RSPO | Roundtable on Sustainable Palm Oil

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Compilation of Best Management Practices to Reduce Total Emissions from Palm Oil Production

November 2018

Contents

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List of Abbreviations

AGB	Aboveground Biomass
BMP	Best Management Practice
bio-CNG	Bio-Compressed Natural Gas
bio-LNG	Bio-Liquefied Natural Gas
BOD	Biological Oxygen Demand
BRG	Indonesia Peat Restoration Agency
C	Carbon
CA	Catalytic Absorption/ Amine Wash
CER	Certified Emission Reduction
CDM	Clean Development Mechanism
CDP	Carbon Disclosure Project
CH_4	Methane
CHP	Combined Heat and Power
CIGAR	Covered In-Ground Anaerobic Reactor
CIRAD	The French Agricultural Research Centre for International Development
CL	Cryogenic Liquefaction
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
COD	Chemical Oxygen Demand
CPO	Crude Palm Oil
CSTR	Continuous Stirred Tank Reactor
DEM	Digital Elevation Model
DTM	Digital Terrain Model
EFB	Empty Fruit Bunch
EPC	Engineering, Procurement, and Construction
ERPA	Emission Reduction Purchase Agreement
ERWG	Emission Reduction Working Group
ESIA	Environment and Social Impact Assessment
EU	European Union
EUR	Euro
FBP	Filter Belt-Press
FFB	Fresh Fruit Bunch
FIRMS	Fire Information for Resource Management System
FiT	Feed-in-Tariffs
FPIC	Free Prior and Informed Consent
GAP	Good Agricultural Practices
GAR	Golden Agri Resources
GHG	Greenhouse Gases
GRI	Global Reporting Initiative
GWh	Gigawatt hour
Ha	Hectares
HCS	High Carbon Stock
HCV	High Conservation Value
ICE	Internal Combustion Engine
IGAD	Institut Gabonais d'aide au Developpement
IOI	IOI Corporation Berhad

IOPRI	Indonesian Oil Palm Research Institute
INCAS	Indonesian Carbon Accounting System
IPM	Integrated Pest Management
IPNI	International Plant Nutrition Institute
ISCC	International Sustainability and Carbon Certification
ISPO	Indonesia Sustainable Palm Oil
IT	Information Technology
JV	Joint Venture
KADIN	Indonesian Chamber of Commerce
KLK	Kuala Lumpur Kepong Berhad
LIDAR	Light Detection and Ranging
LNG	Liquified Natural Gas
LUCF	Land Use Change and Forestry
MEC	Malaysia Environmental Consultants
MPOB	Malaysian Palm Oil Board
MT	Metric Ton
MYR	Malaysian Ringgit
MS	Membrane Separation
MWe	Megawatt Electrical
MWh	Megawatt hour
N	Nitrogen
N_2O	Nitrous Dioxide
NaOH	Sodium Hydroxide
NDPE	No Deforestation, No Peat, No Exploitation
NDVI	Normalized Difference Vegetation Index
Nm	Nanometer
O&M	Operations and Maintenance
PFAD	Palm Oil Acid Distillate
PISAgro	Partnership for Sustainable Indonesian Agriculture
PK	Palm Kernel
PKE	Palm Kernel Expeller
PKO	Palm Kernel Oil
PO	Palm Oil
POM	Palm Oil Mill
POME	Palm Oil Mill Effluent
PSA	Pressure Swing Absorption
PT AMNL	Agro Lestari Mandiri
PT SMART Tbk	PT Sinar Mas Agro Resources and Technology Tbk
PWS	Pressurized Water Scrubbing
S&P	Standard & Poor’s
SDP	Sime Darby Plantation
SDG	Sustainable Development Goals
SOP	Standard Operating Procedures
STI	Straits Times Index
t	Tonnes
Tph	Ton per Hour
RSPO	Roundtable Sustainable Palm Oil
R&D	Research and Development

ROI	Return on Investment
UAV	Unmanned Aerial Vehicle
UN	United Nations
UNGC	United Nations Global Compact
USD	US Dollars
WRI	World Resource Institute

Executive Summary

A commitment toward improving sustainability and reducing greenhouse gas emissions has continued to expand across the palm oil industry. A large range of new and improved management practices that result in emission reductions are emerging and being adopted by many companies. To help the overall palm oil industry evaluate what potential practices can be put in place and the magnitude of GHG emission reductions, the Roundtable on Sustainable Palm Oil (RSPO) and Winrock International have collaborated to develop a compilation of best management practices (BMP). Practices examined include those during Plantation Establishment, Concession Management and Mill Management (Table 1). Each BMP identified was evaluated against three criteria: financial feasibility, technical and operational challenges, GHG reduction potential, and technical and operational challenges, environmental and social co-benefits, and replicability.

Table 1. Best Management Practices assessed in this study.

Category	Description
Plantation Establishment and Concession Management	
Improved Plantation Location Establishment	- High Carbon Stock Approach No deforestation commitments - Zero burning techniques - Expansion on degraded lands
Yield enhancement	- Improved seeds and varieties/ certified seeds - Improved fertilizer management
Improved spatial monitoring system	- Use of remote sensing technologies to improve plantation management, fire prevention, and yield enhancement
Improved smallholder management	- Improved management practices resulting in increased productivity and thus reduced GHG intensity
Peat management	- Improved water table management within plantation and entire land holdings
Pest management	- Integrated pest and weed management
Plantation Fuel Usage	- Alternative fuels for transportation and machinery - Reuse of biogas from POME for transportation
Improved Concession Management through conservation and restoration	- After-use planning after the plantation cycle - Ecosystem restoration from conservation areas, degraded lands, biodiversity corridors - Expanded use of buffer zones (around rivers, etc.) - Phasing out some areas of production
Mill Management	
Efficiency Improvements	- Cogeneration or combined heat and power efficiency improvements
Methane Capture	- Methane capture for biogas electricity or transportation
Co-composting	- Creation of organic fertilizer from EFBs and POME
Solid Filtrate Separation	- POME treatment
Innovative Technologies	
Biomass Waste Utilization	- Use of by-products, particularly biomass waste, such as empty fruit bunches (EFBs)

Biogas Upgrading	- Upgrading biogas to biomethane
Advance Biofuel Production	- Creation of biofuels from residue and POME

In addition to the overview and assessment of different BMPs in the industry, five case studies of BMP initiatives implemented by different companies are provided. In each of these case studies, the company's GHG emission reduction BMP portfolio is presented as well as an in-depth evaluation of one particular BMP initiative. These in-depth evaluations include information on motivation, project execution, resource requirements, stakeholder involvement, GHG emission reductions, other impacts and benefits, and lessons learned.

Case study 1: Peat rehabilitation at PT AMNL (Golden Agri Resources)

This initiative takes place in and around the oil palm plantation PT AMNL of PT SMART Tbk, a subsidiary of Golden Agri Resources (GAR). The plantation is situated in Province of West Kalimantan in Indonesia. There are two important elements of this project: biophysical restoration and local community involvement. These build upon the fire management work that PT AMNL already had in place. As part of GAR, PT AMNL already adheres to the zero burning policy discussed in the previous section and has emergency response team personnel and equipment ready in the event of a fire. The justification for the biophysical restoration of peatlands is that they are much less vulnerable to fires than degraded peatlands. Local community involvement is also important since many locals still engage in slash and burn agriculture which can lead to wildfires.

Case study 2: Carbon stock assessments as part of plantation establishment in Gabon (Olam)

Olam Palm Gabon was established in 2011 as a public-private partnership between the Olam Group and the government of the Republic of Gabon (60:40 share) to develop oil palm plantations in the country. Olam Palm Gabon has committed to be carbon neutral or net carbon positive over the first 25 years and to achieve its goal, the low carbon policies and sustainable growth strategies is implemented. In doing so, carbon stock assessments are included in the land use planning as one of the efforts to minimize carbon emissions from oil palm operation. Further, Olam is the first company that was tested by the Technical Committee of HCS+ in Mouila plantation.

Case study 3: Methane capture at the Terusan Mill (Wilmar)

Terusan Palm Oil Mill located in Sabah, Malaysia is owned and operated by PPB Oil Palm Berhads, a subsidiary of Wilmar International Ltd (Wilmar). Methane capture is part of Wilmar's strategic focus to reduce emissions in its palm oil production. By end of 2016, Wilmar had 17 operating methane capture plants, with 8 more under construction. Terusan Palm Oil Mill developed its methane capture facility, a Covered In-Ground Anaerobic Reactor (CIGAR), in 2015, and it became operational in 2016.

Case study 4: Filter belt-press (KLK Berhad)

A major issue that all palm oil mills are faced with is how to manage their palm oil mill effluent (POME), the liquid waste produced from the processing of fresh fruit bunches. The presence of these solids in the conventional open pond treatment system contributes to the production of methane. Furthermore, as these solids accumulate, the ponds begin to fill in and, therefore, dredging is required. To address this issue in its mills, Kuala Lumpur Kepong Berhad (KLK) installed a Filter Belt-Press system to remove solids from the POME before it enters treatment ponds. The filter belt-press (FBP) is a device used to chemically enhance the separation of POME into a filtrate (i.e., wastewater) and a solid press cake (i.e., solid organic matter). The FBP system continuously removes solids from the pond system, thereby reducing the formation of methane gas.

Case study 5: Co-composting (Sime Darby)

Sime Darby Plantations is currently implementing initiatives on methane avoidance through composting. Sime Darby Plantation began piloting composting as a mill waste management initiative in 2004 initially with 5 plants, of which 4 were registered under the Clean Development Mechanism under the Kyoto Protocol. These 4 projects continue to be in operation as part of Sime Darby's Carbon Reduction Strategy, along with 18 other composting plants constructed since 2010, making up a total of 22 compost plants that produce about 500,000 mt of compost per year. The composting system uses a combination of mechanical and biological methods to convert POME and EFB, boiler ash, and decanter cake into organic fertilizer.

Based on the BMP assessments and in-depth case studies, the different BMPs are evaluated in terms of investment costs and technical requirements and potential GHG emission reductions and other co-benefits as summarized in Figure 1 and Figure 2.

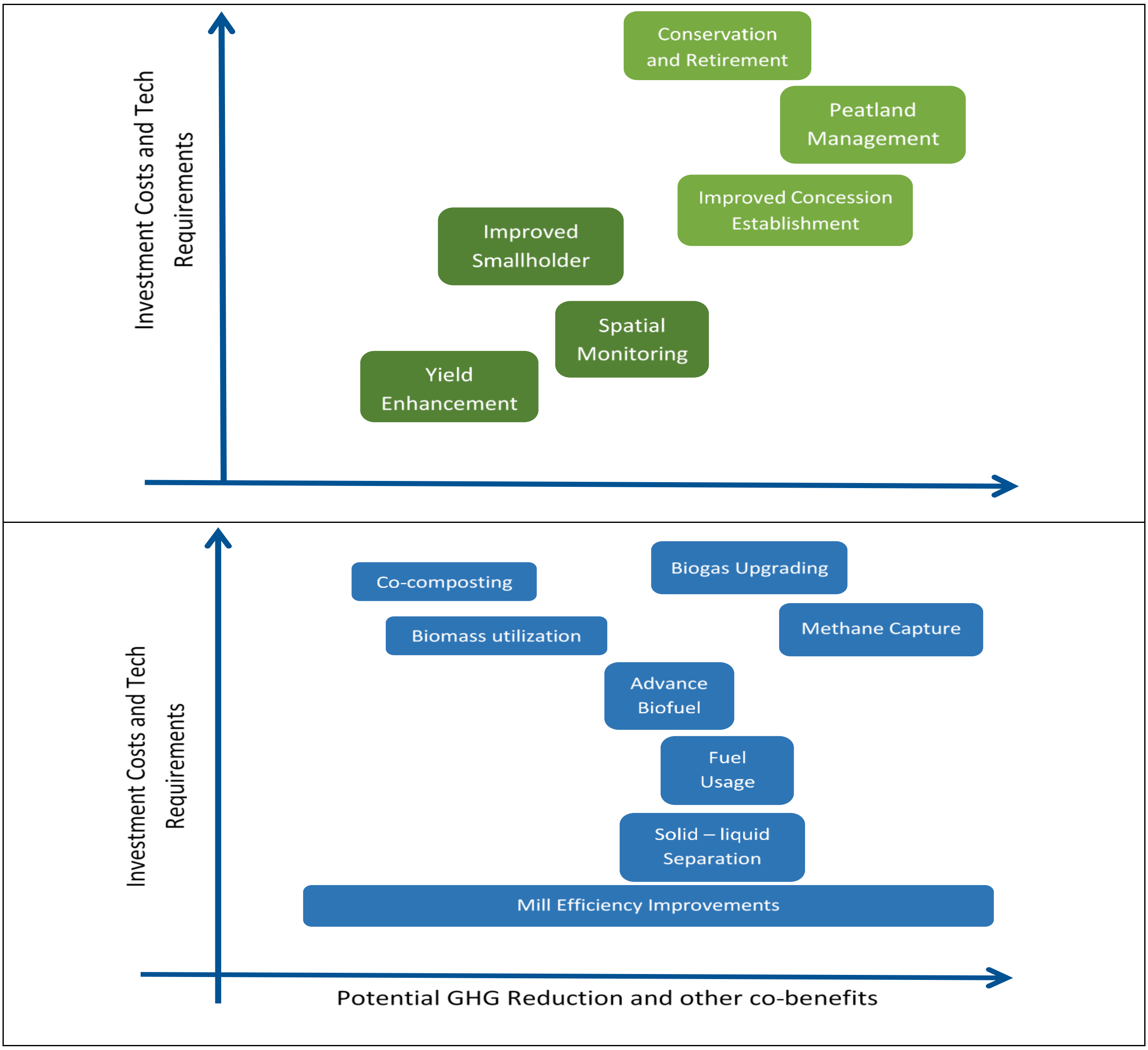

Figure 1. Comparison investment and technical requirements to potential GHG reduction and other co-benefits of the BMPs examined

	RESOURCE REQUIREMENTS	BENEFITS
Concession Establishment	H Potentially high costs due to reduced area under production	H High GHG emission reduction potential and co-benefits
Spatial Monitoring	M Low cost, but technologies changing rapidly	M Improved yields ► reduced PO product emission intensity
Yield Enhancement	L Low investment cost	M Improved yields ► reduced PO product emission intensity
Peatland management	H Significant investment costs	H Extremely large annual GHG emission reduction potential
Improved smallholder production	H Significant investment costs	M Improved yields ► reduced PO product emission intensity
Integrated Pest Management	L Low investment cost	M Improved yields ► reduced PO product emission intensity
Fuel Usage	H High initial investment cost, rapid return	M High GHG emission reduction potential
Improved concession management	H Potentially high costs due to reduced area under production	H High GHG emission reduction potential and co-benefits
Efficiency improvements	L Low investment costs and low tech skills needed	V GHG reductions dependent on technology
Methane Capture and POME-to-Biogas Electricity	H High investment costs	H Very high GHG reduction
Co-composting	H High investment costs; only requires low tech skills	M Replaces use of inorganic fertilizer
Solid Liquid Separation	L Lower investment compared to methane	H High GHG emission reduction potential
Biomass Waste Utilization	M Medium investment cost, low technical skill	M Products can be sold and add revenue for companies
Biogas Upgrading	H High investment cost	H High GHG emission reduction potential and fossil fuel replacement
Advanced Biofuel Production	M Medium investment cost	H High GHG emission reduction potential and fossil fuel replacement

H – High **M** – Medium **L** – Low **V** – Varies

Figure 2. Summary of main considerations for each BMP examined

The assessment found that several of the plantation BMPs, such as improved smallholder production and remote sensing approaches to improve management, would result in increased yield per hectare thereby improving the GHG efficiency of the final palm oil product. Since yields increased, the return on investment of implementing these types of BMPs is expected to be high. Other plantation BMPs focus on establishing plantations in areas determined to have high carbon stocks (HCS) or high conservation values (HCV). While these approaches have direct financial implications, many companies have committed to implementing them regardless in order to comply with their sustainability policies. The action with the most significant GHG emission reduction potential on plantations grown on peatlands would be to either retire the area, or to improve the water table management resulting in reduced annual emissions. Additional piloting and research are needed to identify cost-effective water table management and to evaluate yield impacts.

At the mill level, methane capture offers the highest emission reduction potential. Although the initial investments can be high, installation costs can be recouped relatively rapidly. The technology behind solid-liquid separation techniques has recently advanced beyond the pilot stage, and thus offers a very attractive option, especially in locations where the space for methane capture is less available. Co-composting and biomass utilization offer relatively cheaper investment cost with considerable environmental and social co-benefits. Emerging technologies such as biogas upgrading and advance biofuel production can be the most appropriate option for companies focused on reducing fossil fuel consumption in plantation and mill, although these technologies require high investment costs.

Although the exact costs, emission reductions, co-benefits and challenges will depend on location specific circumstances, a wide range of proven practices are available to the palm oil production community. Using the guidance provided in this report, it is hoped that companies can focus their selection of practices that are most likely to fit their needs. This in turn supports companies in meeting the RSPO principles and criteria and ultimately in helping to mitigate the threat of global climate change by reducing greenhouse gas emissions.

Project Overview and Introduction

Background and objectives

The exceptional versatility, stability, and productivity of palm oil has led to its use in an ever-expanding variety of foods, cosmetics and biofuels. Its consumption has grown dramatically over the past few decades, and in 2016 made up nearly 60% of total vegetable consumption worldwide. Cultivation and processing of palm fruit has raced to meet the soaring demand, with Indonesia and Malaysia accounting for 86% of the world's supply. As in other commodity production, activities along the palm oil supply chain, such as the land preparation, production and processing will result in the emissions of greenhouse gases (GHGs), contributing to global climate change.

However, there are many management decisions that can be taken to lower the impact of palm oil production and increase its sustainability. The Roundtable on Sustainable Palm Oil (RSPO) was established in 2004 to promote the growth and use of sustainable palm products through credible global standards and the engagement of stakeholders. Through certification and the dissemination of information on advancements in oil palm cultivation, processing, and distribution, the RSPO has worked to lower negative environmental and social impacts of this globally vital commodity.

RSPO maintains a set of principles and criteria by which they hold their members to, which includes *Plans to reduce pollution and emissions, including greenhouse gases, are developed, implemented and monitored*; and *New plantation developments are designed to minimizes net greenhouse gas emissions*. Many companies have already put in place practices and technologies to reduce GHG emissions and their environmental footprint, while others are still exploring what interventions can best help them balance financial constraints with standards and goals for environmental and social sustainability.

The RSPO Executive Board established a Greenhouse Gas Working Group (GHG-WG 1) in November 2008 that was charged with reviewing relevant information on palm oil production and GHG emissions. The decisions to convene this commission grew out of an ongoing and still unresolved debate as to the dimensions of GHG emissions from the palm oil supply chain and the need to respond to existing text within in the RSPO Principles and Criteria regarding efforts to reduce GHG emissions. Looking at the positive recommendations coming from GHG-WG 1, the Executive Board convened a second GHG-WG (GHG-WG 2) to address issues of public policy and business strategies, in order to develop a process that will lead to meaningful and verifiable reductions in GHG emissions from the palm oil supply chain.

Then at RT-11 in 2013, the Emission Reduction Working Group (ERWG) was established to support and oversee the successful implementation of Criterion 5.6 and Criterion 7.8 of the RSPO Principles & Criteria 2013 until the implementation phase which ended on 31st December 2016. Looking at the need for continuous support from ERWG with the expanded scope of works in relations to Criterion 5.6 and Criterion 7.8, the working group then continued until 31st December 2017.

During this period, the ERWG has identified key sources of emission from palm oil production and identified the need to have guidelines on best practices to help growers to reduce GHG emissions in their operation.

Winrock International, a global non-profit that works to empower the disadvantaged, increase economic opportunity, and sustain natural resources, was identified as the service provider to conduct literature research to come out with best management practices (BMPs) that are practical and cost effective and suggest these as options available for the growers (implementation by big and small size growers). This report is the final product of the literature review.

The practices identified were evaluated against a consistent set of criteria: GHG reduction potential, financial considerations, environmental and social co-benefits, technical challenges, and replicability. In addition, five in-depth case studies on BMP practices that certain companies are implementing are also provided. It is hoped that companies can use the report to assess what BMPs may fit best with their goals and circumstances and thus aims to help companies in meeting the relevant RSPO principles and criteria.

GHG emissions occur at various stages of palm oil production (Figure 3), and there is the potential for GHG efficiency improvements at each stage. Here GHG sources and sinks at both the plantation and the mill are examined, which can be broken down by the production stages of site preparation; plantation management; agricultural input production; transport of fresh fruit bunches; and processing of fruit bunches in the mill. Emissions occurring farther down the supply chain are not included in this assessment. Additionally, investments in offset programs to reduce emissions outside of a company's direct operations are considered, such as programs to prevent conversions of natural forests or restore degraded peatlands outside of the company's concession.

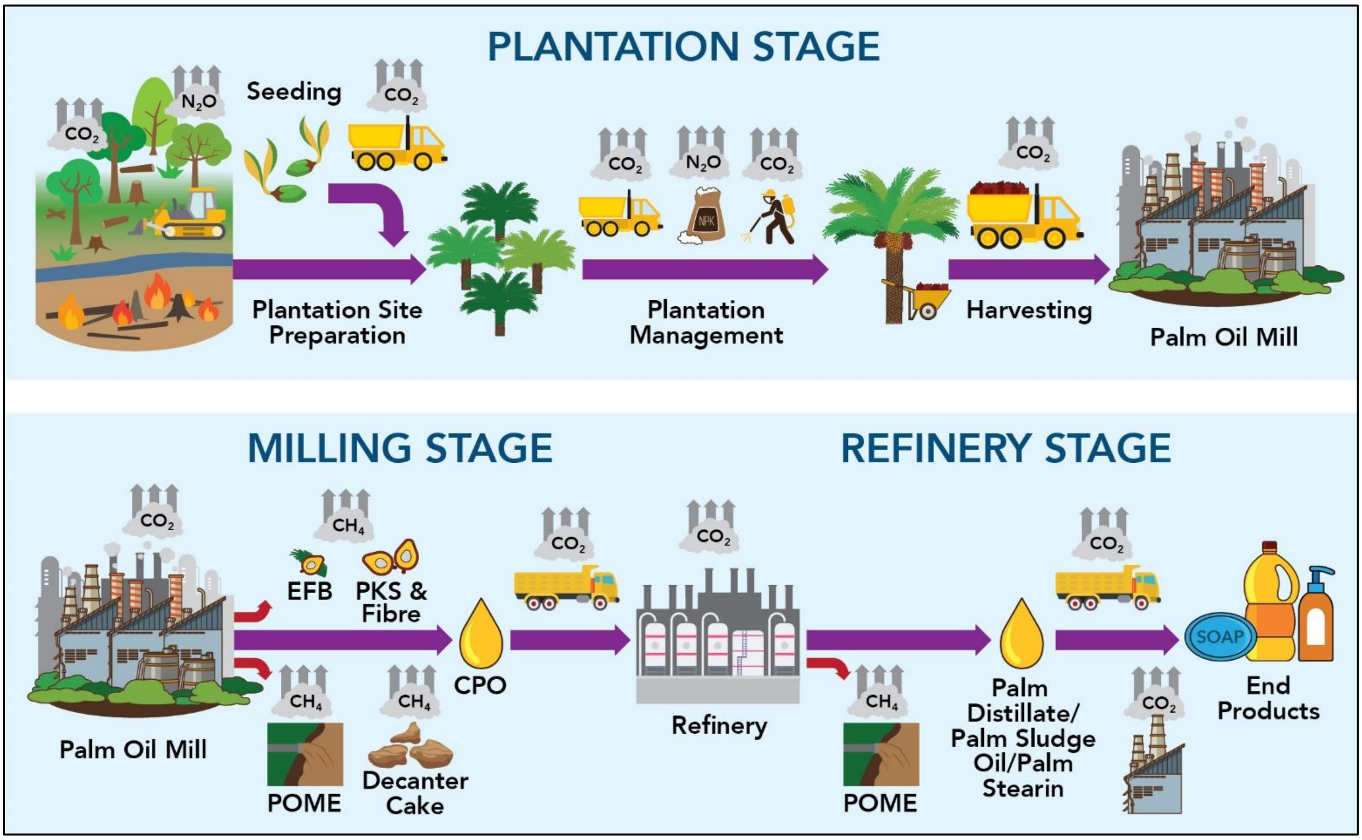

Figure 3. Overview of GHG emissions in different stages of palm oil production (modified from Figure 2 of Eco-Ideal Consulting Sdn. Bhd (2013))

Note: The boundary of RSPO'S Principle and Criteria certification only includes the plantation and milling stage.

The production of agricultural commodities, including vegetable oils like palm oil, plays a key role in global economic growth. In 2014, the global market size for palm oil was estimated to be USD 57.56 billion[1]. The frequent side effects of these economic benefits are the negative environmental impacts, such as greenhouse gas emissions leading to climate change. The magnitude of the negative impacts, however, vary by crop. In one study, life cycle assessments were performed to assess the environmental impacts of five vegetable oils: palm oil, rapeseed oil, soybean oil, sunflower oil, and peanut oil (Muñoz, et al, 2014). More specifically, it looked at greenhouse gas emissions, water use, and land occupation. As Figure 4 shows, rapeseed oil and sunflower oil production has the lowest greenhouse

[1] https://www.grandviewresearch.com/industry-analysis/palm-oil-market.

gas emissions, followed by palm oil and soybean oil production. Peanut oil production has the highest emissions of the five oils analyzed.

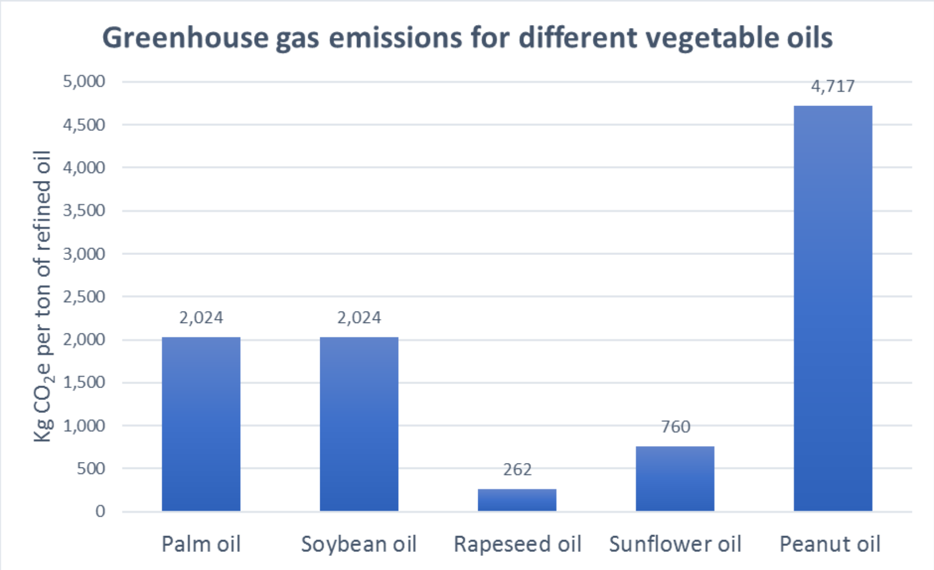

Figure 4. Greenhouse gas emissions from the productions of different vegetable oil (Modified from Figure 3 in Muñoz et al (2014))

With regards to palm oil emissions estimates, the study found that a major source of uncertainty is the portion of oil palm grown on peat soils and what emission factors are applied to peat soils. Palm oil emissions are closer to rapeseed oil emissions when the portion of cultivation that occurs on peat is small.

Palm oil production has received particular scrutiny due to its association with tropical deforestation, which leads to a host of environment impacts like greenhouse gas emissions. A 2014 study published by the Center for Global Development looked at the relationship between four commodities (beef, soybeans, palm oil, and wood products) and deforestation and the resulting GHG emissions in eight countries: Argentina, Bolivia, Brazil, Paraguay, Democratic Republic of the Congo, Indonesia, Malaysia, and Papua New Guinea from 2000 to 2009 (Persson et al, 2014). Of these countries analyzed, only three (Indonesia, Malaysia, and Papua New Guinea) were selected to assess the relationship between deforestation and palm oil production.

While the primary goal of this paper was to understand how global supply chains link consumption of different agricultural and forest commodities to deforestation, it provided estimates of total production (in tons) and total CO_2 emissions resulting from deforestation in 2009, which allowed us to come up with comparable CO_2 emissions per ton of the commodity produced during that year. Table 2 presents the emissions intensity for each ton of commodity produced[2]. It shows that palm oil has a much lower emission intensity value than beef, pulp and paper, and other wood products, whereas its emissions are slightly greater to those of soybeans.

Table 2. GHG emissions intensity for five agricultural and forest commodities in eight countries[3]

Commodity	CO_2 emissions per ton of commodity produced in 2009
Palm oil	1.7
Beef	56.0
Soybeans	1.4
Pulp & paper	45.9

[2] These numbers were calculated by aggregating the country values provided in Table 1 of Persson et al (2014).

[3] Ibid.

Commodity	CO_2 emissions per ton of commodity produced in 2009
Wood products	16.5

In 2009, RSPO commissioned an extensive literature review, carried out by Brinkman consultancy, to assess greenhouse gas emissions in palm oil production (Brinkmann Consultancy, 2009). Table 3 provides a breakdown of each emission source during the production process and the estimated emissions. Based on this analysis, estimated emissions per ton of CPO produced at various stages of production had an extremely large range - from 3,930 to 30,240 kg CO2e. A 2017 study provided another review of GHG emissions from palm oil production, using the RSPO PalmGHG calculator, with the goal of identifying emission hotspots (Gan & Cai, 2017). As the final column of Table 3 shows, the analyses from this study showed a range from +21 to +8,881 kg CO_2e per ton of CPO produced. The differences in the results of the two studies are most likely the results of the differing methodologies used to estimate emissions. The estimated emissions in Brinkmann Consultancy (2009) are based on an extensive literature review, whereas the emissions in Gan & Cai (2017) are based on calculations in the RSPO Palm GHG calculator. These types of analyses can help producers prioritize where to focus efficiency improvements. Both of these studies clearly point out that the large emission source will be from drained peatlands, followed by land cover change during site preparation. These sources dwarf mill operation emissions.

