraded peatland. The very idea of this strategy is to assist the locals in improving their economy via peatland-based economic activities. By 2020, 185,000 ha of peatland is targeted to be restored for economic purposes.

AGRICULTURAL MANAGEMENT PRACTICES

MoA has reported reducing the emissions in the Agricultural sector from 2010 to 2019 through some strategies. Agricultural cultivation technology is applied through rice intensification (SRI), integrated crop management, and low-emission varieties. Organic fertiliser and biopesticides through fertilisers, organic subsidised and procurement of Organic Fertiliser Processing Unit (UPPO) are utilised. The utilisation of livestock and agricultural waste is conducted. Additional activities are the improvement of animal feed supplements by using reforestation. In 2019, the most significant emission reduction in agricultural cultivation technology activities was achieved. MoA recorded 114.74 million tonnes of CO_2 reduction from 2010-2019 (BAPPENAS, 2020).

The Agency for Agricultural Research and Development (Balitbangtan) under MoA has introduced some activities in agricultural management practices, i.e. Water-efficient rice management, through intermittent planting, maintaining soil moisture, cover crop, land clearing without burning, amelioration, paludiculture, and yield optimisation (Litbang Pertanian, 2020). The production targets are achieved by optimising land use, extensification for low-carbon fields, and livestock and fertiliser management. Activities related to livestock and fertiliser management include livestock management with containment, feed quality, biogas (methane capture and energy source), balanced fertilisation based on soil condition, and organic fertiliser (carbon sequestration) (Dariah, 2020).

3.2 Determining the LMT scope for national-level simulation modelling

This section discusses which set of LMTs we will study in detail in Indonesia. Table 2 summarises the main Indonesian LMTs and indicates which ones are included in the LMT portfolio's short-list. The main rationales for including the various LMTs in the national-level scaling simulation assessment are presented below.

Table 6: Long-listing of relevant land-based LMTs

LMTs	Subcategory	Specification	Included in the national LANDMARC LMT portfolio
Biomass-based LMTs	BECCS	Based on domestic biomass (anaerobic digestion) with CCS	Y
		Biomass fermentation	N
	Biochar	Based on domestic biomass	Y
Land Management Practices	Forestland	Sustainable Forest Management	Y
		Afforestation & reforestation	Y
		Deforestation reduction	Y
	Agriculture	System of Rice Intensification	N
		Land optimisation	Y
		Application of crop cultivation technology	Y
		Utilisation of organic fertilisers and biopesticides	Y
		Development of plantation areas on non-forested land	N
		Livestock management	Y
	Coastal & Ocean	Mangrove & Seagrass restoration	N
	Wetlands	Restoration of peat areas	Y
	Waste management	Compost & anaerobic digestion	Y

- **BECCS**

BECCS (bioenergy with carbon capture and storage) has been indicated as a critical potential for emissions reductions in Indonesia (DEN, 2019). Repurposing livestock and agricultural waste can allow for land-based negative emissions, while bioenergy usage can reduce fossil fuel and wood burning. BECCS has been a top priority in Indonesia's renewable energy and negative emission solution through biogas, biofuel, gasification, and biomass co-firing.

- **Biochar**

Biochar technology has been known for a long time in Indonesia through charcoal. Biochar is an abundant resource from agricultural and forestry waste, and MoA includes biochar as one of the sustainable agricultural practices (Balitbangtan, 2019).

- **Forestry management & wetland restoration**

The Low Carbon Development Initiative, initiated by BAPPENAS with various stakeholders, recommends forestry policy changes. The 2045 goal of maintaining 41.1 million hectares of primary forest is among the high priorities, and this priority includes preserving 15 million hectares of peatlands. Furthermore, reforestation, afforestation, and restoration are highlighted, each planning on covering a few hundred thousand hectares a year — 500,000, 325,000 and 300,000, respectively. The potential of GHG emission reduction in these two sectors is estimated at 365,275 tons of CO2 equivalent for seven years of examination. BAPPENAS will conduct the monitoring and evaluation of forestry and wetland preservation.

- **Agriculture optimisation, fertiliser use, & livestock management**

The agricultural sector is one of the top national priorities, as it is responsible for 13% of Indonesia's total greenhouse gas emissions. Furthermore, it is incredibly vulnerable to climate change. Thus, it has a high potential for emissions reductions and sustainability measures to protect from climate shocks. Rice production is already declining, and BAPPENAS has estimated this trend to increase for all Indonesian provinces in the coming 20 years. Thus, field productivity must increase by implementing sustainable or carbon-negative schemes, such as land optimisation, organic fertilisers, and further related research and technological advancement. Sustainable agriculture is a priority, with policy recommendations increasing agricultural land productivity by 4.4% and expanding sustainable agriculture to 45% of all lands. Top priorities are land optimisation, crop cultivation technology, organic fertilisers, and the utilisation of abandoned or previously degraded land. Furthermore, livestock manure/urine and agricultural waste should be repurposed into biogas to achieve negative emissions and capture all waste.

- **Waste management**

Waste management is another sector identified as a national priority. The government has set a target of reducing waste emissions by 9.4% from 2024 to 2030, which has high potential. Anaerobic digestion processes currently contribute to Indonesia's GHG emissions, but compost and other measures of integrated sustainable waste management systems have enormous potential.

The rationale for excluding the other LMTs from any different national scenario scaling analysis is provided below:

- **Mangrove and Seagrass restoration**

Mangroves, the focus of coastal and ocean landscapes, offer many negative emissions potential. However, the relevant methodology and calculations are still in preparation (BAPPENAS, 2020). Thus, it is not yet ready to be included in these LMT analyses.

- **Biomass Fermentation**

The Bioenergy Division of the Ministry of Mineral and Energy Resources (MEMR) focuses on biofuel or biomass fermentation from agro-industrial waste, such as oil palm, sugar, or cassava. There will be considerable potential negative side effects associated with oil palm waste.

- **System of Rice Intensification (SRI) and non-forested land for agriculture**

These practices are applied as sustainable agricultural management strategies. The regulation and policies include these practices as decarbonisation strategies. The number of negative emissions can be estimated based on agricultural areas.

3.3 Discussion on short-listing LMTs

3.3.1 Land-use change dynamics

The National Forestry Plan 2011-2030 (RKTN, 2019) aims at preserving the forest area of around 112.85 million ha through avoided deforestation, fire control, and forest moratorium while dedicating the other 13.07 to be converted for non-forestry purposes by 2030. To achieve these targets, around 3.96 out of 9.3 million ha of critical (degraded) land need to be rehabilitated at a minimum speed of 396,000 ha per year since 2020. Assuming 1,650 trees take up one hectare of land, the total number of trees that need to be planted by 2030 would be 6.53 billion. Should this target be achieved, this rehabilitated forest area would store 55,000 million tons of carbon in 2030 (Ministry of Environment and Forestry, 2019).

Competing land use

Apart from land claims by the National Forest Plan, the ongoing energy transition in the electricity and transportation sector is also making considerable land use claims up to 2030 and 2050, given the anticipated expansion of solar PV parks and biodiesel utilisation.

To meet the B30 biodiesel mandate, which aims to achieve 30% blending in 2025 (Indonesia Regulation 12/2015), 12.2 billion litres of biodiesel is needed. This requires 11.2 Mton of crude palm oil (CPO), equivalent to 370% of the CPO amount used for biodiesel production in 2014. Consequently, the additional land required for reaching the target blends and increased domestic demand by 2025 reaches up to 6.7 million ha, 64% of the total oil palm plantation area in 2014. Oil palm area, which already occupied 18% of total agricultural land, has increased by more than 10% since 1990, while forest land has decreased steadily by an average of 1.1% annually (Khatiwada et al., 2021).

Furthermore, to meet the 2050 electricity demand that has been projected to reach 2,600 TWh (MEMR, 2019), Indonesia needs a total capacity of 1,500 GW of solar photovoltaic power plants, requiring at least 800,000 ha or about 0.4% of the nation’s land area (Silalahi, 2020). While much effort will be made to introduce those solar parks on water and building rooftops, it is expected that the bulk of this expansion will occur at the expense of land currently used for agricultural purposes.

3.3.2 Land management Dynamics

Unlike land-use change, changes in land management do not necessarily involve a conversion of land use. Most land management changes would allow the land to remain used partially or entirely as its original function. Enhancing soil organic carbon (SOC) could be one of the effective negative emission measures. Out of the total agricultural land of around 62.3 million ha, which makes up approximately one-third of the total Indonesian land surface area, about 82% is occupied as cropland, including land for temporary crop cultivation (arable land) and permanent crops (See Table 3).

Table 7: Agricultural land use in Indonesia in 2008 and 2018 (in 1000 ha)

Land use category	2008	2018
Agricultural area, total	54,000	62,300
Arable land	22,700	26,300
Land under permanent crops	20,300	25,000
Land under perm. meadows and pastures	11,000	11,000

Source: (FAOSTAT, 2020)

For instance, adding only 1%-point of the SOC to the agricultural area could provide a significant storage potential. Despite the importance of the organic matter in the soil, data for evaluating SOC change in Indonesia is limited due to the absence of regular SOC stock and change monitoring. However, a study reported SOC levels in Indonesian soil in 2010 (see Table 4). Although SOC change data at the macro-level (nation-wide) is not available, several studies report SOC depletion in Indonesian soils at the micro-level. One study suggested that SOC stock declined by around 30% when a forest was converted to agricultural production (Murty et al., 2002). Another study discovered that the level of organic matter in the 0-15 cm soil of lowland rainforest in Sumatra decreased by 48.1 Mg C ha^{-1} when the forest was downgraded to grassland (Santoso et al., 1997). Another primary source of soil carbon reduction in Indonesia is the loss of carbon from organic soil (peatland), which covers about 14.9 million ha and contains exceptionally high carbon content ranging from 420 to 820 Mg C ha^{-1} (FAO and ITPS, 2015).

Table 8: Levels of organic matter in topsoil in Indonesia (the data year 2010)

Total land area (million ha)	SOC stock (Pg C)	SOC level (Mg C ha-1)
183	20.8	113.4

Source: (Shofiyati et al., 2010)

To reverse this trend, intensive land management systems such as no-till farming, cover crops, nutrient management, manuring and sludge application, improved grazing, etc. and water table level increases would be required to recover soil carbon pool or at least to avoid any further loss of soil carbon (Lal, 2003). For practices that do not involve changing the uses of cropland or grazing land, the extensive primary potentials of soil carbon sequestration have extensively relied on no-till farming and grazing management changes (Searchinger & Ranganathan, 2020). No-till agriculture, where farmers drill seeds into the soil instead of ploughing soils, can reduce soil erosion and prevent carbon releases (Ranganathan et al., 2020). Further, improved grazing management which usually follows practices such as designing proper rest periods between grazing events and adjusting to appropriate stocking periods (matching the yield potential for the grazing area and weather patterns), tends to lead to increased soil carbon stocks up to 0.28 Mg C ha^{-1} annually (Conant et al., 2017).

Also, supplementing carbon to soils such as compost, manure, and digestor from anaerobic digestion (AD) of organic matter (e.g. manure), harvesting residues, or processed organic fertilisers can be performed to improve organic matter levels in agricultural soils. AD-based bioenergy combined with carbon capture storage (BECCS) could provide massive potential in putting CO_2 emissions into negative territory by converting biomass into bioenergy (biogas) and then sequestering the carbon produced into the soils in the forms of organic fertilisers.

Considering the high livestock population in Indonesia (Table 5), which has steadily increased in the last three years, there is a massive potential in biogas and organic fertiliser production from animal manure via AD-based BECCS. A study has estimated the total biogas production from manure in Indonesia to be of 9595.6 Mm^3/year or equal to 1.7 x 10^{10} kWh of electricity (Khalil et al., 2019).

Table 9 Indonesia Livestock Population (2018-2020)

Species	2018	2019	2020
Large livestock			
Beef cattle	16,433	16,930	17,467
Dairy cattle	582	565	568
Buffalo	894	1,134	1,179
Horse	378	375	392
Small livestock			
Goat	18,306	18,463	19,096
Sheep	17,611	17,834	17,769
Pig	8,254	8,521	9,070

Source: (Ministry of Agriculture, 2020)

Volume-wise, animal manure is the single largest potential resource of soil organic matter and other macro-and micronutrients to supplement soils. To date, most animal manure is put on soils without any manure processing. However, upgrading animal manure to a high-quality organic fertiliser through anaerobic digestion could better the outcomes and produce energy in the form of biogas by reducing volumes (hence reducing storage problems), exterminating pathogens, and enhancing soil nutrients. On top of that, as an add-on climate change mitigation technology, further animal manure treatments could also significantly reduce CH_4 emissions.

Knowing this potential, the Indonesian Government has set up an ambitious goal to employ biogas in its energy mix as part of the Nationally Determined Contribution (NDC). This plan includes generating 5.5 GW of electricity from biogas by 2025. However, as of 2020, biogas' utilisation for power is only 96.2 MW or 1.33% of the 2025 target (Ministry of Energy and Mineral Resources, 2020).

In addition to large-scale biogas, as part of President Regulation No. 22 the Year 2017 on National Energy Planning (RUEN) to improve clean energy access and accelerate the substitution of oil fuel with gas in the household sector, GoI is preparing a roadmap to achieve biogas production at 47.4 mmscfd for household uses by 2025. To achieve this target, 1.7 million household-scale biogas digesters need to be installed (Dewan Energi Nasional, 2019). To date, 47,505 small-scale biogas digesters have been installed across Indonesia, resulting from assorted funding from the national government, foreign aid, and private institutions, producing 26.72 Mm^3 annually (Ministry of Energy and Mineral Resources, 2020).

4. Co-design of LMT narratives

4.1 Introduction

The Updated NDC submitted in 2021 reflects the progression beyond the existing NDC as well as new elements, including (1) enhanced ambition on adaptation as depicted in Annex 2, (2) enhanced clarity on mitigation by adopting the Paris Agreement Rules Book (Katowice Package), (3) national context that relates the existing condition, milestones, along with national development, from 2020 to 2024, and indicative pathways towards a long-term vision, (4) translating the existing NDC into the language of the Paris Agreement, and (5) translating Indonesia's updated NDC also seeks international cooperation options to help the attainment of the conditional target of up to 41% compared to the business as usual scenario.

Indonesia presents the Long-term plan for Low carbon and Climate Resilience in 2050 following the mandates of Article 4, Paragraph 19 of the Paris Agreement, and Paragraph 35 of the Dec. 1/CP.21 (LTS-LCCR 2050). Considering economic growth, climate resiliency, and impartiality, Indonesia is laying the groundwork for reaching a peak emission level by 2030, with forestry and other land uses as the leading sector and net-sink towards net-zero emission. The LTS-LCCR 2050 paper represents Indonesia's higher 2030 NDC ambitions (Ministry of Environment and Forestry, 2021).

Through LTS-LCCR 2050, Indonesia will increase its ambition on GHG reduction by achieving the peaking of national GHG emissions in 2030 with a net-sink of forest and land-use sector, reaching 540 Mton CO2e by 2050 and exploring the opportunity to progress toward net-zero emission in 2060 or earlier rapidly. In order to reach this objective, the forestry sector will contribute significantly to the maintenance of the net-increasing sink trend after 2030, as well as to the significant transformation of the energy sector by increasing the proportion of renewable energy in the energy mix, boosting energy efficiency, reducing substantial amounts of coal consumption, and implementing Carbon Capture Storage/Utilisation (CCS/ CCUS) and Bioenergy with carbon capture and storage (BECCS).

This ambitious goal necessitates transformational changes in both the energy system and the food- and land-use system, which must account for potential trade-offs among many objectives, including energy security, food security, biodiversity conservation, avoiding deforestation, freshwater use, and competing land use. Indonesia believes adaptation and mitigation play complementary roles in responding to climate change at distinct spatial, temporal, and institutional scales. The LTS-LCCR 2050 establishes the objective of adaptation pathways to reduce the impact of climate change on national GDP loss by 3.45% by 2050 through strengthening resilience in four fundamental necessities (food, water, energy, and environmental health), with three resilience target areas (economy, social and livelihood, ecosystem and landscape) (Indonesian Ministry of Forestry and Environment, 2021).

Based on Operational Plan Indonesia's FOLU Net Sink 2030 published by the Ministry of Environment and Forestry in 2022, in the long-term strategy, the emission level in the LCCP scenario is significantly lower than in the present policy scenario (CPOS), which is an extension of the NDC scenario without conditions. By 2030, the forestry and other land use sector (FOLU), which was previously a net emitter, will become a net sink according to the LCCP (Low Carbon Compatible with Paris Agreement aim). The FOLU sector's net sinks are anticipated to increase until 2050. This sector plays a significant role in achieving the national NZE target, particularly in offsetting emissions from difficult-to-reduce sectors such as the energy sector. Significant efforts to cut FOLU sector emissions and convert them to net sinks by 2030 (under the LCCP scenario) will depend significantly on the success of the following actions:

a) reducing emissions from deforestation and forest degradation by expanding protected natural forests, increasing community participation, and strengthening community partnership in forest management;
b) increasing the carbon sequestration capacity of natural forests by reducing forest degradation and increasing its regeneration through the enrichment or implementation of a sustainable forest management system;
c) increasing the carbon sequestration of land systems by maximising the use of inefficient or low-carbon land use for the development of forest plantations and other perennials (industrial crops);
d) reducing emissions from fires and peat decomposition by enhancing peatland management systems;
e) enforcing the law.

As a baseline for implementing the NDC, the Indonesian government has prepared a mitigation road map. The Road Map guides stakeholders, including the government, local governments, businesses, and the community, to achieve NDC targets by providing information on the planning, timing, and setting of detailed GHG emission reduction targets by subsector, as well as identifying all relevant factors that contribute to achieving targets.

Table 10 Sector emission reduction targets in NDC

No	Sector	2010 Emission (million tonne CO_2e)	2030 Emission Level (million tonne CO_2e)			2030 Emission Reduction			
						million tonne CO_2e		% from BAU	
			BAU	CM1	CM2	CM1	CM2	BaU	CM1
1	Energy[1]	453,2	1.669	1.355	1	Energy[1]	453,2	1.669	1.355
2	Waste	88	296	285	2	Waste	88	296	285
3	Industry	36	70	67	3	Industry	36	70	67
4	Agriculture	111	120	110	4	Agriculture	111	120	110
5	Land & Forestry[2]	647	714	217	5	Land & Forestry[2]	647	714	217
	Total	1.344	2.869	2.034		**Total**	1.344	2.869	2.034

Note: [1] including fugitive emission; [2] including peat fire

The literature review and a few interviews with relevant experts provided guidance and information to narrow the long list LMTs to the four selected ones. These four are considered for further analysis (with the help of model simulations) within the LANDMARC project. Before such an assessment can be done, a narrative or storyline for each selected LMTs needs to be developed. The following sections provide the qualitative narratives of the four LMTs for Indonesia.

- Afforestation and Agroforestry (see section 4.2)
- Peatland Management (see section 4.3)
- Agriculture (see section 4.4)
- Soil Carbon Enhancement (Biogas and Compost) (see section 4.5)

4.2 Afforestation and Agroforestry

4.2.1 Introduction

Since forests cover 65% of Indonesia's total area, forestry and land use are the main contributors to Indonesia's greenhouse gas (GHG) emissions (Ministry of Environment and Forestry, 2016). Indonesia lost 26.8 million ha of tree cover from 2002 to 2019, where 37% occurred in the humid primary forest. The tree cover lost in the primary forest is equivalent to a 17% reduction in total loss since 2000, contributing to the release of 10.9 Gt of CO2 emissions in this period (Global Forest Watch, 2021).