Table 3. Estimates of GHG emissions across CPO production system

	Brinkman Consultancy (2009)		Gan & Cai (2017)
GHG emission factor	Emissions per ha ($kgCO_2e$/ha*annum)	Emissions per ton CPO (kg CO_2e/ton CPO)	RSPO PalmGHG calculator (kg CO_2e/ton CPO)*
Operations			
a. Fossil fuel use transport and machinery	+180 to +404	+45 to +125	+10
b. Fertilizer use	+1,500 to +2,000	+250 to +470	+260
c. Fuel use in mill & utilization of mill by-products	0	0	+1
d. POME	+2,500 to +4,000	+625 to +1,467	+650 without methane capture; + 70 with methane capture
Total operations	*+4,180 to +4,000*	*+920 to +2,007*	*+341 to +921*
Emissions from carbon stock change			
a. Land conversion	+1,700 to +25,000	+425 to +7,813	+960
b. Annual sequestration by oil palms	-7,660	-1,915 to -2,393	-1,280
c. Emissions from oil palm on peat	+18,000 to +73,000	+4,500 to +22,813	+7,280 (+1,000 from N_2O emissions)
Total emissions related to carbon stock change	*+12,040 to +90,340*	*+3,010 to +28,233*	*-320 to +7,960*
Total	**+16,220 to +96,565**	**+3,930 to +30,240**	**+21 to +8,881**

* Converted from tonne of CO_2e

Note: a plus sign indicates net GHG emissions, whereas a negative sign indicates net GHG sequestration.

A number of tools have been developed that can be used by palm oil companies to calculate emissions from CPO production. Tools such as RSPO PalmGHG calculator (used in the Gan & Cai (2017) study and discussed in Box 1), ISCC GHG calculator, and GHG Protocol were developed based on life cycle assessment (LCA) approach to quantify GHG emissions per tonne product. The RSPO PalmGHG calculator assumes the largest causes of GHG emissions on a plantation include land use, peat land oxidation, chemical fertilizer, and POME. Palm oil companies can utilize the RSPO PalmGHG calculator as a tool to identify and analyze emissions hotspots in their establishment and mills, and subsequently identify suitable management practices to reduce GHG emissions from their CPO production.

Oil palm cultivation by smallholders also plays a significant role to the total GHG emission in the supply chain. In Indonesia alone, smallholders manage around 40% of all plantations. However, the critical roles of smallholders are often overlooked and excluded from the sustainable palm oil efforts limiting smallholders' access to knowledge in best management practices. This has led to lower productivity and lower concern for sustainability. Smallholders with limited knowledge on sustainable palm oil tend to cultivate oil palm in new area to accommodate low productivity. Without proper land planning, these new plantations can take place in high carbon stock area, leading to bigger GHG emissions.

Box 1. RSPO tools and other resources

RSPO Principles and Criteria for Sustainable Palm Oil Production

The RSPO Principles and Criteria (P&C) describe the requirements for becoming RSPO certified. They are developed and revised every five years. Since 2013, the RSPO P&C also includes indicators and guidance for producing palm oil sustainably. As discussed in the introduction, criteria relevant to greenhouse gas emissions include *Plans to reduce pollution and emissions, including greenhouse gases, are developed, implemented and monitored*; and *New plantation developments are designed to minimizes net greenhouse gas emissions*. For each of these criteria and for the others, the P&C include indicators and guidance on how to fulfill them.

RSPO PalmGHG Calculator

The RSPO PalmGHG Calculator was first launched in 2012, and two updated versions were made in 2014 and 2016. This tool is used to quantify annual net GHG emissions in CO_2 equivalent per hectare and per unit of product as (CPO, FFB, PKO and PKE from estates or mills). In the latest version (Version 3.0.1), a "no mill" option is available. All of the important gases (CO_2, CH_4 and N_2O) from agricultural soil are included in the RSPO calculator. Sources of emissions that are quantified in this tool include: land conversion, manufacture of fertilizers and transport to the plantation, fertilizer application, fossil fuel combustion in the field and mill, POME, and peat decomposition. Moreover, three classes of sequestration are calculated: carbon sequestration by oil palm growth, carbon sequestered from forest/vegetation growth in conservation areas, and GHG emissions avoided when mill energy byproducts (PKS) are sold to cement industries to displace the burning of coal.

In addition to RSPO calculator, ISCC and ISPO calculators also provide a life-cycle approach for estimating net GHG emissions in the palm production chain. According to one study, the RSPO calculator yields higher estimate of GHG emission compared to ISPO and ISCC calculators (Gan and Cap 2016). The different default values for carbon stock and emission factor are the main cause of the variation. In addition, peat decomposition is the dominant source of GHG emissions for oil palm planted on peatlands which can be quantified using ISPO and RSPO calculators. However, this source is excluded in ISCC report because this certification system prohibits oil palm planted on peat soil.

RSPO GHG Assessment Procedure for New Development

The RSPO GHG Assessment procedure for New Planting Development provides estimation of corresponding carbon stock fluxes (above and below ground) and GHG emissions associated with new development plans to minimize GHG emissions. The procedure provides guidance on selection of preferred development options and preparation of a plan to minimize GHG emissions for new developments. This includes presence of peat area, emissions from mill and plantations and avoidance of area with high carbon stocks. The selection of preferred development is done by considering carbon stock assessment, GHG emissions assessment for new plantings, emission management and mitigation plan and finally reporting of GHG Assessment for New Plantings.

RSPO Support to Smallholders

RSPO recognizes the importance of smallholders and the need to include them in sustainable palm oil production. Since 2014, RSPO has been supporting smallholders through the RSPO Smallholder Support Fund (RSSF). The funds are used to support smallholders with the costs incurred for training, project management, High Conservation Value (HCV) and Social and Environmental Impact Assessment (SEIA), audit costs, as well as the tools and techniques to support smallholder development.

Furthermore, in June 2018, the RSPO Board of Governors endorsed four Smallholder guidance documents and tools. These include:

- Guidance on Map Submission for Land Use Change Analysis (LUCA) for Independent Smallholder (Version 1, December 2017);
- Greenhouse Gas (GHG) Assessment Procedure for New Development (Reference Tool for Smallholder) (Version 1, December 2017);
- Smallholder-Friendly Manual for Social and Environmental Impact Assessment (SEIA) Tool (Version 1, December 2017);
- Simplified High Conservation Value (HCV) Approach for Independent Smallholder in the RSPO

Management practices to reduce net greenhouse gas (GHG) emission within the palm oil sector

In recent years, significant innovation has occurred in the palm oil sector. Companies have been incorporating new technologies and practices into the different stages of CPO production that help reduce GHG emissions.

In plantations, a variety of good agricultural practices are now applied or are being piloted. In response to issues of land scarcity and adverse environment impacts caused by new land expansion, the industry has shifted its focus from identifying new areas to establish plantations to improving productivity in existing plantations and reducing environmental and social negative impacts. For instance, high conservation value (HCV) and high carbon stock (HCS) criteria are being applied to reduce these impacts, and high yield seed cultivation is a top industry priority to improve productivity. Further, integrated pest management (IPM) is used to control pest and diseases, organic fertilizers are more commonly applied (although unlikely to replace chemical fertilizers use completely), and the use of sensors and GPS-enabled machinery are being explored to enable more efficient production.

Responsible low emission new oil palm development is becoming a necessity for the industry. RSPO's GHG Assessment Report submissions (through RSPO New Planting Procedure) from the years 2015 to 2017 demonstrated the use of RSPO GHG Assessment Procedure for New Development in land use planning to ensure that new plantation developments are designed to minimise net GHG emission (Gan et al., 2018). The results of projected GHG emission associated with new oil palm development by RSPO members in Malaysia, Indonesia, Papua New Guinea, South America and Africa were presented during ICOPE 2018 at Bali.

This study showed that new oil palm developments are planned on 193,857.24 ha of which 127,620 ha (66%) is proposed to be developed and the balance in set-aside areas resulting in an RSPO estimated net emission reduction of about 2 million tCO2eq or 1.54 tCO2eq/tCPO. Since no new plantings will be established on peat areas, the total emissions are minimized. In addition, in about 34% of the area, conservation areas will be established, further minimizing emissions. Based on these finding, the RSPO GHG Assessment Procedure for New Development is a useful tool to assist growers in achieving low carbon new oil palm development.

Using the Procedures, the potential GHG sources and sinks are identified, enabling the design of new oil palm development to minimize net greenhouse gas (GHG) emissions and create any needed mitigation plan.

In palm oil mills, innovation related to reduced GHG emissions has been focused on improvements in waste utilization. Examples include using biogas as an energy source produced from facilities which capture methane from palm oil mill effluent (POME) and composting of mill waste, which is then applied as fertilizer on plantations.

These updated management practices have direct and indirect effects on GHG emissions. The primary motivation to implement some of the BMPs is GHG emission reductions while for others these reduced emissions are simply a co-benefit. For an example, integrated pest management is implemented with the goal of controlling pests and diseases such as Ganoderma, Rhinoceros beetles and leaf eating bagworm while reducing the use of chemical pesticides. The co-benefit of IPM are lower GHG emissions associated with producing and applying these pesticides.

The implementation of best management practices by companies is influenced by multiple factors. These factors include: whether or not the BMP will provide significant potential GHG reductions; the potential economic and environmental benefits of implementing the BMP (for example, cost savings from substituting fossil fuels for biogas produced from methane capture facilities and improved biodiversity benefits from restoring peatlands); and the financial feasibility of implementing the BMP.

Based on a thorough review of the previous RSPO BMP study, multiple published case studies, conference proceedings, and scientific articles, we have classified the influencing factors for BMPs implementation into two overarching categories: internal and external factors to the company (Figure 5).

A. Internal factors

Internal factors include a company's vision and strategy, its desire to grow, its available resources, and its sustainable policy. A company's overall vision and desire to grow defines its strategy which, in turn, determines what commitments will be pursued and how it allocates its resources, including human and financial capital. The size of these resources will play an important role as well, especially if the company is considering investing in an expensive, labor intensive practice. A company's sustainability policy, influenced by the company's vision and strategy, more specifically outlines how decisions related to BMPs are made. It is important to mention that these internal factors are very much influenced by the external policies discussed below.

B. External factors

There are many external factors that influence a company's decision to implement BMPs. These include government regulations, the market, industry trends, available sustainability standards, climate change impacts, stakeholder demands, and technology development. Complying with government regulations is required for any company doing business. Governments also influence how sectors interact. Markets, including buyers and end customers, and sustainability standards often complement one another in creating incentives and providing guidelines for companies to implement certain BMPs. Furthermore, trends in the overall industry, such as the widespread adoption of a particular technology, will influence whether a company will also adopt it. Climate change can create extreme weather conditions which impact overall production and motivate companies to implement BMPs to mitigate climate change and adapt to its impacts. Stakeholders such as investors, local communities, and NGOs can all sway company decisions in different. Some companies have the capability to develop their own technologies, for example through research and development facilities for selective breeding. Most of the time, however, companies have to rely on existing technology to meet their needs. There are cases also when the technology is ready but the company is not due to financial reasons.

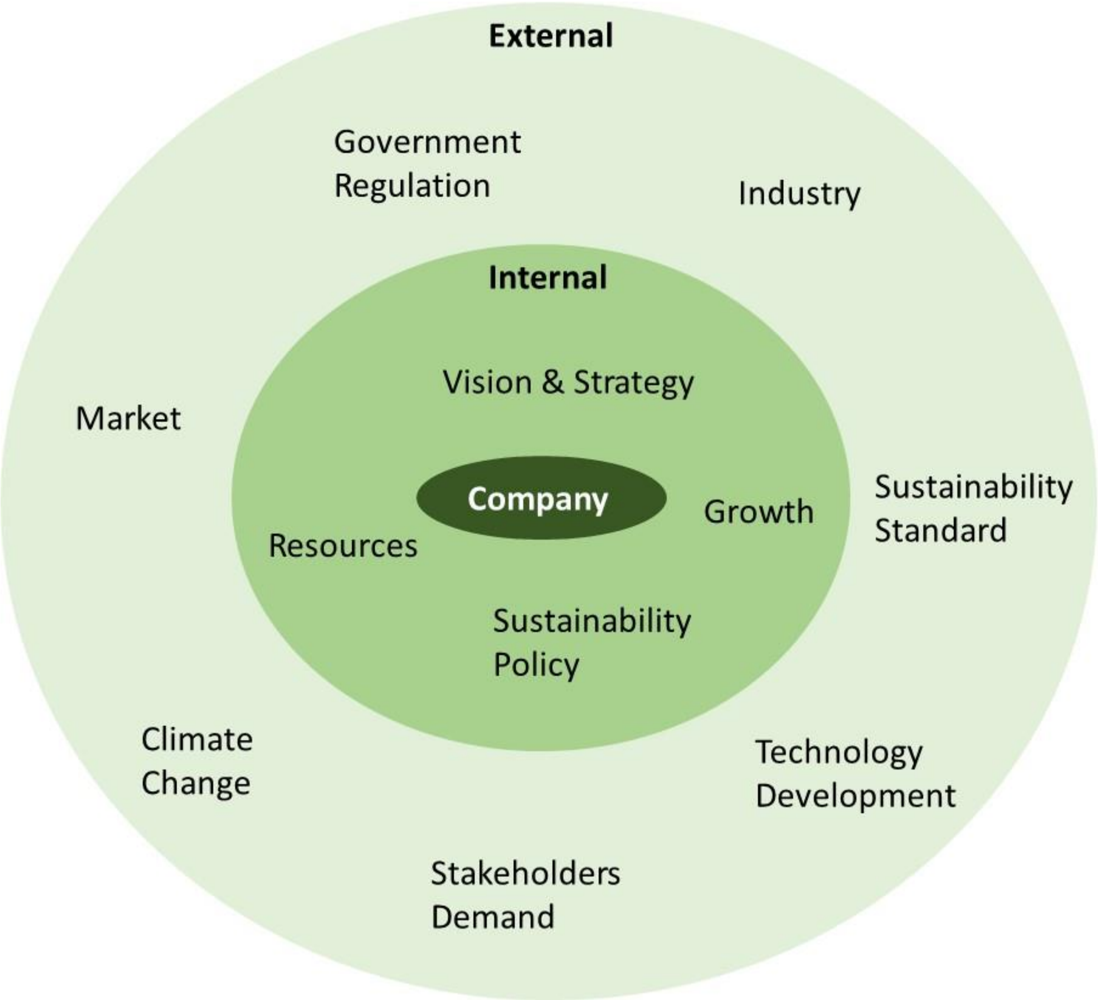

Figure 5. Influencing Factors of BMPs Implementation in a Company

Box 2. Management practices to reduce GHG emissions in other agricultural sectors

All agricultural commodities produced will generate a profile of greenhouse gas emissions that has many similarities to those in the palm oil industry. This will include emissions due to site preparation and establishment; ongoing emissions on plantations including fertilizer usage, soil emissions, and fossil fuel usage; and emissions during any milling and processing. In addition, many industries must contend with the efficient reduction in the volume of any crop residues and effluent. In fact, the agriculture, forestry, and other land use (AFOLU) sector contributes about 24% of global emissions (Smith et al, 2014). Between 2001 and 2010, agricultural emissions increased by 1.1% annually reaching 4.6 billion tCO_2e per year in 2010 (Tubiello et al, 2013). As a result, other agricultural industries are working to reduce their emissions and improve the GHG efficiency of their production through the adoption of improved practices. The information below provides examples of the types of activities being implemented to help reduce emissions in supply chains.

Pineapple industry example

The pineapple producer Great Giant Pineapple, located in Lampung Province of Indonesia, is implementing a number of BMPs to help reduce greenhouse gas emissions from its supply chain. In particular, the company is focused on producing zero waste. In 2011, the company constructed a plant designed to convert wastewater from its pineapple and tapioca factory into biogas. This plant has helped the company reduce its use of heavy fuel oil (HFO) by 100% and its coal use by 7% in its power plant thereby reducing GHG emissions by approximately 40 thousand tCO2e. It was the first member of the pineapple industry to use the technology Up-flow Anaerobic Sludge Blanket (UASB) to produce the biogas.

Further, the company has a composting initiative in which cattle dung is applied as fertilizer in the pineapple plantation, thereby reducing the need to apply chemical fertilizers. The pulp from pineapples the company produces is also used to feed the cattle. In addition to composting, the company also produces liquid organic fertilizer consisting of rhizo-bacteria to promote nutrient uptake and phyto-hormones to promote plant growth. These soil enrichment efforts not only reduce the need to apply chemical fertilizers but also enhance yield.

Sources: Enterprise Asia, 2017; WBCSD. 2016.

Soybean industry example

Cargill, in collaboration with the Nature Conservancy and the Brazilian government, has been working with 15,000 farmers at different production levels in Brazil to remove deforestation and the associated GHG emissions from its supply chains and help farmers comply with the Brazilian Forest Code. They helped register more than 60 percent of their suppliers in the Rural Environmental Registry (CAR), which is used to assess who is complying with the Forest Code and not. They have provided training to 300 Cargill employees to evaluate progress on the implementation of the Forest Code in their supply chain. Cargill also uses geospatial analysis and satellites to track compliance in their supply chain. They have provided educational material to farmers and farmers associations about the Forest Code as well as require documentation from producers that they are in compliance.

In Paraguay, Cargill is engaged in similar activities to monitor and evaluate deforestation risks in its soy supply chain. It is educating soy farmers on best agricultural practices and relevant policies.

Source: Cargill, 2018.

Sugarcane industry example

A 2018 study published in the scientific journal Agronomy for Sustainable Development provided a review of different advances to improve the sustainability in sugarcane production in Brazil (de Oliveira Bordonal et al, 2018). These practices included the following:

- Non-burning harvesting. The common practice to burn residues before the harvest which has been estimated to emit 941 kg CO2e ha-1 yr-1, or a total of 30.3 % of total GHG emissions from sugarcane agricultural production.
- Replacement of diesel use during harvesting by renewable fuels as well as improved efficiency of transportation vehicles.
- Application of vinasse (wastewater produced during the processing of sugarcane biofuel) as a fertilizer on sugarcane fields. This practice reduces the need for chemical fertilizers and the emissions resulting from them. There are also specific BMPs related to the the transport and application of vinasse designed to reduce emissions as included:
  - Adoption of new technologies, such as closed pipes instead of open channels, to transport vinasse;
  - Application of concentrated vinasse compared to fresh vinasse;
  - Anaerobic digestion and concentration of vinasse.

Source: de Oliveira Bordonal et al, 2018

Pulp and paper industry example

The APRIL Group has a pulp and paper mill and plantation forests in Riau Province, Sumatra, Indonesia. APRIL is engaged in a number of practices that have reduce its GHG emissions:

- They have conducted 37 High Conservation Value (HCV) assessments and currently conserve more than 250,000 HCV forests within their concession area;
- They are currently in the process of restoring 40,000 hectares of high conservation value forests in the Kampar Peninsula;
- Water table management through weirs in the parts of their concessions on peatland to minimize GHG emissions;
- Fire management through investments in fire prevention and fire suppression capabilities and engagement with local communities on education and incentive-based fire prevention initiatives.
- Generation of renewable energy from waste and production processes thereby reducing dependence on fossil fuels
    - Operation of 3 recovery boilers that capture energy from black liquor, a byproduct of the pulp making process. The energy is used to produce steam for power generation and in the drying process for paper production.
    - Methanol capture through a distillation process and evaporation involving black liquor. The energy produced is used in kilns.
    - Excess energy produced is passed to the local grid.
- Currently in the process of establishing the requirements to identify and protect High Carbon Stock (HCS) areas.

Source: APRIL, 2015

Conclusions

As these examples demonstrate, emissions in other sectors are similar to those in the palm oil sector and, as such, certain actors in the industry are implementing similar BMPs as those discussed in this report. All four examples show that the industries are actively working to improve their plantation establishment and concession management practices to reduce emissions through a variety of means including: engagement with smallholders to reduce deforestation, the implementation of no burn practices, substituting synthetic fertilizers with mill byproducts or organic fertilizers, reducing fossil fuel use, and conducting HCV and HCS assessments. Further, the sugarcane and pulp and paper cases show that other industries are also finding solutions to dealing waste generated in their mills, such as by using them to produce biogas, resulting in reduced emissions from the mills.

GHG emissions take place across nearly all stages of palm oil production, and thus there are many options for reducing emissions. Through interventions that improve efficiency and employ innovative technologies and process in cultivation, mill management, and effluent management, lower overall emissions can be achieved and the GHG intensity of palm oil reduced. A significant number of palm oil companies have made myriad investments in improving the efficiency of their palm oil production. These early movers, researchers, and innovators are providing the industry with an ever increasing understanding of the initial investment costs, the return on investment, and the GHG and other co-benefits.

At the plantation level, the majority of companies examined have committed to a zero burn policy for all new plantations and when replanting. An ever increasing number have adopted a commitment to not establish new plantations in areas that would result in deforestation of intact forest or areas of high conservation value and/or peatland drainage. At the replanting stage, a selection of companies plan to re-evaluate which areas will be restored, both to comply with any local regulations and as an approach to reduce GHG emissions and increase environmental benefits. This is especially true for peatlands areas and riparian zones.

Many companies have also initiated integrated pest management as an approach to reduce costs and reduce health risks. A range of approaches are being used by plantations to reusing mill biomass residue as a soil supplement. This ranges from simply stacking debris in-field to decompose, mulching / shredding material and then applying, use of remaining digested effluent to irrigate, along with more complex co-composting systems. Many plantations are investing in improving yields – including fertilizer management, high yield seeds, and smallholder training.

Using fibers, shells, and other residues as fuel for boilers is relatively ubiquitous and the use of POME in biogas plants have become more and more common at larger mills. However, other types of increases in mill efficiencies are less common and some are still only emerging from the piloting stage.

A full list of BMPs studied in this assessment are summarized in Table 4. Some of the management practices discussed have a direct GHG emission impact while others provide overall improvement in efficiency and productivity, resulting in increases in the GHG efficiency of the CPO produced. Along with the presented overview, each BMP was also evaluated against a set of five criteria: financial feasibility, technical and operational challenges, GHG reduction potential, environmental and social co-benefits, and replicability (Table 5).

Table 4. Best Management Practices assessed in this study.

Category	Description
Plantation Establishment and Concession Management	
Improved Plantation Location Establishment	- High Carbon Stock Approach - No deforestation commitments - Zero burning techniques - Expansion on degraded lands
Yield enhancement	- Improved seeds and varieties/ certified seeds - Improved fertilizer management
Improved spatial monitoring system	- Use of remote sensing technologies to improve plantation management, fire prevention, and yield enhancement
Improved smallholder management	- Improved management practices resulting in increased productivity and thus reduced GHG intensity
Peat management	- Improved water table management within plantation and entire land holdings
Pest management	- Integrated pest and weed management
Plantation Fuel Usage	- Alternative fuels for transportation and machinery - Reuse of biogas from POME for transportation
Improved Concession Management through conservation and restoration	- After-use planning after the plantation cycle - Ecosystem restoration from conservation areas, degraded lands, biodiversity corridors - Expanded use of buffer zones (around rivers, etc.) - Phasing out some areas of production
Mill Management	

Category	Description
Plantation Establishment and Concession Management	
Improved Plantation Location Establishment	- High Carbon Stock Approach - No deforestation commitments - Zero burning techniques - Expansion on degraded lands
Efficiency Improvements	- Cogeneration or combined heat and power efficiency improvements
Methane Capture	- Methane capture for biogas electricity or transportation
Co-composting	- Creation of organic fertilizer from EFBs and POME
Solid Filtrate Separation	- POME treatment
Innovative Technologies	
Biomass Waste Utilization	- Use of by-products, particularly biomass waste, such as empty fruit bunches (EFBs)
Biogas Upgrading	- Upgrading biogas to biomethane
Advance Biofuel Production	- Creation of biofuels from residue and POME

These BMPS were assessed against a set of criteria, described in the table below.

Table 5. Scoring criteria for BMPs

	Criteria	Description	Scoring System
1	**Financial evaluation**	This can be evaluated based on capital expenditure, payback period, RoI or other financial parameter, abatement costs. Money invested by company to obtain technology, develop the facility, train personnel, etc. Abatement cost (if data is available): Effectiveness of money invested to reduce GHG emissions per tCO2e.	Investment High: above USD 1.5 million Medium: USD 500,000 to USD 1.49 million Low: below USD 500,000
			ROI[4] High: more than20% Medium: 10% to 19.99% Low: less than 10%
			Payback period High: Less than 1 year Medium: 2 to 8 years Low: More than 1 year
			Abatement costs High: above USD 30/tCO2e Medium: USD 10 to 29.99/tCO2e High: below USD 10/tCO2e

[4] Return on investment

2	**GHG emission reduction potential**[5]	Emission reductions contributed by BMP compared to overall supply chain unit emission (in percentage).	High: Above 30% Medium: between 5% to 29.9% Low: below 5%
3	**Technical and operational challenge**	Level of challenge faced by the company in implementing BMP in term of required skill, deployment time (preparation, construction, development), availability of technology in domestic market, and operational practicality.	High: large challenges (i.e. require permit from government to implement, need to hire expert) Medium: challenges in many aspects (i.e. requires skilled personnel, maintenance should be done by other party) Low: few specific challenges prevail in term of skill required, technology availability, relatively easy to develop and implement
4	**Environmental and social co-benefits**	Additional benefits of BMP to social and environment aspects.	High: more than 3 co-benefits Medium: one to three co-benefits Low: one or none co-benefit
5	**Replicability**	Applicability of BMP to other companies in the sector in term of technical, approach, and method.	High: BMP is applicable to any scale of company group, including SME companies. Medium: BMP is mostly applicable to large group; applicable to SME with some adjustments or considerations. Low: applicable to specific type of company only.

While palm oil production occurs across the tropics, and these BMPs are generally universally relevant, this assessment focuses on production in Indonesia, Malaysia and African countries where the majority of palm oil is produced.

Plantation Establishment and Concession Management

Plantation Establishment

Plantation establishment can have either a net positive or negative carbon flux depending on the kind of lands the conversion occurs on, and the kind of land uses it is displacing. If high carbon natural forests are cleared, this results in large emissions from lost biomass that can only be partially mitigated by the regrowth of plantation stock. Conversely, creating plantations on lands that have been severely degraded through past natural or anthropogenic disturbances can result in a net carbon removal. By undertaking carful spatial planning of the lands to be converted,

[5] Using RSPO PalmGHG calculator

it is possible to minimize the impact on high carbon areas, while diverting as much conversion as possible to already degraded lands.

Two existing frameworks have already been developed to guide this process, the HCV approach and HCS Approach[6]. A simplified version of HCV analysis has been developed for smallholders while this is in currently in process for the HCS approach[7].

Whether these specific standards are pursued, the general principles apply of prioritizing conversion on lands with lower quality forests. In all cases, this practice requires that the pre-conversion conservation and/or carbon values of the landscape are transparently and credibly cataloged, and that widely accepted techniques for evaluating forest viability are employed.

As discussed in Box 1, the RSPO GHG Assessment procedure for New Planting Development[8] serves as a resource to estimate carbon stock fluxes (above and below ground) and GHG emissions associated with new development plans to minimize GHG emissions. The procedure provides guidance on selection of preferred development options and preparation of a plan to minimize GHG emissions for new developments.

In many countries, existing laws already stipulate some form of consideration of environmental impact when expanding plantations. Furthermore, there is growing pressure from consumer groups for sustainable sourcing and signing on of pledges including deforestation-free supply chain. In some cases, complying with local law or requirements of various sustainability standards may already result in a company's reduction of some of the potential emissions from conversion.

The timing of when such an assessment would take place relative to conversion is dependent on the local legal process for acquiring and developing lands, as well as a company's internal planning cycles. In general, the assessment is needed before lands are delineated. In some cases, this might actually be most strongly influenced by the concession planning stage, before a particular company is even licensed to the property. Depending the local circumstances, there are several times when a company could employ a reduced impact strategy. After concession acquisition and prior to conversion, a company would likely have the greatest ability to influence which specific lands are impacted. In some legal contexts, the percent or types of lands that must be converted is written into the concession lease leaving less room to maneuver. A second strategy is to selectively pursue concessions where it is known that the existing proportion of non-forest land cover is already sufficient to avoid the necessity of converting forests, while still meeting business objectives for the acquisition. Finally, companies can consider working directly with or providing inputs to local or national government to supplement their ability to identify and delineate concessions that would result in lower impact on forests.

A number of companies are already pursuing sustainability policies that include variations on no-deforestation pledges. Golden-Agri Resources follows a "Forest Conservation Policy" that includes a no deforestation footprint comprised of a prohibition on conversion of HCV, HCS and peatland areas. Golden-Agri developed the first technical methodology for identifying HCS areas. Unilever and Wilmar have also announced their intent to protect HCS areas. Indofood Agri Resources has pledged no development on HCV areas, as well as to buy palm fruit only from smallholders and external supplies that do not originate from areas cleared of primary forests since 2011. The use of such approaches by Olam is featured as a case study.

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[6] https://www.hcvnetwork.org/; http://highcarbonstock.org/

[7] https://www.hcvnetwork.org/about-hcvf/hcv-for-smallholders; http://highcarbonstock.org/the-hcs-approach-toolkit/

[8] https://www.rspo.org/certification/ghg-assessment-procedure

Financial implications

There are four main financial dimensions to reduced impact conversion. The first is that resources are required to survey and map the ecological, carbon, and social benefits of lands over a potentially large and complicated landscape. Secondly, the recommendations from such an approach may result in a plantation configuration that is sub-optimal from a logistics and transportation perspective, or may restrict development to areas with poor growing conditions. Thirdly, production will be forgone in all areas not put under production but legally allowable. Finally, there is typically an ongoing need for company involvement to ensure that the remaining forest tracts are adequately protected such that they purported sustainability benefits are actually persistent over time. Depending on the local threats to forests, this could require investments in such activities as fire prevention, forest patrolling and spatial monitoring alert systems (Parker 2018).

Regarding the first set of resource requirements pertaining to landscape evaluation and monitoring, there are numerous approaches that combine some form of field and satellite/airborne assessment to map priority areas. The costs increase with the complexity and size of the landscape, but on a per hectare basis, economies of scale can be achieved especially as it relates to any remote sensing approaches employed. For this reason, a rigorous pre-conversion assessment to a technical standard required under the HCS Approach is expected to be a viable option for large producers with the resources to employ a team of staff researchers and analysts. Smaller producers and smallholders at a minimum could consider following the simplified HCV and HCS guidance and a combination of consulting with local authorities and communities on any particular areas of known forest value, along with reference to existing freely available and global spatial data layers indicating such landscape features as canopy density, land use, and history of disturbance.

The second financial consideration regarding the orientation of plantations to logistical networks, processing infrastructure, labor, etc., as well as the inherent ecological suitability if the land for plantation production, would need to be assessed using a producer's own knowledge of its internal business practices and requirements. In general, it would be anticipated that a more dispersed operation would incur higher operational fixed costs per hectare managed versus a centrally concentrated plan.

Depending on the local threats to forests, protection of high value forests could require investments in such activities as fire prevention, forest patrolling and spatial monitoring alert systems. Some of these costs may able to be shared with activities focused on plantation areas (e.g. fire prevention). The key point is that these lands, despite being left in a 'natural' state, will nevertheless require per hectare costs to be borne by the company.

GHG Reduction Potential

The total amount of GHG reduction potential is strongly related to the existing state of the landscape. If the proposed site is already dominated by low carbon and non-forest lands, the additional opportunity for reduction using this strategy will be minimal. Likewise, if the landscape is characterized by high carbon forests, there will be a limited opportunity for conversion without deforestation. However, in landscapes that have a mix of lands in various states of degradation and forest quality, reorienting development could have a significant role in limiting impact. Table 6 and Table 7, which include default values of carbon content in different land use/land cover types provided by the RSPO PalmGHG calculator and the 2006 IPCC guidelines provide a sense of what could plausibly be achieved on a per-hectare basis by diverting conversion that would have under a business as usual scenario taken place on natural forests.

Table 6. Potential for avoiding emissions by diverting conversion to non-forest lands using the PalmGHG default values for different land cover types

	Tonnes of carbon per hectare (tC/ha)	Avoided emissions by prioritizing conversion of shrubland (168.67 tCO_2/ha) over forest	Avoided emissions by prioritizing conversion of shrubland (18.33 tCO_2/ha) over forest	Avoided emissions by prioritizing conversion of tree crops (275 tCO_2/ha) over forest	Avoided emissions by prioritizing conversion of food crop (275 tCO_2/ha) over forest
Undisturbed forest	268	814	964.3	707.7	951.5
Disturbed forest	128	300.7	451	194.3	438.2

Table 7. Illustrative example of potential for avoiding emissions by diverting conversion to non-forest lands. Values derived from IPCC 2006, Vol. 4 AFOLU, Ch 4, table 4.7, and estimates for root-shoot ratio taken from table 4.4 used to convert from AGB to emission reduction potential.

	Tropical moist deciduous forest aboveground biomass (t DM ha^{-1})	Tropical shrubland aboveground biomass (t DM ha^{-1})	Avoided emissions by prioritizing conversion of shrubland vs primary forest (tCO2e ha^{-1})
Africa	260	70	411
Asia (continental)	180	60	255
Asia (insular)	290	70	480
Americas	220	80	295

In locations where opportunities to divert conversion away from forests does exist, it is often the case that this practice can represent the largest means to reduce total concession emissions with the exception of avoided development on peat soils. Peat soils are a special case, as once disturbed they have the potential to release long term emissions far in excess of the original loss from conversion. The Indonesia Carbon Accounting System (INCAS) uses a default value of 40.3 tCO2e ha-1 y-1 to represent the emissions from peat soil managed as palm oil plantation per year. Peat soils are well recognized in Indonesia and Malaysia, but there is growing awareness and appreciation for their presence elsewhere in tropical Asia, Africa and South America.

Technical and Operational Challenges

The most rigorous approaches such as those under the HCS Approach require creating detailed land cover maps indicating the distribution of High, Medium, and Low Density Forests, Regenerating Forests, Scrub, and Cleared/Open Land. This task can require sophisticated remote sensing capabilities that may not currently exist within the company. In many cases existing maps are available from national or local governments, such as those used in national forest inventories or those used to construct REDD+ reference levels, however their focus is typically at a scale that is too coarse to be used reliably as the sole basis for applying the HCS Approach.

Beyond the need to maintain appropriate staff, there are obstacles presented by commonly used remote-sensing approaches. There are decades of experience in the international remote sensing community of employing medium and high-resolution imagery to differentiate forest type and, in some applications, even assign carbon stocks. These approaches remain viable for many situations, but they can be prone to a high degree of systematic bias.

Innovations in biomass assessment using the addition of lidar technology to traditional techniques have shown promising improvements, but these lidar techniques are only recently moving into more widespread operational use. This means that the near-term ability to recruit staff familiar with application of lidar to tropical forests may be a challenge.

Forest parcel viability and connectivity is a key requirement of HCS areas identified using the HCS Approach and requires an additional analysis beyond simply mapping the current distribution of land cover types. Connectivity and viability can only be assessed at the landscape scale rather than the parcel, which requires a modeling approach that evaluates the likely impact of various configurations of converted versus protected lands. A number of modeling tools exist for spatial habitat assessments, but the skillset required to implement this aspect of the assessment would not necessarily be found within the individuals leading remote sensing work, thus requiring additional recruitment.

Environment and social co-benefits

Protecting viable parcels of high quality forest has numerous co-benefits that extend beyond GHG mitigation. Depending on the landscape, these benefits can be hydrologic, biodiversity, food security, disaster prevention. Forests in some landscapes play a large role in the availability of water to downstream communities. This is particularly true in regions where cloud capture represents a significant supplement to precipitation-provided water. High value forests preserve soil, mitigate local climate extremes, and provide pollination and pest control services that contribute to human food security. Lastly, in virtually every society, forests play an important role as a reservoir of cultural heritage. By protecting the highest quality forests, there remains the greatest chance for culturally important animal and plant species to be preserved.

Replicability

Because this practice is focused on the stage of plantation conversion, it is only applicable to areas that anticipate additional expansion to occur. Concessions or regions that are already fully converted to the extent expected or allowed by land availability, company policy, or local law would not be able to pursue this strategy.

Within a given operator, there are opportunities to replicating improved plantation establishment across various operations or landscapes, particularly as it relates to the internal capacity that will have been developed within analytical staff in implementing the spatial assessments. However, there may be a need to re-learn or develop new approach if transition experience from one landscape to another in a very different ecological or economic context, such as from one continent to another.

Summary

For companies looking to expand their area of production, improved plantation establishment design offers by far the greatest potential for avoided GHG emissions. The investment costs will be significant and due to economies of scale will be more cost effective when larger areas are evaluated. However, such an approach will also be in line with RSPO and additional requirements of some markets that do not allow deforestation or peatland conversion. The environmental and social co-benefits are significant as biodiverse habitats will remain intact. In locations where there are significant areas available for potential additional plantation establishment, this approach is highly recommended. Additional details on this BMP can be found in the Olam case study below.

	Criteria	Score	Remark
1	Financial evaluation	High	Financial costs can be significant. Depending on local regulations, dominated by forgone production
2	GHG reduction potential	High	In areas where conversion of peatlands and intact forests are prevented, emission reductions are very high

3	Technical and operational challenge	High	Methods known, however, technical expertise will be required
4	Environment and Social co-benefits	High	Protection of biodiverse habitats and other ecosystem services
5	Replicability	High	Highly replicable in areas where many locations still available for conversion

Yield Enhancement

Palm oil expansion has been a major driver in the destruction of forests and other natural habitat across the tropics. While there is growing awareness and concern for the conservation of tropical forests and the climate impact of emissions associated with deforestation, demand for palm oil continues to grow. Improving the productivity of existing palm oil plantations to meet production requirements through interventions such as better nutrient management, seeds, or harvesting practices is a pragmatic way to address these conflicting needs.

Around the world, plantations are performing well below their potential. The current global average yield is estimated at around 3.5 tons of oil per hectare (Barcelos et al., 2015), yet productive plantations can generate 8.9 tons of oil per hectare. Through closing yield gaps to achieve global production of 15–20 Mt oil yr−1, Woittiez et al. (2017) claim oil palm expansion could be halted altogether.

Palm oil yields are affected by a wide range of factors such as quality of planting material, planting density, soil type, topography, rainfall, canopy, fertilizer management, and pest and disease control. Large-scale plantations usually have higher yields than smallholders due to differences in capacity and financial resources for plantation management, high quality planting material, and inputs. For example, smallholders usually only have the capacity to harvest monthly, yet harvesting in shorter cycles of 7-10 days would result in significantly higher yields (Lee et al., 2014). Harvesting standards also impact yields. Large plantation companies generally have harvesting standards designed to maximize palm oil yields, whereas smallholders may not have these well-defined standards and therefore have lower yields.

As the two leading producers of palm oil in the world, Indonesia and Malaysia have been in the spotlight for deforestation and associated emissions driven by the expansion of oil palm. In 2016 alone, 12 million hectares of oil palm were planted in Indonesia (MoA, 2017) and 5.7 million hectares in Malaysia (MPOB, 2016). Without significant interventions, this expansion is likely to continue as Indonesia ambitions to double palm oil production by 2020 (Koh and Ghazoul, 2010). Malaysia also plans to increase its production along with other countries such as Brazil, Peru and Central and Western African countries whose governments are increasingly promoting palm oil (Pirker et al. 2016).

Given these trends, enhancing yields on palm oil plantations to intensify production could mitigate further deforestation, lower net emissions from the industry, and improve outcomes for countries with developing palm oil industries.

High-Yield Seed Varieties

Increasing yield and production efficiency can be achieved through improved seeds. These enhanced seed varieties have been under development for years by research institutions such as the Malaysian Palm Oil Board (MPOB) and Indonesian Oil Palm Research Institute (IOPRI), as well as private companies such as Asian Agri in Indonesia. Asian Agri successfully developed "Gen-3 Topaz" as the 3rd Generation of high planting materials after more than 20 years of research and established an expansive 300-hectare nursery in Riau with that variety capable of producing 25 million seedlings year^{-1}. In 1996, Asian Agri also initiated an oil palm breeding program using a wide diversity of ABPRO germplasms from the oil palm seed development company ASD Costa Rica.

After decades of research and field trials, Sime Darby developed the Calix 600 seed variety that can be harvested early (24 to 36 months after planting) that produces up to 10 ton ha^{-1} year^{-1} of CPO. This is significantly higher than the annual production rate of 8.9 t ha^{-1} (Rajanaidu et al., 2005) produced by tenera palms or DxP hybrids, the most common planting material used by large scale companies (Mutert et al., 1999). Furthermore, Calix 600 improves efficiency in field operations due to homogeneous growth.

Figure 6. Example of improved oil palm seeds from Sime Darby's Calix 600 breeding program http://www.simedarbyplantation.com/our-businesses/research-development/overview

Tissue culture or clonal seed techniques also offer promising ways to enhance yield whereby seeds are reproduced as exact copies of the genotype as a parent material. This guarantees homogenous high seed quality, and this technique has been shown to boost production by 15-30% as compared to hybrids (Mutert et al., 1999, Soh 2004). Among tenera palms, clones in a 7-year-old plantation can yield up to 15.7 t oil ha^{-1} yr^{-1} (Simon et al., 1998) while Tenera semi-clones produced 11.1 t oil ha^{-1} yr^{-1} in a 5-year-old plantation (Ng et al., 2003).

PT Sinar Mas Agro Resources and Technology (SMART) started research in 1997 on high planting material and successfully developed "Dami Mas 1-4", with the capacity to produce 7.5 - 8 tons CPO ha^{-1} year^{-1}. Over the past 10 years, their research has utilized tissue culture or clonal techniques to improve seed quality. The varieties Eka 1 and Eka 2 were developed through selection and tissue culture from elite palms and under optimal weather and soil conditions are expected to yield 10.8 ton CPO ha^{-1} and 13 ton CPO ha^{-1} respectively, which is 30% higher than the current production. In addition, this innovation has cut harvest time by 24 months. SMART plans to initiate commercial use of the seed in 2022.

GHG Reduction Potential

The potential for emission reductions from avoiding deforestation varies greatly on the ecosystem and soil types, with the conservation of forests on peat soils having the greatest potential impact. Avoided emissions from converting one hectare of natural forest on mineral soils to an oil palm plantation has been estimated at 561 Mg of CO_2 (Agus et al., 2003) while conserving primary peat swamp forest could conserve 700 Mg of CO_2 (Hergoualc'h et al., 2011). However, the positive impact of greater productivity on net emissions will only be achieved under the strict condition that increasing production will not stimulate further plantation expansion (Angelsen and Kaimowitz, 2001; Angelsen, 2010; Phelps et al., 2013). On existing plantations, increasing productivity has the potential to reduce the GHG emissions per ton of palm oil produced.

If increased yields require additional inputs such as fossil fuels for machinery or nitrogen fertilizer, these practices will create emission that will counteract some or all of the per production unit reductions. To pursue such a strategy, an assessment would first need to be taken on the specific yield improvement strategies considered, including estimating their required additional inputs and the expected yield increase. In cases where it can be demonstrated that better management will produce yield gains with minimal additional GHG-generating inputs required, this can be a very important strategy for meeting company emission objectives.

Technical and operational challenges

While the benefits from intensifying production are clear, the financial burden of research and development as well as technical and operational challenges are not insignificant. Developing new high-yield seed varieties is extremely expensive and time consuming. Between general research and development, clonal propagation, and field trials, countries and companies spend vast sums of money to create seeds that lead to higher profits. Malaysia alone has spent tens of millions MYR over the past 20 years in researching and developing improved varietals (Soh et al., 2011).

There are also ethical and cultural challenges. Varieties of palm oil that have been developed through biological engineering such as clonal seedlings have been the subject of significant concern for impacts on human health. As such, their product has been mostly used for bio energy, rather than for human consumption. This subject therefore necessitates further research.

While there is a steady market for palm oil, there are operational challenges in expanding use of oil palm as a biofuel due to concerns over sustainability. In an effort to lower dependence on fossil fuels and their associated emissions, countries are shifting their energy balance use more renewable biofuels. Indonesia has set a 5% target for biofuels to meet their energy needs and there are plans for 10% of the transport fuel of every European Union (EU) to come from renewable sources such as biofuels by 2020. However, citing concerns over the environmental impacts of palm oil production, in April 2017, the EU voted to phase out biofuels made from vegetable oils, including palm oil by 2020. The loss of this key market means there may be less incentive to increase yield to meet market demands.

Environment and social co-benefits

Enhancing oil palm plantation yields can offset the need for expansion of production area, avoiding further deforestation and associated emissions and detrimental impacts habitat loss has on biodiversity.

Replicability

Given the high costs of developing new high-yield oil palm varietals, it is unlikely that small and medium enterprises will pursue generating original materials. As such, smaller oil palm producers will likely rely on purchasing seeds and planting material.

As briefly discussed above, the development of high quality of seeds is typically undertaken by research institutions and private corporations such as ASD Costa Rica (Costa Rica), the Indonesian Palm Oil Research Institute (Indonesia), Socfindo (Indonesia), Applied Agricultural Resources Sdn Bhd (Malaysia) and Felda Global Ventures (Malaysia). The Malaysian Palm Oil Board MPOB has the largest oil palm germplasm collection in the world (E. guineensis and E. oleifera) and conducts advanced research in developing new high planting material.

Improved fertilizer management

Achieving maximum potential yields requires careful attention to nutrient management. Fertilizers can improve soil fertility and boost production and allow for the cultivation of oil palm on lands that would otherwise be unsuitable. To optimize costs, plantations work to balance the exact needs of the crops with fertilizer application, but over or under utilization of fertilizer is common at both large and small-scale plantations. Optimum fertilizer application depends on the age of the oil palm, planting material, soil type and condition. While fertilizers can improve yields, they are also a source of emissions and water pollution so the application of fertilizers needs to be carefully managed. The RSPO has included the maintenance of soil fertility among its Principles and Criteria. Practices maintain soil fertility at, or where possible improve soil fertility to, a level that ensures optimal and sustained yield.

Financial Implications

Common practice in West Malaysia is 50–100 N kg ha-1 y-1 for immature palms to 120–160 kg N ha-1 yr-1 for mature palms on peatland (Mutert et al 1999). In Indonesia the standard application rate is slightly higher from 102 -170 kg N ha-1 y-1 (Darmosarkoro et al 2003). Studies in Malaysia found an increasing trend of the cost of fertilizer over the past years where in 1999 fertilizer cost contributed around to 24% to total production costs while in 2008 accounted for 50%- 60% (Goh et al, 1999; Whid and Simeh, 2009). Thus, increasing the efficiency of fertilizer use can reduce costs while maintaining productivity.

GHG reduction potential

Direct emissions from the application of synthetic fertilizers mainly comes in the form of nitrous oxide (N2O). Nitrous oxide is classified as long-lived GHG and has a global warming potential 268 times higher than that of CO2 over a 20-year time horizon, including climate–carbon feedbacks (Myhre et al 2013). Direct N2O emissions are 1% of N fertilizer applied to soil (IPCC, 2006), although recent studies have found higher emission factors of 1.5 to 4% (Shcherbak et al., 2014, Crutzen et al., 2008). Using this emission factor, 1-4 kg N2O is released into atmosphere for every 100 kg of N fertilizer applied. This translates to around 250 – 470 kg CO2 -eq/tonne CPO (RSPO, 2009), or according to IPCC (2007) 3.5 kg CO2eq per kg N fertilizer production.

While this emission factor is small, total emissions from synthetic fertilizers increased more than nine-fold between 1961 and 2010 from 0.07 to 0.68 GtCO2eq yr-1 (Tubiello et al 2013) due to excessive use of fertilizer to boost crop production. Furthermore, nonlinear response of soil nitrous oxide (N2O) emissions to nitrogen fertilizer was discovered in some recent studies, which conflicts with the linear response reported by IPCC (Oktarita et al., 2017, Shcherbak et al., 2014). This implies emissions could be significantly higher than previously assumed. This is illustrated in Figure 7 which shows a simulation of N2O emissions from different fertilizer rates using different models.

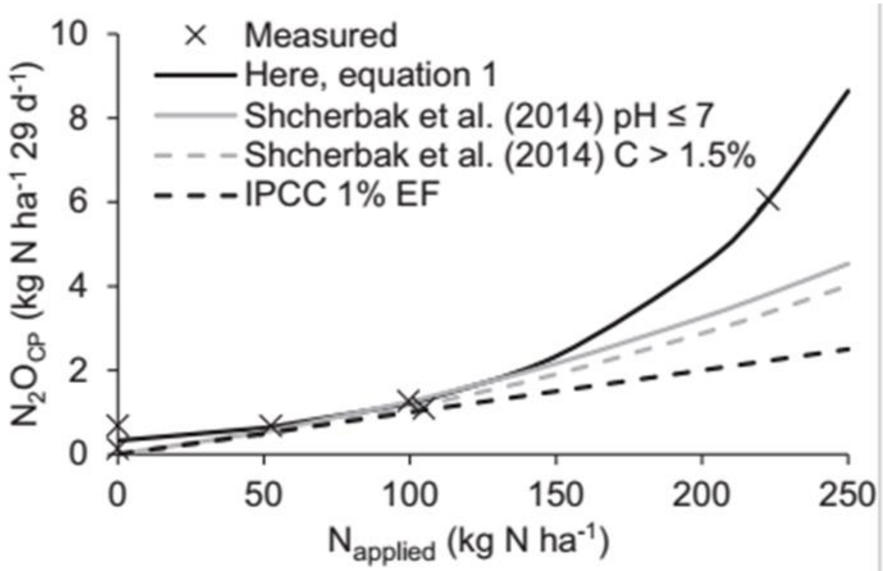

Figure 7. Response of cumulative post-fertilization N2O emission in the close to palm (CP) area to the average N applied compared to the response obtained using the models Shcherbak et al (2014) and the IPCC (De Klein et al., 2006). Source: Oktarita et al., 2017

The potential for emission reductions from optimum fertilizer management depends on the baseline rate that is applied, yet achieving optimum fertilizer dosage to sustain plant growth and high yield is clearly important for any operation looking to both maximize profits and keep fertilizer emissions to a minimum.

Technical and operational challenges

A recent study indicated that intensification through increases in fertilizer application above current practice could increase yields from the current 67% to 80% of attainable yields[9] without negative effects on the footprint of Indonesian palm oil (van Noordwijk et al., 2017). Fertilizer cost contributes to almost half of the production cost and increasing current rate to further boost yield should be done cautiously.

Given the high costs, smallholder farmers typically apply fertilizer at lower rates than larger enterprises. Smallholders also rarely have the resources to conduct leaf and soil analyses to determine optimum fertilizer dosage.

Environment and Social co-benefits

In addition to emissions, the over-use of fertilizers can result in other environmental consequences. Excessive fertilizer use can pollute water bodies by causing algae blooms that deplete oxygen in water bodies (hypoxia), leading to fish die-offs and N contamination in drinking water. Adopting practices that ensure the optimum amount of fertilizer applied will lead to less fertilizer runoff into water bodies and ozone layer depletion. Soil health can be improved incorporating the use of organic fertilizer such as compost which can reduce costs and improve environmental outcomes. The production of organic fertilizers themselves have lower emissions in comparison to inorganic fertilizer production as discussed in the Co-Composting Section of this report.

Replicability

Large palm oil companies likely have the resources to perform the testing and analyses to determine optimum fertilizer application rates and utilize byproducts from palm oil production for fertilizer, and thus improved fertilizer management is a highly relevant approach for improving yields and lowering greenhouse gas emissions. Small and medium sized enterprises also stand to benefit from optimizing fertilizer use, yet they likely lack the resources to perform leaf and soil analyses. Nevertheless, they can likely pursue this option and maximize returns by drawing upon guidance provided by research institutes and larger companies on optimizing resource use.

Summary

Improving the productivity through improved seeds and fertilizer management can also result in reduced GHG intensity of palm oil production while reducing environmental pollution. However, the investments required can be significant and thus only available to larger companies or done through research institutions.

[9] The average N fertilizer application level of 141 kg ha^{-1} yr^{-1} reported on the 23 plantations surveyed in the study was associated with 67% of maximum attainable FFB yields, whereas fertilizer application rates of 200 kg ha^{-1} yr^{-1} was associated with 80% of maximum attainable FFB yields. An emission factor of between 1% and 4% N_2O-N/N/ fertilizer ratio was applied.

No	Criteria	Score	Remark
1	Financial evaluation	Low-Medium	We suggest that the financial cost to implement best management practices is low due to recommendation to reduce where fertilizer rate is over the plant need, in opposite where fertilizer rate is lower than what plan need (in smallholder case), additional cost will be involved
2	GHG reduction potential	Low	Increasing productivity reduces GHG emissions per ton of PO produced
3	Technical and operational challenge	Medium	Significant research is required to identify improved seeds.
4	Environment and Social co-benefits	Medium	Reducing fertilizer use has significant environmental co benefits
5	Replicability	Medium-High	Most plantations have the potential to increase yield, thus any improvements to seeds or fertilizer management are widely replicable

Improved Spatial Monitoring System

A spatial monitoring system involving ground and satellite/airborne generated data can help to improve plantation yields while prioritizing poorly performing plantation areas for restoration. A monitoring system can also support rapid response efforts to fire and incursions on company-managed plantations or natural lands.

For existing plantations, improved yields have the potential to increase the GHG efficiency of the CPO, e.g. fewer emissions per unit of output, even if net emissions per hectare of land remain unchanged or increase. If companies currently only monitor crop condition within an aggregated spatial unit encompassing tens or hundreds of hectares (e.g. blocks), significant spatial variation in conditions can be missed.

Such intra-farm conditions can be and are more frequently being monitored using remote sensing. Remote sensing products range from free satellite images (such as NASA Earth Observation programs like MODIS and Landsat) to aerial photos taken from technologies like unmanned aerial vehicles (UAVs), colloquially known as drones. Such products are being used across a wide range of agricultural commodities to detect general plant health, plant biomass, weeds and the effects of fertilizers, diseases and natural disasters. This spatial monitoring allows growers to improve management of their crops, for example more-targeted irrigation, fertilizer and pesticide application. This could lead to less losses from diseases, more cost-effective application of agricultural inputs and overall improved yields. The GHG emissions associated with any change land use management of fertilizer use will need to be incorporated into total GHG emission estimates for production.

The type of remote sensing used depends on the monitoring needs and the cost implications. The advantage of satellite images are their low cost and reliability—many satellite images are free of cost to the general public and take images of the same location at a specific time step—which varies between a few days and several weeks. The disadvantage of these products is their coarse scale—most cheap satellite products have a spatial resolution of ≥30 meters, which can be too coarse for individual plants or smaller farms. Satellite products are ideal for large-scale monitoring—showing or predicting impacts of climatic phenomena such as drought and flood, widescale

UAVs have a much finer spatial scale which is their great advantage, allowing for what is called "precision agriculture". They can be flown over a specific area and their images can be at the sub-meter scale. They are often used for monitoring of sub-farm issues such as catching the beginning of a disease outbreak, detecting slight differences in growth in different areas of a farm or tracking damage after a storm. Their drawback however is the high costs to operate them and fly them repeatedly for continuous monitoring; a cost that must be budgeted for by the producer.

Figure 8. Spatial partitioning of plantation for tree health and productivity monitoring with unmanned aerial vehicle (UAV) http://myspatial.com.my/services/data-acquisition/unmanned-aerial-vehicle-uav/uav-services-for-oil-palm-plantation/

Some companies, for reasons of company policy or local law, will maintain certain lands within their palm operations in a natural state, such as conservation buffers, high conservation value, or high carbon stock. These lands are often vulnerable to incursions by actors not affiliated with the palm company itself. Unplanned clearings of conservation lands can jeopardize a producer's attainment of sustainability objectives. A spaceborne remote sensing platform with a high frequency of imaging or spectral resolution (i.e. daily or weekly) can help to initiate enforcement actions sooner and limit damage. Global platforms such as Global Forest Watch can also be used to monitor long term changes in forest cover (https://www.globalforestwatch.org/). Users can sign up to receive free alerts when any deforestation in a specified location has been uploaded to the database.

Remote sensing solutions for fire monitoring and prevention also have some potential benefits over traditional ground-based observation. Firstly, fire risk can be mapped as it relates to meteorological conditions, surface moisture, and available fuel, allowing prevention efforts to be prioritized in high risk areas. Secondly, daily fire activity alerts can be derived spaceborne sensors helping to better coordinate countermeasures. For example, the Fire Information for Resource Management System (FIRMS) can be used to create free alerts in a user's area of interest for fire detections from the MODIS and VIIRS satellites[10]. The user can specify an area of interest using coordinates, choose the frequency of the alert (weekly, daily or rapid near-time) and will then receive an email alert showing the fire detection.

[10] https://firms.modaps.eosdis.nasa.gov/alerts/

A final advantage to an improved spatial monitoring system is the ability to plan plantations with respect to local hydrology. Flooding and persistently high-water tables can inhibit yields. Accurate digital elevation models (DEMs) combined with a hydrologic model can help to direct replanting away from areas anticipated to be prone to flooding.

Financial Implications

Due to the huge diversity of remote sensing platforms and their potential uses, it is not possible to say for a given plantation operator what the direct net financial impact would be of developing an improved spatial monitoring system. Increased costs can be expected from purchasing commercial imagery, operating manned or maned aerial vehicles, supporting imagery analysts to process data, and in upgrading local computing and network hardware. Cost savings could be realized in cases where increased reliance on remote sensing obviates the need for ground sampling in some management applications. In general, however, a company would likely pursue such a platform out of goals beyond direct savings in management costs, such as improved yields or better compliance with local law.

GHG reduction potential

While improve spatial monitoring would not directly reduce GHG emissions, it has the potential to improve palm yields and limit losses from natural and anthropogenic disturbances to plantation and natural lands. As stated above, almost all plantations have the opportunity for significant gains in productivity, which will lead to increases in the GHG efficiency of the palm oil production (Woittiex et al 2017).

Unplanned fires and clearing of land can have a large emission associated with it. Forests in particular hold large quantities of carbon that is converted to GHGs when combusted, but plantations themselves also can contribute to emissions. Table 8 presents an illustrative example of emissions per hectare burned from fires on generalized land cover types on mineral soils. Values for forest, shrubland, and grassland derived from IPCC 2006 Vol.4, Ch.2 defaults (tables 2.4-2.5). Estimates for palm plantation are derived from a combination of biomass estimates from Syahrinudin (2005) table 5.1, and IPCC default emission factors (Vol 4. Ch.2 tables 2.5-2.6)

Table 8. Illustrative example of emissions per hectare burned from fires on generalized land cover types[11].

Land cover	AGB Emissions from fire (t CO2e ha-1)
Primary tropical forest	218
Secondary tropical forest	77
Shrubland	25
Grassland	4
Oil palm plantation (3-y stand)	28
Oil palm plantation (10-y stand)	61
Oil palm plantation (20-y stand)	118
Oil palm plantation (30-y stand)	152

[11] Values for forest, shrubland, and grassland derived from IPCC 2006 Vol.4, Ch.2 defaults (tables 2.4-2.5). Estimates for palm plantation derisive com combination of biomass estimates from Syahrinudin (2005) table 5.1, and IPCC default emission factors (Vol 4. Ch.2 tables 2.5-2.6)

In regions with organic soils that are sufficient carbon-rich to combust as in the case of drained topical peatlands, significant emissions can be caused by fire on these soil types (Table 9). These emissions have the potential to far exceed those from the above ground biomass combusted, meaning that even recently cleared peatland can be a large emitter if burned.