A study in 2019 reported three significant deforestation causes in Indonesian forests between 2001 and 2016 (Austin et al., 2019): 1) large-scale oil palm and timber plantations, which together contributed more than two-fifths of nationwide deforestation, 2) conversion of forests to grasslands (pastures), which made up around one-fifth of total deforestation, and 3) small-scale agriculture and plantations, which also comprised one-fifth of national deforestation. Hence, negative emission solutions are implemented to reduce deforestation activities. Based on LMTs, the main contributor to emission reduction in 2019 was the forestry and peatland sector. More than 80% of emission reductions are achieved through afforestation, forestation, and restoration (BAPPENAS, 2020a).

Climate mitigation in forestry refers to all actions that can reduce carbon emissions and sequestrate carbon into forestry carbon stock through preserving and improving forest area and coverage. This can be achieved by carbon stock preservation and carbon stock enhancement. Carbon stock preservation will include all technologies and practices to prevent deforestation or forest degradation, forest fires, illegal logging and forest clearing/conversion, and land utilisation beyond the concession area by certain groups. Carbon stock enhancement includes forest rehabilitation, i.e. afforestation and reforestation (I. W. S. Dharmawan, personal communication, May 6, 2021). Referring to REDD+ (Reduction Emissions from Deforestation and Forest Degradation), five land-based mitigation actions in the forestry sector are reducing deforestation and forest degradation, forest carbon enhancement, carbon conservation, and sustainable forest management (SFM). SFM includes agroforestry, reducing illegal logging, and forest rehabilitation, and covers 30 million ha of forest. The forestry sector has a potential Nationally Determined Contribution (NDC) of 17.2% of dryland and wetland land use. This contribution is large compared to other sectors (Y. Rochmayanto, personal communication, May 5, 2021).

FOLU Sector Mitigation Actions to Achieve Net Sink by 2030 (Ministry of Environment and Forestry (KLHK), 2022):

a. Conservation of forest resources against deforestation and degradation

The results of the spatial template analysis indicate that 10.48 million hectares of diverse forest functions are at risk of destruction in natural forested regions. The risk is greatest outside the forest area (APL) and lowest within the PBPH-HT. The threat of deforestation is classified as either deliberate or unplanned. Planned deforestation is the legal conversion of natural forest to non-forest, including within the production zone designated for agriculture operations (production directive) and HPK that may be changed for other purposes. Unplanned deforestation is the conversion of natural forests to non-natural forests due to illicit activity (forest encroachment) or natural calamities like forest fires. According to the LCCP scenario (MoEF, 2021), the total amount of natural forest that can be transformed until 2050 is restricted to 6.8 million hectares. To preserve the goal of zero net emissions, natural forest conversion must be minimised as much as feasible.

b. Prevention of deforestation in concession areas

Included in protecting primary natural forests in concessions are safeguards against both planned and unexpected degradation. Protection against planned degradation entails updating the forest management plan to retain primary natural forests exclusively for NTFP. In contrast, protection against unplanned degradation focuses on the disturbance of primary natural forests maintained inside the concession area. For the 2030 net sink target to be met, the maximum allowable area for primary forest degradation is 2.28 million hectares. In primary forest areas, there is a need for an incentive program for concessions to alter their business plans from timber forest production to non-timber forest products or environmental services.

c. Plantation forest development

To meet emission reduction goals, efforts must be made to expedite the establishment of industrial forest plantations. This will aid in decreasing industrial timber's reliance on domestic and international natural forest supplies. According to the Indonesian National Forestry Plan's (RKTN) forecasts of future wood demand, industrial forest-planted lands are required. It is estimated that 11,2 million hectares of forest have been created. The potential area accessible for forest plantation expansion in the PBHP HT and PIAPS (Indicative Map of Social Forestry Area) areas is only 2.04 million hectares, based on template evaluation. The development of planted forests has reached 5.12 million hectares, leaving a shortfall of 4.07 million hectares. To address this shortfall, plantation forest growth can be implemented in concession lands already occupied by the community to cultivate seasonal and permanent crops under the Forestry Partnership's social forestry initiative. As part of the Rehabilitation with Rotation activity, one method to address the deficiency is establishing agroforestry systems that blend plantation and crops with plantation forests. This is accomplished by expanding social forestry lands in Community Plantation Forests (HTR).

d. Sustainable Forest Management (SFM)

The availability of land to enhance carbon stocks (rehabilitation) is limited, and the increase in carbon uptake can be accomplished by enhancing the capacity of secondary forests to absorb carbon through ENR and RIL. To attain the net sink objective (at least until 2030), the concession area that has implemented a sustainable forest management system through enrichment activities (such as SILIN) and RIL must reach 2,2 million hectares. However, the implementation of SILIN and RIL activities has only reached 0.43 million hectares until 2019. Consequently, the implementation of SFM towards the net sink objective until 2030 must be at least 1.77 million hectares. According to the analysis, the potential area for RIL implementation reaches 1.52 million hectares in the PBPH Natural Wood and PBPH-HT. The ENR implementation covers 0.25 million hectares across many forest functions.

e. Reforestation and land restoration

A component of the carbon stock-increasing mitigation activity is rehabilitation efforts with rotation. To reach the FOLU Net Sink target by 2030, 2.79 million hectares must be rehabilitated using a rotation method. The progress of rotational reforestation through 2019 reached 2.73 million hectares; therefore, the area for rotational reforestation through 2030 is just 0.05 million hectares. To accommodate the plantation expansion (4.07 million hectares), approximately 4.12 million hectares must be rehabilitated and rotated. Most fulfillments are located outside the forest area (APL) in the form of unproductive land (non-forest cover). They are included in the area designated for the development of community forests. 2.51 million hectares of non-rotational restoration are required until 2030 to reach the net sink target. As a result of the implementation's expansion through 2019, the land area only reached 0.62 million hectares. The required land area is, therefore, 1.89 million hectares. The largest areas are in the provinces of Central Kalimantan and Riau. This area contains a portion of the mangrove environment, which comprises around 90,000 hectares. Some of the coastal swamp ecosystems (tidal swamps) have the potential to be converted into mangrove forests.

f. Conservation of biodiversity

As part of the endeavour to minimise greenhouse gas emissions in the forestry and land sector, biodiversity conservation can be regarded from multiple angles, such as the conservation of wild plants and animals, the conservation and protection of habitats, and the participation of local communities. Currently, there are 38 million hectares of high conservation value (HCVF) lands, of which 1.51 million hectares are in high-risk areas that must be safeguarded from conversion. There are more animal deaths outside of protected areas. Therefore, the protection of HCVF outside the conservation area is crucial for ensuring animal protection and preventing animals from leaving the corridor—the distribution of places for executing mitigation efforts to reduce greenhouse gas emissions based on spatial analysis. Mitigation actions in the FOLU sector are focused on five main mitigation actions, as shown in Figure 1.

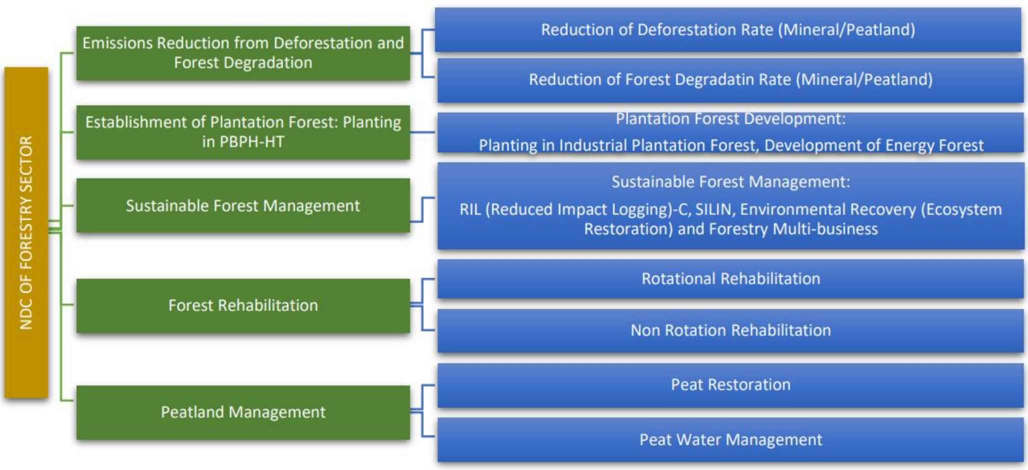

Figure 1 Action diagram of NDC mitigation road map (Ministry of Environment and Forestry, 2021).

4.2.2 Policy context

Policies and Regulations

To contribute to the REDD+ and Paris Agreement on Climate Change, Indonesia formulated NDC and pledged to reduce 29% of carbon emissions by 2030, which 15% out of 29% had been achieved. The goals are further formulated in Regulation of MOEF SK.679/MENLHK/SETJEN/KUM.1/12/2017 on Monitoring the Implementation of NDC. NDC is further derived into more refined regulations corresponding to each strategic climate mitigation action.

In general, there are two major activities of climate mitigation in forestry. First, the carbon stock preservation activities include preventing deforestation, forest fires, illegal logging/conversion, and prevention of non-forest land expansion into the forested area. Second, the carbon enhancement efforts include afforestation, reforestation (also known as social forestry projects), and rehabilitation of various high conservation value (HCV) and high carbon stock (HCS) ecosystems (van Noordwijk et al., 2014). These projects aim to increase environmental services such as water cycling, carbon sequencing, and nutrient cycling. These activities are funded by the government fund (APBN and regional fund - APBD) and private fund (bilateral or multilateral donations, NGOs, private companies, and initiatives). Besides, the forestry sector is expected to contribute 17.2% or 498Mt CO_2e out of the 29% commitment. However, this also includes peatland as it is considered to be managed under forestry management (Tacconi et al., 2019).

In the National Forestry Plan 2011-2030, MOEF pledged to rehabilitate 11.55 million ha of the degraded and industrial forest by 2030. A series of regulations issued by MOEF, including MOEF's Regulation No. 70/2017 on Implementation Procedures of REDD+, Role of Conservation, Sustainable Management of Forest, and Enhancement of Forest Carbon Stocks, No. 71/2017 on Implementation of National Registration Systems of Climate Change Mitigation3, No. 72/2017 on Implementation Guidelines on Measurement, Reporting, and Verification of Climate Change Mitigation Actions and Resources, and No. 73/2017 on Implementation Guidelines on Inventory Reporting of National Greenhouse Gas Emissions (Ditjen PPI KLHK, 2021).

The Low Carbon Development Initiative (LCDI), initiated by BAPPENAS (Ministry of Development and Planning) with various stakeholders, recommends forestry policy changes. The forestry policy is also included in Presidential Regulation No. 18/2020 on Medium-term National Development Planning 2020-2024 (BAPPENAS, 2020b). The 2045 goal of maintaining 41.1 million hectares of primary forest is among the high priorities. In response to high deforestation, GOI (The Government of Indonesia) relies on reforestation and afforestation to reduce deforestation rates and other measures such as fire prevention and halting new permit issuance. The permit policy is based on President Instruction (INPRES) No. 5/2019 on Termination of New Permit Issuance and Amendment of Primary Forest and Peatland Management). This regulation is a revision from its preceding regulations – INPRES No. 6/2017 and INPRES No. 10/2011 on Halting of New Permit Issuance and Amendment of Primary Forest and Peatland Management. The regulation limits land deforestation and encourages HCV and HCS areas (JDIH BPK RI, 2019). Based on 2009-2019 spatial data, the deforestation trend in Indonesia has been decreasing (Tacconi et al., 2019). On the national level, the One Map Policy aims to harmonise the land-use map and recognise land ownership of the private sector.

On the new FOLU Net sink 2030 document (Ministry of Environment and Forestry (KLHK), 2022), mitigation actions based on priority locations in the forestry sector are:

1) Preventing deforestation and forest degradation (FD) Priority locations for adopting this mitigation measure are natural forest areas situated in relatively high IPL and within protection and production zones determined by IJL (Location Priority index). High IPL areas are susceptible to conversion to non-forest or degradation. To ensure the continuance of the forest's provision of environmental services and forest products, the area still covered by natural forest under protection and production must be maintained.
2) Preventing Forest Loss in Concessions (Forest Utilisation Business Permit or PBPH). A management approach geared toward using NTFPs (Non-timber Forest Products) is required to prevent the degradation of forested lands in the PBPH under the protection zone, given that part of the areas are still in the form of the primary natural forest.
3) PBPH-HT Plantation Forest Development (plantation forest). Priority places for establishing plantation forests in PBPH-HT concession and social forestry areas (PIAPS) are all unproductive lands in the production zone. In the rehabilitation zone, unproductive land is used for a non-rotational rehabilitation program.
4) Sustainable Forest Management (PHL). In both PBPH-HA and PBPH-HT concession areas, forest enrichment activities (enhanced natural regeneration, ENR) and low-impact logging methods (RIL) are a priority for implementing PHL activities. ENR initiatives focus on concession areas dominated by natural forests in the conversion and rehabilitation zone and secondary forests in the production zone with a high IPL. SILIN Technique's application is that ENR can raise the production of natural forests by three to four times the current productivity or by 90 to 120 m3/ha/cycle. Meanwhile, RIL activities focus on concession areas where primary forest still covers the land, which is included in the production zone.
5) Enhancement of carbon stock in forests (PCK). To increase forest carbon stocks, the land is rehabilitated either inside dryland or wetland (Mangrove and Peatland Forests) by planting trees that can be harvested for wood (rotation) and those that cannot be harvested (non-timber forest products) (non-rotation). Priority places for rehabilitation with rotation are production forest lands with relatively high IPL covered by unproductive lands and agricultural lands within the production zone that is not peatlands. Priority places for rehabilitation without rotation are lands with relatively high IPL in both production and protection forests. The land cover of these areas consists of unproductive, seasonal, and perennial crops located in the protected zone and not on peatlands. Agroforestry refers to rehabilitating degraded land with seasonal and perennial crops.
6) Natural Forest Protection The current natural forest, both within forest areas (conservation forest, protection forest, and production forest) and outside forest areas (APL), must be preserved, including through conservation efforts. Natural forest conservation is practised outside the protection zone to preserve places with high conservation value, as identified by IJLH within the protection zone.

For law enforcement to have a continuous and consistent implementation, efforts must be made to establish appropriate policies and procedures. Since 2016, law enforcement has focused mostly on forest fires, forest encroachment, and illegal logging cases, which will be conducted continually.

Based on the earlier criteria for identifying the priority site and considering the emission reduction target for the 2030 net sink, Table 4 depicts the land distribution for implementing mitigation actions in each forest function. It is vital to consider institutional typology to create synergies between the Ministry of Environment and Forestry and other partners in priority areas. It is anticipated that FMUs (Forest Management Units) with Types 1 and 3 will be able to coordinate and establish synergies between programmes from diverse organisations at the site level due to their high institutional capacity. In the meantime, in key regions where the FMU Types are 2 and 4, institutional capacity remains poor, necessitating institutional strengthening efforts.

Table 11 The area of implementing the mitigation action programme according to area stakeholders (Ministry of Environment and Forestry (KLHK), 2022).

Area	Type of Management	Deforestation/ Degradation[3]	Degradation in Concession	PFD	SFM[5]		EFCS[5]		PLM		HCVF[6]	Total[8] (Ha)
				HT/HTR[4]	ENR	RIL	Rotation	Non Rotation	WM[4]	Restoration[5]		
Non Forest area (APL)	Non HGU-PEMDA	3.973.073	-	-	-	-	1.640.824	92.689	-	-	1.350.742	5.706.586
HGU-APL	HGU-PEMDA	642.685	-	-	-	-	349.600	34.499	956.682	65.769	440.471	2.049.234
Conservation Forest	Conservation	915.775	-	-	548	-	-	647.229	-	9.351	-	1.572.902
Protection Forest	Non SF-Ptn	476.196	-	-	4.597	-	-	126.185	-	-	14.128.824	606.978
	SF-Ptn	71.728	-	-	1.060	-	-	39.235	-	43.440	1.459.031	155.464
Production Forest	Non Concession-Pdn	942.184	-	-	3.260	-	146.198	231.225	-	-	11.095.028	1.322.867
	Pdn-CPF	215.003	-	-	1.882	-	317.243	128.576	-	763	840.150	663.467
	PBPH-NATURALLY GROWN TIMBER	613.324	4.398.626	-	110.502	1.460.332	321.205	6.508	-	18.772	5.460.254	6.929.270
	PBPH-HT	1.974.995	233.885	1.346.427	118.953	64.122	1.243.630	383.201	718.021	210.408	1.443.708	6.293.643
	KPHP-SF	324.310	-	697.901	2.627	-	77.730	177.058	-	147.428	1.750.410	1.427.053
	PBPH-RE	326.313	58.130	-	2.859	-	22.768	20.596	-	9.209	360.930	439.874
Peatland Management by BRGM[7]		-	-	-	-	-	-	-	-	1.382.019	-	1.382.019
TOTAL		10.475.586	4.690.641	2.044.328	246.288	1.524.454	4.119.197	1.887.000	1.674.703	1.887.159	38.329.548	28.549.356
TARGET of Net Sink 2024[1]		**3.142.141**	**1.705.000**	**9.307.332**	**1.413.203**		**1.951.493**	**1.756.344**	**785.439**	**1.996.762**		
TARGET of Net Sink 2030[1]		**4.225.877**	**2.282.500**	**11.227.332**	**2.207.061**		**2.787.847**	**2.509.062**	**946.050**	**2.724.866**		
Progress until 2019[2]		**4.803.000**	**441.416**	**5.116.662**	**436.319**		**2.734.992**	**622.269**	**N.A.**	**835.288**		

Main Actors

Several actors play roles in the forestry mitigation sector, such as MOEF (regulator and planner), local government (at the provincial and city level), NGOs, private actors, and local communities. Some private companies harvest carbon stock and then monetise their carbon stocks through results-based payment or voluntary carbon markets. The private sector has quite high control where nationally, 30-40% of forest land is generally owned by the private sector, which must have mandatory restoration and is proven to undergo sustainable forest management (reduce impact logging). On the other hand, local communities, including indigenous people, hold social forestry in Peatland Care Village/Desa Peduli Gambut. Indigenous people living within the customary forest (Hutan Adat) prevent forest fires and protect the forest. Leaders of customary forests are usually respectable local figures. Forest area provided by the government to be utilised and managed by indigenous people as the customary forest is 4.2 million ha.

The demand for fast-growing plant products from community forests is significant and can even contribute to negative carbon emissions. The community also has a big share, where community activities determine land use, for example, in social forestry or community forests. This activity can be seen in forest management by the community in Kalibiru (a tourism place in Yogyakarta, Java Island), where the forest is cleared for eco-tourism. However, the people's growth of community forests and forest utilisation is still lacking outside of Java, in contrast to Java Island (Y. Rochmayanto, personal communication, May 5, 2021). The use of forests by the community can refer to article 6 of Presidential Regulation No. 88/2017 on Settlement of Land use in Forest Areas. This policy states that parties as owners of TORA (Land the Object of Agrarian Reform) could be defined as individuals, agencies, social/religious bodies, and indigenous peoples.

Funding

The government employs two strategies to achieve this target: intensive and incentive rehabilitation. While intensive rehabilitation is centred on priority areas and relies entirely on national funding (APBN) and government activities, its counterpart focuses on involving local communities in reward-based rehabilitation activities. The idea of incentive rehabilitation is to provide financial incentives for local communities that promote their commitment to maintaining and rehabilitating adjacent forestlands near their residence. This dual-objective forest utilisation by local communities could fall under the agroforestry umbrella (MOEF, 2020b).

Indonesia has generated preliminary financial projections for FOLU Net Sink 2030 based on the standard cost of mitigation activities outlined in the NDC's roadmap for implementation. Estimates indicate that the overall funding for executing mitigation initiatives leading to a net sink might reach 15,379,817,300 USD by 2030. The cost of forest conservation from deforestation is $7,142,927,700, with the private sector contributing approximately 34% and the public and state budgets covering the remainder.

Forest conservation from deterioration requires a private sector investment of $3,024,482,900, which must be remunerated with a results-based payment for environmental services. The private sector contributed 94% of the 39,125,225 USD required for enrichment activities, whereas all 49,356,986 USD required for RIL operations came from the private sector. Rehabilitation initiatives using rotation require a total of 514,805,600 USD, with 47% coming from the private sector. Non-rotational rehabilitation efforts require a budget of 257,402,800 USD, with a contribution of 24% from the private sector.

4.2.3 Current Land Use and Potential Land-Use Competition

Indonesia’s forests are the third largest, with tropical forests and donations from Kalimantan and Papua’s rain forests. According to data from Forest Watch Indonesia (FWI), an independent Indonesian forest monitoring agency, 82 hectares of Indonesia’s land area is still covered by forests (KLHK, 2020b). Land-use change in the forestry sector will be the main discussion regarding land-use management and emission production. Once land-use change or forest fires occur in the primary or secondary forests, massive carbon emissions will be produced. Based on its historical utilisation, primary forests are referred to as forests that have not been altered and still contain a natural ecosystem. Secondary forests are forests regrown naturally from previously disturbed primary forests. This disturbance can be intentional, such as through forest clearing to obtain wood or unintentional, such as natural disasters. The regrown forest in the new area used for other land use, such as agriculture, would be planted or industrial if the planting were intended for lumber production (FAO, 2000).

In 2019, there were 17.3 million hectares of forest cover, of which 12.5 million ha were covered by primary forest and 4.7 million ha was secondary forest. Primary and secondary forests are limited in use for the public, in which any activities within primary forests aside from scientific research projects are prohibited from the public. The activities within the secondary forest were also limited, but various indigenous, religious, and social activities were still allowed to a limited extent. A secondary forest would also function as a buffer to the effect of activities carried out of the forest. There are 0.12 million hectares reserved for wood production utilisation, including Industrial Lumber Forestry and Planted Forest (MOEF, 2019).

Currently, there is a decrease in deforestation (See Table 3). Based on the interview result (Y. Rochmayanto, personal communication, May 5, 2021), forest areas are considered a development resource in developing countries. It will be difficult to stop land-use change in forestry. Therefore, planned deforestation was announced. Oil palm plantations are still the number one driver, followed by land alteration into mixed farming. Population growth did not directly affect forest area for settlement since population growth is concentrated in urban areas, so land expansion is not required. Deforestation was mainly generated by urban consumption, food, fuel, and fibre demand (Deribew, 2020).

Other than that, there is also another land-use antagonism against forests. For example, the lumber production forests can procure threats as they might be transformed into other plantations or competing land use (A. Hani, personal communication, May 4, 2021). These activities lead to partial deforestation in the forest's centre, such as deforestation for the mining and energy sector and infrastructure development, such as road works. Besides, there are some shifts from one type of forest to another, e.g. from a primary forest to a production area. The direct utilisation of HCV and HCS forest areas is expected to be reduced. Other efforts, such as starting social forestry, limiting forest utilisation to assigned areas only, and agroforestry development, are also initiated.

Table 12 Forest, deforestation and reforestation area in Indonesia 2014-2019 (in a million ha)

	2014-2015	2016-2017	2017-2018	2018-2019
Forest area	-	-	125.92	125.91
Gross deforestation	1.29	0.68	0.64	0.65
Reforestation	0.2	0.2	0.2	0.19
Net deforestation	1.09	0.48	0.44	0.46

Source: (BPS, 2021; KLHK, 2020b)

4.2.4 Climate Risk & Sensitivities

The forests are naturally more resistant to disturbance, mainly areas with high reservation value. A forested area tends to stay as a forest unless there is a huge disturbance. Besides that, Indonesia's natural forest has high biodiversity and is resistant to various pests and pathogen attacks (Shroff & Cortés, 2020). Climate mitigation in forestry is vulnerable to all climate hazard risks but most sensitive to drought and desertification, forest fires, floods, and biodiversity loss. As for forest fires, the risks/probability of fire occurrence can be minimised through various fire prevention actions (A. N. Armanto, personal communication, April 22, 2021). However, the forest is not sensitive to heavy rain. When there was heavy rain, trees could hold raindrops on their canopy, so the water did not hit the ground directly, reducing erosion and flowing the rainwater from the higher canopy to the soil slower. One of the problems that were caused by high rainfall is the translocation of the nutrient-rich topsoil. The soil would be acidic and infertile when the water translocated the alkaline layer. The trees can also be utilised as a windbreak and hold back the wind (A. Hani, personal communication, May 4, 2021).

Resistance refers to the ability of the ecosystem to maintain its form under disturbance. In contrast, resilience refers to the ability of the ecosystem to bounce back to its initial form after being disturbed. However, the monoculture wood production area is not as resistant as other forest types or agroforestry land use. Resilience is also risky; for example, if a natural forest is disturbed by a forest fire exaggerated by the heatwave, it might take years to re-establish itself naturally (Cole et al., 2014). Drought and desertification are currently not a national focus. However, due to Indonesia's diversity of ecosystems, there are a few areas with this risk, e.g. East Nusa Tenggara.

Unsuitable methods of forest management could potentially lead to secondary problems; for example, introducing exotic acacia trees (*Acacia* sp.) in Baluran National Park in the 1980s led to biodiversity problems. The acacia was introduced from Africa and has a high resistance to forest fire compared to the native trees. Due to a consecutively occurring forest fire, the introduced acacia thrives better, and the native tree community is threatened (Caesariantika et al., 2011). Therefore, research on local and suitable trees will be required.

In the case of agroforestry with cocoa trees, the main related climate risks are drought and heavy rainfalls, which will affect the longevity of the plants and their production. Heavy rainfalls can also cause flooding, making the fruits rot. Unlike palm tree plantations, forest fires are not a great threat to cocoa tree plantations in Indonesia as plantations are small scale and farmers do not fire the land to clear the land. Also, intercropping is often practised in cocoa plantations in Indonesia, contributing to increasing resilience. Strong winds can have an impact on pollination and fruit harvesting. In the case of coffee plantations, frosts can ruin the harvest (high altitudes), as coffee plants need temperatures between 15-24 C and altitudes between 1000 and 2000 m. The shade tree *Leucaena leucocephala* is planted to protect coffee trees.

The most important improvements are nutrient retention, prevention of soil erosion and carbon sequestration. Landslides are also prevented as the hydric balance is maintained. Cacao agroforestry in buffer areas helps preserve soil macrofauna and biodiversity. Farmers use biopores to retain moisture in dry periods, producing organic fertilisers. This technique increases the quality and quantity of yields in coffee and cacao plantations.

There are also several risks unrelated to climate risk, such as the conflict between stakeholders. The land tenurial and organisational authority between stakeholders must be made clear. Previously, the lack of clarity in tenurial land authority has resulted in illegal forest utilisation by the rural community around the forest. The lack of clarity in the various governance levels has also hindered the growth of community-based climate change action initiatives due to the lengthy funding application or land use permit procedure.

4.2.5 Economic implications

Currently, the forest has a different purpose economically. Permanent forests, protected forest areas, and forest reserves (for flora and fauna) are not economically important as they do not function economically. However, they have high economic potential as they provide ecosystem services that are still underappreciated. These services are still unaccounted for due to the insufficient data, method, and in-depth analysis that could be brought to relevant stakeholders to invest in natural ecosystem maintenance and enhancement projects (A. Wibowo, personal communication, May 6, 2021).

Furthermore, economically, production forests, convertible production forests, and agroforestry are beneficial. The production forest could produce fast-growing woods such as sengon (*Albizia Chinensis*), bamboo (various species, i.e. *Bambusa* sp. or *Gigantochloa* sp.), and high-value wood such as meranti (*Shorea* sp.) and jati (*Tectona* sp.). In 2018, the production of Indonesian timber forest profited as much as 11,815.56 Million USD (World Bank, 2021). Local communities can benefit from direct and indirect incentives for the programmes with community involvement.

Agroforestry provides short-term income through seasonal and annual crops and essential oils. This practice has the potential for long-term income through lumber (Do et al., 2020). In many practices, high-priced wood such as teakwood (*Tectona grandis*) is considered an individual asset that could be utilised for pension (Pramono et al., 2011). In addition, agroforestry helps create various products in one area, such as coffee and cardamom, requiring shade to grow. Another opportunity also arises when the cardamom market demand increases. On one of the pilot projects, we found that the crops not intended as the major commodity of agroforestry would also result in a new opportunity. Besides, another opportunity might also arise from the international market, in which the export of agroforestry products could be beneficial (A. Hani, personal communication, May 4, 2021).

Another economic value is that the forest form of land use requires low to no nutrient input as they rely on local nutrient cycling. The land managers of production forest and agroforestry do not have to put too many inputs, reducing their reliance on added nutrients. Furthermore, non-production forests such as the National Parks area could also be developed into eco-tourism areas, such as the butterfly as the main attraction in Bantimurung (Sulawesi), Bali starling (*Leucopsar rothschildi*) in West Bali, Komodo Island (East Nusa Tenggara), and savanna in Baluran (Java). However, other factors, such as pollution and habitat disturbance, must be accounted for (Hakim, 2017).

Within the climate change mitigation actions, there are monetary and non-monetary incentives under MOEF for stakeholders who want to participate. For example, there is direct monetary support to initiate climate mitigation action with forestry. Besides, there is an incentive for agroforestry initiatives in seedlings and other facilities. The costs of the LMT implementation have been formulated and budgeted by the Fiscal Policy Agency, Ministry of Finance. BAPPENAS now initiates the implementation of investments in forestry within the governmental sector through their green growth investments. The investments would focus on helping to fund green initiatives that focus on environmental sustainability. Through the modelling done under the current EU Emission Trading Scheme on Indonesian forest, the trade of carbon sequestration in forestry would also potentially increase carbon storage by up to 22% under governmental management (Indrajaya et al., 2016).

4.2.6 Co-benefits and trade-offs

Risks

Permanent forests, protected forest areas, and forest reserves provide high environmental services. However, land use is not flexible, and direct utilisation is prohibited. This limitation in use would also result in a lack of direct benefit reaped by the smallholders and the rural community (Wani & Sahoo, 2021). This would lead to the limitation of livelihood strategy by smallholder farmers and the rural community, making them more vulnerable.

When the scale is too large, revegetation and reforestation generally fail. The average size of a WWF (World Wide Fund for Nature) pilot project is 50 to 100 acres (Z. Warta, personal communication, September 27, 2021). The most difficult aspects of this endeavour are sprouting, planting, and caring for the seedlings. Other obstacles include the inability of technology to achieve adaptation/mitigation objectives. During the dry season, peatland initiatives frequently fail because of dryness and fire danger. Therefore, hydrological and season assessments are necessary to prevent failure. This approach includes a component of assisted revegetation to ensure its success. Rarely is mitigation required in regions with poor infrastructure since the land is deemed pristine. In addition, afforestation poses fewer hazards than rewetting peatland in achieving mitigation objectives.

In addition, micro-level regulations, such as technology, are poorly conceived. In addition, it is preferable to decentralise data integration and funding. This gives local governments greater flexibility over the allocation of financing and incentives. If the data between the landowner and national/international governments are connected, incentives can be offered. By decentralising this initiative, local governments can improve the effectiveness of their interventions. Importantly, conservation or restoration programmes must be site- and objective-specific (Harrison et al., 2020).

The Job Creation Act strengthens the one-map policy. However, execution is inconsistent because it depends on the motivation of each government. Numerous specialised policies and objectives exist in the forestry and peatland industries. However, executing these rules and objectives would be difficult due to complex factors (environmental, social, and political issues). Changes in policymakers also impede the implementation of the LMT. After the transition from centralisation to decentralisation in the forestry and peatland sectors, all decision-making will occur at the provincial level. The capability of the stakeholders will be the focal point of this implementation.

On the other hand, community dissemination is required to get community engagement. Without information, it is less likely that the community will be utilised. For example, if the infrastructure developed impedes boat traffic, the community will not hesitate to demolish it. It will take time to introduce and disseminate the technology to the community. As forest and peatland management communities are located in rural locations, they must learn more about new technologies. In addition, there is financial and informational inequality because only some communities can access them. The issue of gender also plays a role. Additionally, technological adaptation is required to ensure the project has no negative effects. Some community members are not receptive to new technology or practices that will cause them to alter their behaviour.

Co-benefits

Forests would benefit from various ecosystem services compared to other land use types such as settlement and agricultural areas. The forest has the potential to sequester more carbon within the woods and soil. The forest could also be beneficial to provide water and nutrient cycling for other land-use types of surroundings (Wani & Sahoo, 2021). The forests also provide other environmental services, such as indirectly housing the hyperparasites that could help control pests in the agricultural area. The diverse forest could provide more niches for higher diversity and further develop a more stable ecosystem. A more stable ecosystem would have higher resilience towards various climate risks (Meli et al., 2019).

Utilising degraded areas with forestry would also require longer time and more research. Naturally, it would require succession to reforest the field. However, planting fast-growing and resistant trees such as sengon (Albizia Chinensis) would make the reforestation process shorter (Prach et al., 2007). The canopy of this tree could create shades to the adjacent seedlings with longer growing times. After the shading facilitation stage, the sengon wood could be harvested and sold later. Ultimately, sengon as the intermediary tree will result in faster economic return while facilitating the forest's growth.

Based on its use, production forests, convertible production forest, and agroforestry could help increase the livelihood of society directly through various activities. In the agroforestry sector, sustainable management practices, i.e. intercropping (*tumpang sari*), can reduce the overall cost of fertilisers, irrigation, labour, etc. These practices could also reduce the risk of weed growth, pest and disease infestation due to the mutual relationship within the crop, resulting in better farm management and increased farmers' income. Agroforestry is considered to have higher economic value for the community. For people with other sources of income, cultivation of the land can be reduced so that the land area is not required to be productive throughout the year. However, seasonal farming is considered more profitable for people who depend heavily on the land because they need income for the seasons (A. N. Armanto, personal communication, April 22, 2021).

Afforestation of agricultural land is supported by agricultural policy to make agriculture more environmentally friendly. Both production forests – aimed at generating wood – and food forests - directed at producing food – can be realised. Promoting agroforestry in Indonesia could increase tree coverage absorbing as much as 30 million tons of carbon (Kahurani and Finestone (2017). Integrating forestry and agriculture, in our case studies are cacao and coffee farms, delivers certain benefits over the conventional way of land use, such as:

- Increase in spatial diversity and biodiversity

Agroforestry allows for a more attractive habitat for insects, birds and other animals. It enhances habitat diversity to support organisms in addition to naturally occurring co-benefits, such as enhanced nutrient cycling, integrated pest management, and increased resistance to diseases.

- Increase in soil structure and health

Planting trees and shrubs into annual cropping systems can protect the exposed land and soil from wind stress and strong precipitation. The transition from agriculture to agroforestry can increase soil organic carbon by 34% on average (Pennsylvania State University., 2018). Additionally, agroforestry increases root diversity that feeds the living organisms within the soil.

- Carbon sequestration and sink

Agroforestry permanently increases the absorption of CO2 permanently from the atmosphere in soil organic matter and thereby stores it effectively, contributing to climate change mitigation.

- Alternative sources of income

Agroforestry may generate an alternative income source for land users if benefits exceed costs. These benefits may originate from both product revenues and reimbursements for carbon storage.

- Food Security

Agroforestry would work as a carbon sink in Indonesia and could have several other beneficial impacts on agricultural systems and food security. It can help systems adapt to greater climate variability by enhancing the structural and temporal diversity of the production system, promoting resilience to shifts in temperature, precipitation variation, and strong winds producing more favourable crop conditions.

Trade-offs

To encourage farmers to adopt agroforestry, programs should also be executed, as agroforestry is considered not economically beneficial in the local market. Funds and resources would be required to help farmers and initiatives to start these activities. It would require capital to develop agroforestry and require yields, which are economically beneficial commodities. Other than that, products grown in this sector could be sold at a higher price in the international market through agroforestry recognition was environmentally good practice. The product or crop certification can improve the value (Zinngrebe et al., 2020). Besides, some risks need to be addressed. In Java Island, for example, the demand for residential and industrial land is still high, and the price of selling land for housing is very high compared to the income obtained from producing food. On the other hand, there is a risk of the so-called emission leaking or emission displacement where local farmers move from protected forest land (due to REDD+) to currently unprotected forest areas. That activity can lead to forest degradation or deforestation as firewood or timber collection (I. W. S. Dharmawan, personal communication, May 6, 2021).

4.2.7 Risks associated with scaling up

Indonesia is a vast country; therefore, applying a method on the national level is often difficult. For example, it is impossible to create just one recommendation on the national level regarding agroforestry, wood standing and crops, as success in one area might fail in other irrelevant areas. Many regions also still have access to the market to be able to sell their produce. On the other hand, while the nutrient efficiency might be higher, as it requires less input, the yield might be lower than the conventionally produced goods. Therefore, there is a lower income if the products have to compete at the same price as conventional goods. While expanding the HCV and HSV areas in the degraded area will be desirable, it might require a long time to develop. Therefore, the expected ecosystem services will not be directly beneficial.

Scaling up can be difficult at the policy level because each government sector has different focus concentrations. Each sector has different priorities regarding what projects each sector will develop. Each forest region has unique characteristics, so scaling up a programme might pose risks unrelated to management. In the agroforestry sector, the practices would differ in each region and be specific to the local geographic and socio-economic aspects. It should always be initiated with a diagnosis stage (land mapping, social mapping on what is preferred by the society, the market access) and design. The design stage includes what crops to grow, what trees would be able to be sown, and how the crops are to market (A. Hani, personal communication, May 4, 2021).

4.2.8 Research Gaps

One of the biggest challenges in climate change mitigation in forestry is to provide useful, accurate and reliable data. This is because the verification ability is insufficient, the effectiveness of the selected method is often doubtful, and the data analysis is not enough. In addition, the data and how we present it should be able to convince stakeholders to be more eager to participate in Indonesia's green investment. Climate change adaptation activities can benefit the environment socially and economically.

On the national level, Indonesia also requires mapping every risk caused by climate change to implement relevant plans in relevant areas. This activity was conducted because Indonesia has a vast territory and diverse natural conditions, so there is no universal solution for implementing climate change adaptation activities. In the future, a clear system will need to be developed to support development towards adaptation and mitigation of climate change. In the future, developing a clear system to support movements towards climate change adaptation and mitigation is also needed.