Table 9. Emissions from fires on peat soils, related to the number of times the land has burned previously. Adapted from Krisnawati et al. (2015), table 7.4. Only CO2 and CH4 emissions are considered.

Sequence of fire	Soil Emissions from fire (t CO_2e ha^{-1})
First	499
Second	305
Third and subsequent	111

Typically, emission reductions must be demonstrated to show additionality, meaning they must demonstrate improvement over would most likely have occurred under business-as-usual practices, i.e. in the absence of an improved management strategy. For yields, this requirement could be met by comparing historical yields to those after implementation of a new policy, once stand age and relevant site characteristics are controlled for (e.g. elevation). In the case of fire, it can be difficult to demonstrate that a policy has had an additional effect, as fires are irregular events on a local scale, and influenced by global climate cycles on a regional scale. Quantification of the impact probable impact may necessitate the use of modeling techniques and long historical records of regional fire occurrence to construct a business as usual projection of fire emissions.

Technical and operational challenges

Remote sensing methods for palm monitoring, management, and yield prediction, are currently showing some effectiveness, especially at high spatial resolutions, but these techniques are limited by the allometric characteristics of oil palm and the lack of well demonstrated hyperspectral techniques (Chong et al. 2017). In other crops, spectral indices such as the Normalized Difference Vegetation Index (NDVI) have been used successfully for detecting spatial patterns in crop biomass. NDVI works best however in crops with less-developed canopies, since it is largely insensitive to changes in greenness in mature canopies (Mulla 2013).

For yield estimation, a fundamental challenge is that the growth pattern of oil palm does not allow direct observation of FFB from above, and no amount of data remote data collection or processing can rectify this restriction at the individual tree scale. Techniques that have shown utility are all based on estimating yields to be a function of both the age of trees and the tree density. Tree age can be reasonably estimated using only spectral methods until canopy maturity and closure, around 10 years of stand age. Following this age, the addition of height is a necessary variable in age estimation. Height estimation is improved significantly with the addition of lidar and SAR-derived remotely sensed data. However, there is a high degree of specialized technical aptitude required for processing and interpretation of these date types into useable allometric information (e.g palm height), and may not be found within geospatial staff currently employed. By identifying at a fine spatial scale location where palm growth is consistently underperforming in relation to the surrounding block, specific treatments could be applied to select areas such as adjusting inputs, modifying local hydrology, or introducing new anti-pest measures.

The ability of remote sensing to identify areas of pest or disease before irreversible damage occurs is still in a research stage. In the case of basal stem rot, while it has been shown that hyperspectral techniques can identify trees with advanced progression of the disease, it has not yet been shown that diagnosis can be reliably made at earlier stages (Chong et al. 2017). For now, the primary benefit is in precise identification of moribund and dead trees for rapid removal and replanting. For this application, high temporal frequency optical imagery combined with high resolution sensors at a more infrequent repeat cycle.

Due to the continuing evolution of remote sensing technologies, and the development of new approaches for analyzing these data types in support of plantation management, it would be advised to consider investing in a number of complementary technologies and capacities, rather than focus on one particular approach. UAVs are a hugely diverse group unto themselves, but they share a common element that they can be more appropriate for 'on-demand' type data collection that can respond to needs at particular locations. This diversity and the rate of their innovation means that there can be significant need for strategic guidance to a company on how and what kind of platforms to employ.

Environmental and social co-benefits

An improved spatial monitoring system can bring about several direct and indirect co-benefits. Direct benefits could come from the opportunities for highly skilled labor required for such tasks as data analysis and UAV operation.

Indirect benefits would derive from examples where the monitoring system is able to effect change in fire frequency, increases yields and thereby reduce pressure on native forests, and lead to restoration of ecosystems in areas that have demonstrated suboptimal palm conditions. Furthermore, more targeted application of substances potentially harmful to human health and native ecosystems such as pesticides, fertilizers and herbicides, could reduce the total amount of these substances applied on the landscape.

Reducing loss of forest land either through fire prevention or intervening in anthropogenic disturbances, allows existing forests to continue to provide ecosystem service benefits such as water provision, pest control, and cultural benefits to local communities. The smoke from extensive fires can have significant social and economic costs from reduced commercial opportunities to limiting human exposure to smoke and the associated heath risks. Thus, smoke prevention is a high priority for all countries, especially Indonesia and Malaysia which historically have had large areas of peatland fires.

Replicability

A certain scale of operation is required for an improved spatial monitoring system to be most beneficial, as it would entail maintaining dedicated staff and IT infrastructure, and a certain amount of in-house research and development to refine methods for application on the local landscape and management context.

Smallholders themselves are not likely to pursue many of these techniques and continue in favor of ground-based observation. However, given the economies of scale involved in spatial monitoring, there is an opportunity for large producers in a particular landscape to offer, either freely or through a licensing agreement, access to information and insights produced through the company's monitoring system. Expanding the spatial coverage to smallholders, either plasma smallholders or independent, would incur some marginal increase in costs, but this could possibly be justified by the expectation that improved management of smallholders would either have indirect benefits such as reduced fire threat originating from smallholder areas, or direct benefits from increased yields.

The opportunities for a spatial monitoring system leading to increased yields would likely be most pronounced in areas or with producers already experiencing a significant yield gap. Currently, lower prevailing yields in West Africa and Latin America (Woittiez et al. 2017) suggest more potential in these producer markets, though variation among individual producers is a better indication.

Summary

Water table management has the potential to reduce emissions, however adequate resources are needed. Since over the long term, continued drainage of peatlands will cause continued subsidence and lead to areas becoming unproductive, approaches that slow and/or halt this subsidence will extend this period of productivity.

No	Criteria	Score	Remark

1	Financial evaluation	High	Significant upfront investment required to install improved drainage systems
2	GHG reduction potential	High	Significant and permanent annual GHG emissions for all hectares
3	Technical and operational challenge	Medium-high	Research still required. Automated gates still costly to install and maintain
4	Environment and Social co-benefits	Medium	Reduced fire risk, increased fish biodiversity, increased length of production
5	Replicability	Low-Medium	Will be more cost effective for larger operations

Peatland management – water table management and fire prevention

Peatlands are unique ecosystems which support a range of habitats and flora and fauna and provide vital ecosystem services to the surrounding area. These inundated and thus oxygen-deprived forest floors also slow down biomass decomposition, resulting in the storage of massive amounts of carbon in the peat soils. Covering an estimated over 40 million hectares globally, tropical peatlands can be found in various locations in Southeast Asia, Africa, and Latin America (Wahyunto et al 2011). Over half of this can be found in Indonesia, Malaysia, and Papua New Guinea.

Any activities that decrease the depth of the water table and expose peatland soils to oxygen, such as building drainage canals for agricultural purposes, alters the peatland's biogeochemical processes and damages these fragile ecosystems. During palm oil plantations establishment, drainage canals are installed to manage the water table at a depth that allows for cultivation. This then changes the water balance and hydrology of the ecosystems, resulting in the release of substantial GHG, increased fire frequency, and peat subsidence. In addition, due to the high porosity of peatland soils, during the rainy season, organic matter is washed out into the canals. This requires that they are dredged regularly to prevent reduction of canal depth. To allow for production of oil palm, a water table depth of 40-60 cm is normally targeted. Given the temporal variation in precipitation, different measures will need to be put in place across the year to maintain this level.

Although the water table is actively managed in most plantations, there will always be room for improvement. This is especially true in plantations with fewer resources and in smallholder production where water tables are only passively controlled. Improving water table monitoring and management systems that more actively control water table levels has the potential to reduce peatland decomposition and mitigate fire risk. The RSPO has taken this potential improvement seriously, including the development of a Best Management Practices manual for existing plantations of oil palm on peat (Lim et al 2012). This document provides an overview of peatland systems and the main factors that should be considered to improve management. The main approaches to improve water table management identified include:

Optimized, well planned drainage system

The site-specific precipitation, topography, the natural drainage system, and hydrologically-connected surrounding areas will all impact the drainage potential of the plantation area and thus site-specific information will need to be collected. Hydrological modeling should take place to determine the most appropriate canal distribution. This type of analysis can also be conducted for existing plantations and will highlight key locations where the canal lay-out should be altered to improve management.

All drainage system should be mapped in detail, including water flow direction and location of any water control structures, water level monitoring points, and bunds. This information can be updated overtime to indicate locations of more extreme flooding or drainage and high or low productivity. Due to subsidence, these maps will need to updated over time (Lim et al 2012).

Water control structures

Structures such as gates, weirs, and bunds will need to be installed throughout the drainage system to allow active water table control. Again, modeling can be used to identify optimal locations. Lim et al (2012) specifically points out that consultation with local community members will provide useful site-specific information and helps ensure agreement on water control structure locations and design. In coastal and tidal areas, soil bunds can be built to protect fields from coastal water and automatic flap-gates should be installed at main outlets.

Based on the information received from on-going water table monitoring, these gates and weirs can be altered to stabilize water tables.

Water table monitoring

The water table in peatland areas rapidly responds to the precipitation it has received. Over the year, even in natural conditions, the water table of peatlands will vary between the wet and dry season. Thus, tools such as manual water table gauges, piezometers, and emerging smart-technologies can be installed throughout the palm oil plantation estates to actively monitor water table over time. This information can then be used to actively alter water gates.

Fire prevention and suppression

Fires in plantations or surrounding natural lands represents a largely unproductive release of GHG emissions from standing biomass and, in the case of peatlands, soil organic carbon. Peat fires also accelerate land subsidence and lead to premature inundation of peatlands. Increasing recognition by governments, including Indonesia and Malaysia, of the severe risks to human health of prolonged smoke inhalation has led to more strict enforcement of fire prevention policies among palm producers. For example, the Indonesian government is pursuing a number of strategies now to reduce the incidence of fire, focusing on rewetting and restoration of degraded peatlands, incentives for villages to suppress fire, investments in haze and fire hotspot monitoring, and extension services to emphasize alternatives to fire in land management. Along with the freely availably global data services that identify fire hotspots within three hours, such as the NASA-operated Fire Information for Resource Management System (FIRMS), [12] there are a number of government programs that implement the national-level fire strategies, such as those articulated by the Coordinating Ministry for the Economy in the 2017-2019 Grand Design.[13] An example is the Manggala Agni[14] firefighting brigades that operate in Kalimantan and Sumatra. Companies can consult with local Malgala Agni office for a brief on the types of services that are available in their region, from monitoring to active fire responding to community education.

Financial implications

Generally, the productivity of palm oil grown on peat is lower than that on mineral soils. In addition, productivity declines more rapidly than that on peat, with declines being seen after only 7 years instead of 15 years on peat

[12] https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms

[13] http://www.cifor.org/publications/pdf_files/Books/GrandDesign2017-2019.pdf

[14] http://sipongi.menlhk.go.id/manggalaagni/sipongi

(Suryardiputra et al 2016; Dolmat et al 2002; Lubis 2008; Socfindo 2008). We are not aware at this time of specific studies examining the productivity implications of improved water table management.

However, given the fragility of peatland ecosystems, the long-term economic viability of oil palm plantations on peat soils is the subject of debate. Sumarga et al. (2016) modeled the impacts of establishing oil palm plantations on peat soils with no history of flooding in 2011 and, even under optimal water management practices (i.e., managing 50 cm water level depth), projected that area would started to have flooding problem within 25 years. This anticipated flood risk would also imply a decrease in yield, whereby fresh fruit bunches (FFB) would gradually decrease. The study also showed that after 100 years, 67% of peatland area in Central Kalimantan that historically did not have flooding issues would become annually flooded after oil palm plantation establishment (Sumarga et al., 2016). Thus, any efforts to reduce unnecessary drainage will reduce decomposition rates, and thus subsidence and the long-term potential productivity of oil palm production.

GHG reduction potential

Maintaining water table within the suggested range will not eliminate peat emissions or peat subsidence. Peat decomposition will occur when water level is lowered, however the oxidation rate will be different depending on the water table depth.

A range of research has taken place examining the GHG emissions and subsidence resulting from palm oil production. In 2014, the IPCC presented an update to its 2006 guidelines specifically for wetlands (IPCC 2014, 2013) in which existing research was compiled and digested. This analysis produced a Tier 1 emission factor of 55 t CO2e ha-1yr-1 for tropical drained palm oil plantations (Hiraishi et al 2014) (Table 10) while The Indonesian Carbon Accounting System (INCAS) assumes a default value of 40.3 t CO_2e ha-1yr-1. These emissions also translate into peat subsidence, which has been estimated to range between about 2 – 5 cm per year (Radjagukguk 1997; Wosten and Ritzema 2001; Hooijer et al 2011; Couwenber and Hooijer 2013).

Table 10. Emission factors for CO_2, N_2O and CH_4 emission in peat land in non-plantation areas

Land Cover Classes	CO2 (Table 2.1 Hiraishi et al., 2014; Table 1 Miettinen et al., 2017)		N2O (Table 2.5 IPCC 2013)		CH4 (Table2.3 IPCC 2013)	
	IPCC Classes	t CO2/ha /year	IPCC Classes	kg N2O/ha /year	IPCC Classes	kg CH4/ha /year
Agriculture-Peat	Tropical plantations, drained, long rotations	55	Tropical plantation	1.9	Tropical plantation: oil palm	0
Bare land (operational)-Peat	Tropical plantations, drained, short rotations, e.g. acacia	73	Tropical forest land, cleared forest land, shrub land	3.8	Tropical forest land, cleared forest land, shrub land	4.9
Bare land (Others) -Peat	Tropical forest land, cleared forest land, shrub land	19	Tropical forest land, cleared forest land, shrub land	3.8	Tropical forest land, cleared forest land, shrub land	4.9
Swamp-peat	Tropical grassland	35	Tropical grassland	7.9	Tropical grassland	7

Although it is helpful to have this type of standard estimate, it is not possible to use this approach to estimate the impact of improved management. Fortunately, additional research has been done looking at this relationship between water table and annual emissions (Figure 9). Using this approach, every 1 cm of raised mean annual water table levels, translates into an emission reduction of over 5 t CO2e ha^{-1} yr^{-1} (Jauhianinen et al 2012). Significant CO2 and CH4 emissions also take place directly from canals (IPCC Tier 1 default values of 3.01 t and 56.48 t CO2e ha^{-1} yr^{-1} respectively; Hiraishi et al 2014), and thus reducing the size and length of canals within concession areas will also reduce annual GHG emissions.

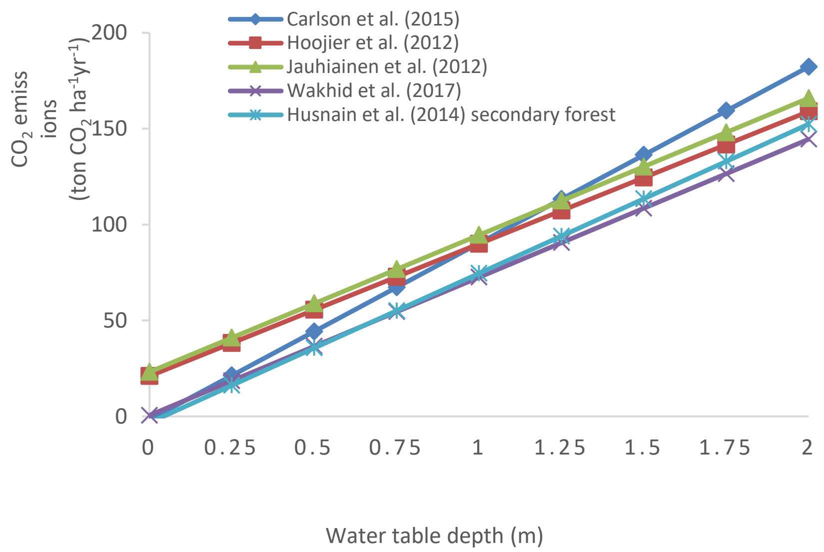

Figure 9. Estimating annual CO2 emissions in comparison to water table measurements from various studies in Indonesia and Malaysia

In addition, water table management is also an important element in fire prevention and management. Peat fires are a significant source of GHG emissions, and while they can occur naturally during the dry season or El Nino events when water depth can drop below 30 cm (Agus and Subiksa, 2008), they are rare in undrained peat areas. Although the most severe fires of recent years can be linked to droughts driven by the ENSO climate anomaly, peat fires are now a regular feature of every dry season, even those of short duration.

The depth of peat burned during a fire event has been found to range significantly, and will in part be associated with depth of drainage. Agus and Subiksa (2008) report that 75 Mg C ha-1 is emitted for every 15 cm peat burned, containing 50 kg C m^{-3}. Peat burn depths have been reported at 0.33 m (Ballhorn et al., 2009) and 0.18 (Konecny et al., 2016) which represent strong and weak El-Nino, respectively. Both of these values were developed using LiDAR, which allows for interpolation of the potential surface prior to fire event, based on the unburned surface. Calculating emissions from peat fires based on the approach in the IPCC Wetland Supplements (Hiraishi et al., 2014) results in GHG emissions of almost 90 t CO2e ha-1 for every 10 cm of peat burned. Thus reducing both the area and the depth of peat burned provides significant emission reduction potential. These estimates only include the emissions from peat burned[15]. If the fires also consumed vegetation, this would add additional GHG emissions to this estimate per hectare.

Manggala Agni Unit

[15] Assuming a bulk density of 0.09 t m^{-3} (Page et al 2011)

Canal gate technologies vary from simple sand bags to metal automated gates. Due to ongoing subsidence and periodic high precipitation events that can cause flooding, cement structures are not recommended materials for dams or gate construction. While automated gates that shift based on water table levels do provide high level of control, due to the expense related to installation and maintenance these will generally be only used for main canals.

These costs, and the risk of productivity reductions do need to be carefully weighed against improved water table management increasing the length of time a plantation can viably be productive before subsidence is too significant.

Water table monitoring approaches can also range from simple water gauges and dipwells, to automated piezometers. Newer technologies that rely on inexpensive water table sensors and mobile towers are currently under development[16]. This holds the promise of reducing overall costs required to understand real time water table levels across a plantation.

Environment and Social co-benefits

Beyond greenhouse gas emission reductions, maintaining suitable water tables slow peatland subsidence and reduce fires. The long-term use of drained peatland areas, leading to extended subsidence has the potential to result in large areas of land that are frequently inundated and unproductive, threatening the livelihoods of a large number of communities. Thus, slowing subsidence is critical to these communities.

Replicability

Adequate resources are needed to manage water table. Big companies are likely to manage drainage canals according to the available best practices. Small and medium companies will face constraint to do so due to limited financial and human resources.

Summary

Water table management has the potential to reduce emissions, however adequate resources are needed. Since over the long term, continued drainage of peatlands will cause continued subsidence and lead to areas becoming unproductive, approaches that slow and/or halt this subsidence will extend this period of productivity.

No	Criteria	Score	Remark
1	Financial evaluation	High	Significant upfront investment required to install improved drainage systems
2	GHG reduction potential	High	Significant and permanent annual GHG emissions for all hectares
3	Technical and operational challenge	Medium-high	Research still required. Automated gates still costly to install and maintain
4	Environment and Social co-benefits	Medium	Reduced fire risk, increased fish biodiversity, increased length of production
5	Replicability	Low-Medium	Will be more cost effective for larger operations

[16]https://www.winrock.org/document/reducing-ghg-emissions-from-peat-lands-and-oil-palm-in-indonesia-a-jurisdictional-approach/

Improved smallholder production

Smallholder farmers are a major producer of CPO in many countries. In Indonesia in 2013, smallholder farmers managed about 40% of total oil palm plantation area, and generated an estimated 35% of CPO nationwide (Table 11). Similar to Indonesia, about 38% of total Malaysian oil palm plantation is managed by smallholder farmers. (Malaysia Palm Oil Board, 2014).

Table 11. Indonesia palm oil overview (Source: Badan Pusat Statistik 2013)

	Managed plantation area (ha)	CPO production (tonnes)
Private Companies	5,366,854	15,012,254
State-owned enterprises	803,817	2,378,214
Smallholder farmers	4,415,796	9,504,982

Smallholders influence GHG emissions in two key ways. Typically, low yields per hectare compared to commercial plantations result in greater demand for new land as demand for CPO increases. Helping smallholders maximize yields on smaller parcels of land will cut the impact on emissions related to clearing of high biomass natural lands, as well loss of soil organic matter in peat landscapes. Secondly, certain unsustainable practices result from the lack of the ability of smallholders to pursue landscape-scale impact reduction strategies that are too expensive to be financed by any individual producer, such as water management or fire suppression.

Figure 10. Smallholders weighing harvest (*source: http://www.wri.org/blog/2018/03/smallholder-farmers-are-key-making-palm-oil-industry-sustainable*)

Yield improvement

Low yields are a worldwide problem that are not unique to smallholders, with global CPO yields reaching only 3.3t ha^{-1} y^{-1} of a potential of at least 8.0 for most regions irrespective of producer type (Woittiez et al. 2017), Figure 11). In Indonesia, smallholder production of FFB has been estimated at around 15 t y^{-1}, compared to 17 t y^{-1} nationally (Woittiez et al. 2017).

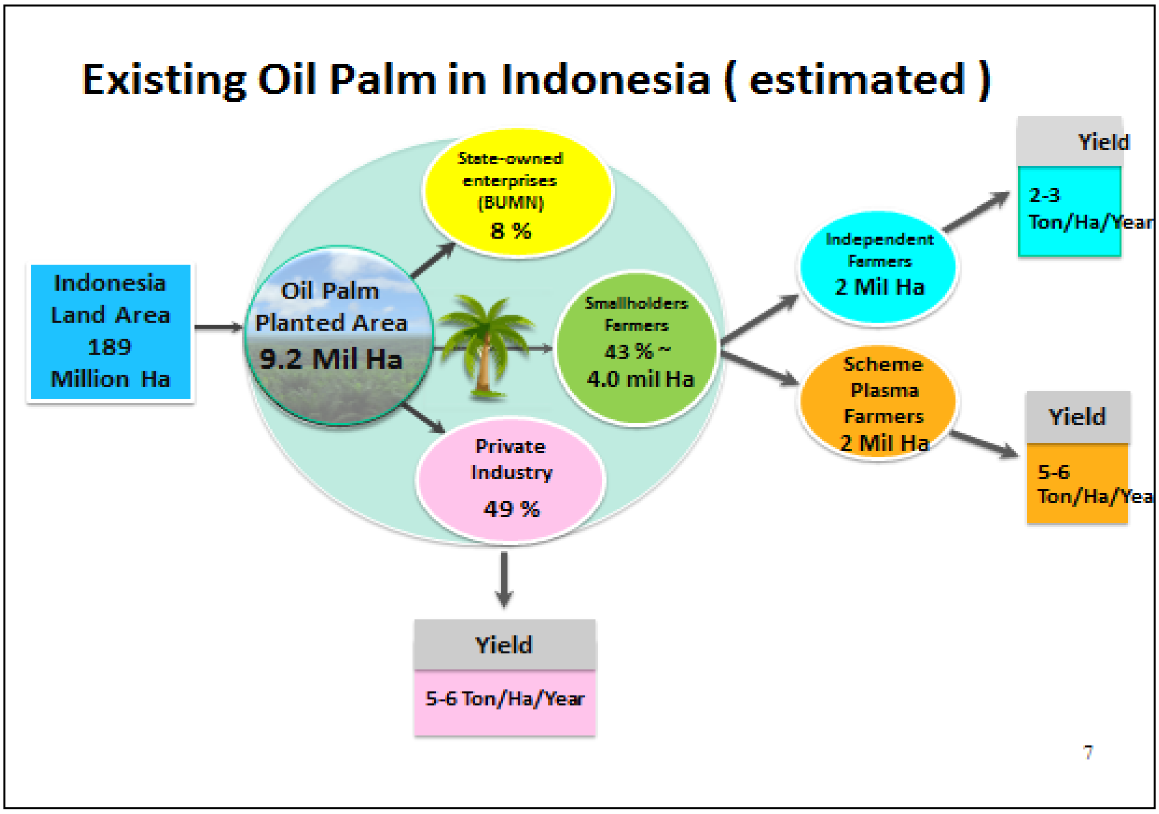

Figure 11. Comparison of dominance and yields of producers in Indonesia (courtesy of KADIN)

Some of the causes of this yield gap are compounded for smallholder producers where access to finance, information, and secure land tenure inhibits making appropriate investments in management practices. These include failing to replant over-mature stands with declining productivity, lack of access to appropriate seeds or presence of counterfeit seeds, insufficient fertilizer application, irregular watering, and failure to account for specifics of site conditions as it relates to optimizing a management strategy.

Companies can help smallholders to improve yields through addressing the four pillars of sustainable inclusion of smallholders described by Fernandez-Stark & Bamber (2012) (Figure 12).

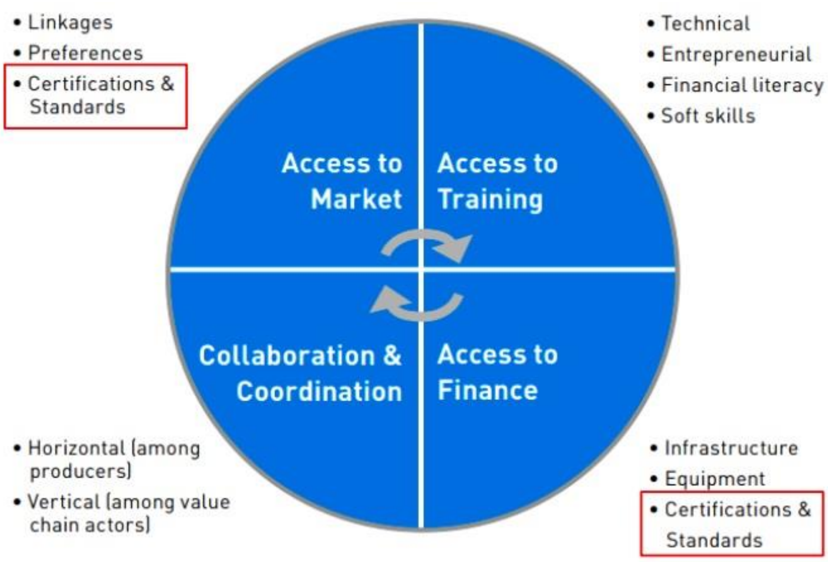

Figure 12. Four pillars for sustainable inclusion of smallholders in the global value chain (taken from: Fernandez-Stark & Bamber,2012)

Companies can provide this assistance to smallholders they are involved with in a number of ways, and the specific strategy pursued in any given landscape or market will depend greatly on local legal, economic and ecological conditions. Ongoing finance is needed by farmers to support yields primarily related to fertilizer purchase, land preparation, and clearing/replanting. Companies can support financing mechanisms that help farmers gain access to these inputs and services at critical times.

Information and training dissemination is also a key area that companies can play in important role. Ground cover management, pest and disease control and genetics selection are all areas where smallholders' yields are impacted due to failure to adhere to best management practices, regardless of access to inputs. Companies can evaluate prevailing practices of local smallholders to determine priorities for BMP extension. In some cases, site specific features like topography, soil conditions, and microclimate influence the selection of management approach. In such cases, companies that are already engaging in this kind of location-targeted management can extend the underlying analyses to smallholder areas and use this to inform the kinds of interventions to support in specific areas.

Efforts to promote yield intensification have started to emerge in palm oil sector. In Ghana, the International Plant Nutrition Institute (IPNI) has initiated a large-scale collaborative project with oil palm plantations and smallholders supported by Solidaridad West Africa across Ghana. The project aims to facilitate the effective use of production inputs, such as crop residues and mineral fertilizers, and to assist plantation staff and smallholders in the identification and implementation of improved agronomic techniques. Demonstration plots were established to introduce the best management practices (BMPs) while also serving as a learning center for smallholders and plantation staffs. The project has demonstrated substantial yield increases with introduction of BMPs and supported knowledge dissemination through training activities and development of BMP knowledge products.

Improved sustainability

In the case of small plantations on peatlands, poorly managed water tables represent a very specific but large emissions source. From a yield perspective, inappropriate or uncontrolled water table levels can result in premature land subsidence and permanent inundation, excessive palm toppling, and increase the severity of any fires that do occur. Ideally, water tables in peatlands are maintained at optimal levels for palm growth, and in compliance with national regulations, through active management of water across the landscape through water table monitoring, damn operation, and canal maintenance. Such water table management is a significant undertaking where success requires the ability to react quickly to changing climate conditions over a hydrologically connected landscape, and to be able to anticipate the results of any intervention to redirect or store water. Smallholders often develop their drainage networks by digging canals that connect into systems put in place by local companies. This means that companies are often already engaged in management of portions of hydrologic provinces that include smallholders. There is potential to expand collaboration with the communities, including extending water table and fire monitoring activities and installing and operating flow control systems into smallholder managed portions of the landscape. This would allow for a more holistically managed peat landscape that would result in improved adherence water table targets for both company and smallholder lands.

In some cases, smallholders may be cultivating peatlands that are unlikely to be productive under any scenario, or that could produce better financial returns under another crop type. By understanding the characteristics and challenges of the peatlands, smallholders can decide the best management option for their plantation hence increase the sustainability concern and productivity. A guideline prepared by Winrock International in collaboration with Cargill, IDH, and Costco was made to encourage smallholders to sustainably and optimally manage their plantations that exist on peatlands in order to fulfill their economic needs and environmental sustainability (Suryadiputra et al 2017). In this guideline, smallholders are invited to understand their plantation conditions such as soil type, depth, and inundation condition. Farmer can therefore decide the best management options and investment according to the condition. For example, if the peat's depth is found to be > 3 m, farmer can focus on the water level management or finding alternative commodities that endemic to peat and have more economic value such as Jelutung, Ramin, and Jabon. If the land is suitable for oil palm cultivation, smallholders can manage and improve their plantation by establishing a joint management (Farmers' organization or cooperative), managing water table, using high quality seedlings, palm tree weeding, and doing integrated pest management (IPM).