Furthermore, the competitive business model of LMTs in the forestry sector also needs carbon pricing implementation with clear guidelines. Forestry research has been widely carried out in Indonesia, but forestry research on how the role of the new futuristic forest function has not been explored much. For example, currently, the main view of the forest is wood, habitat or landscape. If wood is lost, environmental services are lost, and environmental services are limited to the loss of woody trees in the forest. In the future, it is hoped that the analysis of biomaterials, alternative microbes, and other resources in the forest can be carried out. The hope is that when the awareness that there is another potential from forests besides food, fibre and fuel, stakeholders will defend the forest to maintain carbon and potential for future civilisation (Y. Rochmayanto, personal communication, May 5, 2021).

Besides, the government must ensure that local communities receive incentives proportionally to what they have done—identifying an appropriate indicator that can show direct relations between what the locals have done to LMT. It is important to address institutional arrangement issues at the local government level. For instance, there is a need to improve the readiness of local government institutions to implement monitoring and evaluation as well as reporting climate mitigation achievement. The percentage of local regions that report their emission reduction through AKSARA (a platform for city and provincial governments to report their emission reduction) is still low (I. W. S. Dharmawan, personal communication, May 6, 2021).

Furthermore, the National Forest Monitoring System must monitor and supervise operations executing FOLU sector mitigation efforts towards the 2030 net sink, following PP23/2021 on Forestry Implementation (NFMS). Norms, Standards, Procedures and Indicators (NSPK) for controlling, monitoring, assessing, and reporting on the execution of mitigation actions for emission reduction from the land and forestry sector would increase the monitoring of mitigation actions in the FOLU sector (FOLU). In addition, it is a component of the Geospatial Information Network (JIG) of the MoEF and is integrated with the National JIG. This activity entails regular institutional monitoring of reporting plans and implementation of emission reduction initiatives and their accomplishments.

On the other hand, Indonesia has a long history of forestry sector capacity-building collaboration. In the past two decades, there has been an increase in forest and climate-related capacity-building programmes, both as stand-alone programmes and as part of a broader scope of collaboration. To support the achievement of the FOLU Net Sink 2030, international support for capacity building under the Paris Agreement (UNFCCC) and forest-related Conventions will continue to be mobilised.

The research will be crucial in supporting the FOLU net sink 2030 implementation. Indonesia will enhance research collaboration between domestic universities and national institutions with overseas partners. Regarding technological advancement, Indonesia will bolster indigenous technology's role while pursuing technological cooperation opportunities within the Paris Agreement and Convention.

4.3 Peatland management

4.3.1 Introduction

Peatland covers 20.6 million ha or 10.8% of the total land area in Indonesia. Peatland and forestry are the main sectors of NAMA and NAPA programs. Data from MOEF reported soaring figures in carbon emissions from peat fires and peat decomposition. Emissions peaked in 2015 due to extreme warming effects attributed to *El Niño*, wherein peatland fires and decomposition contributed to 802.87 million TCO_2e and 359.52 million TCO_2e, respectively (Table 4) (MOEF, 2020). Aside from natural phenomena such as *El Niño* that frequently triggers fires and decomposition, human activities such as peatland clearings and conversion contribute to the increased vulnerability of peatland. Those activities make forests and peatlands more prone to fires and decomposition. Within the last decades, 6 out of 14.4 million ha of peatland has been converted from natural peat forests into agricultural land and industrial plantation (MOEF, 2017).

Control of peatlands, which includes water level management and restoration, is the primary mitigation measure that determines the forest and land sector's performance in becoming a net sink. Through Minister of Environment and Forestry Regulation No. 15 of 2017, PBPH and HGU authorize landowners in peat ecosystems to maintain the water level of peatlands in their territory to no more than 40 centimetres by enhancing the peatlands' water system. Maintaining the water level as a mitigation measure will lower emissions relative to the baseline water level for commercial crop development. It is predicted that 0.95 million hectares will need to install a good water management system by 2030 to meet the net sink goal.

Restoration activities include rebuilding peatlands by blocking or filling canals, followed by revegetation or planting crops adapted to peatlands' natural properties (paludiculture system). Following the successful implementation of restoration works, the risk of emissions from fires and peat decomposition will decrease. To accomplish the aim set for peat restoration, the area must increase by 2.72 million hectares by 2030. The implementation of restoration works has only reached 0.83 million hectares by the end of 2019. (i.e., there are still around 1.887 million hectares that must be restored by 2030). The research suggests that the potential area for carrying out restoration work is dispersed among forest areas and concessions, both inside and outside (Ministry of Environment and Forestry (KLHK), 2022).

Table 13 Changes in peatland area, peatland area impacted by fire, degraded peatland area, and emissions produced

Year	Peatland area (ha)	Peatland area impacted by fire (ha)	Associated emissions (tCO2-eq)	Area of degraded peatland by biological oxidation (ha)	Associated emissions (tCO2-eq)
2001	1,263,637	109,638	33,421,181	85,987	307,128,896
2002	2,250,157	613,303	179,920,945	238,235	308,503,274
2003	2,030,537	249,046	62,299,323	228,510	309,816,441
2004	2,338,964	410,989	97,093,898	284,551	312,987,663
2005	2,167,285	343,905	77,267,691	350,129	316,588,324
2006	2,951,553	796,588	182,619,459	524,131	319,823,569
2007	2,027,415	113,318	22,315,312	262,858	321,767,378
2008	2,073,015	127,648	24,797,451	274,848	324,341,906
2009	2,527,155	483,517	92,761,804	409,098	327,690,706
2010	1,501,311	89,281	14,701,421	202,130	329,794,183
2011	1,635,292	331,484	57,340,566	258,214	332,869,828
2012	1,507,028	352,500	56,689,395	261,759	334,793,736

To address this problem, MOEF established the Peatland Restoration Agency (BRG) in 2016 to manage and facilitate peatland restoration in seven priority provinces, which make up around 40% of the nation’s total land area: Riau, Jambi, South Sumatra, West Kalimantan, Central Kalimantan, South Kalimantan, and Papua. Peatland restoration, which includes three main activities, known as 3R – Rewetting, Revegetation, and Revitalisation, plays roles in preserving and enhancing carbon stock in peat biomass (BRG, 2016). The followings are the detailed explanation for each activity (B. Wardhana, personal communication, May 4, 2021):

Rewetting

Rewetting is important to ensure the required standard of water level is constantly maintained. It aims to prevent excessive drainage (droughts), which can ultimately lead to fires; in the worst scenarios where fire occurs at the surface vegetation, as long as the bottom layer is wet, carbon-rich peat in the bottom would not catch fire. By considering its role in preventing peat fires, rewetting contributes to climate change mitigation by preserving carbon-rich peatlands. 2.5 million ha of peatland will be subjected to rewetting by 2020 to restore its hydrologic characteristics by maintaining peatland surface water level and groundwater table, especially during drought periods (BRG, 2016). Also, rewetting could minimise the risk of peat fires and restore peatland to its original condition.

Revegetation

Revegetation is planting or replanting endemic vegetation in a peatland area. Vegetations above the peatland are the source of biomass that form peats. Peat formation is the result of the incomplete decomposition of accumulated vegetation biomass. Therefore, without vegetation, peat would not be formed. This means revegetation is a form of carbon sequestration, starting with plants' natural carbon capture and then carbon storage when peat mass is formed. Hence, revegetation contributed to climate change mitigation by enhancing carbon stock—the target of revegetation by 2020 covers 670,000 ha of peatland (BRG, 2016).

Revitalisation

Revitalisation is a set of actions to ensure that any economic activities performed on or around the peatland area are well-aligned with the peatland preservation. Many local farmers use peatland to plant commodity crops in Indonesia. The problem arises when farmers purposefully convert peatland into dry land (mineral land) to plant crops that can only thrive in mineral land. This conversion would usually lead to fires from overly drained peatland. In order to prevent peatland conversion and unsustainable management, BRG relies on revitalisation programmes that aim to ensure that farmers that plant commodity crops on peatland always maintain the water level. If plants do not grow well under wet conditions, farmers are advised to convert to plants that favour peatland. By 2020, 185,000 ha of peatland is targeted to be restored for economic purposes (revitalisation activities). Planting commodity crops suitable to the wetland is also called Paludiculture (BRG, 2016).

BRG has been helping farmers by introducing alternative crops that thrive in wet soils. Also, under the revitalisation umbrella, BRG aims to increase sustainable peatland governance and management among the locals by introducing Peatland Care Village, a community-based peatland management programme. Initially, there were only 700 villages, but the number surged to 1000s villages. Besides, this programme also contributes to increased local climate adaptation and resilience since farmers can plant various crop commodities instead of single-crop dependence. Also, this programme can contribute to an improved local economy since BRGM also supports and helps local farmers to market the commodities from paludiculture (B. Wardhana, personal communication, May 4, 2021).

The three NDC scenarios for the forestry and land sector (BAU, CM1, and CM2) are based on the same socioeconomic assumptions, such as the rate of national economic development and population growth. The variables that differentiate the three scenarios are the mitigation policy assumptions and the degree of mitigation measures, which impact the land use dynamics in each scenario. The mitigation measures implemented for each NDC scenario are displayed in Table 14.

Table 14 Area targets for implementation of NDC mitigation actions

No	Action	Scenario	Annual Average	Cumulative			
				2013-2019	2013-2024	2013-2029	2013-2030
1	Mineral Land Deforestation Rate (000 hectares)	BAU	802	6,023	9,956	13,692	14,433
		CM1	400	3,183	5,056	6,837	7,193
		CM2	229	2,081	3,072	3,943	4,117
2	Peatland Deforestation Rate (000 hectares)	BAU	61	408	668	1,025	1,104
		CM1	4	32	56	72	75
		CM2	2	19	28	32	33
3	Mineral Land Degradation Rate (000 hectares)	BAU	818	6,114	10,129	13,960	14,721
		CM1	400	3,191	5,065	6,848	7,205
		CM2	233	2,110	3,124	4,022	4,203
4	Peatland Degradation Rate (000 hectares)	BAU	62	410	672	1,030	1,109
		CM1	4	33	56	73	76
		CM2	2	20	29	33	34
5	Sustainable Forest Management (000 hectares)	BAU	23	83	202	369	409
		CM1	170	647	1,542	2,773	3,058
		CM2	321	1,276	2,982	5,265	5,784
6	Rate of Non Rotational Rehabilitation (000 hectares)	BAU	97	680	1,166	1,652	1,749
		CM1	104	727	1,246	1,765	1,869
		CM2	173	1,211	2,076	2,942	3,115
7	Rate of Rotational Rehabilitation (000 hectares)	BAU	110	769	1,318	1,867	1,977
		CM1	173	1,211	2,076	2,942	3,115
		CM2	156	1,090	1,869	2,648	2,803
8	PBPH Development Rate (000 hectares)	BAU	150	1,050	1,800	2,550	2,700
		CM1	320	2,240	3,840	5,440	5,760
		CM2	320	2,240	3,840	5,440	5,760
9	Peatland Restoration (000 hectares)	BAU	-	-	-	-	-
		CM1	70	489	837	1,186	1,256
		CM2	156	1,091	1,871	2,651	2,807
10	Peatland Water System Improvement (000 hectares)	BAU	-	-	-	-	-
		CM1	-	634	864	864	864
		CM2	-	749	864	864	864

Referring to Article 4 of Decision 1/CP.21, Paragraph 2, the NDC is the heart of the Paris Agreement and a promise that must be met by ratifying countries, which must be reaffirmed every five years. In the meantime, the Long Term Strategy (LTS) is a country's long-term vision or aim for achieving the 1.5°C temperature target. In this instance, the achievement of the LTS target (Table 15) considers the national conditions on a national scale and the worldwide context of emissions, which are global externalities (Ministry of Environment and Forestry (KLHK), 2022).

Table 15 Mitigation action targets for NDC-CM1 dan LTS-LCCP (000 ha)

Mitigation action	NDC CM1			LTS-LCCP		
	2013–2020	2021–2024	2025–2030	2013–2020	2021–2024	2025–2030
Deforestation on minela land	3.638	1.418	2.136	2.279	675	1.019
Deforestation on peatland	36	19	20	145	43	65
Degradation of concession forest	NA	NA	NA	1,320	385	578
PHL	798	1.542	3.058	1,010	1.413	2.207
PBPH-HT	2.560	1.280	1.920	2.560	1.280	1.920
Rotational RHL	831	415	623	1,004	502	753
Non rotational RHL	1.384	692	1.038	1.115	558	836
Peatland water management	713	864	864	624	785	946
Peatland restoration	558	279	419	1,140	579	728
Integration of livestock with plantation and forestry	NA	NA	NA	1,280	580	812

4.3.2 Policy context

Climate Agreement, International Treaties, and Peat Plan

In the national context, the primary national policy that regulates peatland restoration is Law No. 32/2009 on Environmental Conservation and Management Law, including peatland conservation and management. There are also UNFCCC agreements and guidelines that the Government of Indonesia has ratified. Another international policy ratified in Indonesia is The Ramsar Convention on Wetlands of International Importance, especially as Waterfowl Habitat, an international treaty for the conservation and sustainable use of wetlands originally aimed to preserve habitats for migratory birds. Ratification of The Convention on Biological Diversity, informally known as the Biodiversity Convention, is also one of the key policies that address peatland restoration (B. Wardhana, personal communication, May 4, 2021).

To reduce emissions from peat decomposition and fires, peatland management operations should be conducted by enhancing water management and restoration (rewetting, revegetation/rehabilitation/revitalisation, and revitalisation). Priority is given to improvements in water management in PBPH and HGU with plantation woods and plantation agriculture, respectively. Priority places for restoration initiatives are peatlands with high IPL in all forest functions. For land with an unproductive land cover, the activities aim to restore the peatland by rewetting the soil, allowing for natural or enhanced forest regeneration. For sites the community has used for seasonal and perennial crops outside of concessions, the activities focus on restoring the land through developing a paludiculture system.

Institutional Foundation

BRGM is the executor of land-based mitigation in the peatland sector. Through Presidential Regulation No. 57/2016 (later amended to Presidential Regulation No. 17/2014), the President of Indonesia mandated the formation of BRG. Besides, its role refers to Presidential Regulation No. 120/2020 on Peatland and Mangrove Restoration Agency (JDIH BPK RI, 2019). This cross-sectoral agency is responsible for implementing programmes to conserve and restore degraded peat ecosystems and facilitate all sectors implementing peatland-friendly activities. In December 2020, BRG was extended to include mangroves (hence BRGM), another carbon-rich ecosystem. BRGM now works in 13 provinces adding six mangrove-rich provinces of North Sumatra, Riau Islands, Bangka-Belitung, East Kalimantan, North Kalimantan and West Papua (B. Wardhana, personal communication, May 4, 2021).

Peatland Restoration Targets

In the strategic planning of BRG in 2016-2020, there are three restoration targets, i.e. restoration of hydrology and socio-economic capacity of peat ecosystem, protect peat ecosystem for life support and sustainable peat management. BRG targeted to restore a total of 3.35 million ha of degraded peatland by the end of 2020, consisting of 2.5 million ha from rewetting, 670,000 ha from revegetation, and the last 185,000 ha revitalisation programme (BRG, 2016). By the end of 2020, BRG had managed to restore 25% of its target (835,288 ha). With the four-year extension from 2020-2024, BRGM has additional time to hit the target while also rehabilitating 600,000 ha of degraded mangroves (MOEF, 2020).

Main Actors

From the regulator side, besides BRGM and MOEF, another ministry whose sector is highly interrelated with the peatland restoration MPW (Ministry of Public Works). Within MPW, Water Resources Division covers the peatland's water supply for rewetting programmes. Besides, MPW provides irrigation and drainage for peatland utilised for cultivation (paludiculture) (B. Wardhana, personal communication, May 4, 2021).

Landowners are also among the key stakeholders in peatland restoration. Landowners whose land contains peat are mandated to maintain and monitor the peatland water level. The monitoring and enforcement mechanisms are regulated in Perpres No. 16 2016, which mandates landowners to report the water levels to MOEF biweekly. If their water levels are not up to standards three times a row, MOEF will take over their peatland to restore it to its initial condition. Local communities, including indigenous people, also hold social forestry in Peatland Care Village. They are the implementers of LMTs in the peatland sector at the local level. Lastly, private companies also play important roles in restoring peatland within the ecosystem restoration concessions (ERC) area (please see section 4.3.5).

Funding

The main source of funds comes from the government budgets, either from the central government (APBN), provincial government (APBD) or local government (APBDesa). At the local level (village level), an additional budget is dedicated exclusively to peatland restoration called PRORATA, which has allocated 1 billion IDR annually for each peatland-rich village since 2017. In addition to public funds, there is financial support from bilateral/multilateral donors and international aid agencies. Since 2016, a total of 50 million USD has been garnered from international donors. Besides that, non-fiscal funds are the National Government mandate funding initiative under the Ministry of Finance. Lastly, there is also funding for various proposal-based activities, where the funding can be accessed by various parties, including NGOs and the community, with certain proposals and certain targets.

4.3.3 Current land use and potential land-use competition

Historically in the 1980s, peatland was massively converted for agricultural land. This was attributed to the transmigration programme that mass-transfer people from Java island to less-populated islands. Many of these migrants were farmers who demanded vast agricultural land. In the 1980s, a policy regulating primary forest conversion (non-peatland) to HTI (Industrial Plantation Forest) was issued. However, in the 1990s, due to mineral land being scarce, a new scheme was issued that allowed peatland conversion to HTI. Since 2010, the competition between HTI expansion with peatland conservation was no longer happening due to the low demand for HTI commodities, e.g. timber. The timber market entered stagnancy due to the increased use of artificial woods (wood composites), reducing demands for land (B. Wardhana, personal communication, May 4, 2021).

In addition, current and future land-use competition are also non-existent since 2018 due to the revision of the 2011 Forest Moratorium Law. That regulation previously only halted the issuance of new permits for primary forest and peatland conversion to the complete termination of new permit issuance. The President Instruction now regulates this (Inpres) No. 5/2019 on Termination of New Permit Issuance and Amendment of Primary Forest and Peatland Management, a revision of its preceding policies – Inpres No. 6/2017 and No. 10/2011 on Halting of New Permit Issuance and Amendment of Primary Forest and Peatland Management (Ditjen PPI KLHK, 2021). The main competition of the peatland sector includes agricultural expansion, mainly oil palm plantations. In addition to agriculture, peatland conversion is risky for infrastructure development. However, due to a more collaborative relationship between BRGM and MPW, MPW has always pledged to avoid peatland construction.

Farmers are frequently lured to cultivate palm oil due to market demand. Consequently, peatlands are dried to make room for palm oil plantations. Land use competition occurs, and implementing permission policies or moratoriums might be problematic. Furthermore, human activities such as intense drainage alter the ratios of CO2 and CH4 emitted by peatlands (Landry and Rochefort, 2012). Moreover, higher temperatures will result in a greater loss of these two gases (Landry and Rochefort, 2012). Low emission reduction will be a danger in this sector as a result.

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4.3.4 Climate risks & sensitivities

Peatland is most sensitive to *El Niño*, which usually causes prolonged drought seasons and extreme temperatures. However, no matter how dry the peatland is, it would not cause fire unless it is intentionally lit. The human factor is much more prevalent than climate-related changes, such as extreme temperature, and human activities have been reported to cause 99% of peat fires in Indonesia. Additionally, sea-level rise impacts peat ecosystems negatively, while impacts from floods could be positive or negative depending on the salinity level of floodwater. Floods that bring water from rivers benefit peat ecosystems as floods can provide favourable conditions for peat formation and maintain water levels. However, when the floods come from the sea, salt-concentrated seawater could decompose peat masses, and as a result, the remains will get flushed off with the water. Storms, tropical cyclones, increased weather variability, erosions and landslides can destroy peat ecosystems/landscapes (B. Wardhana, personal communication, May 4, 2021).

The government has paid more attention to peatland due to increased fire activity. Peatlands are drained for several reasons, including a stabilising substrate for construction, increasing soil productivity, or supporting heavy machinery for industrial activities (Landry & Rochefort, 2012). To protect Indonesian peatlands, the government released a new policy under Government Regulation no. 57, where peatlands below 3 meters can be used for cultivation. In comparison, peatland above 3 meters is protected. Drought is as important because dried peatland has a higher risk. Also, drought can cause peat fire. Lastly, flood is a huge risk because drained peatland has a reduced ability to absorb water. Consequently, the water level will increase. As a result, surface runoff and flooding occur when precipitation intensity is high (N. Priyono, personal communication, September 15, 2021).

Loss of biodiversity is also one of the biggest threats to peatland since peat is formed from vegetation remains in the first place. When vegetation biodiversity was lost due to monoculture vegetation or overharvesting, there would be less chance of peat formation. Besides, since vegetation in peat ecosystems is also a habitat for migratory birds, and birds can indirectly and directly provide nutrition for peat vegetation, loss of bird biodiversity could significantly impact peatland (Y. Rochmayanto, personal communication, May 5, 2021).

Tropical peatlands are carbon-dense systems suffering from drainage recently, leading to high GHG emissions and a high risk of fires in peat soils. The fire risk can be reduced by re-establishing hydric balance in peat areas. Peatlands can be restored by raising the water level, re-vegetating and implementing paludiculture. Climate risk factors are fire, droughts (increase in the risk of fire and GHG emissions) and floods, as drained peatlands have a limited capacity to absorb water, increasing the water level and risk of surface runoff.

4.3.5 Economic implications

Presently, policies regulating carbon's economic value are not in place yet. Therefore, there is still no valuation of peatland restoration. However, based on REDD+, mitigation activities can reduce emissions while contributing to the local economy (result-based payments). Local communities can participate in restoring peatland and getting payments based on results (A. N. Armanto, personal communication, April 22, 2021). In addition, many companies venture into a profitable carbon farming business from peatland restoration by trading their stored carbon in voluntary carbon markets. PT Rimba Makmur Utama is a private company that runs such a business. In Indonesia, there are 15 ecosystem restoration concessions dedicated to peatland-based carbon farming.

4.3.6 Co-benefits and trade-offs

Changes in agricultural production

Peatland restoration has co-benefits with agricultural production in terms of increased variety of commodity crops. Several crops can grow naturally in the wetland. For instance, transmigrated families (Javanese) used to plant mineral-land-grown paddy converted to farming wetland-grown paddy in their peatland-dominated destination regions. Javanese paddy can only grow in mineral land due to the absence of wetlands on Java island (B. Wardhana, personal communication, May 4, 2021).

Landscape changes

Peatland restoration is also beneficial for landscape development since designing the landscape for peatland, e.g. channel construction needs to consider peat hydrologic law. So, all designs need to ensure that water will flow naturally (slope-like landscape) from the dome (upstream) to downstream. When the landscape is poorly designed, causing downstream peatland to dry out, there is a higher risk of fires.

Biodiversity

The risks and co-benefits between peatland and biodiversity are explained in section 4.3.4.

Nitrogen emissions

Peatland restoration will also reduce nitrogen emissions long-term through nitrogen fixation. However, within the first few years (e.g. three years) of peatland formation, nitrogen emissions are usually peaking due to increased fertiliser uses and the outputs of biodigesters. Similar effects also apply to methane emissions.

Water quality/quantity

One peatland's ecological role is to control the water cycle and retain water during drought, especially in the downstream area.

Local economy and social capital

On top of ecological and agricultural co-benefits, peatland management, especially under revitalisation, can contribute positively to the local economy and economic independence through paludiculture and carbon farming. Also, community-based peatland management activities have patched up a close-knitted society among local communities through collaborative programmes such as Peat Care Village. This program will eventually lead to increased entitlement or a sense of ownership among local communities, which will help prevent land-related conflicts.

Other Risks

The greatest threats are infrastructure and technical obstacles. To regulate the water level in peatlands, it is necessary to construct a water gate, canal, or dividers. During the dry season, the gate is closed to provide moisture for the peatland. This technique has a negative effect on the local population, as people will be unable to access water during the dry season. In addition, the greatest risks stem from technical mishaps, scalability, and the failure of LMT to meet mitigation targets, as there are hazards of drought, peat fire, and flood if the peatland is not rewetted. LMT implementation will depend on regional circumstances.

The government bears a significant percentage of the risk. The first factor is a lack of political support; it has been noted that massive fires occur around election times. It is assumed that this results from landowners receiving concessions to resolve land or land use permission concerns, and the candidate receives more votes. Second, political instability poses a significant threat since different presidents implement different policies. Fortunately, the president comprehends the issue's central and underlying mechanics. In addition, the period between governments (vacuum of power) also adds to political instability. Corruption poses an enormous threat to the adoption of LMTs.

The local government is responsible for protecting and managing peat bogs. Many municipal governments, however, refuse to act because they believe there is no return on investment. Since BRGM is an agency, its jurisdiction over policy execution is limited. BRGM primarily coordinates and facilitates the plan of the ministry. MOEF, for instance, expects BRGM to rehabilitate 83,000 hectares of mangrove. Peat Ecosystem Rehabilitation Plan is the current national policy for peatland restoration.

In contrast to the national policy, the provincial policy is the Peat Ecosystem Protection and Management Plan, which has a different substance. Other hazards include institutional misalignment, difficulties with policy execution, a lack of institutional legitimacy, and competing local and national stakeholder priorities. For instance, the national strategy cannot be applied locally since both levels prioritise conflicting growth objectives.

Furthermore, when revegetation is impractical, rewetting peatlands effectively reduces the risk of wildfire (Sirin et al., 2018). However, there is no connection between peatland rewetting (R1) and BRGM's revitalization (R3). Revitalisation employs peatlands for economic purposes, such as agriculture, cattle management, and paludiculture. BRGM approaches this issue via the lens of community development. The agency offers a programme to give crop cultivation, animal husbandry, and facilitators to the community. The majority of communities are glad to receive R3. However, once they no longer receive wages from pursuing R3, they prefer to abandon R1. This is a regrettable circumstance because R3 was intended to give compensation for declining agricultural yields. Risks include the lack of technology proximity to local populations, resistance to behavioural change, cultural resistance, the influence on daily life, and priority needs. Since communities are solely interested in raising their income through an instantaneous process, they do not wish to exert additional work, modify their behaviour, or alter their priorities to implement LMTs.

The greatest economic danger comes from trade imbalances. This is due to the gap between community business and infrastructure. The primary objective of BRGM is peat restoration, not community economic development. However, to accomplish this objective, community needs must be satisfied. As a result, trade imbalances will be the greatest threat, given that the market and a supporting system will be necessary to facilitate the environment. The second risk is market dominance/oligopoly. Farmers are dependent on middlemen. To eliminate middlemen, BRGM gives entrepreneurial training to farmers, enabling them to collaborate and market their products to cooperatives, Cooperation and Village-owned Enterprise (BUMDES), or Community Groups (POKMAS). However, this organisation has internal issues. In addition, product quantity and quality will positively affect farmers with enhanced knowledge and the ability to attract more clients. Farmers are also instructed on organising and utilising existing resources, such as social media and the marketplace. These actions will positively affect the peatland region's LMT implementation (N. Priyono, personal communication, September 15, 2021).

4.3.7 Risks associated with scaling up

There is a lack of homogeneity in peat characteristics across regions, e.g. Sumatera peat has different characteristics from Kalimantan counterparts. These differences are attributed to the historical events that led to basin-like area creation, which later provided a favourable microclimate for peat formation. Due to these differences, peatland restoration has to be tailor-made to each region's unique localities and characteristics. Scaling up local restoration actions to the national level will always possess risks associated with characteristic peat incompatibility (B. Wardhana, personal communication, May 4, 2021).

There is a risk of vertically uneven wetting in peatland rewetting, where the peat's top surface is dry while the bottom is wet. This would happen when the water balance in Peat Hydrological Unit (KHG) is not maintained, leading to fires. Besides, rewetting can also increase the risks of floods and groundwater quality around the peatland area is usually negatively impacted (A. N. Armanto, personal communication, April 22, 2021).

Farmers in peatland regions are less inclined to maintain water levels if they are not informed that dry peatlands have a greater risk of catching fire. Due to increasing revenue, farmers are more likely to cultivate seasonal crops than annual crops. Waste issues, technical difficulties, and scalability are possible dangers in the agriculture and agroforestry sectors. Waste segregation has not been fully implemented, and there are insufficient resources to scale up the LMT. In addition, there are possible dangers associated with using LMT to achieve mitigation and adaptation goals, as well as technological lock-in in the community due to a reluctance to implement new technologies/practices (A. Dariah, personal communication, September 15, 2021).

4.3.8 Research Gaps

The research gap in the peatland sector is not about the management practices (in fact, most studies on tropical peatland were conducted in Indonesia) but rather about instrumentations and tools, e.g. remote sensing and satellite imagery. There are very limited uses for those advanced instruments and tools. On the other hand, the government needs to ensure that local actors receive incentives proportionally to what they have implemented and improve the readiness of local governments to implement LMTs.

Tropical peatland is a carbon-dense ecosystem. However, anthropogenic activities such as forest clearance and peatland drainage lead to high GHGs emissions (Landry & Rochefort, 2012; Sirin et al., 2018). As a result, peat fires are more likely to occur (Sirin et al., 2018). The BRGM was initially formed to handle peat fires in Indonesia. One popular method to rehabilitate peatlands is restoring the hydric balance, as dry peatlands are prone to fires. To monitor the water balance in peatlands, BRGM installed 150 units of water balance monitoring sensors.

Although peatlands are wetland ecosystems (Sirin et al., 2018), soil protection techniques are important to protect peatlands. Additionally, the biodiversity and soil in peatlands should be protected as they are usually composed of specialised species. Maintaining the water level, revegetating peatland, and implementing paludiculture will reduce emissions and store carbon. The BRGM team analysed to identify phytodiversity, and they found that the top 10 cm is rich with micro-organisms and decreases with depth. Therefore, accurate peatland management is important to maximise the biodiversity potential of peatlands (Lunt et al., 2010).

4.4 Agriculture

4.4.1 Introduction

The agricultural sector is one of the country's highest priorities because it accounts for 13% of Indonesia's total greenhouse gas emissions. In addition, agricultural activities are extremely vulnerable to climate change. Meanwhile, climate change mitigation through agriculture is not the main focus of agriculture in Indonesia. Agricultural sustainability is important aside from production, and Indonesia's top priority is rice self-sufficiency or food security. All the activities focus on adapting to the ongoing climate change. Rice production is already declining, and BAPPENAS has estimated this trend to increase in the coming 20 years for all Indonesian provinces. Thus, field productivity should increase by implementing sustainable or carbon-negative schemes, such as land optimisation, organic fertilisers, and further related research and technological advancement (BAPPENAS, 2020a).

The adaptation and mitigation activities are executed in the Indonesian agricultural context to maintain and increase food production. However, mitigation activities are counted as co-benefits from adaptation actions in agriculture. The current agricultural activities focus on increasing the yield of important crops such as vegetables and rice through agricultural intensification. Climate change will result in lower soil health, a higher uncertainty in water availability, and erratic weather changes. An effort to be able to tackle these problems has been made. For example, to lower reliance on more water, the farmers are suggested to do intermittent flooding irrigation rather than flood the rice field the whole cropping period.

This adaptation activity would also benefit mitigation efforts, as the field will release less methane. The rice was only irrigated for a few days, which was considered important, such as the first 110 days of the rice development. The dry-wet irrigation method also reduces carbon emissions. The rice irrigation was cut up to 10 cm after each flood and would not be irrigated before the water level reached –15cm below the soil surface; each cycle lasted for 20 days. However, there is no further verification on how much area was assigned for the new novel crop or the alternative practices to know the real impact (Maswar, personal communication, May 3, 2021).

Aside from the intermittent flooding practices, The Agricultural Research and Development Agency (Balitbangtan) under MoA has also introduced other good agricultural management practices related to climate adaptation, i.e., water-efficient rice management through maintaining soil moisture and cover crop. Other activities, such as avoiding using fire for land clearing, using the otherwise burned straw for livestock feed, or increasing soil organic content, are also suggested for mitigation actions (Litbang Pertanian, 2020). Optimising land use, reducing intensification on vulnerable soil, and better livestock and manure management will benefit adaptation and mitigation. Furthermore, in some ways, Indonesia implements agroforestry as an LMT. First, intercropping or *tumpang sari* for the crop, plantation, and horticulture land. In less populated areas, agroforestry practice is implemented to improve land intensification and optimisation. Second, the complex agroforestry system utilises the forest margin and produces high-economy plantations, such as coffee, cacao, clove, and others (Dariah, 2020). MoA recorded 114.74 million tonnes of CO2 reduction in 2010-2019 (BAPPENAS, 2020a). Overall data on land-based mitigation practices in the agricultural sector is shown in Table 5:

Table 16 LMTs in the Agricultural Sector

Year	Potential Emission Reduction (ton CO_2eq)
2010	12,080,000[1]
2011	16,000,000[1]
2012	14,480,000[1]
2013	13,640,000[2]
2014	16,060,000[1]
2015	1,880,000[1]
2016	6,950,000[2]
2017	8,100,000[3]
2018	12,670,000[3]
2019	12,885,000[3]

4.4.2 Policy context

Policies and Regulations

Indonesian agriculture's main framework relies on 20 years of development planning from 2005 to 2025. This long planning term is further segmented into 5-year middle-term planning (RPJMN) of 2020-2024 (BAPPENAS, 2020b). Each RPJMN period has its importance, and for the agriculture sector, the main goal of the 2020-2024 term is to modernise and optimise current agriculture. The efforts include the development of infrastructure to increase productivity (Gregorio et al., 2015). Other than that, the Indonesian government also recognises the agricultural impact on climate change mitigation. Therefore, the effort to participate internationally in the climate change mitigation movements could be found, such as joining the 2017 Koronivia Joint Work on Agriculture (KJWA), Bonn, conference.

In 2007, Indonesia hosted the Conference of Parties (COP) 13 in Bali regarding climate change policy. This conference helped accelerate Indonesian commitment to joining the international effort to tackle climate change. Regardless of how Indonesia shows its commitment to tackling global climate change, Indonesia still has not formulated policies specifically on climate change mitigation in the agricultural

[1] Land Optimisation, Organic fertiliser and biopesticide, biogas from livestock waste
[2] Sustainable farm practice in degraded land, peatland management for sustainable farm practice, intermittent irrigation
[3] Agroforestry, intercropping, biochar

sector. In defining its framework, the government refer to National Action Plan for Climate Change Adaptation (RAN-API) and RAN-GRK (National Action Plan for Reducing Greenhouse Gas Emissions). These reports are known as NAMA (Nationally Appropriate Mitigation Action) and NAPA (National Adaptation Programme of Action) of Indonesia. In 2009, Indonesia voluntarily promised to reduce emissions by 26% by 2020. In 2015, this target was increased to 29% by 2030 (FAO, 2017)

Currently, no established policies, infrastructure, or system allows for tracing the mitigation impact in agriculture. The budget tagging system was introduced by the Ministry of Finance, with the supervision of other relevant ministries. The budget tagging method was initiated to assess how much fund is used to move towards more sustainable development. The Ministry of Agriculture's tagging method covers projects funded by national funding (APBN) or provincial/city funding (APBD) to enhance farm sustainability. Those programs are research, incentives for infrastructure that support sustainable agricultural practices, and knowledge transfer practices to adopt by the farmers through training (Halimatussadiah, 2020).

However, sustainable agriculture is a priority, with policy recommendations increasing agricultural land productivity by 4.4% and expanding sustainable agriculture to comprise 45% of all lands. Top priorities are land optimisation, crop cultivation technology, organic fertilisers, and utilising abandoned or previously degraded land. Lahan Pertanian Pangan Berkelanjutan or Sustainable Agriculture Land (LP2B) is a policy issued under MoA, limiting the land-use change of rice fields into non-rice field land use. The main issue that LP2B address is the intensive change of rice fields to settlements. The main goal of LP2B is to maintain the current rice field area so any deforestation due to the demand for more rice field areas can be reduced (BAPPENAS, 2020a) while managing the rice reserve to ensure food safety.

While food reserve goals could be easily achieved by importing the commodity, the governments would want to avoid reliance on rice stock from other countries (Timmer, 2019). In terms of climate change mitigation, the shorter chain is desirable as it would reduce the profit spread across the stakeholder within the chain and further reduce the carbon footprint (Canfora, 2016). Other than managing the carbon emission based on land use management, more localised food with lower food miles is preferred as it would have a lower carbon footprint and lower movement of locally cycled nutrients such as nitrogen, phosphorus, and potassium between geographical boundaries (Caputo et al., 2013). However, we also acknowledge the risk of food reserve oversupplies, such as price drops, poor supply quality due to incorrect storage, and food waste not being discussed as much (Waarts et al., 2011).

Main Actors

The government and the NGOs are currently some of the actors within the agricultural adaptation and mitigation to climate change; for example, there is an effort to develop social forestry to rehabilitate the soil. The stakeholders involved in the LMT and defining the land use planning are National Government and Local Government. The local government will have a bigger say in planning land use. In contrast, the Central Government will support the plan. Farmers were also important stakeholders. The farmers are the main stakeholders in applying better field practices. However, they do not understand what they are doing to mitigate or adapt to most of their activities. Most farmers were also more interested in their productivity rather than mitigation. Their participation is also mainly defined by their willingness to change their organic agriculture or agroforestry practices. Besides, the researcher involved in the application of LMT indirectly might be applied and replicated on a larger scale by the farmers due to lab-scale research.

Funding

Not all environmentally sustainable practices are recommended to the farmers. The recommended sustainable practices should be economically beneficial, easy to follow, affordable, and effective in increasing agricultural productivity. Nationally, some LMTs have been planned to be executed at the national level and are given the budget allotted. Most activities in various sectors deemed to be in line with Low Carbon Development (LCD) or low carbon development by the Central Government are given a certain budget, including agriculture practices. However, currently, there is no funding directly budgeted at the national level for LCD activities in agriculture. Most of the funding for agricultural activities is allocated from the Regional Expenditure Budget (APBD), a locally managed budget on the regional level.

LMT in Agriculture has not been given much attention, and there is less donor funding for LMT in agriculture than in other sectors. The donor funding also goes to big agricultural fields such as oil palm plantations. Compared to other sectors, the agricultural sector is more focused on supporting the economic sector. Investments in sustainable development are also given in agriculture within the Green Investment programs under BAPPENAS. However, donors from various parties are rarely found in the sector since most of the funding is given by the government or initiatives to Farmers Group (GAPOKTAN) rather than individual farmers.

4.4.3 Current land use and potential land-use competition

Currently, 47.3 million ha of land use is utilised for Indonesia's agricultural production (Food and Agriculture Statistics (FAOSTAT), 2020). Most of the land use is for the rice field, covering around 10.6 million hectares in 2018. Rice is one of the important crops in Indonesia (MOA, 2021), in which it is responsible for the emission of 71 Gg CO2eq greenhouse gasses (GHGs) through the intensive cropping system that is currently still adopted (Food and Agriculture Statistics (FAOSTAT), 2020). However, intensification is considered to be important to feed the increasing population. The rice field's productivity will not suffice to feed the growing Indonesian population, and there would be a need to import rice (F. Agus, personal communication, May 6, 2021).