In peatland smallholder production areas, improved fire prevention and fire suppression will be another key approach to both increasing long term sustainability and farmer incomes, but also reducing greenhouse gas emissions. Along with the support provided by government agencies, such as in Indonesia Manggala Agni, and provincial level Disaster Mitigation Agencies, in fire alert and suppression, village fire brigades can serve as the first line of defense. After receiving training and the appropriate equipment, such brigades are an important approach to slowly the expansion of fires as they arise.

Examples of financing schemes

Financing schemes and policy framework play important roles in palm oil development, however, to date they still mainly focus on large companies and there is less reliance on supply chain financing schemes. According to ISCC (2017), financing the smallholder farmers also struggles with lack of data, information, and high operational costs due to remote location which results in a perceived unattractive risk. An integrated financing scheme based on supply chain while also allowing access to finance, market, and best management practices for smallholder farmers is needed to overcome this issue. This scheme also requires more programmatic approach, involving national and provincial government, the financial sector, farmer organizations, mills and other stakeholders in the palm oil supply chain.

One of this integrated model was proposed by Financial Access Netherlands and SNV (Figure 13). The model aims to increase the mobilization of long-term finance for oil palm smallholders. It is focused on the key enabling conditions such as incentives to meet sustainability standard certification, land tenure security, improved market linkage between smallholders and mills, risk management, and smallholder organization. Further, it also allows smallholders to receive knowledge on best agricultural practices hence improving productivity and smallholders' livelihood.

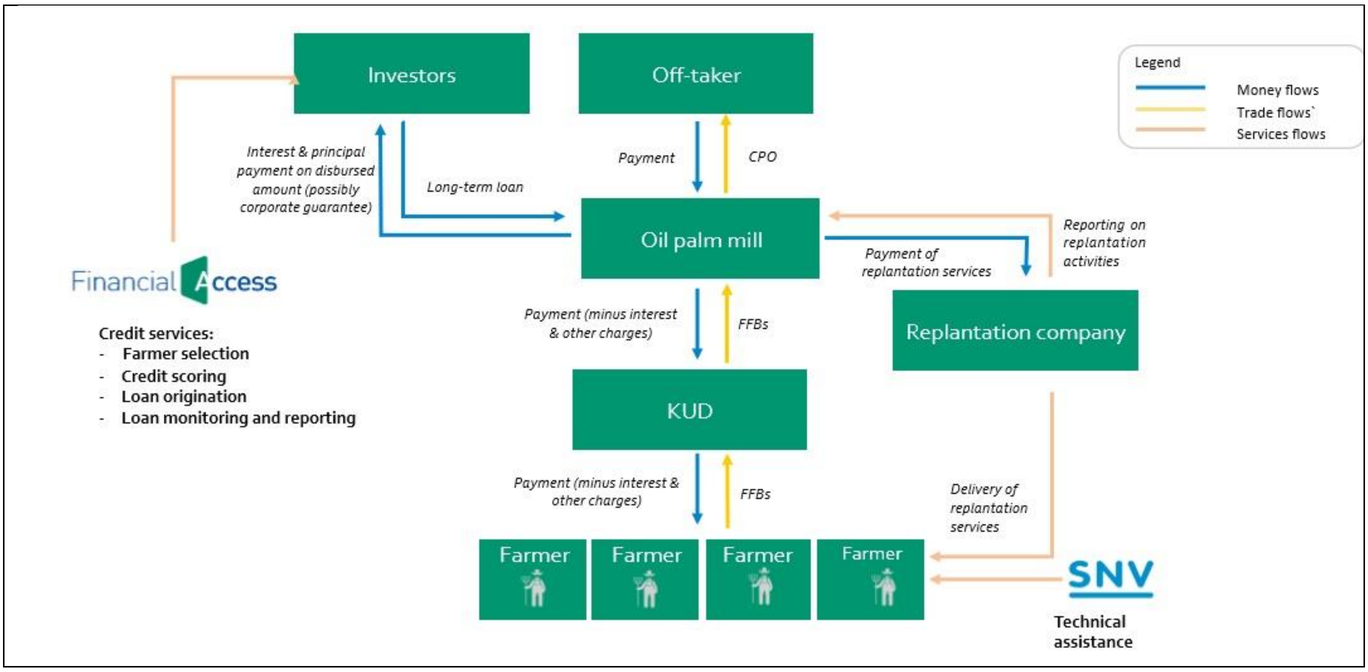

Figure 13. Financing scheme proposed by Financial Access and SNV (taken from Financial Access)

The Indonesian Chamber of Commerce (KADIN) recently started a new financing scheme for 1 million independent oil palm planters (Jupesta and Lakitan, 2014) (Figure 11). Using this scheme, independent farmers will be supported by KADIN's facilitation of funding from financial institutions through cooperatives. These cooperatives will develop loan products with interest rates affordable to farmers looking to receive additional capital for investment including replanting. It is hoped that this type of investment will double annual yields and lead to a replanting of 2 million hectares involving 1 million independent smallholders. If this is born out, an additional 6 million tons of oil would be produced, resulting in an additional income of approximately US$4 billion to US$5 billion a year, based on the CPO price of US$800 per ton (Jupesta and Lakitan 2014). In addition, it is hoped that this scheme would also significantly reduce additional areas being converted from natural forest.

The Partnership for Sustainable Indonesian Agriculture (PISAgro) program was launched in 2012 by Sinar Mas Agro Resource and Technology (SMART) as a financial mechanism for smallholder farmers. Within this scheme, SMART serves as a guarantor for the credit given by the state-owned bank to the smallholder, with a 6% interest rate for the initial four years and 10.5% afterwards. Training programs on best agricultural management practices are taking place, with the goal of increasing productivity, and thus GHG efficiency. The scheme has 20-20-20 goals: a productivity increment of 20%, poverty reduction by 20% and reduction of CO_2 emissions by 20%[17]. In return, the company will be allowed to collect the harvest from smallholders under a price mechanism monitored by local government.

Summary

Both integrated smallholder financing scheme and yield intensification provide high social and environmental benefits to the palm oil production. Smallholders' inclusion into the supply chain would result in increasing sustainability concerns therefore help reducing environmental risks especially deforestation. Through dissemination of best management practices to improve productivity, smallholders would gain more profits thus improve their livelihood. However, it also depends on the financing model applied. Most of the financing models have just been developed or launched, making it too early to determine whether they are best for replication and scaling-up.

	Criteria	Score	Remark
1	Financial evaluation	Medium to high	High upfront cost to initiate financing scheme and coordinate with related stakeholders in the supply chain
2	GHG reduction potential	Medium to high	Avoided land use change by smallholder/intensification can lead to high GHG emission reduction
3	Technical and operational challenge	Medium	Good knowledge of best agricultural practice is needed
4	Environment and Social co-benefits	High	Avoided unsustainable practices, environmental risks, and danger for deforestation. Improve farmers' livelihood
5	Replicability	High	Can be implemented by all scale of plantation.

Integrated Pest Management

Pests such as leaf web worm, rhinoceros beetle, slug caterpillar, and mealybugs have the potential to disrupt plantation productivity, with reported yield losses between 25% and 50% 50% in heavy infestation (Kalidas, 2012; Woittiez et al., 2017). As a preventative measure, insecticides and pesticides can be applied to manage pests in the

[17] www.pisagro.org

plantation. The use of them contribute to greenhouse gases emissions associated with manufacture process and transportation. Integrated Pest Management is not a new method and is already applied in the palm oil sector.

In the case of good agricultural practices (GAP) implementation, improved pest management is the priority in controlling pest and diseases such Ganoderma, Rhinoceros beetles and leaf eating bagworm, to minimize the impact of chemical pesticides on the environment and food chain (Corley and Tinker, 2003). The use of the natural predators to pests can also lead to GHG savings due to reduced chemical pesticide application (Table 12).

Table 12. Ecologically based classification of pests (source: Smith and Reynolds 1966)

Pest Type	Description	Management
Key pests (i.e. Arthropods, mammals)	Perennially occurring, would cause severe damage in the absence of control measures.	Limitation by natural enemies is generally inadequate (i.e. owl as natural predator of rat)
Occasional pests (i.e. bag worm, grass hoppers)	May cause sporadic economic damage. Outbreak occurs when natural balance is disrupted, possibly caused by past broad-spectrum, persistent-residue, and insecticides.	Good environment control, including biological control.
Induced pests	No significant damage under current condition but have the potential to do so.	Control agricultural practice to avoid disruption to their environment.

A study reported that implementation of sustainability practices, including IPM, in palm oil company operation has enabled annual reduction of pesticide and herbicide costs by $250,000 and $73,859 per hectare, respectively (WWF, 2012). Yet, the figures do not provide specific IPM costs as reference. Costs of IPM implementation can vary from one alternative to another. It depends on the type of pests, and the methods used. As an example, having owl for rat control ranges from USD 0.4 to 4-6 ha^{-1} y^{-1} (Table 13).

Table 13. Costs of rat control using barn owls in various conditions (source: Caliman 2017)

Method	Cost of rat control (USD/ha.y)
No barn owl	4 – 6
Barn owl & 'Low' local biodiversity (small carnivores)	2 – 4
Barn owl & high local biodiversity (small carnivores)	0.4 – 0.5

Specific studies on the GHG savings from IPM, particularly in palm oil sector are limited. The potential reduction can be attributed to reduced pesticide application in estates with IPM implementation. Emission factors of pesticides range from 0.15 to 0.95 mgCO2e/kg pesticide application (European Environment Agency, 2003). GHG savings from IPM are relatively small when compared to overall carbon footprint of plantation, but provide extensive co-benefit such as maintaining the natural balance of ecosystem in palm oil plantation and minimizes other adverse impacts of chemical pesticides to the environment.

IPM can be difficult in practice since it deals with the balance between pests and their natural enemies which may no longer exists in the plantation. According to Corley and Tinker (2003), implementation of IPM requires knowledge and control and/or monitoring system in place as the following:

- Knowledge of the life cycle and ecology of the pest and its natural enemies to extent to be able to manipulating biological control.
- A monitoring system to ensure early detection of outbreaks, to enable timely control measures.
- Establishment of economic damage and action thresholds, to ensure that control measures are carried out when necessary.
- Selective control measures to promote swift re-establishment of natural balance.

Complementing IPM implementation, research and development of stable nanoparticles/ nanocapsules/ nanofibers of pheromone could advance the practice of pest management in the future. The nano-formed can be designed to hold the pheromones in sufficiently high concentrations and can control the dissipation rate due to either evaporation or adsorption in an environment (Kalidas, 2012).

IPM is considered as one good agricultural practices (GAP) to reduce GHG emissions through avoided pesticides use (Subramaniam, et. al, 2017). It enables plantation to avoid yield loss and also keep the natural balance in palm oil plantation. IPM can be applied by any scale of plantation or company. However, establishing economic damage and action threshold requires set of knowledge and skill in pests life cycle in which this expertise might not exist in small plantations and individual growers.

Summary

	Criteria	Score	Remark
1	Financial evaluation	Low	Low investment and maintenance costs
2	GHG reduction potential	Low	Relatively low when compared to total GHG emissions
3	Technical and operational challenge	Low	Yet it requires knowledge and skill to maintain the balance.
4	Environment and Social co-benefits	Medium	Avoided adverse impacts of pesticide application, maintain natural ecosystem.
5	Replicability	High	Can be implemented by all scale of plantation.

Fuel Use in Plantation

Fossil fuel, dominated by diesel, is still the primary energy source used for nursery, maintenance, harvesting, collection, and transportation of Fresh Fruit Bunches in oil palm plantation. GHG emissions related to diesel consumption for machinery and transport vary depending on fuel consumption, trucks capacity, FFB yield, and distance covered. RSPO (2009) has summarized the GHG emissions related to diesel plantation for internal transportation and machinery as ranging from 180 – 404 kg CO2e ha-1 yr-1. Research conducted under the CIRCLE, found that fossil fuel use accounts to 10% of the total GHG emissions from plantation (CIRCLE, 2015) thus finding alternative fuels to replace fossil fuel consumption could help palm oil companies to create positive impacts on climate change mitigation through the GHG emissions reduction.

Palm oil mill effluent (POME) can be an excellent renewable energy source. Many companies have started to invest in methane capture technology, where the biogas is captured. This is used mainly for heating and electrification for internal demand, however, in many locations the potential amount of biogas supply exceeds the internal demand and thus could be employed externally. Unfortunately, one of the main barriers hindering the installation of biogas plants is that palm oil mills are often located far from the existing national grid and point of demand, hindering effective application of biogas. Exploring biofuel potential could be an option to further utilize POME in the form of upgraded biogas (biomethane) or biodiesel that can be applied for on-site use as shown in Figure 14. In the plantation, biomethane or biodiesel could potentially replace the use of fossil-based diesel for machinery and trucks transporting FFB or CPO to and from palm oil mills.

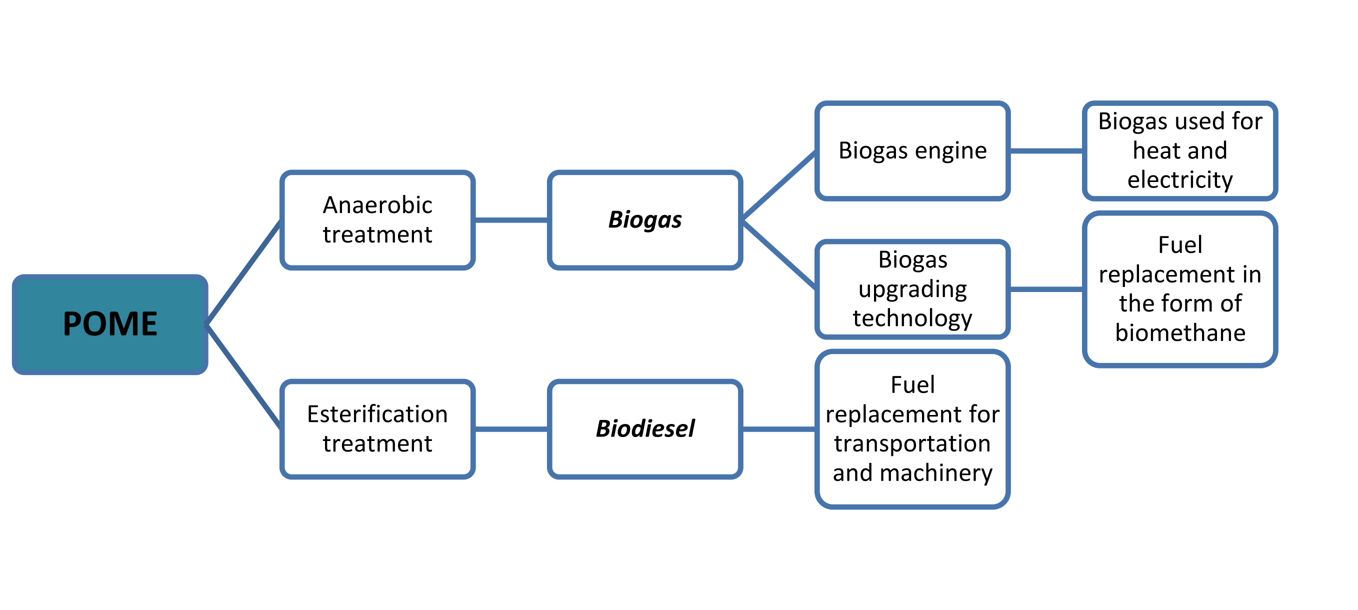

Figure 14. Potential options for developing biomethane and biodiesel from POME

Biogas upgrading resulting in biomethane

Biogas is formed naturally when POME decomposes in the absence of oxygen (anaerobic process) and is comprised of 50 – 75% methane, 25 – 45% CO2, and trace amounts of other gases. While most of the biogas is flared, some companies have started to install methane capture technology, in which the biogas is utilized to generate power through biodigester technology and use it for heat or electricity. 'Biogas upgrading' is the process of separating methane and carbon dioxide from the raw biogas resulting in pure methane or known as biomethane. This process involves first scrubbing and then compression. Biomethane can then be stored, transported, and used as replacement to natural gas for industrial uses, injected into gas grid, used as vehicle fuel (bio-CNG), or polished and liquefied to produce bio-LNG. In the form of biomethane, more than 90% of energy can be used (FNR, 2009).

A number of different technologies are commercially available for use today, such as pressurized water scrubbing (PWS), catalytic absorption/ amine wash (CA), pressure swing absorption (PSA), membrane separation (MS), and cryogenic liquefaction (CL) (Hoo et al., 2017). The most widely used method is pressurized water scrubbing, given it is the most simple and inexpensive technology (Kapdi et al.,2005). Applying these different technologies removes the CO2, purifying the biogas until it is equivalent to natural gas in term of its composition (> 94% methane content). The choice of method depends on several factors including volume rate of biogas production; raw and product gas quality; flexibility; and availability.

Figure 15. View of fuel storage for truck after conversion from diesel to CNG or liquified biogas operation. http://www.g3industries.com/page/pressed-steel-tanks

In addition to injection into any existing natural gas grid, biomethane can also be used as a transport fuel in the form of bio-compressed natural gas (bio-CNG) and bio-liquefied natural gas (bio-LNG). With its similar characteristics to natural gas, biomethane is suitable as renewable natural gas used in all engines running on natural gas. While LNG is mostly used for high-fuel demanding vehicles such as highway trucks and construction equipment, CNG is more common for other type of vehicles. Converting POME to bio-CNG offers a clear opportunity for the palm oil companies to increase the sustainability of palm oil production. Using bio-CNG as transport fuel for trucks delivering FFB and CPO in palm oil industry will also widen the biogas utilization beyond electricity generation and heating.

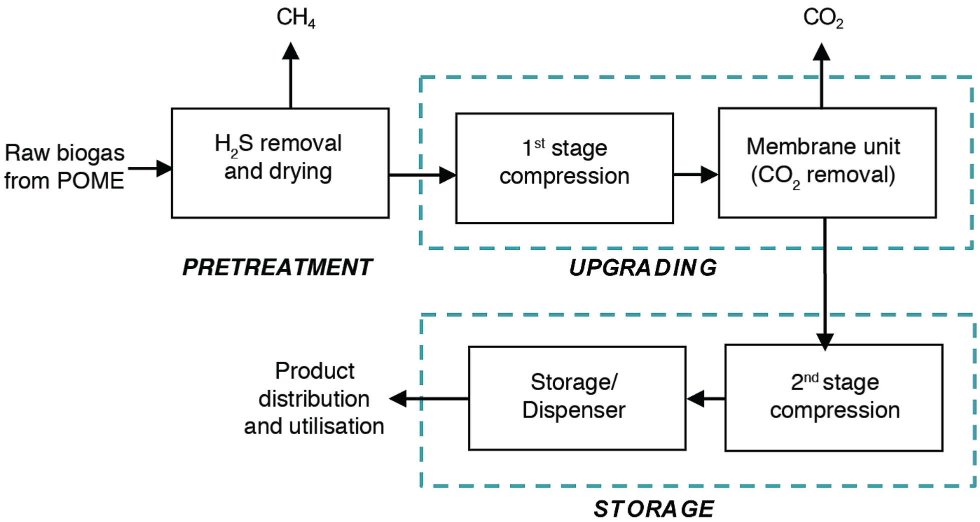

Figure 16. Process flow diagram for the production of bio-CNG from POME (taken from: Nasrin et al., 2017)

To create Bio-CNG from POME requires a biogas upgrading plant. This consists of three main operation units: pre-treatment, upgrading, and storage as depicted in Figure 16. The investment cost for a biogas upgrading plant depends on the type of upgrading technology applied. Hoo et al. (2017) summarizes the cost for upgrading technologies ranges between US$4,167 to US$12,369 per m3/h of Bio CNG production once installed. Given this range, a 400 m3/h plant would need around US$ 1.7 million of investment. O&M costs will vary but are estimated between US$10,701 to US$16,640 per m3/h (Hoo et al., 2017). The first commercial biogas upgrading plant from POME at Felda Palm Oil Mill Sg Tengi, Kuala Kubu Bahru, Selangor, Malaysia cost around US$ 1.7 million to produce 400 m3/h of bio-CNG. The POME raw biogas is upgraded from composition of 60% methane, 35% CO2 and 3000 ppm H2S to bio-CNG with > 94% methane content. The bio-CNG is then compressed and dispensed into CNG trailers to be delivered to factories. OMI Alloy (M) Sdn Bhd, located about 45 km away from the plant, is the first factory receiving POME-based bio-CNG.

Table 14. Economic analysis of a 400 m3/hour bio-CNG (biomethane) plant

Description	Value	
	Bio-CNG Plant Only	Biogas and Bio-CNG Plant
Investment cost (USD million)	1.78	3.04
Annual production (million m^3, 72000 h/year)	2.46 (~80,000 MMBTu)	
Net present value 10%, (USD)	461,000	43,040
IRR (%)	14.36	10.25
Payback period (year)	6.03	7.5
Assumption: Bio-CNG selling price @ MYR 40.00 – 46.00 $MMBTu^{-1}$ Operational expenditure @ MYR 25.50 $MMBTu^{-1}$		

Source: (Nasrin, 2017)

For a palm oil company's fleet to utilize the Bio-CNG produced would also require conversion from gasoline to bio-CGN for each vehicle. This includes incorporating several additional parts, including fuel storage cylinders (usually placed underneath the vehicle or in the trunk), stainless steel fuel lines, a regulator to reduce the pressure, and a special fuel-air mixer. The cost for the conversion varies from approximately US$6,000–US$12,000 per vehicle depending on the vehicle model, engine type, engine size, type of conversion and the number of fuel storage cylinders. For example, converting a gasoline-fueled Ford F150 5.4 L to bio-CNG operation costs approximately US$6,600. Although this capital outlay is relatively large, the annual fuel savings, estimated by Enbridge Gas Distribution, is approximately $3,500 (based on $1.30/L gas and $0.75/L compressed natural gas) are also significant (Clarke, 2012) and thus can be recaptured within two years.

Thus, Bio-CNG is a real potential alternative to replace transportation fossil fuel consumption in the palm oil industry. It offers economic and environmental benefits through cost savings and GHG reduction. A vehicle operated with biomethane reduces CO2 emissions by up to 90 % compared to a conventional petrol-fueled vehicle. However, support and incentive systems for biomethane as transport fuel are still needed to promote the system in the industry which may include Feed-in-Tariffs (FiT), regulation, tax reduction, quota system (renewable energy shares), and support on infrastructure. Successful projects like bio-CNG plant at Felda Palm Oil Mill Sg Tengi could also motivate palm oil companies to adopt the system.

Esterification resulting in bio-diesel

In addition to biomethane, another potential untapped energy source is the production of biodiesel from POME. Research conducted by Paryanto et al. (2015) found that integrating biodiesel plant with the palm oil mill complex is a strategy to produce biodiesel fuel with lower investment cost compared to non-integrated biodiesel plant. Further, this biodiesel product could be used as a substitute for conventional diesel used internally by the palm oil industry.

This biodiesel can be produced through a set of chemical processes called esterification followed by transesterification system or direct transesterification. The exact method applied is dependent on the quality of the oil raw material. Oil raw material with relatively low content of free fatty acid (< 5%) such as crude palm oil (CPO), is processed with the direct transesterification reaction by adding the methanol mixed with a base catalyst, followed by separation and purification processes. Oil raw material with higher content of free fatty acid (> 5%), such as PFAD and low-grade crude palm oil from POME, is processed with the esterification reaction followed by the transesterification reaction. Biodiesel produced is then separated from glycerol and excess methanol by washing process and purified by vacuum evaporation and filtration (Paryanto et al.,2013) (Figure 17). The pre-treatment process and selection of catalyst used in esterification stage play important roles in generating a good quality of POME biodiesel.

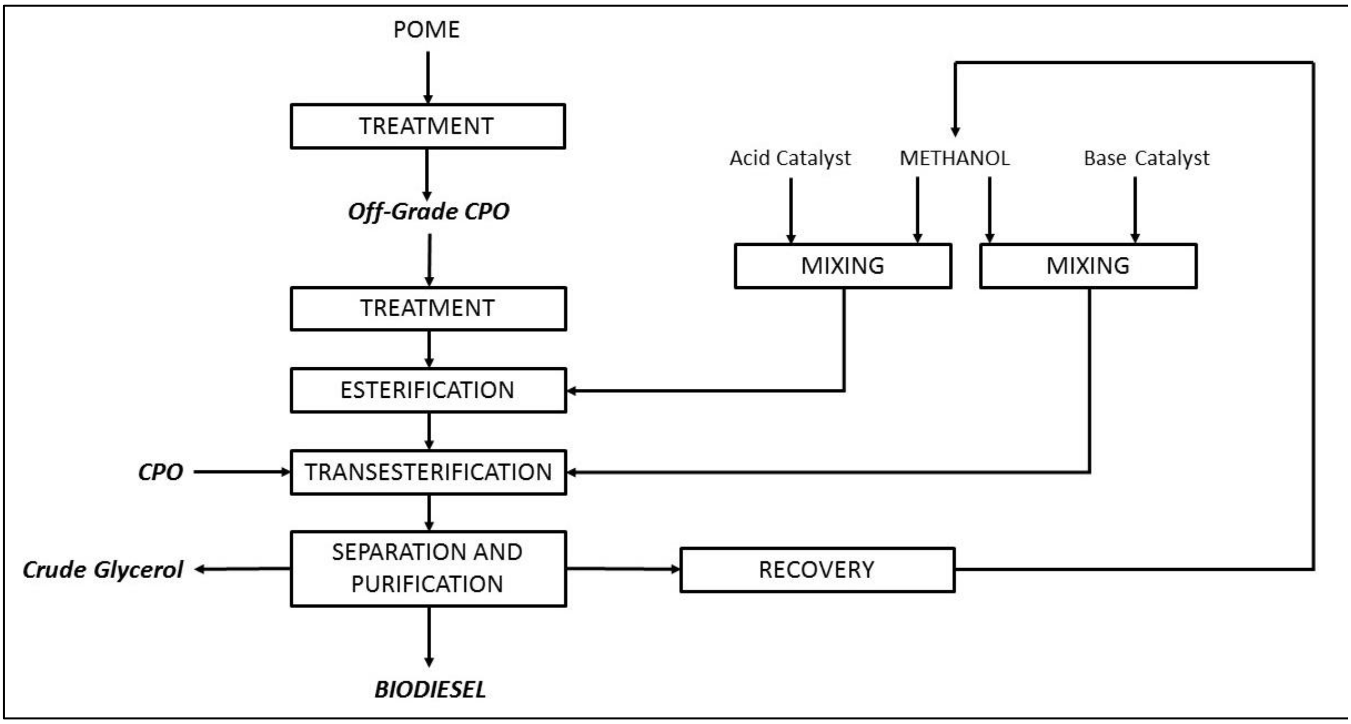

Figure 17. Biodiesel production process (taken from Paryanto et al 2013)

Imam et al. (2014) estimates the investment cost of a 1 Ton/day biodiesel plant using POME as raw material could reach around US$175,000. This cost includes civil works, equipment, storage tanks, pumps, piping and cost of feasibility study as shown in Table 15. This cost is approximately 15% lower compared to biodiesel plant that is not integrated with palm oil mill and uses CPO as raw material. POME-sourced biodiesel can then be used as a sole biofuel or blended with fossil fuels.

Table 15. Estimated investment cost of a 1 TPD biodiesel plant from POME (taken from Imam et al 2007)

Item	IDR
Building and civil works	400,000,000
Equipment	745,000,000
Storage tanks	90,000,000
Pumps and motors	170,000,000
Utilities (steam, electricity/genset, water)	100,000,000
Electrical and instrumentation	125,000,000
Piping	270,000,000
Feasibility study and engineering	250,000,000
Commissioning and training	110,000,000
Overhead	125,000,000
Total	2,835,000,000 ~ USD 175,000

Generating biodiesel directly from palm oil (CPO) has caused concern around the sustainability of crop-based biofuels and the European Union has voted to cap crop-based biofuel at the member states' 2017 consumption level and no more than 7% of all transport fuel until 2030. Palm oil alone is planned to phase-out by 2021. This action was driven by negative impact of palm oil production such as deforestation and GHG emission, with palm oil biodiesel being considered the highest emitting biofuel. However, generating biofuel from waste and not from crops has clear added value in improving the sustainability of palm oil production and provides clear message of a mill or company's commitment in mitigating environmental-related issues in palm oil production.

Summary

No	Criteria	Score	Remark
1	Financial evaluation	High	US$4,167 to US$12,369 per m^3/h for biomethane. A 400 m^3/h biomethane plant could cost around US$ 1.7 million US$ 175,000 for a 1 TPD biodiesel plant
2	GHG reduction potential	High	Biofuel (biomethane and biodiesel) could potentially reduce CO_2 emissions by up to 90 % compared to a conventional fossil-fueled vehicle and machinery
3	Technical and operational challenge	Medium	Mill personnel needs to be trained to operate the facility/plant, service contract with technology provider could ensure smooth operation.
4	Environment and Social co-benefits	High	RE generation, fossil fuel replacement, GHG reduction.
5	Replicability	Medium	Technically replicable, yet utilization scenario and financing could be determining factors for small and medium company group.

Improved concession management through conservation and restoration

Within established plantation concessions, there are many opportunities to reduce emissions through better management of natural forests and conservation lands. Natural forests capture and sequester carbon, but this ability often does not reach its full potential within a concession landscape due to issues of past or continuing degradation, loss of stand viability due to fragmentation, secondary impact from altered hydrologic system, and land use practices that suppress natural regeneration. The term 'conservation lands' is used here to refer to any land that is set aside from planting as palm, either to protect existing forest resources or encourage forest recovery in degraded lands.

The overriding principle of improved conservation management, as it pertains to emissions, is to maximize the sequestration potential of existing protected lands, and to protect against the risk of carbon loss in locations that are at risk of degradation or deforestation. This review presents several discrete actions that companies can pursue, that combine some or all aspects of forest protection, forest enhancement, and reforestation. Every operation is unique, and these recommendations are not intended to delimit all the forms that restoration activities can take.

The types of activities available to an operator depend highly on the legal and environmental context of the concession, and all activities may not be suitable for all operators (Table 16).

Table 16. Generalized conservation management approaches

Activity	Best suited for	Note
Protection	Company manages significant areas of high-quality forest, where ongoing or future risks to forest maintenance can be clearly demonstrated by historical proxy. Also applies where a company has the opportunity to assume responsibility for managing a natural forest (i.e. restoration concession).	GHG emission prevention is more easily demonstrated in locations with clearly identifiable threats are more suitable. Threats can include encroachment, illegal logging, and fires. Protecting non-threatened forests does not result in real emissions reductions.
Enhancement	Company manages tracts of land that are in a degraded natural state, such as areas having suffered from devastating fire, heavy logging, etc.	If degradation is ongoing, protection must be combined with enhancement.
Afforestation, Reforestation (AR)	Can be pursued anywhere within a concession that legal framework allows it.	Monitoring is required to demonstrate that AR has been maintained over time.

Four such discrete strategies are presented here: optimizing existing managed conservation lands, engaging in internal land swaps and/or modest increase in conservation coverage, absolute retirement of plantations and conversion to natural forests, and finally acquisition of ecosystem restoration concessions outside of the bounds of currently managed concessions.

Retirement of plantations, rewetting and reforestation

If a company is willing to accept a net reduction in hectares of commercially cultivated plantation, and if the legal framework allows this, then retirement and replanting with native species is an option that can produce large emissions reductions especially in peatland areas. Plantations with persistently low productivity, that produce high and unavoidable emissions such as drained peat, and areas that could provide large ecological or social co-benefits as native forests, can be identified as priority lands for retirement.

In Indonesia, regulations were enacted in 2016 to restrict cultivation of areas with peat deeper than three meters[18]. While the future regulatory environment is unknown, the trend to date has been for increasing attention to the emissions producing capacity of peat soils. In order to halt ongoing emissions from drained peat, a retirement and reforestation program would require restoration of natural water table through altering, damming, or eliminating canals.

Smallholders may be reluctant to transition away from palm without confidence that alternative livelihoods will be equally or additionally beneficial to palm. Companies working with smallholder producers, especially in peatland areas, either as suppliers or as local communities, may need to invest in demonstrating financially sustainable alternative livelihoods to foster more widespread acceptance of non-palm land uses.

Rewetting prevents and slows down peat decomposition by reducing microbial decomposition of peat organic matter (Giesen, 2018). Furthermore, it is essential that peat is rewetted to delimit peat loss by drainage. Canal

[18] http://www.siiaonline.org/wp-content/uploads/2017/06/SIIA-Special-Report-Peatland-23062017.pdf

blocking is the most used approach to rewetting in peatland restoration in Indonesia. Because of the low peat density, the hydraulic head difference between canal blocks needs to be properly analyzed.

Various dam designs have been tested in rewetting. Prior to initiating rewetting, significant stakeholder engagement with local communities is critical. Experience elsewhere has found that where local community members actively use specific canals, dams need to be designed to accommodate this use to reduce the threat of people damaging the dams.

One type that had traditionally been constructed by civil society organizations is the 'box-dams'. These dams are made of creating a 'box' of wood planks that must be staked into the mineral soil below, infilled with sand bags or compacted peat (Figure 18). These can be constructed rapidly, use locally available resources and capacity, and temporarily create local labor. However, given the number of dams that are needed, they can become expensive. Costs are reported to range from USD1500 per dam for larger dams to USD150 per dam for very small dams (Surjanto et al 2018). The design of this type of dam can allow for continued passage for small boats, however, this then also prevents full rewetting. Construction manuals have been developed by Wetlands International (Suryadiputra et al 2005). This construction approach has had varying success. They have been found to degrade after only a few years and thus require frequent maintenance and rebuilding.

Figure 18. Examples of a box dam to rewet degraded tropical peatland forest (source: WWF)

Another approach is to create a compacted peat dam. This design uses an excavator that moves peat from nearby into the canal and then it is compacted through driving the excavator itself across the newly created dam. In pulp and paper concessions, these are built with a by-pass included, to allow water to continue to flow. However, for full rewetting, this by-pass should not be included. These can be constructed rapidly and do not require outside materials to be transported to the location and do not require specialized skills beyond excavator expertise. The costs have been estimated to range from USD600 for a 4 m wide dam to USD5,000 for a 20 m wide dam. Of course, since an excavator is needed, this approach will only work in accessible locations. In addition, since the dam is only made of peat, it is relatively easily damaged by people if not designed to allow needed access. A manual of the construction methods has been created by APP and Deltares (2016). The Peatland Restoration Agency (BRG) of Indonesia is actively recommending this approach to canal blocking[19] (Euroconsult Mott MacDonald 2018).

This approach can also be combined with canal infilling, especially in smaller canals in which again, using an excavator, peat is moved from nearby into the canal and compacted. Wooden planks can be placed in front to prevent peat from flowing out during high precipitation events.

[19] https://www.cbd.int/doc/meetings/ecr/ecrws-2016-02/other/ecrws-2016-02-presentation-day1-03-en.pdf

Figure 19. Example of compacted peat dam, with by- pass (source: Euroconsult Mott MacMcDonald 2018)

Paludiculture, the planting of flood-tolerant crops, is a promising alternative to restoration of native forests where livelihood, legal, or economic considerations preclude transitioning away from agricultural use (Sovy and Budiman 2018_. Industrial scale paludiculture is still a young field and markets for its products are not well developed, but it presents an option for companies wishing to contribute to the development of future lower-impact commodity sectors. The Sago palm has been demonstrated to grow on peatland areas, however, additional research is needed on the most appropriate variety and agricultural best practices (Herman 2017, Washingun 2016). Direct planting or enrichment planting of native peatland tree, Jelutung, which produces latex, also shows some promise but again trials are still underway for monoculture production (Hasti et al 2015; Budiningshi et al 2013). A verity of liberica coffee, originally from West and Central Africa) has been shown to be able to grown in peatland areas, and is currently under production in Jambi, Indonesia (Kementan 2014; Brembo 2016). Timber trees, including ramin (ITTO and Indonesian Ministry of Forestry 2008) and Balangeran (Indonesian Ministry of Forestry 2012) also hold promise either for monoculture or for interplanting. Fish farming can also be included as part of a suite of agronomic activities in formal canals and natural waterways.

Optimizing potential of existing conservation lands

If a concession contains conservation lands, and if there is not the potential to add to or reconfigure the distribution of those concession lands, then a strategy of protection and enhancement may provide GHG reduction benefits. In general, concession parcels that are in a highly degraded or threatened condition present the most potential benefit from protection and/or enhancement. The GHG reduction potential of such activities would need to consider factors such as the types and severity of threats to forests, the growth potential of trees, and the amount of carbon currently stored in forests. These activities can be pursued selectively on particular high-potential conservation lands within a concession, or extensively throughout the operation.

Even mature native forests within a concession can be an emission source where fire risk or ongoing drainage of peat soils is observed. Fire prevention is a particularly good strategy on organic soils where the combustion of soil carbon or peat can dramatically increase the emission impact. For palm operators managing peatlands with natural landcover, often those lands were subject to past canalization and draining prior to the licensing of the land. That legacy of impact will continue to have a large ongoing emission until the natural water table is restored. Because this type of drainage does not serve an agricultural purpose, it should be among the first mitigation options considered where it is available.

Conservation Land Swaps

The idea of a land swap is to reconfigure the location of lands zoned either for plantation or conservation, such that a net balance is maintained across the concession or landscape regarding either the hectare totals of those lands, or in some other measure such as provision of a benefit (i.e. the ratio of the number of hectares of plantation exchanged for conservation does not need to be 1:1). The purpose of this land swap is that by modifying the location of these lands, that it can be possible to achieve net increases in both commercial production and emissions reduction. Ideally, highly degraded land with low potential for reforestation are turned into plantations, while plantations in highly desirable locations, areas with low productivity, or high emissions such as peatlands are retired. Ecological benefits of land swaps are consolidating small non-viable conservation parcels into larger sustainable tracts, the widening of riparian buffers, and the creation of biodiversity corridors. Another case is utilizing land swap as part of a strategy of migrating more production to mineral soil lands and away from highly emitting peat soils.

Land swaps are only feasible where the legal framework pertaining to concessions allows it. There are social and environmental risks associated with any conversion of even very degraded natural land to plantations. However, it is entirely possible that within a concession there are clear opportunities where a land swap is an appropriate activity.

Manage a restoration concession

In the case of protection of existing forest, the company must demonstrate that the protection activity is sensible and appropriate given the prevailing threats. While approaches exist to help estimate the magnitude of these future threats (i.e. develop a 'baseline,' or business as usual scenario), the nature of projecting the future means there is a high level of uncertainty, and companies can expect a strong degree of scrutiny industry-produced baselines by scientific community. In some regions, national or subnational governments may be able to provide these baselines from their REDD+ programs. While some restoration concession are under national level management, there is increased interest in restoration concession being held by the private sector. For example, one case study included in this report looks at the peat restoration area managed by Golden Agri Resources (GAR). The peat rehabilitation project covers about 2,600 ha of conservation area (mostly peat soil). that were affected by devastating fire occurrences during strong El Niño season in 2015.

GHG Reduction Potential

Greenhouse gas accounting in the forestry sector is a highly varied and scale-specific undertaking. If a company is interested in pursuing opportunities to reduce emissions through protection, reforestation, or enhancement, it is strongly recommended that they consult with a specialist in this field to conduct an initial feasibility study to identify major GHG reduction opportunities and provide potential path for addressing them.

Because of the diversity of the landscape, the emissions reduction potential will vary across each concession for these activities. However, in many cases, largest emissions reduction opportunities available to companies as it relates to conservation land are as follows:

- Peat retirement, which includes retiring palm cultivation on peat soils, restoring natural water table depth, and reforesting
- Protecting highly threatened natural forests from clearing or degradation

- Reforesting degraded or non-forested natural lands

Retirement of palm on peat lands and restoration of water level produces immediate and often substantial reduction in emissions. The choice of post-retirement land cover has an impact on emissions, but because oil palm biomass is being replaced by tree biomass, the net benefits from regrowth are modest, at least in the near them. Retirement of palm on mineral soil can have substantial non-carbon benefits, but in most cases does not contribute substantially to a GHG mitigation objective. If retirement of palm on mineral is pursued, the GHG reductions can be maximized by undertaking the conversion after the scheduled end of the current palm cycle. The Indonesian Carbon Accounting System (INCAS) assumes a default value of 40.3 tonnes of CO2 emitted per hectare per year for as long as peat soil remains cultivated with palm. In areas of deep peat, this ongoing emission can persist for decades where drainage necessary for oil palm is maintained. For plantation operators with palm on peat, retiring this land from cultivation is often the single largest opportunity for GHG mitigation within the conservation management group of best practices, and in some cases, across all plantation management options.

Existing Natural forests can store immense amounts of above and belowground biomass, and clearing of these forests generally results in their rapid releases of CO2 through decomposition (see Table 6 and Table 7). The use of fire in clearing only adds to the impact with the production of CH4 and N2O. The carbon stocks in any area that under normal cases would have been converted, but that is ultimately protected through company actions, can be considered an emission reduction. If a national or subnational REDD+ Reference Level is available for the geography the concession is located in, this document can provide a good starting point to understand the range of carbon value found in native forest, and the types of threats that the government has identified. Of course, in peatlands areas, if the water table has been affected either by the surrounding land use, or if remnant canals or other types of drainage are present, the largest opportunity for GHG emissions will be through increasing the average water table levels. It is recommended that significant engagement take place regarding the design and location of proposed dams with any surrounding communities.

Restoring degraded and non-forested natural land through either replanting or allowing natural regeneration has the benefit of producing tangible carbon sequestration benefits beginning immediately upon planting and protection. While reforestation is the inverse of deforestation and theoretically these activities can balance one another, they are accounted for on much different timelines. Whereas deforestation emissions are often accounted for entirely in the year of clearing, reforestation accrues only incrementally over time, but can persist for decades or even centuries. Published growth curves, mean annual increments, or stand tables can give a good indication of what kind of annual benefit the growth will provide (Table 17).

Table 17. Examples of sequestration benefit of afforested lands, from Bernal et al 2017.

AR type	Mean annual increment 0-20 years, AGB+BGB (tC ha-1 y-1)	Sequestration benefit AGB + BGB (tCO2e ha-1 y-1)	Source
Agroforestry – Africa	2.0	7.3	Bernal et al. 2017
Agroforestry - Asia	2.6	9.5	
Agroforestry - Latin America	3.0	11.0	
Natural regeneration - Africa	4.7	17.2	
Natural regeneration - Asia	3.2	11.7	
Natural regeneration – South America	5.1	18.7	

Native peat forest – Indonesia	7.1	25.8	Osaki, Tsuji (eds.) 2016

In most cases, a planted forest is replacing some other vegetated landscape, even a very low-carbon one like from the first year of growth, meaning it could in some circumstances take several years or even up to a decade before the stand provides any net GHG benefit (Table 18).

Table 18. Examples of one-time emissions from converting land

Land cover before reforestation activity	Biomass AGB+BGB (tC ha^{-1})	Emission from replacing pre-AR land cover (tCO$_2$e ha^{-1})	Citation
Oil palm (long term average)	*36 (AG only)	132	Agus et al. 2012
Annual cropland	5	18	IPCC 2006 v4 ch5
Perennial cropland (wet region)	10	37	IPCC 2006 v4 ch5
Grassland – tropical moist	8	29	IPCC 2006 v4 ch6

Technical and Operational Challenges

All mitigation activities incur costs related to technical assessments, implementation costs, and ongoing monitoring. Some activities, like conservation restoration licenses, have higher upfront costs and work better with larger economies of scale, while others like peat restoration can be scaled effectively from very localized to widespread. This section highlights some of the key challenges associated with each main activity type.

Retirement removes the land from oil palm production and therefore is an immediate loss in palm yield to either the company or smallholder. While alternative livelihood options exist such as paludiculture or ecotourism, it may not be feasible for some producers to undertake this strategy over very large areas due to lost production alone. For peat areas undergoing retirement, restoring full natural water table may require expensive investments and ongoing patrolling to protect dams. In some cases, local residents accustomed to utilizing canals for transport may resist efforts to alter them. This will be especially important in peatland areas where the design of any dams built will need to be appropriate to the conditions in that area.

Afforestation of non-plantation areas within a concession is relatively straightforward to implement, but consideration should be made during the activity design to account for the land's capacity to support forest growth. If severe past degradation of the soil or water table has occurred, this may need to be corrected before planting. Most of the real challenges to afforestation are tied to managing human relationship with the land. Some degraded lands may be currently utilized by communities that hold some claim. There needs to be careful consideration for how to protect the afforested land from ongoing use detrimental to regrowth, while also ensuring communities' rights are upheld.

Forest protection can require a significant up-front investment if land needs to be purchased. In addition, the uncertainty of the magnitude of GHG emission prevention will be extremely dependent on the probability that the existing area was under threat of deforestation or degradation. If an independent and defensible 'with-out protection' scenario is to be developed, technical experts will need to be employed and thus incorporated into the investment costs. If the major emission threats are fires, a conservative estimate of fire probability and resulting emissions will need to be created. This estimate will be significantly lower than the standing stock of the forest since the probability of the entire area burning is likely very low. This will similarly be true with illegal encroachment. A historical encroachment estimate will need to be developed and then projected within the protected area. In addition, significant stakeholder engagement with the local communities will be required and ongoing protection will need to occur.

Environment and social co-benefits

Increasing the area of natural forest and reducing fragmentation will provide large and varied ecosystem services. Clearly this will increase natural habitats, increasing the biodiversity and allowing more viable forest and animal populations. For many human populations, the most important benefit will be an increase in water security and other water-based ecosystem services such as fisheries, paludiculture, and fire protection. Annual haze currently endemic to parts of Indonesia, Malaysia, and Singapore due to large fires causes pervasive health problems and thus focus on methods to reduce fire prevalence are of high priority to governments, companies, and local communities. It has been estimated that the fires of 2015 burned over 2.6 million hectares of land in Indonesia, hampering economic and social growth to the cost of over USD16 Billion (World Bank 2016).

Replicability

Removing areas from production is highly replicable, but attention must be paid to legal implications of retirement and conservation. Peatland areas and areas containing or surrounded by highly threatened species should represent the highest priority locations for retirement.

Summary

No	Criteria	Score	Remark
1	Financial evaluation	High	Removing area from production will have long term persistent costs. Continued monitoring and protection will also require ongoing costs.
2	GHG reduction potential	High	Retiring and rewetting peatland areas will have the highest emission potential
3	Technical and operational challenge	Medium	Implementation methods are well known. However, additional research is needed on cost effective monitoring and protection technologies
4	Environment and Social co-benefits	High	Conversion to natural forest will significantly increase the ecosystem services the area provides
5	Replicability	Medium	As long as the regulatory environment enables retirement and conservation, these are highly replicable

Mill Management

GHG emissions in mill mainly contributed by POME and solid waste decomposition, fossil fuel use for vehicle, and fossil fuel use for heavy machinery or equipment. Mills meet demand of steam and electricity for CPO production and to power the mill's activity by combusting biomass, mostly shell and fiber. Due to its high moisture content, empty fruit bunches (EFB) are less suitable for feedstock to boiler and turbine. Mills usually mulching EFB and put them back to plantation as fertilizer, or pile and left them to decay in mill area. Mills can sell the excess shell to other party to use them as feedstock to generate energy somewhere else. POME is treated in series of open lagoon to lower the COD[20] level and meet the environmental standard for water discharge or land application. Decaying process of both POME treatment in open lagoons and EFB piling form and release methane to the atmosphere and foul odor. Processing and milling palm oil results in an effluent that is a mixture of water, oil, and organic material known as palm oil effluent (POME). To meet environmental standards, this wastewater mix is commonly treated in a series of open ponds. This process requires a large area, frequent desilting, and results in significant methane emissions (a potent greenhouse gas) released through the decomposition of the organic material. Figure 20 below depicts wastes generated from processing FFB to CPO and kernel and how the wastes are treated. The green boxes represent lower GHG treatment in mill own area when compared to the orange boxes.

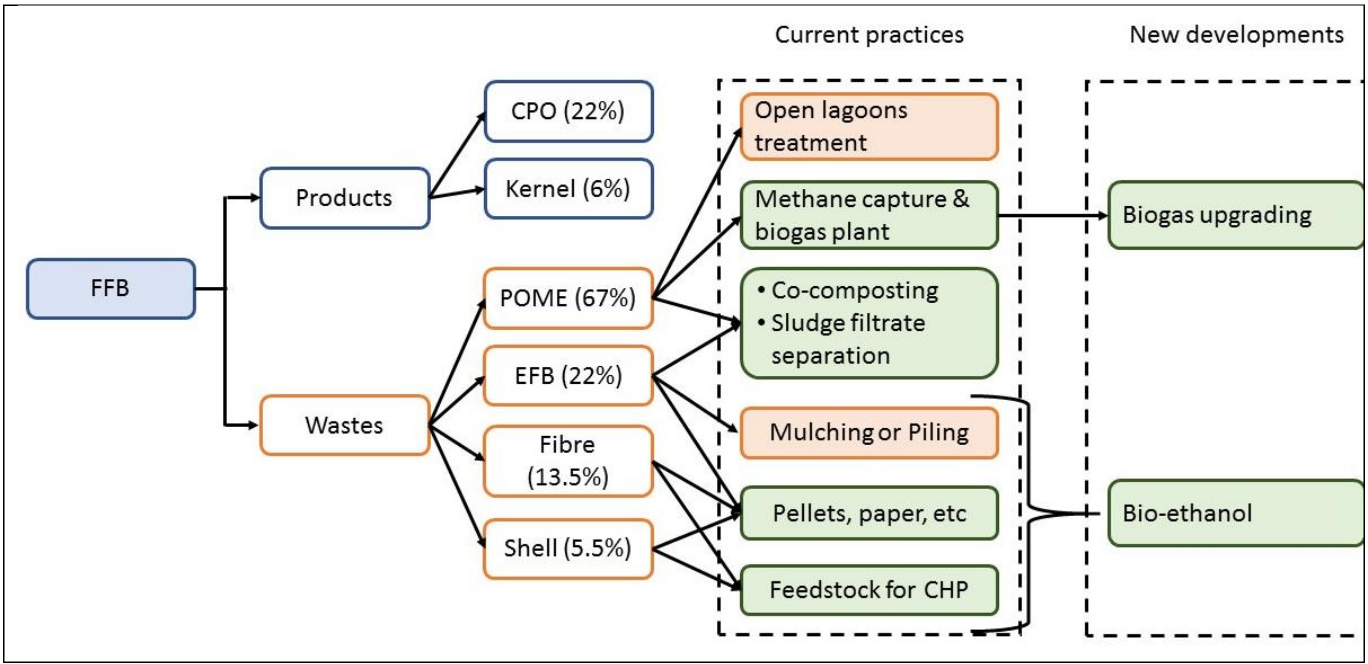

Figure 20. Waste Utilization in Palm Oil Mills

This section discusses BMPs that directly and indirectly reduce GHG emissions in mill. Some BMPs, such as methane capture and co-composting, were covered in the previous RSPO BMPs report. Despite their effectiveness in reducing GHG emissions, they have not yet become common practice in the industry. Therefore, they are considered still relevant to be discussed in this report. Methane capture and co-composting is potentially applied together to achieve zero waste palm oil mill. POME treated in the methane capture can generate biogas which can be further utilized for renewable energy production for captive or grid connection. In the case of renewable energy from biogas is used to replace existing biomass-based power production, combined with efficiency improvement on CHP, they lead to excess biomass available for fuel somewhere else or other use (i.e. paper production). POME can also be utilized in co-composting facility to produce organic fertilizer. This BMP leads to GHG emissions reduction in mill as well as in plantation through reduction of chemical fertilizer application. This section also covers emerging technologies such as biogas upgrading for transportation fuel; that have been proven in other sectors, but haven't been adopted by the palm oil sector.

It is important to note that BMP implementation in mill could promote GHG emission reductions somewhere else or contribute to wider context. For example, biogas generated by methane capture which converted to electricity can replace fossil fuel-based electricity generation on grid or as captive power. CHP improvement could lead to biomass saving. The excess biomass can be sold or transported somewhere else for renewable energy generation.

[20] Biochemical Oxygen Demand

Biomass can also be used as materials to produce paper, hence avoiding cutting down trees. On the other hand, co-composting using EFB and POME can reduce chemical fertilizer in plantation.

Furthermore, mills implement multiple BMPs to find the optimum GHG emissions reduction within reasonable economic investment. Some of BMPs implementations were not solely motivated by GHG reduction but sustainability, efficiency and process improvement purpose. Mills evaluate and select BMP to implement in accordance to their capability –technical, financial- market orientation, and priority issues that they want to address. Most mills with internal demand for electricity or close to the grid opt methane capture and biogas for electricity generation. KLK fitting filter belt press to solve recurrent sludge problem in POME treatment, Sime Darby started with co-composting and followed by methane capture to achieve zero waste mills, whereas IOI adopted green tubes to remove solids in POME and investing in its cogeneration plants to achieve 90% energy efficiency improvement.

Efficiency Improvements in CHP

Cogeneration or combined heat and power (CHP) is one of the approaches to produce energy simultaneously from single energy source. Palm oil mills have been using the abundant biomass waste, in the form of empty fruit bunches, fibre, and kernel shell, as fuel combustion in CHP plants to generate steam and electricity for CPO production process. The main components of this technology are boilers, turbines, generators and a back pressure receiver. Processing fresh fruit bunches into CPO requires 0.35 ton of steam and 17.87 kWh per ton FFB[1]. Combusting biomass waste enable palm oil mills to meet this power demand sufficiently, thus no imported electricity from the grid is needed. CHP plants in palm oil mills are configured to generate low power output to cater for the low power-to-heat demand ratio of oil extraction process.

Currently, generally the boilers and turbines used in palm oil mills have a low to moderate efficiencies of <80% and 35% respectively (Nasrin, et. al., 2011). Efficiency improvements in existing CHP can be achieved through various methods with purposes of increasing the amount of power produced and reducing the amount of biomass waste needed. A mill could consider efficiency improvements of its existing CHP plant when it expects an increasing energy demand (i.e. due to mill expansion) or possibility to sell excess power to the grid. The increased efficiency leads to lower fuel consumption; hence the mill will have excess biomass waste available for other use or sale to external parties such as refinery plant.

Three approaches are presented below:

1. **Improved waste heat recovery**
   About 60% of feeding energy to boiler is converted to waste heats. However, recovering and utilizing waste heat results in an improvement of thermal efficiency from 37.34% to 75.60% compared with the conventional approach. It could lead to biomass saving about 2,748 tons per year with simple payback of 1.3 years (Booneimsri, et al., 2016).

2. **Improved flue gas recovery**

   Major energy losses at the boiler happen due to hot flue gas and moisture in flue gas. A study by Sommart and Pipatmanomai (2011) states that in a mill processing 260,000 ton FFB per year found that energy efficiency improvements can be achieved by recovering the hot flue gas and instead using it for removing moisture in boiler. The improvement is implemented by installing a rotary dryer with capacity of 12 tons of fuel per hours. The dryer fitting to existing boiler increases the recovery of flue gas to reduce moisture in fuels from 35.5% to 17.5%, leading to increased boiler thermal efficiency by about 7% or equivalent to 2,776 tons/year of biomass. Capital and operational expenditure was estimated to be USD 122,000 and USD 26,400/year respectively. Calculating additional income from the selling of excess biomass (i.e. biomass plant), the efficiency improvement project gave a payback period2 of 1.5 years (Sommart and Pipatmanomai, 2011).

3. **High efficiency steam turbine**

There are several types of high efficiency steam turbines which can improve efficiency and thus increase total energy supply produced. In a recent study, three technologies were compared to evaluate which was the most economical way to meet an increase in energy demand (**Error! Reference source not found.**Table 19) (Abd Majid, et. al. 2014). Fitting a high efficiency back pressure steam turbine has the highest return but has vented out steam while installing a high Capacity Extraction Steam Turbine still has a moderate return and produces no vented-out steam.

Table 19. Investment costs and rate of return for various efficiency improvement methods

Method	Capex (USD)	Opex (USD)	Vented out steam kg h^{-1}	Extended Rate of Return
Fitting of high efficiency back pressure steam turbine	230,000	70,800	900	28.79%
Installing high capacity boiler (water tube boiler) to current CHP system	823,000	91,000	12,150	17.17%
Installing high Capacity Extraction Steam Turbine (CEST)	343,000	202,500	No steam vented out	26.03%

Source: Abd Majid, et. al. (2014)

Efficiency improvements in CHP plant leads to more power generation and excess biomass waste that can provide additional revenues from selling. A study in CHP plant in six mills in Malaysia found that mills with improved efficiency have potential to export excess power to the grid ranged from 113 kW for 20 tph mill to 900 kW for the 54 tph mills (Nasrin, et al., 2011). For a mill located close to the grid or other industry facility that requires power, selling extra power could shorten the payback period. However, the efficiency improvements discussed have not been widely implemented.

Another example of CHP efficiency improvement is carried out by IOI. IOI invested MYR 30 million into the installation of a 6.5 MW CHP plant in Penang. The investment is expected to boost energy efficiency from the usual efficiency of 39% and 75%-85% to above 90%. This initiative is projected will cut energy costs by at least 40% and reduce emissions of GHG such as CO2, Nitrogen, and Sulphur oxides.

GHG emissions from biomass combustion for energy generation is considered negligible, thus efficiency improvement in CHP does not lead directly to GHG emission reduction. However, optimum configuration can be achieved to deliver efficiency and conserve biomass which can be used for other purposes such as co-composting (see Co-composting BMP), creating alternative biomass-based products (see biomass utilization BMP), or selling the excess biomass for energy generation elsewhere. In locations where energy had formally used fossil fuels, the palm oil mill can serve as clean energy production center.

Summary

	Criteria	Score	Remark
1	Financial evaluation	Low	Low investment and maintenance costs
2	GHG reduction potential	Low to high	Highly depends on the utilization scenario. Biomass combustion generates negligible net GHG emissions, however GHG reduction can be significant when electricity is used to replace fossil-based electricity generation. Supplying electricity to grid can lead to GHG emission reduction beyond CPO production boundary.
3	Technical and operational challenge	Low	No additional skills needed
4	Environment and Social co-benefits	Medium	Potentially provides excess energy or biomass for use elsewhere in production
5	Replicability	High	Technically feasible for many mills

Methane Capture and POME-to-Biogas Electricity

Solid waste from CPO production is mostly reused as a feedstock to provide heat and power for the production process or office facility, yet the common treatment of POME remains inefficient. In the oil extraction process, POME is generated from three major operation: sterilizing fresh fruit bunches, clarifying extracted crude palm oil, and EFB pressing. For every ton of fresh fruit bunches processed, the mill discharges from 0.7–1 m3 of POME. Fresh POME is hot (temperature 60–80°C), acidic (pH of 3.3–4.6), thick, brownish liquid with high solids, oil and grease, COD, and Biological Oxygen Demand (BOD) values (Rihayu et al 2015).

An open ponding system is the most common method to treat POME. In this process, POME flows through a series of ponds and several treatment stages to collect the remaining oil, decrease temperature, and create optimal conditions for the decomposition of organic material. After these stages of treatment, POME will be discharged to water bodies or used as fertilizers. Even though the open ponding system is considered the most economical option of POME treatment, it is still land and time intensive and releases considerable amount of methane into the atmosphere from POME decomposition in the absence of oxygen (anaerobic pond). Channeling POME into land application or water bodies, on the other hand, can pollute vegetation or aquatic environment if it does not meet environmental standards set by the government.