Each year, the satellite data shows that about 96,000 ha of rice fields are transformed into other land-use types. Based on statistical data, about 50,000-60,000 ha of rice fields transformed, in which currently, there is 7,4 million ha of rice fields left out of the initial 8 million ha (Mulyani et al., 2016). These rice fields were mostly being pushed due to urban and infrastructure expansion.

Rice fields are also now under the pressure of land-use change. Indonesia has various types of agricultural land (See Table 6). The demand for settlement areas had been pushing the rice field around the urban area. Other than that, the lack of land-use impact planning left many rice fields unproductive. The land that can no longer generate income is then sold and transformed into other land-use types. Limiting land openings from forests to agricultural fields positively impacts climate change mitigation. However, with this limitation, it is almost impossible to expand the agricultural field.

This activity would lead to reliance on production in a limited area (N. Mustikasari, personal communication, April 21, 2021).

Table 17 Agricultural land use in Indonesia in 2008 and 2018 (in 1000 ha)

Land use category	2008	2018
Agricultural area, total	54,000	62,300
Arable land	22,700	26,300
Land under permanent crops	20,300	25,000
Land under perm. meadows and pastures	11,000	11,000

Source: (Food and Agriculture Statistics (FAOSTAT), 2020)

Moreover, food production should be able to feed an increasing population, and farmers being given the burden of food production are now under pressure due to limited resources. In many cases, the agricultural sector is considered unattractive for the youth who would leave the agricultural area, abandoning their land (Chaudhary et al., 2020). This issue would also increase the possibility for this left-out land to be built into other infrastructures, leaving only limited land to utilise as agricultural areas (Huijsmans et al., 2021).

Land use optimisation should be optimised to utilise the limited agricultural land as a potential LMT. The depleted nutrient taken out of the farm has to be replenished, and adding fertiliser is one way to ensure soil nutrient availability. The addition of nutrition would be needed to avoid soil mining. Therefore, organic fertiliser would be more beneficial in reducing the environmental impact of agricultural activities (Schjoerring et al., 2019). Reducing synthetic pesticide use would also reduce carbon emitted (Skinner et al., 2019). Developing agroforestry or tree-based land use around the agricultural field would also help provide a habitat for the pests' predators as a form of natural pest control (Zewdie et al., 2021). Intercropping would help to optimise land use and reduce pest attacks. It provides more niches for various organisms within the same temporal range, while crop rotation will help cut the life cycle of the pests throughout the seasons (Risch, 1983; Umaerus, 1992).

4.4.4 Climate risks & sensitivities

The current agriculture is very vulnerable to heatwaves, drought, heavy rain, flood, storms, weather variability, erosion, and ocean acidification. For example, heat waves could kill the plants and weather variability could affect the cropping season. Both drought and heavy rain could affect the productivity of the commodities. The heatwave effect of El Niño and the heavy rain effect of La Niña results in drought and flood that result in failed harvest. The temperature change also potentially results in increased pests and weeds. Ocean acidification mainly impacts coastal agriculture, and change in salinity has caused a problem, and many fields have also become infertile due to the sea-level rise. The effort to flush the salt out of the soil could be made by pouring freshwater or rain. Biodiversity loss is not an immediate problem in the agricultural field, and it might be more relevant to forestry. However, in dry areas and areas lacking freshwater availability, soil salt flushing would be hard to do as it would require manual watering. Forest fire could affect agricultural activities in the area with a proximity to the forest (Maswar, personal communication, May 3, 2021).

On the field level, it was also reported that the rice fields' intermittent irrigation would result in a denser weed community around the rice. Then it would take up the nutrient intended for the growth of the rice, resulting in a lower yield (F. Agus, personal communication, May 6, 2021). The application of organic manure on the soil could also be considered a more sustainable effort to increase agricultural soil health. However, manure over-fertilisation increases the sensitivity of the crops to pests (Altieri & Nicholls, 2003). Other practices, such as low to no soil tillage, would also result in a flourishing weed community that would reduce productivity per hectare compared to the conventional method. However, the minimum tillage practice would be more sustainable in the long run (Busari et al., 2015).

As food security is the primary objective of the agriculture industry in Indonesia, productivity is crucial. Nonetheless, variable weather and extreme weather occurrences pose a threat to productivity. In Indonesia, climate-related occurrences include drought, forest fires (typically not driven by climate variables), river and coastal flooding, and high rainfall. In addition, an excess or deficiency of water reduces soil productivity, resulting in lower crop output. In addition, El Nino and La Nina have reduced land production. Therefore, farmers cannot rely on lunar calendars to determine planting and harvesting dates (A. Dariah, personal communication, September 15, 2021).

4.4.5 Economic implications

The agricultural sector contributed 861 billion US$ in GDP (Gross Domestic Product) in 2015. However, the sector also contributes to a big portion of GHG emissions. A rice field mostly emits this emission, contributing to approximately 30% of the emission (Food and Agriculture Statistics (FAOSTAT), 2020). The change of practices would also reduce this emission and increase farmers' income. However, most of the farmers only have limited income in which it was reported that, on average, each farmer has a monthly profit of approximately IDR 750,000 or EUR 45 (BAPPENAS, 2019).

Unlike the global north countries, Indonesian farms' size is generally small and resource-poor. There are also complex socio-economic problems within the agricultural system. One of the efforts to help these smallholder farmers are to increase their resilience resulting in higher income. To help them apply better practice, incentives would be required. These incentives will be essential for adopting adoption practices, as infrastructure and resources are needed. Reducing intensification might also decrease temporary yield (Abraham & Pingali, 2020).

However, Indonesian farmers tend to use the higher profit for consumption rather than reinvest it due to the lower living quality. Giving farmers subsidies or helping them invest in new resources would help them adopt new practices. However, they would continue to rely on these funds if their farm size is small because it will also yield only low economic returns. It would be important to encourage the farmers to continue adopting the practices and ensure their income during the transition period. In the long run, the reduced emission and agriculture's ability to provide food more sustainably would be beneficial economically, socially, and environmentally. Another strategy, such as corporate funding, might also be applicable. However, this would require further study (F. Agus, personal communication, May 6, 2021).

There is still no official calculation of economic loss on the impact of agricultural activities released by the government and adding the price of mitigation required to the food. By calculating how much money would be required for the current conventional land management in the agricultural sector, we could also compare how much money will eventually be spent in the agricultural sector to revive the natural resources used in food production (Macháč et al., 2021).

4.4.6 Co-benefits and trade-offs

Risks

As previously mentioned, currently, there is no policy addressing the mitigation action in agriculture. Climate action in the Indonesian agricultural sector revolves around the adaptation effort, in which the governments focus mainly on production. As a result, many sustainability types of research in Indonesia would result in both environmentally better performing practices. It would have a similar yield with current production, if not more (F. Agus, personal communication, May 6, 2021).

Different technological implementations exist in the forestry and agriculture sectors. In the forestry sector, the government makes decisions, whereas farmers make decisions in the agriculture and agroforestry sectors. To entice farmers into the agriculture industry, technologies must offer co-benefits. Farmers place greater emphasis on productivity than on mitigation. Therefore, a technology designed purely for mitigation will not be implemented. Organic fertilisers are a successful illustration. Farmers recognise that organic fertilisers generate superior harvests to chemical fertilisers and increasingly apply organic fertilisers to their farms voluntarily.

The inability to incorporate new technology is due to a lack of money. In addition, government entities do not prioritise their activities, making integrating new technologies and/or rules challenging. Nevertheless, this is not a significant danger if the private sector provides the funds. The second threat is political unrest. Each government often has its objectives and programs. For instance, the current administration promotes Porang (Amorphophallus muelleri) extensively. Consequently, many farmers cultivate this crop on their land. However, neither party realises that other crops can give them greater benefits.

The two greatest economic hazards are trade imbalances and market dominance. Productivity is the primary contributor to the trade imbalance. Since market needs substantially impact commerce, farmers seek to employ highly productive technologies. Similarly, market dominance has both positive and negative consequences. Middlemen collect agricultural products from farmers and distribute them across the supply chain. This is more cost-effective for farmers because the middlemen will distribute the sales. However, many middlemen do not engage in fair trade, thus impacting the revenue of farmers.

On the other hand, the decrease in the budget due to corruption diminishes the benefits for farmers. To win political support, the government will delay or prioritise a program based on the needs of the people during election season. As a result, implementing new policies is likely to be delayed and ineffectual. The final threat is slow policy changes, which may have positive and negative consequences. Quick policy changes may produce long-term problems, but gradual changes may impede positive progress. Nonetheless, policies must mention their implementation features (A. Dariah, personal communication, September 15, 2021).

Co-benefits

Adopting organic practices in horticultural commodities in agriculture would increase manual weeding and labour hour. However, the premium price paid for organic produce would increase the farmers' income, and the farmers must undergo the certification procedure to obtain the premium selling price. Other risks include increased costs, requiring economic capital and energy from the farmers. For example, a physical labour increase would be required to reduce weeds and pests manually as the farmers reduce synthetic fertiliser and pesticide use. This risk would also hinder the farmers from adopting organic practices (N. Mustikasari, personal communication, April 21, 2021).

Trade-offs

To meet the target and demand, food production would still be ensured. For example, the rice of variant "Ciherang" would have lower emissions than other variances (Kinose et al., 2020). However, the discovery of the Ciherang breed was not intended for its lower emission but rather for higher production. Other practices, such as minimal soil tillage, could also help empower the farmers by allowing them more free time, as the method requires lower labour time. The lower labour time would lead to more free time for farmers that could be utilised for other livelihood strategies that could profit more income, such as working off-farm (Chrisendo et al., 2020).

4.4.7 Risks associated with scaling-up

While much intervention in agriculture is promising, several precautions should be considered to scale up the practices. Agriculture is heavily based on its biogeographic condition (Coe et al., 2014). Each region's differences in natural conditions would result in different suitable practices. In the agricultural sector, there is a big tendency for peer learning, and the farmers tend to duplicate other practices that are perceived as successful. This way, unfit practices are selected naturally. If the farmers are mandated to change their practices, unfit practices will not happen. The failed harvest might lower the farmers' trust in other stakeholders (F. Agus, personal communication, May 6, 2021). Therefore, scaling the practice to a similar area might be an alternative rather than scaling up to the national level (WIjeratna, 2018).

Due to the mitigation action from the lower regional level to a national level, losses have not yet been reported. However, with the knowledge of Indonesian natural resources, it is clear that some practices that would suit one region might not be best applied to other regions. For example, increasing Indeks Penanaman or Planting Index (IP) might be feasible in Java. IP shows how many harvests could be done in a year. Knowing that Borneo's soil is not as fertile as Java, the increase of IP would not benefit Borneo, and it might further threaten the farmers with unprofitable yields. Some varieties and breeds of crops should be considered as they might not be sown in other areas. Therefore, pushing the farmers to sow the crop might cause yield loss and economic loss (N. Mustikasari, personal communication, April 21, 2021).

4.4.8 Research gaps

There are a few knowledge gaps in the effort to carbon capture various land use in agriculture. The knowledge of what agricultural practice will be suitable in each area will be beneficial. These recommendations should be beneficial, easy to follow, and clear for the farmers as the main agricultural land managers. The agricultural land use potential to capture carbon and provide environmental services will also be beneficial in defining the contribution that the agricultural land-use type could make. A deeper analysis of the socio-economic implication of the recommendation should also be executed. The analysis will be important in defining what strategy should be proposed in applying the practices recommended to the farmers.

4.5 Soil Carbon Enhancement (Biogas and Compost)

4.5.1 Introduction

Waste management is another sector identified as a national priority related to soil carbon enhancement (SCE) activities. The government has set a target of reducing waste emissions by 94% from 2024 to 2030, which has high potential. Anaerobic digestion processes currently contribute to Indonesia's GHG emissions, but compost and other measures of integrated sustainable waste management systems have enormous potential. Furthermore, enhancing soil organic carbon (SOC) in the agricultural sector can be an effective negative emission measure. Out of the total agricultural land of around 62.3 million ha, which makes up approximately one-third of the total Indonesian land surface area, about 82% is occupied as cropland, including land for temporary crop cultivation (arable land) and permanent crops (Food and Agriculture Statistics (FAOSTAT), 2020). For instance, adding only 1%-point of the SOC to the agricultural area could provide a significant storage potential.

Despite the importance of the organic matter in the soil, data for evaluating SOC change in Indonesia is limited due to regular SOC stock and changes monitoring. Although SOC change data at the macro-level (nationwide) is not available, several studies report SOC depletion in Indonesian soils at the micro-level. One study suggested that SOC stock declined by around 30% when a forest was converted to agricultural production (Murty et al., 2002). A study discovered that the level of organic matter in the 0-15 cm soil of lowland rainforest in Sumatra decreased by 48.1 Mg C ha^{-1} when the forest was downgraded to grassland (Santoso et al., 1997). Another primary source of soil carbon reduction in Indonesia is the loss of carbon from organic soil (peatland), which covers about 14.9 million ha and contains exceptionally high carbon content ranging from 420 to 820 Mg C ha^{-1} (FAO and ITPS, 2015).

Also, supplementing carbon to soils, such as compost, manure, and digestor from anaerobic digestion (AD) of organic matter (e.g., manure), harvesting residues, or processed organic fertiliser, can be performed to improve organic matter levels in agricultural soils. AD-based bioenergy can potentially put CO_2 emissions into negative territory by converting biomass into bioenergy (biogas), sequestering the carbon produced into the soils in organic fertilisers. Considering the high livestock population in Indonesia (Table 7), which has steadily increased in the last three years, there is a massive potential in biogas and organic fertiliser (bioslurry).

Bioslurry is a co-product of anaerobic digestion of wet organic waste) production from animal manure via anaerobic digestion processes. Organic matter content in bioslurry can reach up to 27%-weight 29% and 26% for cow dung, poultry manure and buffalo dung, respectively (Islam, 2011). A study has estimated the total biogas production from Indonesia to be 9,595.6 Mm3/year (Khalil et al., 2019). Since bioslurry is produced three times more than biogas of total dry matter of manure, bioslurry has become a promising carbon sequestration agent through SCE.

Table 18 Indonesia Livestock Population,2018-2020 (unit)

Species	2018	2019	2020
Large livestock			
Beef cattle	16,433	16,930	17,467
Dairy cattle	582	565	568
Buffalo	894	1,134	1,179
Horse	378	375	392
Small livestock			
Goat	18,306	18,463	19,096
Sheep	17,611	17,834	17,769
Pig	8,254	8,521	9,070

Source: (Ministry of Agriculture, 2020)

Volume-wise, animal manure is the single largest potential resource of soil organic matter and other macro-and micronutrients to supplement soils. To date, most animal manure is put on soils without any manure processing. However, upgrading animal manure to a high-quality organic fertiliser through anaerobic digestion could improve the outcomes by producing energy in biogas. This activity can reduce carbon emissions from fossil gas or firewood, reduce volumes (hence reducing storage problems), exterminate pathogens, and enhance soil nutrients. On top of that, as an add-on climate change mitigation technology, animal manure's further treatments could also significantly reduce CH_4 emissions (Ministry of Agriculture, 2020).

Biogas is a viable option for Indonesia to diversify their national energy mix in moving towards sustainable energy (International Energy Agency (IEA), 2019). It can be produced from feedstocks, including organic and agricultural wastes and dedicated energy crops (DEC). Animal waste, such as dairy manure and chicken litter, municipal solid waste, wastewater, sludge and industrial waste, and food processing waste, are all ideal for biogas production (Kulichkova et al., 2020). The demand is also ever-increasing due to the dire need to shift to cleaner energy and increase electricity production within Indonesian regions. However, biogas feedstock utilisation is restricted to specific types, and applications with several renewable possibilities must be prioritised. For instance, biogas can generate electricity and contribute to renewable energy.

4.5.2 Policy context

In 2017, GOI issued a new regulation of national strategy and policy of waste management. Based on this regulation, GOI targets reducing 30% emission reduction, managing 70% of total waste, and developing waste facilities for households. Besides, in the RPJMN of BAPPENAS, the waste management programs will include solid waste and wastewater. Solid waste management will include the domestic and industrial sectors, such as disposal sites, composting (biological treatment), and incineration. For wastewater, the activities are around wastewater treatment plants (aerobic and anaerobic digestion process) and domestic sewage (BAPPENAS, 2020a).

In addition, MoA has reported reducing emissions by applying various agricultural sector strategies from 2010 to 2019. First, agricultural cultivation technology was applied through rice intensification

(SRI), integrated crop management, and low-emission varieties. Second, organic fertiliser and biopesticides through fertilisers, organic subsidised and procurement of Organic Fertiliser Processing Unit (UPPO) are utilised. Third, the utilisation of livestock and agricultural waste is conducted. Additionally, animal feed supplements can be improved by using low-emission products, for example, leguminous plants (*Gliricidia* sp., *Leucaena* sp., and *Calliandra* sp.). The production targets are achieved by land-use optimisation, extensification for low-carbon fields, and livestock and fertiliser management. Activities related to livestock and fertiliser management include livestock management with containment, feed quality, biogas (methane capture and energy source), balanced fertilisation based on soil condition, and organic fertiliser (carbon sequestration) (Dariah, 2020).

Knowing the potential of SCE, the Indonesian Government has set up an ambitious goal to employ biogas in its energy mix as part of the Nationally Determined Contribution (NDC) with dual objectives (climate mitigation-wise), fossil fuel substitution and SCE. This plan includes generating 5.5 GW of electricity from biogas by 2025, although as of 2020, biogas' utilisation for power is only 96.2 MW or 1.33% of the 2025 target (23%) (Ministry of Energy and Mineral Resources, 2020). Aside from the energy sector, biogas implementation contributes to LMTs in the agricultural sector. Besides President Regulation No. 22/2017 on National Energy Planning (RUEN), GOI is preparing a biogas roadmap. It aims to improve clean energy access and accelerate oil fuel substitution with gas in the household sector. The target is biogas production at 2,203 Nm3/day for household use by 2025.

To achieve this target, 1.7 million household-scale biogas digesters must be installed (Dewan Energi Nasional, 2019). In addition to manure, Indonesia also produces a large amount of organic waste, which is contained in domestic solid waste, also called municipal solid waste (MSW). In 2017, the country's MSW generation reached 65.8 million tonnes, estimated to grow rapidly for the foreseeable future (KLHK, 2020a). Since organic waste makes up around 60% of the total MSW (KLHK, 2020c), composting processes, either aerobic or anaerobic, could become a significant organic fertiliser source, which ultimately can contribute to SCE.

Furthermore, in the Presidential Regulation No. 97/2017 on National Policy & Strategy on Management of Household Waste and Household-like Waste (JAKSTRANAS), GOI sets the target of 30% waste reduction and 70% waste handling (from 67.5 million tonnes of waste handled in baseline 2019 to 339.4 million tonnes) by 2025 (KLHK, 2020a). The waste handling strategy includes the rollout of composting organic waste processes in Integrated Waste Management Sites (TPST) to reduce the volume of waste to be processed in the Final Waste Collection Sites (TPA). GOI aims to increase the number of households covered with composting services in TPST to 494,152 households (MOEF, 2020), about 0.98% of the total population.