A **Methane Capture and POME-to-Biogas Electricity system** is a potential alternative option to reduce the volume of residues but at the same time capture the methane, thus reducing GHG emissions from POME. The biogas produced from this system therefore can be used for different utilization, including generating power for electricity. Before being utilized, the pre-treated POME is processed through an anaerobic bio-digester system (AD). In the AD process, POME is first channeled through the pre-treatment system to lower the effluent temperature. Then the effluent is pumped into the bio-digester system where the digestion takes place with the help from bacteria. To date, two major technologies (bio-digester system) have been used for anaerobic digestion in palm oil sector: covered lagoon and tank reactor. The biogas produced in the AD system is pumped into a biogas utilization system which consists of a hydrogen sulfide (H_2S) scrubber and dehumidifier, prior to being injected to boiler and gas engine. The excess biogas is pumped into a flaring system to destroy the methane (Figure 21).

The biogas produced from this process can generate power for electricity. The mill or project owner could sell off electricity produced to power grids or use it for their internal demand of the mills, non-mills and estates. Selling electricity to the national grid has two options, either connected on-grid or off grid (isolated). Both options are profitable for project owners interested in renewable energy business, but it depends on the power purchasing price or feed-in-tariffs applied in the project location.

Reducing methane from POME has started to become a major strategic action for reducing GHG emissions. Major companies have started to adopt the installation of methane capture facilities at their mills given greater incentive for major producers to comply with certain standards and certifications, bigger production, wider targeted market, and intense attention from the public. However, utilizing the biogas into electricity is solely the decision of the company or the project owner. Regulatory drivers have played a part in this shift, and motivate some companies to look at the economic benefits of using the methane in biogas for electricity generation. For instance, Indonesia's 2012 Ministerial Regulation No. 04/2012 about FiT for renewable energy from biomass and biogas increased interest in grid-connected power from POME-to-energy projects. Under the regulation, biogas project owners were allowed for the first time to sell power through Power Purchase Agreements (PPAs) or excess power through excess power agreements with PLN (a state owned utility company).

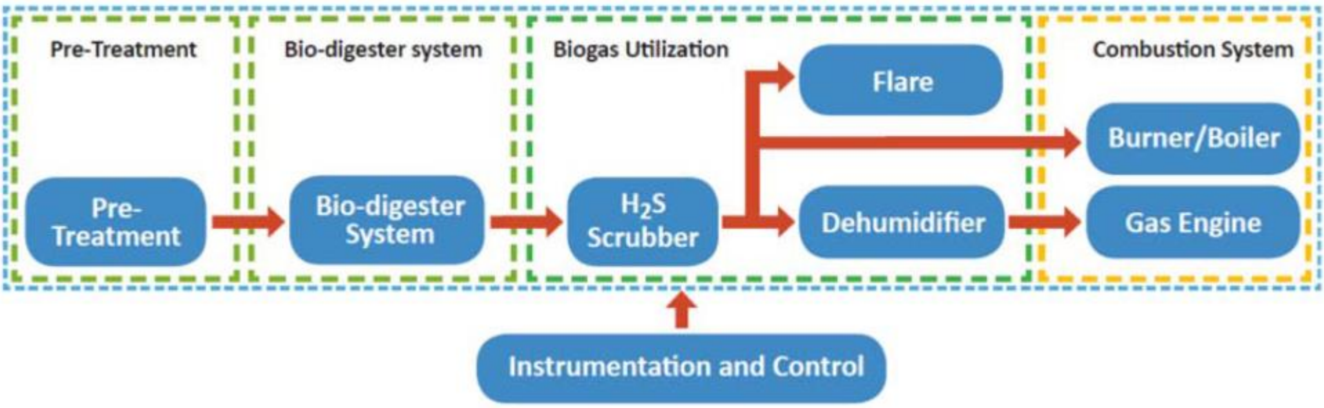

Figure 21. Palm Oil Biogas Process

Methane capture and flaring system can avoid methane release by about 82%, whereas methane capture and electricity generation avoid about 90% methane release to the atmosphere when compared to the baseline. Using the RSPO PalmGHG Calculator, GHG emissions from POME shows 0.65 $tCO_2eq/tCPO$ and 0.07 $tCO_2eq/tCPO$ with methane capture facilities installed (Gan & Cai, 2017). Therefore, according to these numbers, the emission reduction is around 89%.

Methane capture requires high investment cost which often becomes a challenge to palm oil mills, particularly for small to medium palm oil company groups. The costs of biogas projects consist of engineering, procurement, and construction (EPC) costs and non-EPC costs. The bio-digester and biogas conversion system are generally the two most expensive elements in the EPC costs. In general, tank systems cost more than covered lagoons for bio-digester. The investment costs for tank systems range from USD2.5–3.5 million per MWe, while the covered lagoon costs range from USD1.5 – 3 million per MWe (CIRCLE Project, 2015). Table 20 below compares EPC costs for covered lagoon and tank reactors.

Table 20. Example of costs for covered lagoon and tank reactor associated with a1.2 MWe gas engine

Technology	Bio-Digester cost	Gas engine (1 x 1.2MWe)	Total Investment Cost	Investment cost (USD/MWe)
Covered lagoon	USD 2.7 million	USD 640,000	USD 3.33 million	USD 2.77 million
Tank reactor	USD 3 million	USD 640,000	USD 3.66 million	USD 3 million

Source: Rahayu et al 2015

The investment cost of methane capture facility will be varied, depending on the technology applied, type of biogas utilization (either for electricity/combustion/flaring), size and brand of engine, scope of supply (partial/turnkey), grid lines (for electricity scenario), and site-specific information that affected on civil work (e.g soil condition, topography), as well as logistical costs. The breakdown of the indicative investment cost is presented in the Table 21 below which uses a case study for 2.5 MW POME-to-electricity project in Jambi, Indonesia. Investment costs for such project consist of two large groups which are EPC (engineering, procurement, and construction) and non-EPC costs. Non-EPC costs comprise of components such as pre-development cost, financing cost, and working capital.

Table 21. Breakdown of Investment Cost for Methane Capture Projects

System		Components	Costs
EPC Costs			As % of EPC Costs
Bio-digester System	1	Preliminary works and mobilization	~25%
	2	Civil and hydraulic works	
	3	Equipment	
BiogasTreatment/Utilization System	1	Preliminary works and mobilization	~16%
	2	Civil and hydraulic works	
	3	Equipment (scrubber, blower, flaring system)	
Biogas Conversion	1	Biogas engines and installation	~20-25%
	2	Shipping and insurance	
	3	Equipment and instrumentation system	
Electrical and Instrumentation (E&I) System	1	Control and electrical room	~10%
	2	Instrumentation and control	
	3	E&I connections for digester and biogas system	
	4	Electrical works for connection to biogas MSB (main switch breaker)	
Other Costs	1	Logistics	~20–25%
	2	Shipping and insurance	
	3	Installation, commissioning and start-up (including biomas seeding)	
Gas engines (including accessories and installation)*			~20–30%
Grid connection (per km)			~USD 20-30,000
Contigency (2%)			~5–10%
Total EPC Costs			**USD 5,341,000**
Other Costs			
Other Costs	1	Financing costs	2% of loan size
Total Investment Costs			**USD 5,486,000**
ROI			**10-12%**

Source: Rahayu et al, 2015

Despite its potential and benefits, there are still several challenges to methane capture project implementation. From the technical side, challenges such as limited familiarity with the technologies, lack of expertise, and distance from the local grid often hinder the implementation. For larger companies, there are various factors affecting the company decision thus different challenges to develop methane capture facilities such as requirement from sustainability certification, market requirement, local regulation regarding discharge limits of the effluent, and company initiatives to reduce GHG emissions. Moreover, high upfront costs for uncertain return is also an issue for the mills, specifically for the small-scale company that has local market orientation.

Small Scale Anaerobic Digester

Anaerobic digester is well known technology, proven, and applied in multiple sector for wastewater treatment. Application is not limited to large scale, i.e. brewery factory and palm oil mill, but also medium to small scale such as household bio-digester using manure as feedstock. Biogas generated is used for lighting, cooking, or upgraded for vehicle fuel. An example of small scale POME digester installation is presented in the case study section.

The implementation of methane capture facility has started to become major concern by palm oil producers in the past few years. Companies started to use the anaerobic digestion for methane capture to treat POME thus reduce the GHG emission. In palm oil industry, a combination of national standards and the demands of external consumers is driving greater interest in methane capture among palm oil operations. As a result, the desire for projects is being driven both internally and externally.

Summary

No	Criteria	Score	Remark
1	Financial evaluation	High	Investment cost USD 1.5 to 2 million per MWe for methane capture and RE utilization
2	GHG reduction potential	High	Potentially reduce about 50% of mill's emission
3	Technical and operational challenge	Medium	Mill personnel needs to be trained to operate the facility, Service contract with provider could ensure smooth operation.
4	Environment and Social co-benefits	High	Cleaner air, RE generation, improving access to electricity, supporting national target in GHG reduction.
5	Replicability	Medium	Technically replicable, yet utilization scenario and financing could be determining factors for small and medium company group.

Co-Composting

Crude palm oil (CPO) production generates abundant solid waste, with empty fruit bunches (EFB) constituting about 22% to 23% by weight. EFB has a lower calorific value when compared to fiber and shell, but has a higher moisture content, making it less suitable for boiler feedstock.

Instead, EFB is commonly used as a fertilizer in plantations because of its nutrient content. Application of EFB mulch in plantations can replace the use of chemical fertilizers and thus reduce GHG emissions produced in plantations. 1 ton of EFB displaces 3.0 kg Urea, 0.4 kg Rock Phosphate, and 12.0 kg Muriate Potash; and lead to 3.3. kg CO_2e/t FFB of GHG savings (0.003 2 t CO_2e /t FFB) (Subramaniam et al, 2017). The GHG savings are calculated from the avoided chemical fertilizer applications.

Co-composting of EFB and POME together is commonly implemented by mills and considered to be efficient and cost-effective process for organic waste decomposition that yields manure or fertilizer. The application of this compost enriches the soil, improves sustainability of palm oil plantation, and reduce GHG emission. The common method of co-composting is done by shredding EFB, adding POME to maintain the required level of moisture and aeration, and turning the mixture on regular basis (Figure 22). POME is rich with micro-nutrients; hence it not only maintains the moisture and reduce heats, but also enables a nutrient-rich compost product. Optimum mixing of POME to EFB is 3.2 m3 POME/ton FFB and at maximum 5.3 m3POME/tonFFB (Schuchardt, et al., 2002). Composting process can take up to 20 weeks.

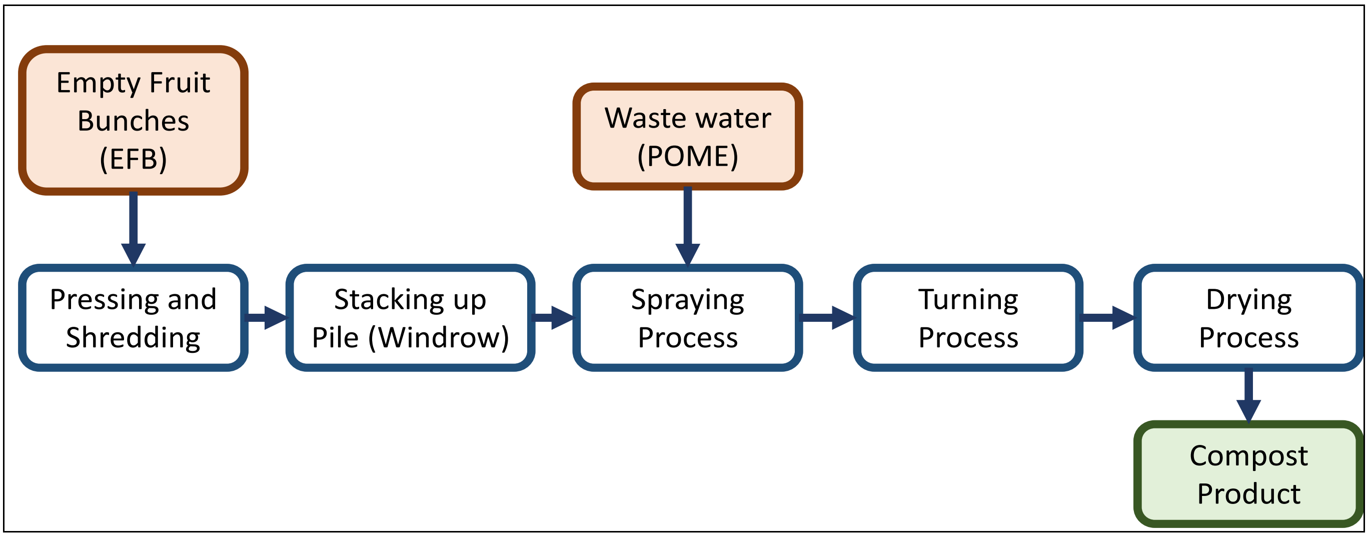

Figure 22. Schematic Process of Co-composting EFBs and POME

Research and pilot projects have been carried out to improve co-composting methods to shorten length of decomposition process, create easier operating techniques, and vary combination of organic matters. Several trial or pilot projects are presented below:

- Co-composting of pressed-shredded EFB and POME anaerobic sludge from methane capture using ratio of POME to EFB of 1:1 in a controlled condition (co-composting block). Co-composting period reduced to 40 days with final C/N ratio 12.4 (Baharuddin, et. al., 2010).
- Co-composting of EFB and partially treated POME in an open and traditional windrow composting pile. Co-composting period reduced to 60 days with C/N ratio 12 (Baharudin, et. al., 2009).
- Co-composting of EFB and all raw POME produced from mill with Eco-D two phase decanter and continuous steriliser system. The produced compost can be used as fertilizer, zero wastewater as all POME are used, and C/N ratio below 20 after 30 days (Seng, 2011).
- Adding nitrogen-fixers bacteria, worms, and fungi in the mixture to enhance decomposition process (Alkarimiah and Rahman, 2014; Gandahi and Hanafi, 2014).
- Aerated static piles to have composting with fast biodegradation and without any physical manipulation and can be managed in controlled aeration on perforated piping, windrows, or in closed, open or covered containers (Gandahi and Hanafi, 2014).

Referring to project design documents of Co-composting CDM registered projects, investment cost for co-composting facility can start from USD 650,000 for open and simple system to about USD 2 million for in-vessel co-composting system. Co-composting can be implemented by any scale of mills. The costs cover equipment and civil works procurement and installation. Indicative investment is USD 9/ton FFB processed. Operation and maintenance costs consist of two main components which are operation and maintenance costs of composting plant, and manpower and supervision costs. Co-composting does not require personnel with specific skill of set. Co-composting provides financial benefits of revenues of compost selling or savings from fertilizer purchase. The prevailing issue is not in the co-composting operation but the transportation of compost product. Mills address this transportation issue with scheduling the trucks; trucks transporting FFB from plantation will transporting compost to plantation.

Emission reduction is realized by the avoidance of the methane emissions that would have occurred during the anaerobic decay of POME and EFB in the absence of co-composting. Emission reduction of co-composting is estimated to be between 0.12 tCO_2e/tFFB to 0.2 tCO_2e/tFFB compared to baseline of practice to let EFB decay in piles. The potential emission reduction of co-composting is higher than the conventional EFB mulching that is 0.033 $tCO_2e/tFFB$. Leakage emissions possibly occurr from the use of fossil fuel for compost transporting truck and electricity production to run the co-composting equipment.

Co-composting provides additional environment co-benefits in the form of preservation of water and oil quality by the reduction of the final POME discharge into rivers or plantation. The displacement of chemical fertilizers by organic compost also offers a softer fertilization option, serve as soil condition, and avoids the risk of eutrophication of water. Palm oil sector is always exploring methods to minimize waste production and that includes exploring innovation in co-composting such as enabling optimum nutrient return to soil, more efficient production methods, or efficient compost distribution.

Summary

	Criteria	Score	Remark
1	Financial evaluation	Medium	Starting from USD 650,000
2	GHG reduction potential	Medium	Bulk GHG saving to be evaluated based on replacement of inorganic fertilizer and fossil fuel combustion for transportation of compost product.
3	Technical and operational challenge	Low	Does not require highly skilled workers
4	Environment and Social co-benefits	Medium	Organic fertilizer can be produced, minimizing POME discharge
5	Replicability	High	Technically applicable in almost all mills

Solid-Liquid Separation

Solid-liquid separation plays important role in separation of solid particles and liquid in the industry. The technology for carrying out this process is often referred as 'mechanical separation' because the separation is accomplished by physical means. Chemical or thermal pre-treatment is used to enhance the separation process. Chemical separation uses coagulation and flocculation to increase of the effective particle size, higher settling or floation rates, higher permeability of filtration cakes, or better particle retention (Table 22). Coagulation pre-treatment adds inorganic chemicals such as hydrolysis coagulants like alum or ferric salts, or lime, to enable agglomeration forming up to 1 mm size of particle. Flocculation uses flocculating agent, usually in the form of natural or synthetic polyelectrolytes of high molecular weight into giant flocculants up to 10 mm in size (Svarovsky, 2000). Solid liquid separation is separated into two main types which are sedimentation and filtration.

Table 22. Types of solid-liquid separation

Process	Force Field	Equipment
Sedimentation	Gravitation	Clarifying thickener
	Centrifugal	Hydrocyclone, Solid bowl centrifuge
Filtration	Gravitation	Dewatering screens, Deep bed filters
	Different pressure	Pressure filters, Vacuum filters, Hyperbar filter

	Centrifugal	Pressure centrifuge, Vacuum centrifuge, Hyperbar centrifuge

Source (Wagner, 2016)

Alternative Methods of Solid Liquid Filtration

IOI Palm Oil Group has adopted the application of greentubes to remove solids in POME to reduce BOD level. The BOD level of its POME is within the acceptable limit as required by the Department of Environment of Malaysia Government, with the lowest BOD level recorded of 23 ppm in 2015.

Common practice of POME treatment requires large space for open lagoon and emits methane emissions to the atmosphere. Methane recovery can offer a means for mills to lower these GHG impacts, but investment and financing constraints, distance from the national grid, or limited on-site power demands present substantial challenges. Alternative technologies such as **solid filtrate separation** may offer a viable alternative for treating effluent (Figure 23, Table 23). This approach removes suspended solids (organic material) as cake to be repurposed as organic fertilizer and treated water is channeled to existing open ponds. This process improves efficiency of mill's wastewater treatment as the remaining effluent does not requiring desilting procedures and has lower levels of COD and BOD, thus lowering methane release to the atmosphere. Furthermore, with additional system upgrades and additional filtration and separation systems, it is possible to process the filtrate enough so that the remaining water can be used for the boiler, the cleaning process, and be discharged to a water body -- meaning zero waste.

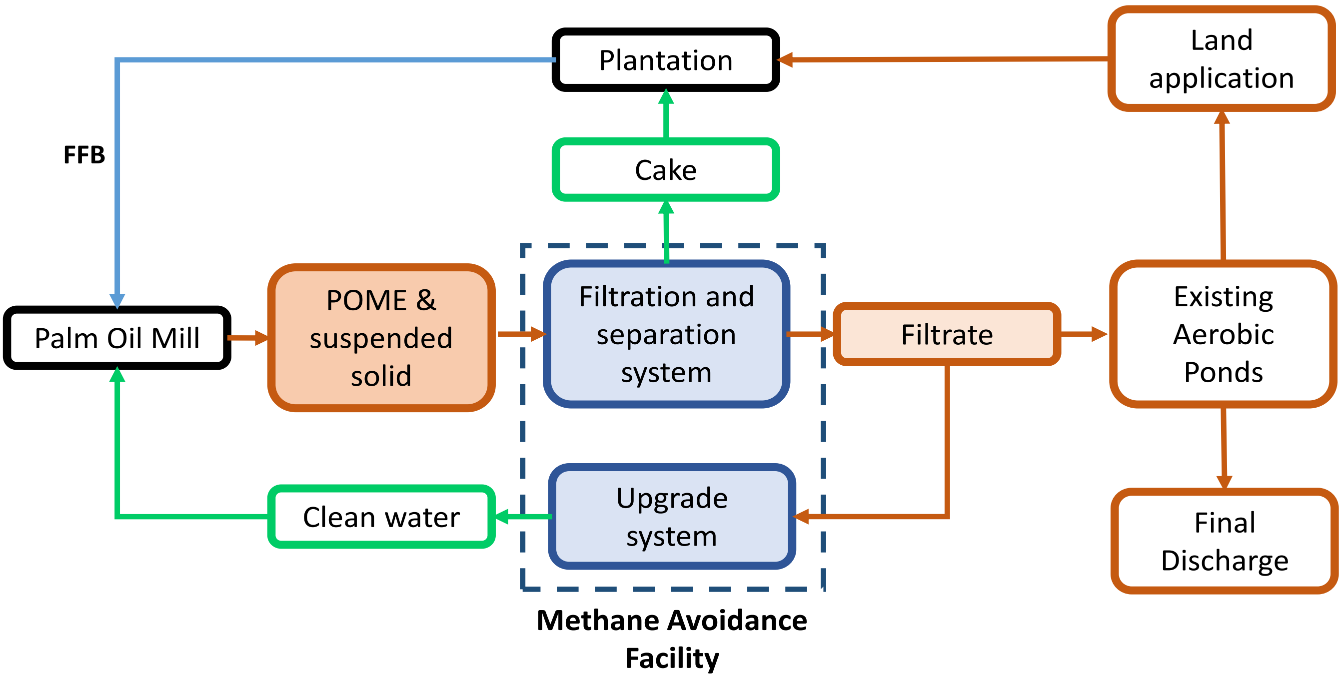

Figure 23. Schematic Diagram of Solid Filtrate Separation Facility applying the solid filtrate and separation system

While the solid and filtrate separation system has the potential to lower emissions and increase efficiency, effectiveness varies across the different technological options (Table 23). In addition, unlike methane capture technologies and facilities that benefit from a wealth of data on GHG reduction potential, the reduction of methane emissions associated with of sludge filtrate separation has received little attention. One study assessing the GHG reduction of sludge separation using the filter belt press method (see below for details) reported potential reduction of 130 kgCO_2e/t CPO (Eström, 2017).

Table 23. Solid Filtrate Separation Systems

Technology	Description	Investment, maintenance costs	Removal efficiency or Potential GHG reduction
Filtration and evaporation[a]	System separates raw sludge into oil, solids, and water. Evaporation provides zero effluent discharge to mill.	Investment: USD 30,000 – USD 50,000 per set evaporator Maintenance cost: USD460 to USD570/month	About 70% reduction potential in COD and BOD.
Membrane filtration[b]	Filtrate wastewater into reusable water to use within mill	Investment: USD 250,000 for 100 GPM capacity* Maintenance cost: unknown	About 99% removal in COD and BOD
Filter belt press[c]	System removes sludge from effluent water. Water can be used for cleaning	Investment : USD 160,000 Maintenance cost: unknown	50% GHG emission reducti on. 130 $kgCO_2e$/ ton CPO

Source: [a] Liew, et. al., 2017
[B] Samcotech, * Effluent production of a mill with capacity of 45 tph and effluent rate 0.6 m3/hour
[c] Eström, 2017

A further elaboration of the various technologies for solid and filtrate separation is offered below.

a. Filtration and evaporation

One technology provider offers a patented filtration and evaporation system that separates raw sludge into oil, solids, and water. The system, only compatible with 3-phase decanters, removes suspended solids as decanter cake which can be used as organic fertilizer. The resulting filtrate can be 1) discharged to effluent ponds for further treatment to meet BOD standards for discharge, 2) condensed, recovered and recycled for mill use, or 3) evaporated to provide mills with zero effluent discharge. Condensed water from the first evaporation column is pure and can be recycled back for boiler use without any treatment. An upgrade system of evaporation is most suitable for a company that aims for zero wastewater discharge.

As an example, to process 10 tons of filtrate, power requirements to run this system is 5.8 tons of steam, 320 kW for 60 tph mill capacity (including 2 decanters) for the filtration system, and 180 kW for evaporation system. This means a complete system of filtration and evaporation will require 500 kW. Consumable costs for chemicals (sodium hydroxide and nitric acid, or citric acids) are estimated to be MYR,000 to MYR 2,500 or USD460 to USD570 per month. Revenue can be generated from selling or recovering oil. The payback period is 2.5 – 3.5 years for the separation system only, and 5 – 6 years for a complete separation and evaporation system (Liew, et. al., 2017).

b. Filter Belt Press

The filter belt press system uses a device for chemically enhancing solid-liquid separation to separate effluent into a filtrate and a solid press cake. The separation process is achieved by passing the wastewater through a pair of filtering cloths on belts through a system of rollers. The system takes sludge, which has been pre-treated with flocculants, and separates them into cake and filtrate. The cake can be used as organic fertilizer, whereas filtrate water is discharged to existing aerobic ponds. This system was developed and initiated by KLK Berhad, a palm oil company group based in Malaysia. Investment costs of the filter belt press is about MYR 700,000 -- equivalent to USD160,000. Potential GHG reduction is measured and estimated to be about 50% of the baseline measure of open pond treatment. Detailed information about filter belt press is presented in the case study section of this report.

c. Membrane Filtration

Membrane filtration is a proven technology used across industries for water filtration or wastewater treatment. It is a physical separation process that uses a semipermeable membrane to remove suspended solids from a liquid stream. Membranes are thin and porous sheets of material able to separate contaminants from water when a driving force is applied. Membranes are made from synthetic organic polymers, organic materials such as ceramics or metals. It emerged as a viable means of water purification in 1960s. Implementation of membranes for water treatment has progressed using more advanced membranes made from new materials and employed in various configurations. This system can be fully automated without the need for highly skilled operators, offers benefits in time savings, and the reclaimed water can be used for operating purposes. However, high installation and maintenance costs have resulted in low adoption of this technology in palm oil sector (Azmi and Yunos, 2014).

The installation costs of the membrane system depends on wastewater character, flow rate, and materials used. A smaller high-end system for a power plant with a capacity of 100 to 200 GPM (Gallon per Minute) might be $450,000, whereas a commercial version might be $250,000 (Samcotech). Maintenance costs can be high, but pre-treatment to lower sludge and colloidal particles which can cause damage to the membrane can have a positive impact. A pilot project exploring membrane ultrafiltration using PKS-AC (Palm Kernel Shell-Activated Carbon) for pre-treatment reduced suspended solids by 71.26% and COD by 63.23%. Pre-treated POME was further treated using an ultrafiltration membrane technique, achieving total COD removal of about 99% (Azmi and Yunos, 2014).

Table 24. Typical industrial membrane system capital costs

Components	% of total investment
Pumps	30%
Replaceable membrane components	20%
Membrane modules	10%
Pipework, valves, framework	20%
Control system	15%
Other	5%

Source: Accepta.com (capital costs include automated cleaning activities)

Table 25. Typical operating costs of membrane filtration system

Components	% of total O&M Costs
Replaceable membrane components	35 – 50%
Cleaning	12 – 35%
Energy	15 – 20%
Labor	15 – 18%

Source: Accepta.com

Overall, these solid filtrate separation technologies offer mills compelling options for reducing their emissions from CPO production while enhancing overall production efficiency. While they offer benefits to companies of any size and location, they may represent a particularly enticing for mills with limited available land for open ponds, those located close to critical water bodies or local community, or those facing barriers with implementing methane capture systems. Considering the investment costs, the filter belt press may offer the most viable option for small and medium size companies.

In considering systems for effluent management, mills should consider the complete range of implementation and maintenance costs (summarized in the table below) as well as real cost savings each offer. The three solid filtrate separation systems explored here do not require highly skilled operators and mills can train their existing personnel to operate the system. These systems also offer a number of co-benefits, including:

- Production of cake as organic fertilizer
- Reduction of desilting procedures, hence lowering cost of open pond treatment
- Reduction of open pond load, increasing efficiency
- Cleaner air and less foul odor
- Reclaimed water can be used for production

Table 26. Comparison of Solid Filtrate Separation System

Solid Filtrate Separation System	Investment	COD Removal/ GHG Reduction Potential	Quality of water produced by the system
Filtration and Evaporation	High	High	Pure water
Filter Belt Press	Medium	Medium to high	Water for cleansing or channeled to open ponds
Membrane Filtration	High	High	Clean water

Summary

	Criteria	Score	Remark
1	Financial evaluation	Medium	Starting from USD 165,000. It is a lower investment when compared to methane capture.
2	GHG reduction potential	High	About 50% of the baseline or higher. Unfortunately, study or quantitative data on GHG reduction of this BMP are still limited at this moment.
3	Technical and operational challenge	Low	Does not require highly skilled workers

4	Environment and Social co-benefits	Medium	Decanter cake can be used for fertilizer, water can be recycled, and overall lower methane release
5	Replicability	High	Technically viable for any sized company

Emerging and potential technologies for palm oil sector

Biomass Waste Utilization

The palm oil milling process typically produces biomass waste in the form of empty fruit bunches (EFB), kernel shells, and fibers. Fibers and shells are usually used directly at the mill as combustion fuels to generate steam and electricity for the CPO production process. The mill's energy demand can be met with a biomass-fired power plant that uses shell and fiber as a fuel. The EFB which are less suitable for fuels than fibers and shells, have created problems for its disposal. To date, common practices of EFB include mulch and landfilling. Application of EFB as mulch can contribute to the GHG emission reduction as it may reduce the need of artificial fertilizers and improve soil organic matter. However, the practice can increase cost of labor and transportation (Wageningen UR,2013). Landfilling of EFB leads to methane emission as a result of anaerobic digestion process. These methods are wasteful and inefficient use of a potential energy source.

The utilization of biomass residues to create added-value products is an option to minimize and recycle the waste in palm oil mill. EFB, fiber, and kernel shells have a huge potential to be utilized as renewable energy resources in more useful forms such as **pallets and briquettes**. Furthermore, some studies have also identified the possibility of using EFB fiber as material for **pulp and paper production**. Table 27 shows the list of practical and proposed use of biomass waste in palm oil.