Main Actors

The government and the NGOs are currently some of the actors in the agricultural adaptation to climate change; for example, there is an effort to develop social forestry to rehabilitate the soil. As mainland managers, farmers are one of the main stakeholders in agriculture. The farmers possess knowledge of practices such as using palm oil fronds over the soil, which could help mitigate the soil carbon emission. Practices such as applying nitrogen fertiliser would also help increase soil fertility, fertilise the crops, and help the carbon uptake by the crops (F. Agus, personal communication, May 6, 2021).

Funding

Currently, APBN (national funding) is one source to increase the yield in agriculture, covering funding for various programs such as livestock quality improvement and training. 47,505 small-scale biogas digesters have been installed across Indonesia, resulting from assorted funding from the national government, foreign aid, and private institutions, producing 26.72 Mm^3 annually (Ministry of Energy and Mineral Resources, 2020). Indonesia refers to Koronivia Joint Work on Agriculture (KJWA), Germany, since 2017. LMT in Agriculture has not been given much attention, and there is less donor funding for LMT in agriculture than in other sectors.

The donor funding also goes to big agricultural fields such as oil palm plantations. Funding for organic food farmers is still less and would only cover small-scale agriculture. Other practices, such as biogas and composting stations, are included in the agricultural LMT. Most of the funding available for biogas and composting is for small-scale projects. Funding at the national level does not exist as the previous national-scale biogas project, SIMANTRI/SIPADU (Integrated Agricultural System), has been stopped. The projects include giving farmers livestock of cows and a biogas installation. The funding was stopped as the project was considered successful and had been replicated sufficiently by other farmers (N. Mustikasari, personal communication, April 21, 2021).

The potential for implementing the water management reform activities considerably surpasses the LTS target, with total private sector funding of 19,369,560 USD. The business sector must contribute 16% of the total 772,208,400 USD for peatland restoration initiatives. Currently, the majority of funding for mitigation efforts comes from APBN sources (state budget), which is grossly insufficient (Ministry of Environment and Forestry (KLHK), 2022). Indonesia has adopted various measures that create prospects for greater diversification of national and international, public and private, financial sources. In addition, Indonesia continues to mobilise international financial resources via bilateral, regional, and multilateral channels, including result-based payment for REDD+ under the Paris Agreement, grants, and other relevant sources and procedures.

4.5.3 Current land use and potential land-use competition

Sustainable agricultural land is expected to reduce the land-use change from rice fields to settlements. The main competing land use for agriculture, livestock farms, and the LMTs in agriculture will be the settlement. The key stakeholder that decides whether the agricultural land could be transformed into a settlement is the provincial and city government, as the regional land use planning will be under their jurisdiction. However, the technical side of the land-use change process should be further verified to assess whether there are other stakeholders involved. In Java, most agricultural fields (including husbandry or livestock farms) change to settlement and industry areas. At the same time, out of Java, palm oil plantation was found to overtake many other agricultural fields.

Ideally, with the current land use management based on the existing policy, there should not be a major land-use change in the agricultural sector (including livestock farming). However, many activities are unrelated to real agricultural activities risking the sector. For example, the blockage of irrigation could reduce productivity, disturbing the farmers' livelihood and leading to land abandonment by the farmers. These abandoned lands are further transformed into various land use. In Java Island, the most common land use transformation is as settlement or industry; meanwhile, outside of Java Island, the land use was changed to palm oil (F. Agus, personal communication, May 6, 2021).

Feedstock plays a crucial role in biogas quality as a renewable energy source (Kulichkova et al., 2020; Zhu et al., 2019). Given the availability of feedstock, there is abundant potential for biogas to utilise municipal solid waste, agricultural residues and animal manure (ASEAN Centre for Energy (ACE), 2020; International Renewable Energy Agency (IRENA), 2022).

In Indonesia, agricultural waste (e.g., animal manure and crop residues) is the primary feedstock for biogas in the electricity sector. Additionally, crops, municipal solid waste (MSW), and wastewater are other biogas feedstock resources. Most Indonesian regions have at least one potential feedstock available for biogas-to-electricity (Ahmed et al., 2017; Jain, 2019; Kyaw & Greater Mekong Subregion Economic Cooperation Program, 2009; Mojares, 2015; Mustonen et al., 2013; National Environment Agency, 2019; Peace Independence Democracy Unity Prosperity, 2011; Prasertsan & Sajjakulnukit, 2006; Rianawati et al., 2021; Roubík et al., 2018).

Agricultural land covers 62.3 million hectares (ha) of land in Indonesia, making up approximately one-third of Indonesia's land surface area. About 82 percent consists of cropland, including temporary and permanent crop cultivation (Food and Agriculture Statistics (FAOSTAT), 2020). Given the scale of cropland, agricultural waste could serve as feedstock for large-scale biogas plants (Sardiana, 2021).

4.5.4 Climate risks & sensitivities

Erosion and landslide are affected by land use, in which an open agricultural area is more prone to these problems than an agricultural area with cover. Besides that, biodiversity is also at risk and reduced soil quality, as the poor carbon soil would lose its capacity to provide habitat for microbes and microfaunas. Moreover, heavy rain (extreme precipitation) is one of the biggest threats, as it could flood low-lying areas. It also potentially erodes the topsoil layer and leads to soil carbon translocation, reducing the soil quality. River floods and sea-level rise risk the agricultural yield, and sea-level rise could affect soil salinity which can be tackled by freshwater soil flush. In areas with high rainfall, the freshwater could be rain sourced. However, applying underground water to flush the soil in drier areas will only increase farmers' vulnerability (F. Agus, personal communication, May 6, 2021).

Droughts and floods threaten agriculture, and food security is a priority for Indonesia. The emphasis is that farmers will prime higher yields over environmental protection, so they must see how these techniques can benefit them or otherwise, they will probably not apply them. These techniques can improve carbon sequestration and resilience, and Biochar can maintain water retention, prevent landslides, strengthen the soil structure, and store carbon. However, farmers need to be socialised in using these techniques as they can be reluctant to change their practices unless they see short-term benefits (such as improved yields), so it is important to emphasise these advantages.

4.5.5 Economic implications

Integrating livestock into the farm would also be intended for better nutrient cycling by reducing fire for field clearing and increasing farmers' income through livestock products to ensure better economic income rather than addressing climate change directly. If the farmers could make organic fertiliser within their farms, their fertiliser costs could be reduced. Organic practices will increase the labour required, but they will also produce higher-priced produce (Maswar, personal communication, May 3, 2021).

Another benefit of using organic fertiliser for SCE is micro and macronutrients essential for biomass growth in agriculture and agroforestry, bringing about further decarbonisation. While integrating livestock could also increase the farmers' freedom by reducing their reliance on input and the required amount of fertiliser that should be bought (Uddin et al., 2016), incorrect feed rations will result in higher methane emissions (Jiao et al., 2014). Therefore, knowledge transfer regarding livestock feed will be required. The correct feeding will help increase the quality of livestock products and ultimately reduce methane emissions while empowering the farmers.

Currently, there is no information regarding the cost or the price of emission reduction in agriculture, and there is also no standardised price for carbon sequestration environmental services. However, implementing specific LMT such as Organic Fertiliser Processing Unit (UPPO) or organic fertiliser management facility is worth IDR 200 million for each project according to national funding (APBN), starting from the planning, developing, building, and maintenance. Analysis of regional funding (APBD) has not been done (N. Mustikasari, personal communication, April 21, 2021).

4.5.6 Co-benefits and trade-offs

Risks

For chemical fertiliser use, the farmers report lower productivity. The farmers who adopt the practices on the field might see this usage as dangerous. However, the yield would increase over time as the soil health improved. Ideally, this will lead to more sustainable production. This increase in yield would take time, and the farmers might not have the patience to wait for the yield to increase again. Organic fertiliser and biogas slurry to the soil can help increase the soil carbon, sequester more carbon in the soil, reduce carbon emission, reduce nitrogen loss, and increase water quality. The manure processing in the biogas facilities would also help reduce water pollution caused by the manure. As soil health increases, soil biodiversity increases (N. Mustikasari, personal communication, April 21, 2021).

Other risks include the increase in cost, requiring economic capital and energy from the farmers. For example, a physical labour increase would be required to reduce weeds and pests manually as the farmers reduce synthetic fertiliser and pesticide use. This risk would also hinder the farmers from adopting organic practices. Besides, fertilising is required in agriculture; over-fertilising could pollute water and be economically wasteful. High-dosage fertiliser application would lead to greener and fresher-looking produce. However, it will also increase the crop's sensitivity towards pathogen and pest attacks. In rice production, over-fertilising was correlated to a higher empty husk percentage than balanced fertiliser application (F. Agus, personal communication, May 6, 2021).

In addition, institutional mismatch is a danger in this industry. There have been instances where different industries have prioritised distinct characteristics. To ensure Indonesia's food security, the Ministry of Agriculture seeks to enhance agricultural productivity, and the Ministry of Environment and Forestry wishes to reduce emissions and environmental damage. In order to achieve their objectives, the institutes must present a unified face. The third risk is the policy implementation's scalability. Due to societal and/or cultural factors, the upscaling and downscaling of policies can be problematic.

The greatest threat to society is resistance to behavioural change. Farmers are typically resistant to adopting new technologies or practices. In addition, farmers are hesitant to experiment with new ways when it affects their daily life and the customs of their communities. For instance, they might not wish to invest additional time and resources in implementing LMT. As a result of their long-term investment, farmers with more capital tend to take better care of their land than those with less wealth.

From a business owner's perspective, the four greatest business risks are limited and unclear resources and supply, investment problems, increased capital cost, uncertain income stream, and extended payback period. Frequently, it is difficult for business owners to locate raw materials for the production of fertilisers. In addition, they have limited access to banks and microfinance schemes, relying solely on cooperatives and community organisations. In order to manufacture bio fertiliser and biochar from anaerobic digestion or a waste management method, for instance, upfront costs and resources are required.

In addition, farmers are frequently unaware of or reluctant to implement better farm management. For instance, they refuse to employ intercropping because of the uncertainty that they would reap the benefits of their labour; they need to earn money quickly and therefore choose to use an instant method. This is a common pattern among farmers who migrate to a new location and require food security. The proximity of technology to local companies is the final factor. This can benefit them since they will be better equipped to absorb new farming technology (A. Dariah, personal communication, September 15, 2021).

Co-benefits

The major carbon emitter in agriculture is the rice field due to soil waterlogging and the large land assigned for the rice field. Livestock is in the second position, as there are carbon emissions from ruminants and livestock manure. Accordingly, livestock integration would help cycle the usually burned biomass by processing them as feed, yielding livestock products. Also, processing biomass as an organic fertiliser could help to reduce the carbon emitted due to the burning of straws.

Biogas and livestock waste management are currently the second priority of LMT for carbon emission. Several projects, such as organic-based villages, aim to transform 100 villages into organic-oriented ones with the cropping system and composting. The projects are targeted to be completed by 2024. Other projects such as SIPADU/SIMANTRI have also been done. However, the amount of carbon reduced is still unclear as it has not been assessed previously. LCDI Agriculture uses the calculation based on land use currently used by MOEF. Therefore, a non-land-used carbon emission reduction after the biogas and compost station installation has not been calculated. Moreover, the indigenous practice of integrating livestock, for example, ducks, within the organic rice field results in the mutualism between the livestock and the rice. The livestock would clear up the pest that attacks the rice while yielding higher rice production (Khumairoh et al., 2018).

Trade-offs

In integrated farming or carbon precision farming, the size of the land is also fixed, but with the integration of livestock components, it also increases. However, organic plant residue biomass previously burned in integrated agriculture can be used as compost or animal feed. Thus, carbon emissions can be reduced. However, these new practices would require starting capital, so that the funding source would be needed (Y. Rochmayanto, personal communication, May 5, 2021). In addition, farmers may have the initial capital to add a livestock component to their farm, but the capital to continue and maintain this new component will be difficult. For example, we can provide livestock and biodigester, but it will not be easy to continue the facility if the farmers do not have the ability and capital.

Another aspect of biogas in Indonesia is the relationship between feedstock and the food sector. The key signals for the food sector are the susceptibility of existing crops and livestock to climate change and the loss of croplands to tourism infrastructure. Additionally, concerning transportation, GHG emissions and health implications (particulates) have been highlighted due to a rapid increase in motorcycles, commercial trucks, and car fleets. The infrastructure may be inefficient relative to current and future demand. Hence, human population trajectories, settlement patterns, mean temperature indicators, sea level rise, coastal inundation, tourism person-days (i.e. a tourism activity day and all that is involved in consumption and transport) or potential for livestock manure for biogas can also be assessed.

4.5.7 Risks associated with scaling-up

There is no research on mitigation action to measure the suitability of the action in each region. For example, organic fertiliser (UPPO) and Biogas projects are given as a grant. However, any follow-up sustainability research at all the provinces being executed has not yet been done. Therefore, any risks related to differences in each region have not been assessed in any way. In many cases, the unsuitable practices that might threaten the farmers would be selected on the farmer group level. The farmers would naturally choose the practices that would better suit their needs by learning through their peers, and the unsuitable practices would be selected (N. Mustikasari, personal communication, April 21, 2021).

Socialising farmers to new technologies is equally crucial to ensuring the long-term use of technology. Applying organic fertiliser or adding organic materials (e.g. biochar) will most contribute to carbon sequestration and soil conservation since carbon materials will be stored in the soil. In addition, this LMT will benefit air quality, fire risk reduction, and water balance due to emission reduction. However, farmers are less likely to use these measures if they do not see results. Therefore, the technology supplied to farmers must deliver co-benefits. Increasing farm production is the key benefit that farmers expect. One of the instances of soil carbon augmentation in the agriculture sector is biochar, where corncob has been utilised to raise land productivity in Lampung, Sumatra. Biochar helps sustain water retention, avoid landslides, enhance the soil structure, and store carbon. Furthermore, climate resilience also influences the surrounding ecology, so intermittent irrigation in rice fields assists farmers in adapting and reducing climate change (A. Dariah, personal communication, September 15, 2021).

4.5.8 Research gaps

For SCE, a pilot project is important before applying the technologies in the field. Creating an inventory of ongoing pilot projects is also as important. That inventory can monitor, evaluate, verify, and validate the technology and practice. To develop and improve the technology and practice for SCE, BECCS and biochar can be considered. However, there is yet BECCS/U implementation in Indonesia. Bioenergy is implemented through decentralised and non-decentralised biogas, biofuel or biomass without a carbon capture storage system. Various stakeholders, such as MEMR, BAPPENAS, and DEN (National Energy Council), have not set a roadmap and planning for BECCS/U in Indonesia. There is still a lack of research and studies on BECCS/U implementation in Indonesia. Besides, GOI is concerned about this technology's high implementation cost and technology readiness.

In addition, biochar technology has been known for a long time in Indonesia through charcoal. It is used abundant resources from agricultural and forestry waste, and MoA includes it in LMTs on agricultural land. However, BAPPENAS, MoA, and MOEF have not set specific targets and planning for biochar implementation (Balitbangtan, 2019). Biochar or bio charcoal from agricultural or forestry waste is utilised through research or pilot project implementation in Indonesia, and there is no massive-scale biogas implementation.

Conclusion

Existing land-based mitigation technologies (LMTs) include afforestation and reforestation, biochar and soil carbon sequestration (SCS), ocean fertilisation, bioenergy with carbon capture, storage, and utilisation (BECCS) and utilisation (BECCU), increased weathering, and direct air capture (DAC) (Minx et al., 2017). In addition to the technologies, land-based mitigation technologies for land-use change are categorised by land-use type, including forest, farmland, wetland, and grassland. In Indonesia, certain technologies and methods have been applied, while others are still in the study phase.

Bioenergy without carbon capture storage is implemented in Indonesia through anaerobic digestion (biogas), fermentation (ethanol production), thermal biomethane, hydrogen/ammonia production, top-gas recycling (blast furnaces), industrial processes with large amounts of waste heat, mineral processing (cement kilns), bio-CNG (Compressed Natural Gas), co-firing, and combined heat and power (CHP) mode. However, the high cost and lack of technological knowledge prevent using some technologies (Grönkvist, 2012). The conventional initial route to introduce BECCS technology in Indonesia is via biomass, biogas, biofuel, thermal biomethane, and co-firing at coal power plants (DEN, 2019). The State Electricity Company (PLN) launched corporate action using the co-firing approach. Indonesia requires 17,470 tonnes per day of biomass or 5 million tonnes per year of wood pellets to satisfy the co-firing demands of its coal power plants at 1%. PLN has adopted co-firing technology in five coal power facilities (EBTKE ESDM, 2020). BECCS has, therefore, not been adopted in Indonesia. Cofiring biomass in coal-fired power plants is the initial stage in BECCS deployment.

Another potential LMT is biochar. It is a viable approach for restoring damaged land and enhancing soil quality, and a slower disintegration rate and resistance to microbes are additional benefits. In agriculture, biochar lowers soil acidity, enhances nutrient availability, and binds nutrients. For instance, biochar can improve the pH of acidic soil (pH between 3 and 5). In addition, biochar can be utilised in locations with little water to bind this water. In many areas, the Agency for Agricultural Research and Development (Balitbangtan) of the Ministry of Agriculture (MoA) introduced the production and application of biochar via technical supervision. Utilizing the Kon tiki model, introducing the charcoal production process to farmers is simple and economical. This variant features a cone-shaped hole with a 150 cm top diameter and 75 cm height, and it is easy and appropriate for farmers (Bardono, 2018). Nonetheless, this possible LMT is not currently a government priority. Therefore, the adoption of biochar in Indonesia is currently in the pilot stage.

After completing the literature research and a few interviews with relevant specialists, the vast list of LMTs was whittled down to four candidates: 1) Afforestation and Agroforestry; 2) Peatland Management; 3) Agriculture; 4) Soil Carbon Enhancement. These four are under consideration for more investigation (using model simulations) inside the LANDMARC project. Before such an evaluation can be conducted, a narrative or plot must be constructed for each selected LMTs.

For afforestation and agroforestry, since forests cover 65% of Indonesia's area, the forest sector is the main contributor to greenhouse gas (GHG) emissions. Indonesia lost 26.8 million ha of tree cover from 2002 to 2019, contributing to 10.9 Gt of CO2 emissions. Negative emission solutions are implemented to reduce deforestation activities. 10.48 million hectares of diverse forest functions are at risk of destruction in natural forested regions. Risk is greatest outside the forest area (APL) and lowest within the PBPH-HT. The total amount of natural forest that can be transformed until 2050 is restricted to 6.8 million hectares. To meet emission reduction goals, efforts must be made to expedite the establishment of industrial forest plantations. It is estimated that 11,2 million hectares of forest have been created, and the development of planted forests has reached 5.12 million hectares, leaving a shortfall of 4.07 million hectares. To reach the FOLU Net Sink target by 2030, 2.79 million hectares must be rehabilitated using a rotation method.

There are 38 million hectares of high conservation value (HCVF) lands, of which 1.51 million hectares are in high-risk areas. Climate change adaptation activities can benefit the environment socially and economically. Forestry research has been widely carried out in Indonesia, but forestry research on how the role of the new futuristic forest function has not been explored much. A clear system to support movements towards climate change adaptation and mitigation is also needed. The government must ensure that local communities receive incentives proportionally to what they have done to LMT. The National Forest Monitoring System must monitor and supervise operations executing FOLU sector mitigation efforts towards the 2030 net sink. Indonesia will bolster indigenous technology's role while pursuing technological cooperation opportunities within the Paris Agreement and Convention. Peatland covers 20.6 million ha or 10.8% of the total land area in Indonesia. Emissions peaked in 2015 due to extreme warming effects attributed to El Niño. To accomplish the aim set for peat restoration, the area must increase by 2.72 million hectares by 2030.

In Indonesia, wetlands include mangrove swamps and in-land wetlands (peatlands). The Ministry of Environment and Forestry (MOEF)'s Peatland Restoration Agency (BRG) was established in 2016 to manage and facilitate peatland restoration in seven priority provinces, which comprise around 40% of the nation's total land area. Three main activities, known as 3R – Rewetting, Revegetation, and Revitalisation, play roles in preserving and enhancing carbon stock. Revitalisation is a set of actions to ensure that any economic activities performed on or around the peatland area are well-aligned with its preservation. Planting commodity crops suitable for the wetland is also called Paludiculture (BRG, 2016). BRG has been helping farmers by introducing alternative crops that thrive in wet soils. Indonesia's government needs to ensure that local actors receive incentives proportionally to what they have implemented and improve the readiness of local governments to implement LMTs. Maintaining the water level, revegetating peatland, and implementing paludiculture will reduce emissions and store carbon.

Moreover, agriculture, as one of the LMTs, accounts for 13% of Indonesia's total greenhouse gas emissions. Agricultural activities are extremely vulnerable to climate change. Climate change will result in lower soil health and uncertainty in water availability. BAPPENAS has made an effort to be able to tackle these problems. MoA recorded 114.74 million tonnes of CO2 reduction in 2010-2019 (BAPPENAS, 2020a). Overall data on land-based mitigation practices in the agricultural sector is shown in Table 5. There are few knowledge gaps in the effort to carbon capture various land use in agriculture. The Indonesian government has targeted reducing waste emissions by 94% from 2024 to 2030. Anaerobic digestion processes currently contribute to Indonesia's GHG emissions.

Lastly, improving soil organic carbon (SOC) in the agricultural sector can be an effective negative emission measure. Bioslurry is a co-product of the anaerobic digestion of wet organic waste. Organic matter content in bioslurry can reach up to 29%, and 26% for cow dung, poultry manure and buffalo dung. A study has estimated the total biogas production from Indonesia to be 9,595.6 Mm3/year. For SCE, a pilot project is important before applying the technologies in the field. Creating an inventory of ongoing pilot projects is also as important. There is still a lack of research and studies on BECCS/U implementation in Indonesia. GOI is concerned about this technology's high implementation cost and technology readiness.

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ANNEX III

OVERVIEW OF INPUT TABLES FOR SIMULATION MODELLING PER COUNTRY

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9. Indonesia

9.1. Qualitative storylines by identifying measures and actions from interviews for each LMT scenario

Indonesia LMT 1: Reforestation

	1. Wishes of the future for the LMT: include timing	2. How to achieve the wishes • Who pays? • Who implements?	3. Target/Actions • Policies, strategies, projects
Scenario 1: "HIGH" **Stakeholder representations:** DKLH	• [ALCES] Bali government initiates restoration on the significant area of the degraded land by 2030 (Stakeholder Interview, 2023). • [LANDSHIFT] The Indonesian government put the 20 year-target (2011 – 2030) of the significant forest area for reforestation (KLHK document).	• [ALCES] International Donors fund projects while DKLH (Bali forestry agency) and local stakeholders (KPH) implements and maintains. • [LANDSHIFT] International donors will fund projects in different scale (local/pilot, city, and province). • [LANDSHIFT] All monitoring will be done by DKLH (provincial forest agency) and the database is submitted nationally to KLHK (Ministry of Environment and Forestry - MOEF).	• [ALCES] Reforestation of 2,000 Ha / year from DKLH (Bali forestry agency). • [LANDSHIFT] The Indonesian government published ***the National Forestry Plan 2011-2030.*** • ***[LANDSHIFT] Intensive rehabilitation is centred on priority areas and relies entirely on government funding (APBN), its counterpart focuses on involving local communities***

			in reward-based rehabilitation activities. • ***[LANDSHIFT] Within 2015-2019, intensive and incentive methods have contributed to forest and land rehabilitation as vast as 308 thousand ha and 873 thousand ha.***
Scenario 2: "LOW" **Stakeholder representations:**	• [ALCES] Bali government keeps the initial effort in restoration (20%) on the degraded land without any improvement. • [LANDSHIFT] The Indonesian government keeps the initial effort in reforestation (25%) on the forest area without any improvemet.	• [ALCES] Only depend on the National Budget (APBN). • [LANDSHIFT] Only depend on the national budget (APBN).	• [ALCES] Achieve 50% of the restoration on the degraded land in Bali. • The Indonesian government keeps the incentive method only for big players in reforestation (big companies and organisations), and not improve the incentive method for smallholders.

Indonesia LMT 2: Peatland Restoration

	1. What are the wishes of the future for the LMT • include timing	2. How to achieve the wishes • How much does it cost? • Who pays for the cost? • Who implements?	3. Actions • policies, strategies, projects

Scenario 1: "HIGH" **Stakeholder representations:**	• [LANDSHIFT] Indonesia aims to keep emissions from • peatlands constant to the 2010 level (the draft National REDD+ Strategy). • [LANDSHIFT] The Indonesian government will reduce emissions from peat decomposition and fires through peatland restoration (revegetation/rehabilitation) in the significant area of degraded peatland.	• [LANDSHIFT] MOEF established the Peatland Restoration Agency (BRG) to manage and facilitate peatland restoration in seven priority provinces, which make up around 40% of the nation's total land area: Riau, Jambi, South Sumatra, West Kalimantan, Central Kalimantan, South Kalimantan, and Papua. • [LANDSHIFT] International funds under REDD+ will have some projects for peatland restoration in Indonesia	• [LANDSHIFT] The amended regulation increases protections for the peat ecosystem, by permanently stopping the issuance of new license on selected areas of peatland in 2019 through the Permanent Moratorium Policy.
Scenario 2: "LOW" **Stakeholder representations**:	• [LANDSHIFT] The Indonesian government keeps the initial effort in peatland restoration (38%) without any improvemet.	• [LANDSHIFT] Only depend on the national budget (APBN).	• No improvement in monitoring the peatland moratorium.

Indonesia LMT 3: Agroforestry

	4. What are the wishes of the future for the LMT • include timing	5. How to achieve the wishes • How much does it cost? • Who pays for the cost? • Who implements?	6. Actions • policies, strategies, projects
Scenario 1: "HIGH" **Stakeholder representations:**	• [ALCES] Bali government will fulfill the target to implement agroforestry in all potential areas (Stakeholders Interview). • [LANDSHIFT] The government set a target of accelerating agroforestry in 2023-2030.	• [ALCES] Bali government will increase the area of the social forest. • [ALCES] International donors will fund more agroforestry projects. • [LANDSHIFT] Aspects of agroforestry management access are spread across 33 provinces, 380 districts, 2,315 sub-districts, and 4,294 villages in Indonesia. Beneficiaries are 1.2 million families or equivalent to 5 million people. • [LANDSHIFT] The development of Social Forestry Business Groups (KUPS) until 2022 has formed 10,068 KUPS.	• [ALCES] North-east Bali projects. • [ALCES] Award Program for CSR contribution by DKLH (Bali Forest Agency). • [LANDSHIFT] Agroforestry is the program priority of the current president and ministry. • [LANDSHIFT] To strengthen collaboration among facilitators, a Social Forestry Facilitator Communication Forum has been established in five regions.

Scenario 2: "LOW" **Stakeholder representations:**	• [ALCES] Bali government keeps the initial effort in agroforestry (20%) without any improvement. • [LANDSHIFT] The Indonesian government keeps the initial effort in agroforestry implementation (19.5%) without any improvement (KLHK doc).	• [ALCES] Depend only on the National Budget (APBN). • [LANDSHIFT] Only depend on national budget (APBN). • [LANDSHIFT] There is no acceleration on legal access/permission for the agroforestry implementation.	• [ALCES] Engage with current communities (ALCES). • [LANDSHIFT] Less additional members for facilitators. • [LANDSHIFT] Less additional members for Agroforestry Business Group in the community scale.

Indonesia LMT 4: Soil Carbon (Biogas and Bioenergy)

	7. What are the wishes of the future for the LMT • include timing	8. How to achieve the wishes • How much does it cost? • Who pays for the cost? • Who implements?	9. Actions • policies, strategies, projects
Scenario 1: "HIGH" **Stakeholder representations:**	• [E3ME] The Indonesian government will focus on the clean energy transition, including the increase of bioenergy installation (IESR doc). • [E3ME] The GHG production will increase till 2030, then	• [E3ME] Indonesia will implement a carbon tax for coal-fired power plants starting April 1, 2022. The tax will be based on an emission cap and will apply a rate of **Rp30.00 per kilogram of CO2e.**	• [E3ME] Potential feedstock for bioenergy Indonesia are varied from palm oil waste, sugarcane, tapioca, paddy, and other agriculture and agroforestry waste. The total potential electricity from all feedstock are 56.97 GW.

	decrease gradually till 2050 (IESR doc). • [E3ME] Indonesia will be predicted to have the booming commodity export in 2030 and 2050.		
Scenario 2:" LOW" **Stakeholder representation**s:	• [E3ME] The Indonesian government will use current and low scenario where there is no significant improvement in renewable energy and coal power retirement (IESR doc). • [E3ME] There is no significant change in the increase trend of the GHG production (IESR doc). • [E3ME] The Indonesia government use the current condition where there is no improvement in the commodity export in 2030 and 2050.	• [E3ME] Only depend on current key players in the renewable energy plantation.	• [E3ME] There is no prohibition for new coal power plant.

Indonesia LMT 5: Cropland Management

	10. What are the wishes of the future for the LMT • include timing	11. How to achieve the wishes • How much does it cost? • Who pays for the cost? • Who implements?	12. Actions • policies, strategies, projects
Scenario 1: "HIGH" **Stakeholder representations:**	• [ALCES] 0.79% of the rice field area will decrease annually due to the land use change. • [ALCES] The Bali government targets 7,132 ha/year of organic rice field increasing. • [LANDSHIFT] The Indonesia government targets all rice farming practices to be rice intensification process (SRI). • [LANDSHIFT] The Indonesian government targets 1.9% of rice production increasing annually. • [LANDSHIFT] The Indonesian government targets to have 100% organic farm of the total agriculture farm in 2050.	• [ALCES] The Bali government through the Agricultural agency and Center of Agricultural Technology Assessment take in charge in monitoring the rice field area. • [LANDSHIFT] The Indonesia government will collaborate with local farmer groups through the agricultural agency at the city level to access the national (APBN) and donor funds.	• [ALCES] The subak system will manage the sustainable water and field management in the sub-village level. • [ALCES] The regional regulation No 08 Year 2020 about organic farming. • [LANDSHIF] The first rice intensification implementation was introduced in 1999. • [LANDSHIFT] The National Regulation No 41 Year 2009 about the protection of sustainable food land.

Scenario 2:" LOW" **Stakeholder representations:**			
	• [ALCES] 2.05% of the rice field area will decrease annually due to the land use change. • [ALCES] The Bali government targets 5,000 ha/year of organic rice field increasing. • [LANDSHIFT] The Indonesian government targets 0.61% of rice production increasing annually. • [LANDSHIFT] The Indonesian government targets to have 50% organic farm of the total agriculture farm in 2050.	• [ALCES] Bali government only depend on DAK (Special Allocation Budget) from each village. • [LANDSHIFT] The Indonesia government only depends on the national budget and there is no improvement in the number of projects.	• [ALCES] Some subak systems are not working well. • [LANDSHIFT] The sustainable farming practices are not applied in all regions well.

9.2. Quantitative storylines: pace of implementation for each LMT

	Current situation (baseline)	SCEN-"HIGH " SH perspective: DKLH Bali		SCEN-"LOW" SH perspective:	
Year	Now (provide sources)	2030 (change relative to the current situation) (provide sources)	2050 (change relative to the current situation) (provide sources)	2030 (change relative to the current situation) (provide sources)	2050 (change relative to the current situation) (provide sources)
LMT 1: Reforestation	• [ALCES] 43,000 Ha of Degraded land in Bali	• [ALCES] 20,000 Ha of degraded land are restored	• [ALCES] All degraded land are already	• [ALCES] 50% or 10,000 ha of degraded land with annual	• [ALCES] restoration on 50% or 21,500

	(Stakeholder Interview, 2023). • [LANDSHIFT] 800,000 ha per year nationally ith survival rates of 90 percent (BAPPENAS, 2022).	through annual restoration of 2,000 Ha (Stakeholder Interview, 2023). • ***[LANDSHIFT] 11.55 million ha of reforestation in 2030*** (KLHK, 2018)**.** • [LANDSHIFT] Reach an emission level at minus 140 Mt CO2e by 2030 (MOEF, 2022b).	reforested / afforested (Stakeholder Interview, 2023). • [LANDSHIFT] 24 million ha of reforestation in 2050 • [LANDSHIFT] Reach an emission level at minus 304 Mt CO2e by 2050 (MOEF, 2022a).	restoration 1,000 ha. • [LANDSHIFT] 2 million ha of reforestation in 2030 with 200,000 ha per year nationally (KLHK, 2020).	ha of degraded land. • [LANDSHIFT] 6 million ha of reforestation in 2030 with 200,000 ha per year nationally.
LMT 2: Peatland Restoration	• [LANDSHIFT] 301,800 ha of peatland restoration in 2020 and 272,000 ha annually (BAPPENAS, 2022).	• [LANDSHIFT] the area for peat restoration until 2030 should reach 2.72 million hectares (KLHK, 2021).	• [LANDSHIFT] 8.16 million ha achieved for peat restoration by 2050.	• [LANDSHIFT] 1.04 million ha of peatland restoration by 2030 with 104,000 ha per year (38% of the target) (KLHK, 2021).	• [LANDSHIFT] 3.12 million ha of peatland restoration achieved by 2050.
LMT 3: Agroforestry	• [ALCES] 23,000 Ha of	• [ALCES] More farmers are	• [ALCES] All agroforestry	• [ALCES] 5,000 ha of potential	• [ALCES] 15,000 ha of potential

	agroforestry exists in Bali with another 55,000 Ha of potential agroforestry land (Stakeholder Interview, 2023). • [LANDSHIFT] 5 million ha agroforestry in 2020. 770,000 ha of agroforestry annually (MOEF, 2021).	more open to implementing agroforestry in social forests. 15,000 ha of potential agroforestry implemented with annual implementation 1,500 ha (Stakeholder Interview, 2023). • [LANDSHIFT] 12.7 million ha of agroforestry with legal access and the addition of 25,000 facilitators.	potential has been fulfilled (Stakeholder Interview, 2023). • [LANDSHIFT] 22.7 million ha of agroforestry by 2050.	agroforestry are implemented with annual potential agroforestry implementation 500 ha. • [LANDSHIFT] 6.5 million ha of agroforestry with 150,000 ha (19.5%) annually.	agroforestry can be implemented with annual potential agroforestry implementation 500 ha. • [LANDSHIFT] 9.5 million ha of agroforestry achieved by 2050.
LMT 4: Soil Carbon (Biogas and Bioenergy)	• [E3ME] 0.01 MW of bioenergy installed (biomass, biogas, biofuel and waste-to-energy) in	• **[E3ME] 0.59 GW of bioenergy** (biomass, biogas, biofuel and waste-to-energy)	• [E3ME] Bioenergy in the energy mix is 23 GW by 2050. • **[E3ME]** Reducing coal power	• [E3ME] 50% of coal plantation in the energy mix [ESDM doc]. • [E3ME] 3% of bioenergy installation in	• [E3ME] 60% of coal plantation in the energy mix. • [E3ME] 2% of bioenergy installation in the energy mix.

	2020 (MEMR, 2023).	**installed by 2030.** • **[E3ME]** Reducing coal power generation by **11% by 2030.** • **[E3ME] National Electricity Company** (PLN) plans to retire **2-3 coal-fired power plants** with a combined capacity of about **1 gigawatt by 2030.** • **[E3ME]** GOI aims to reduce CO2 emissions by **17.2% in the energy sector.** • **[E3ME]** GOI aims to increase the share of **renewable energy in the**	generation by **11% by 2030.** • **[E3ME] National Electricity Company** (PLN) plans to 43 **gigawatt of coal power plant by 2050.** • **[E3ME]** GOI aims to reduce CO2 emissions by **100% in the energy sector by 2050.** • **[E3ME]** GOI aims to increase the share of **renewable energy in the national energy mix to 100% by 2050.** • [E3ME] GDP Indonesia will be $ 10.502	the energy mix [ESDM doc]. • [E3ME] 100% generation capacity for coal. • [E3ME] the emissions from the energy sector are to around 947 million to CO2eq (IESR doc). • [E3ME] GDP Indonesia will be $ 28.4 billion by 2030 (Cabinet secretary, 2021).	• [E3ME] 50% generation capacity for coal. • [E3ME] the emissions from the energy system are to around 950 Mton CO2eq (IESR doc). • [E3ME] GDP Indonesia will be $ 9.12 trillion by 2030 (Cabinet secretary, 2021).

		national energy mix to 31% by 2030. • [E3ME] GDP Indonesia will be $ 5.424 trillion by 2030 (WEF, 2017).	trillion by 2050 (WEF, 2050).		
LMT 5: Cropland Management	• [ALCES] Rice 112,000 ha of rice field exist in Bali in 2020 with 1,568 ha decreasing annually (interview with local stakeholders). • [ALCES] 25,000 ha of organic rice field in Bali by 2020. • [LANDSHIFT] 54 million tonnes of rice	• **[ALCES] 96,320 ha of rice field in Bali by 2030.** • **[ALCES] 100% of rice fied will be 100% organic with 7,132 ha increasing annually by 2030.** • **[LANDSHIFT] 64.26 million tonnes of rice field by 2030**	• [ALCES] 64,960 ha of rice field in Bali by 2050. • [ALCES] 100% of rice field will be organic by 2050 • [LANDSHIFT] 84.78 million rice of rice	• **[ALCES] 89,000 ha of rice field in Bali by 2030** with 2,300 ha decreasing annually (interview with local stakeholders). • [ALCES] 75,000 ha of rice field will be organic by 2030 with 5,000 ha increasing annually. • [LANDSHIFT] 57.3 million tonnes of rice	• [ALCES] 43,000 ha of rice field in Bali by 2050. • [ALCES] 100% of rice field will be organic by 2050. • [LANDSHIFT] 64.6 million tonnes of rice field production with 0.61% of

	field production in 2020 (MOA, 2021). • [LANDSHIFT] There are 75,793 ha of organic rice field in 2020 at the national level (AOI, 2016).	**with 1.9% (1.026 million tonnes) increasing annually** (MOA, 2021). • **[LANDSHIFT] 50% of the total rice field will be organic by 2030** (BAPPENAS, 2014).	field production by 2050 **with 1.9% (1.026 million tonnes) increasing annually**. • [LANDSHIFT] 100% of the total rice field will be organic by 2050.	field production with 0.61% (0.33 million) of rice field increasing annually by 2030 (BPS, 2023b). • [LANDSHIFT] **20% of the total rice field will be organic by 2030** (MOA, 2021).	rice field increasing annually by 2050 (BPS, 2023a). • [LANDSHIFT] **50% of the total rice field will be organic by 2030** (MOA, 2021). •

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