Table 27. List of practical and proposed use of biomass waste in palm oil mill

Biomass	Composition	Current or possible use	Remarks
EFB	cellulose, hemicellulose, and lignin	Mulch, fuel, pellet, EFB fiber, pulp and paper	EFB is less suitable as a fuel for mill
Fiber	Cellulose, lignin	Fuel for mill, fiber board	
Kernel Shells	-	Fuel for mill, briquette, activated carbon	Silicate forms scale when burned

Converting biomass waste into pellets or briquette will increase its energy content through the densification process. Densification is a process of compacting the biomass residue into uniform solid fuels that have higher density, energy content, and less moisture compared to its raw materials (Nasrin *et al.*,2008). Through this process, raw EFBs are converted into pulverized and fiber forms by using screw extrusion technology, rather than disposing them. The fibers will be then densified into briquettes or pellets which can be sold in the market. Pellets and briquettes are mostly used for cooking and heating. In developing countries, the use of these biomass products is mainly for household usage.

Finding the biomass source with the most competitive price is very important for the biomass pellet manufacturers. Gemco, a Malaysian technology provider for biomass pellet analyzed that with the relatively low investment cost (around 8 million USD for a plant with capacity 100,000 ton/hour) and payback period of 6 years, EFB pellets are very attractive for investors. The pellets produced in Malaysia or Indonesia can be shipped to East Asia and EU, where the market demand for biomass pellets has been established.

In Indonesia, the analysis of feasibility and economics of EFB pellets and briquettes has been examined as a cost effective approach to minimize palm oil waste and create value-added products. In 2016, a pilot project to utilize

EFB into briquette was conducted in PT. Perkebunan Nusantara Indonesia (state-owned oil palm plantation) in Dolok Sinumbah, North Sumatera. The study found that with the low briquetting cost of around 13,927 USD and payback period of 1.33 year, biomass briquette can be a great investment to be applied in Indonesia (Maitah *et al*. ,2016). In addition, the investment in briquette industry can be more enhanced with a support from the government on the pricing of biomass feedstock to assure the supply of raw material.

It is assumed that no GHG emissions arise from the application of solid waste from palm oil production, thus it does not lead to a significant GHG emission reduction. Leakage emissions might possibly occur from the use of fossil fuel for transportation and the use of machinery for densification process. Application of mulch and disposal to landfill also contribute to GHG emissions. Utilization of solid waste for energy production through pelleting or bracketing, and pulp and paper production is less GHG intensive when compared to other options such as pulp and paper production from timber. However, no quantitative data on GHG emissions or comparison are available.

Biomass utilization as pellets or briquettes is still facing many technical and operational challenges that may hinder wide implementation. To date, the development of biomass pellets and briquettes from palm oil process is mostly limited to pilot projects to prove the economic and technical feasibility. Therefore, the utilization has not been widely implemented and most palm oil mills are still focusing on using the biomass waste as combustion fuels for the CPO production process. From the technical side, lack of familiarity of the process and lack of expertise often make palm oil mills reluctant to apply the practice. Furthermore, the machinery used in the densification process often needs to be modified depending on the raw materials used. For example, the machinery that uses EFB and sawdust as feed will need binder and feeding part modified (Nasrin *et al*., 2008). In addition, since this is an emerging technology, the value chain and distribution channels are not well developed.

A large amount of biomass waste is produced during CPO production. Although some components are currently used for internal power production, it is common for EFBs to be inefficiently managed. Turning this waste product into an additional new commodity, such as palettes, briquettes, or even in pulp and paper manufacturing, has the potential not only to increase financial flows, reduce GHG emissions at the plant, but also serve as a sustainable and renewable energy and paper supply.

Increasing palm oil productivity and maximizing the use of the residues resulting from palm oil production both offer win-win options – reducing GHG emissions and potentially provide added value or economic benefits. Technologies discussed in this section have been applied in other sector, technically proven in multiple scales and commercial stage, yet haven't been explored by palm oil sector. Two technologies, biogas upgrading and advanced biofuel production; are presented here to give overview on the development, potential application, and identified barriers.

Summary

	Criteria	Score	Remark
1	Financial evaluation	Medium	Starting from USD 13,927 for briquetting plant
2	GHG reduction potential	Low to Medium	GHG reduction can be achieved from the landfilling or mulching avoidance. However, no quantitative data on GHG emissions or comparison are available
3	Technical and operational challenge	Low	Does not require highly skilled workers
4	Environment and Social co-benefits	Medium	Pallet or briquette products can be sold and add revenue to companies
5	Replicability	High	Technically viable for any sized company

Biogas Upgrading

Biogas has the potential to be used in place of fossil fuels by industry, transport, and households. Typical raw biogas consists of 50-65% methane (CH_4), 30-45% carbon dioxide (CO_2), traces of hydrogen sulfide (H_2S), fractions of water and other contaminant gases. Pre-treatment is required to remove water vapor and compounds such as H_2S and NH_3. After pre-treatment, biogas can be used as fuel in boiler and turbine or biogas engine for heat or power production with efficiency of <80% and 35%, and 39-42% respectively. Biogas upgrading is separating methane and carbon dioxide to get pure methane. Biomethane can be stored, transported, and used as replacement to natural gas for industrial uses; injected into gas grid, compressed and used as vehicle fuel (bio-CNG), or polished and liquefied to produce bio-LNG. In the form of biomethane, more than 90% of energy can be used. One cubic meter of methane has energy content equivalent to ten kWh (~9.97 kWh) (FNR,2009).

Biomethane injection into national gas grid or used as vehicle fuel has been practiced in Brazil, Netherlands, UK, and other European countries. Plants with capacity of 500 Nm^3/hour to 2000 Nm3/hour biogas are currently supplying biomethane to the grid in UK (European Biogas Association, 2018). A plant in Brazil processing food waste, grass cutting, and sewage was able to create 519 m^3/day of biogas (IEA Bioenergy, 2017). Applying an integrated water scrubbing and pressure swing absorption technology, biogas can be upgraded to biomethane (96-98%) for vehicle fuel with total volume 9,000 m^3/ month and also produces bio-fertilizer as a by-product. Switching from diesel to biomethane also reduces the need to buy fuel, thus adding an additional cost savings. About 11 number of biogas bottling projects of various capacities and technologies have been commissioned in India, upgrading raw biogas generated from cow dung and other organic matters into CNG quality (Min of New and RE of Gov of India). The projects developed under research and development program of MNRE of India Government, use the bottled biomethane for cooking and vehicle fuel purpose. The projects mentioned here are small scale, smaller than palm oil mill potential, but this demonstrates that biogas upgrading is applicable various scale, small to large ones. Palm oil mill with capacity of 45 tph could generate about 15,300 Nm^3/day biogas or 8,400 Nm^3/day methane gas[21].

Assessing biomethane potential in Malaysia, it is estimated that more than 500 kt per year of biomethane could be produced by palm oil mills if all POME is treated anaerobically. The study also identifies 135 – 227 biogas plants, evaluated based on location, technology, and capacity; could replace supply to 40-67% residential fossil gas demand

[21] Assumptions for calculation: 6,000 hours/year of mill operating hours, COD level 70,000 mg/l, 0.6 m^3 POME/ton FFB processed, 85% COD removal, biogas plant operating hours is 8,760 hours/year.

(Hoo, et. al., 2017). Biogas upgrading in palm oil industry in Thailand is estimated can produce approximately 44.91 million m^3 biomethane in 2012 and increase to 238.89 million m^3 in 2030 (Pattanapongchai and Limmeechokchai, 2011).

There are number of systems available in the market for biogas upgrading. Common systems are pressurized water scrubbing (PWS), catalytic absorption/ amine wash (CA), pressure swing absorption (PSA), membrane separation (MS), and cryogenic liquefaction (CL). In the last decade, 2001 to 2012, the number of large biogas upgrading plants has continued to expand (Figure 24). These various approaches have varying advantages and disadvantages (Table 28).

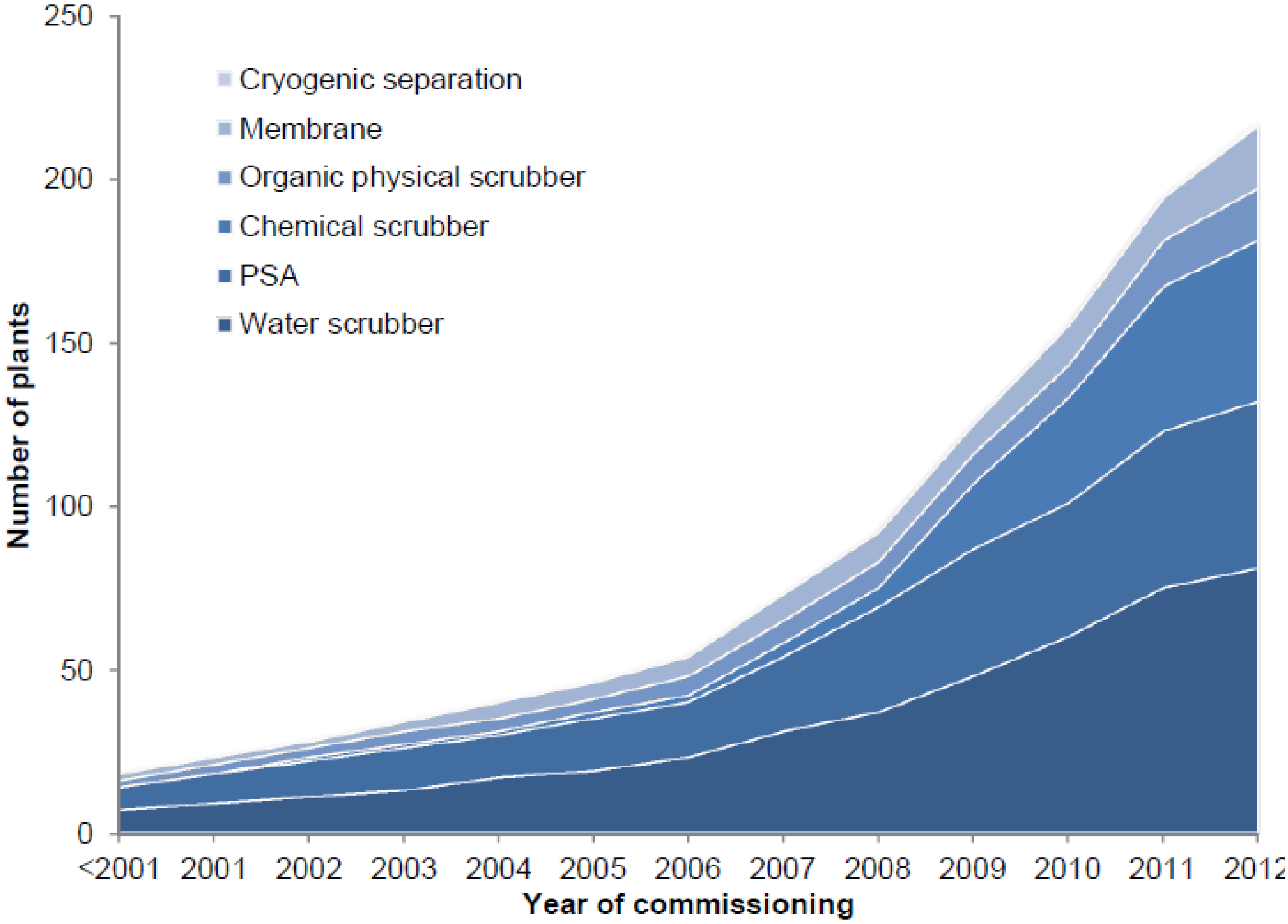

Figure 24. Biogas Upgrading System Population in 2001-2012 (Source: IEA Task 37)

Table 28. Biogas Upgrading Systems (Source: Lems and Dirkse (2015), SevernWay Energy Agency)

Parameter	System					Scale	
	PWS	CA	PSA	MS	CL	Large	Small
Gas quality	High	High	High	High	High	High	High
Gas quantity	High	High	Medium	Low	Medium	High	Low
Investment	Medium	Medium+	High	Low	High	Medium	Low
Maintenance	Medium	Medium	Medium+	Low	High	Medium	Low
Operation	Medium	Complex	Complex	Easy	Complex	Medium	Easy
Compact	Medium	Medium	No	Yes	No	Medium	Yes
Methane efficiency	High	High	Medium	Low	High	High	Low
Emissions	Low	Low	Medium	Medium	Low	Low	Medium

Waste streams	Continues	Continues+	Batch	Batch	Continues	Continues	Batch
Typical methane content	95-99%	>99%	95-99%	95-99%	95-99%	n/a	n/a
Methane recovery	98%	99.96	98%	80-99.5%	96%	n/a	n/a
Electric energy demand (kWh/m^3 biomethane)	0.46	0.27	0.46	0.25-0.43	0.49-0.67	n/a	n/a
Typical investment costs (€/(m^3/h) biomethane - 100 m^3/h - 250 m^3/h - 500 m^3/h	10,100 5,500 3,500	9,500 5,000 3,500	10,400 5,400 3,700	7,600 4,900 3,700	9,500 5,000 3,500	n/a	n/a
Typical operational costs - 100 m^3/h - 250 m^3/h - 500 m^3/h	14.0 10.3 9.1	14.4 12.0 11.2	12.8 10.1 9.2	15.8 11.6 10.1	13.8 10.2 9.0	n/a	n/a
Consumables demand	Antifouling agent, drying agent	Amine solution (hazardous corrosive)	Activated carbon (non-hazardous)	n/a	Organic solvent (non-hazardous)	n/a	n/a

Referring to previous estimation of a 45 tph of FFB capacity mill, generating biomethane of 8,400 Nm3/day, capital expenditure for biogas upgrading plant may range between USD 1.3 to 1.8 million. Upgrading biogas into biomethane for grid injection might be challenging for the palm oil sector since most of mills are located in remote area or distance from the national piping grid. Biomethane use for vehicle fuel is plausible for palm oil sector. Biomethane can replace fossil fuel for trucks transporting FFB and CPO, with some vehicle modifications, thus reducing bulk GHG emissions of CPO production (see BMP on Fuel Use above). However, a concern regarding safety prevails due to hilly areas of palm oil plantations.

Biomethane competes with natural gas or other fuel, i.e. gasoline for vehicle, in the market. To promote biomethane uptake, infrastructure and policy supports are required in countries where fossil fuels are mostly used for energy production. A subsidy could also enable the commercial use of biomethane. A study investigating upgrading biogas plant with CHP technology in palm oil for electricity generation in Thailand from 2012 to 2019 found that a subsidy of 0.3 baht/kWh (less than USD0.001) is needed to make biomethane competitive to other electricity generation technologies (Pattanapongchai and Limmeechokchai, 2011). Biomethane delivered to natural grid in Latvia is approximately 19% more expensive than the natural gas, yet has been shown to be competitive with a minimum subsidy of 22 EUR/MWh or 7 EUR/MWh lower for larger plants (Paturska, et. al., 2015).

Despite multiple biogas upgrading system providers in the market, biogas upgrading is considered new system in palm oil sector. Biogas upgrading system providers work with palm oil companies to carry out pilot projects to demonstrate viability for the sector. For example, Xebec and Sirim are working with a palm oil mill in Malaysia to run a pilot biogas upgrading plant, a hybrid of PSA and membrane systems, producing purified gas equal to CNG quality natural gas to fuel palm oil company's vehicles. A commercial plant of BioCNG has been launched in Felda Palm Oil Mill Sg. Tengi, Selangor Malaysia. The plant, costing around MYR 7 million (USD$1.76 million), processes 600 m3/hour of raw biogas from methane capture to produce 400 m3/hour bioCNG with methane content >94%. BioCNG is sent to factories, about 45 km away from the plant, by CNG trailers to replace LNG fuel consumption. The plant is a strategic venture between Malaysia Palm Oil Board (MPOB), Felda Industries Sdn Bhd, and Sime Darby Offshore Engineering Sdn Bhd. Similar to methane capture, it is expected that successful projects could motivate palm oil companies to adopt the system. biomethane is best transported in a compressed state up to 200 km distance, whereas transport in the liquefied state can be an option for longer distance.

Summary

No	Criteria	Score	Remark
1	Financial evaluation	High	Investment cost USD 1.3 to USD 1.8 for a biogas upgrading plant
2	GHG reduction potential	High	Potentially reduce about 50% of mill's emission. Reduction can also be achieved from the fossil fuel replacement of vehicles in plantation
3	Technical and operational challenge	Medium	Mill personnel needs to be trained to operate the facility, Service contract with provider could ensure smooth operation.
4	Environment and Social co-benefits	High	Cleaner air, RE generation, fossil fuel replacement, supporting national target in GHG reduction.
5	Replicability	Medium	Technically replicable, yet utilization scenario and financing could be determining factors for small and medium company group.

Advanced Biofuel Production from Palm Oil Waste

Conventional biofuel, often referred as first-generation biofuel, can be produced from edible crops (e.g. sugarcane, corn, rapeseed, palm oil), oil-crop based biodiesel and straight vegetable oil, as well as biogas derived through anaerobic digestion, animal fats and used cooking oils. Biofuel production has started to shifting to utilize non-edible crops or dedicated energy crops and residues which also known as second-generation biofuel (Table 29).

Table 29. Feedstocks of Second Generation Biofuel (source: Eisentraut 2010)

Feedstock	Cultivation/ Sector	Plants
Dedicated energy crops	Short-rotation coppice	Poplar, willow, eucalyptus
	Perennial cultication	Miscanthus, switchgrass, reed canarygrass, grasses
Primary residues	Agriculture	Straw, stover
	Forestry and logging	Treetops, branches, stumps
Secondary residues	Crop processing	Coffee, rice, corn, cacao
	Sugar and 1st generation bioethanol production	Sugar cane, sweet sorghum, sugar beet
	Vegetable oil production	Canola, palm oil, jatropha
	Forestry processing	Sawdust, bark
Tertiary residues	Municipal solid waste	Palettes, furniture, demolition timber

Lignocelluloses biomass refers to higher plants, softwood, or hardwood and is mainly composed cellulose (35%-50%), hemicellulose (13-35%), lignin (10-35%), and extraneous materials (Karimi, 2015). The hydrolysis pathway to convert lignocellulosic materials to biofuel requires pre-treatment to breakdown the structure of cellulose and hemicellulose into fermented sugar mixtures (Figure 25). Pre-treatment can be carried out through physical, chemical and physicochemical, and biological processes. The chemical process could use enzymes, acid, or gas. Biological pretreatments use microorganism such as fungi, bacteria, and actinomycetes to degrade the cellulose (Figure 26). Biofuel yield depends on technology and feedstock type that is in the range of 75 to 300 litre per ton dry matter (Sims, et. al., 2010).

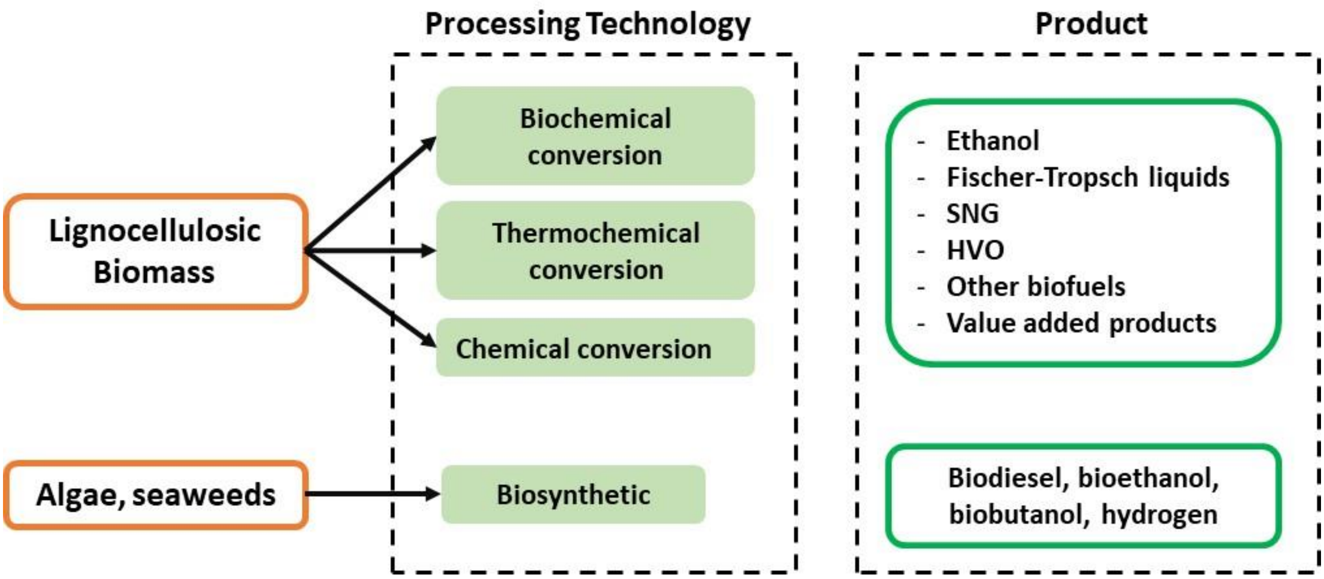

Figure 25. Principle pathways of advanced biofuels technologies

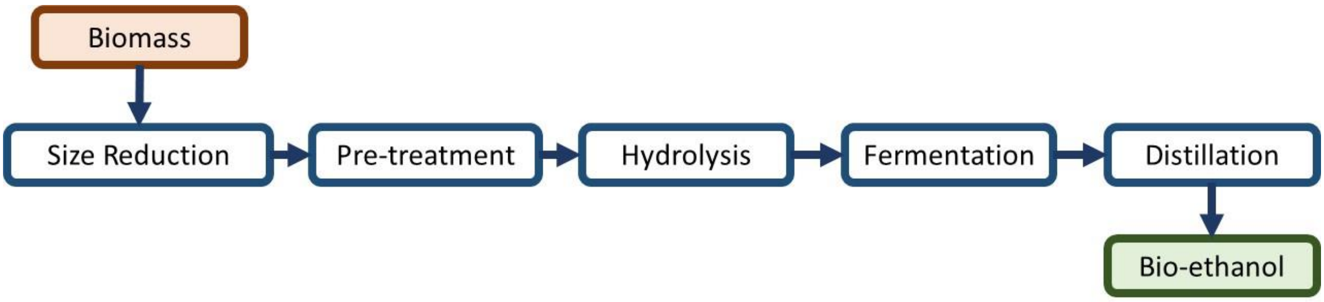

Figure 26. Processing steps in lignocellulose to bioethanol production

EFB contains cellulose (30-40%), hemicellulose (20-30%), and lignin (20-30%) (Li, et. al. 2013. Sic). Moisture content is around 70% due to biological growth and steam sterilization during CPO production at the mill. Assuming 0.2 ton EFB/ ton FFB and 30% dry matter, available dry EFB is estimated to be 0.06 ton dry EFB per ton FFB processed. EFB can be converted to methane after alkali pretreatment with 8% NaOH for 60 minutes and reach theoretical methane value 0f 97% (Carrillo et al., 2011). Research on EFB fermentation to sugar has been carried out using dilute acid, enzymatic, and the combination of two processes resulting in 45.3% to 82% fermentable sugar yield (Li et al., 2014). Theoretical conversion of sugar to ethanol is 3 to 1, however, actual conversion is 5-6 to 1. Sugar yield from EFB fermentations starts at 80-82% and may reach 90-95%. Aiming sugar yield above 90% is possible but the production costs could rise double or triple higher than the best costs scenario (Li et al. 2014).

Balancing yield optimization and cost efficiency is the challenge in designing a optimum conversion biogas plant. There will be a trade-off in reduced yield to achieve an efficient plant. Sourcing sufficient EFB supply for a commercial plant is critical factor. A biofuel plant with capacity of two million liter per year would require 15-20 mills running at full capacity of 90 to 60 ton per hours respectively. It is ideal to build biofuel plant within proximity of 100 km, thus finding a location in mill cluster can be challenging. Resource assessment or feasibility study for biofuel production from palm oil waste is ideally conducted in cluster or region based. Individual mill study might be conducted for pilot, demonstration, or small scale, yet commercial scale will require larger feedstock supply thus study must be extended to wider area. Furthermore, the feasibility of commercial scale will be highly influenced by national policy support. For instance, policy support in Brazil has been enabling it to be one of the world leading producers in biofuel production. Brazil implements 'Social Fuel' seal for more than 90% plants used for biofuel production and support downstream infrastructure; most stations in Brazil sell biodiesel and gasohol, flexible-fuel vehicles suitable to variable ethanol blends.

It is estimated that cellulosic ethanol from energy crops and agricultural residues can reduce GHG emissions by 80-130% compared to gasoline. Novozymes, the world's leading enzyme producer, established partnership with Beta Renewables (M&G) to launch commercial-scale cellulosic ethanol plants using enzymatic hydrolysis technology. Six commercial plants have been developed in Brazil, Italy, and the U.S. by Beta Renewables, Raizen, GranBio, Abengoa, Póet/DSM, and Dupont. In 2012, almost 120 advanced biofuel plants are planned, constructed, and operated; of which 35 or almost 30% are in commercial stage. (Bacovsky, et. al., 2013) (Table 30).

Table 30. Advanced biofuel plants in development in 2012 (Source: Bacovsky, et. al. (2013))

Technology	Commercial stage	All stages*	Total
Chemical	6	7	13
Thermochemical	14	23	37
Biochemical	15	54	69
Total	35	119	119

* all stages include demo, pilot and commercial plants

Summary

No	Criteria	Score	Remark
1	Financial evaluation	Medium to High	US$ 175,000 for a 1 TPD biodiesel plant
2	GHG reduction potential	High	Potentially reduce about 80% GHG emissions compared to gasoline
3	Technical and operational challenge	Medium	Mill personnel needs to be trained to operate the facility and process
4	Environment and Social co-benefits	High	RE generation, fossil fuel replacement
5	Replicability	Medium	Technically replicable, yet utilization scenario and financing could be determining factors for small and medium company group.

Case studies of Best Management Practices

Following initial research on best management practices, a list of priority BMPs was created. We then reached out to the specific palm oil companies which were implementing these priority BMPs and we invited them to participate in our study. Based on this, a shortlisted set of BMPs and companies were approved by RSPO ERWG. For each of the invited companies, we conducted additional desk research on the sustainability, BMPs, and GHG reduction initiatives being implemented by the company prior to our initial interview (Figure 27). An initial interview was then set up with the company to discuss BMPs implementation, general challenges and progress, and future development. After the interview, a detail questionnaire was sent to each company that agreed to participate (Table 31).

Figure 27. Case Study Methodology

Table 31. Information requested during interviews

Category	Questions
Motivation	• Why and how did the initiative start? • What were the key motivation factors? (certification, financial returns, CSR, etc.) • Who initiated and championed the initiative internally? • How was the decision made? What was the approval process? • What was the projected investment and anticipated challenges? • What technologies and practices were considered and how was the ultimate initiative selected?
Execution	• What was the process of carrying out the project? • What technical knowledge or capacity building was needed for the project? • How were the expected emission reductions estimated? • How was the project financed? • What were the final costs? • What were the main challenges in execution? And what were the solutions? • Who did you partner with for the work? What stakeholders did you need to engage? • Did specific policies help or hinder the project execution?
Results	• What was the operational impact to business? • What was the financial impact to business? • What were the emissions reductions and how did they compare to projected emissions reductions? • What are the plans for future development? • What were the costs and revenues? • What advice would you give others interested in implementing this practice? To what extent would others be able to implement this practice?

Data collection and information gathering were facilitated through this questionnaire and further followed up by an additional interview. Data compilation and analysis were then conducted to produce the case study and complete the report. Five palm oil companies have participated in the case study preparation. Two of these focus on BMPs implemented in oil palm plantations: 1) Golden Agri Resources' work in Indonesia on peat rehabilitation and community engagement to help prevent fires; and 2) Olam Palm Gabon's work in Gabon on implementing high carbon stock approaches. Three others focus on BMPs implemented in palm oil mills: 1) Wilmar International's methane capture facilities; 2) Sime Darby's co-composting of palm oil waste materials; and 3) Kuala Lumpur Kepong Berhad's filter belt-press systems. A summary of each case study is presented below while the detailed versions are found in the Annex.

Additional case studies were previously examined in 2013 to present best management practices of RSPO members in Colombia, Indonesia, and Malaysia (Box 3). Key lessons from previous report are (1) methane avoidance projects provide significant GHG reductions in production stage (mills), (2) co-benefits of economics and environment motivated voluntary GHG reduction initiatives, and (3) carbon credit revenues through Clean Development Mechanism was critical to investment decision.

Box 3. Overview of case studies previously completed for RSPO[22]

Production of palm pellet from EFB in Tawau, Sabah, Malaysia

QL Tawau Palm Pellet Sdn. Bhd is recycling empty fruit bunches into renewable fuel in the form of palm pellets. The project reduces emissions through 1) the avoidance of methane production from biomass that would have decayed under the anaerobic conditions of solid waste disposal sites and 2) the substitution of fossil fuels for palm pellet fuel. USD $4 million was invested to build a facility with a capacity of 25,000 MT palm pellet per year, and estimated to reduce emissions up to 30,000 tCO_2eq/ year.

EFB and POME Co-composting by Daabon at Santa Marta, Colombia

Daboon Group in Colombia has developed co-composting of EFB with POME at its mill in Colombia. The project is reducing emissions through 1) avoidance of methane production from decayed EFB in its solid waste disposal site and POME in anaerobic ponds, and 2) the substitution of chemical fertilizers. Daboon Group invested USD $800,000 for a co-composting facility with capacity of 1,700 ton/month. The project is estimated to recover all costs by year 9. Unfortunately, the case study does not include the estimated emissions reductions contributed by the project.

Methane recovery and utilization at PT. Musim Mas Palm Oil Mill in Pangkalan Lesung Riau, Indonesia

In 2010, Musim Mas' mill in Riau installed a methane recovery facility and converted biogas into electricity. With an investment of USD 2.7 million, the project has installed a capacity of 1.5 MWe and generates 10,000 MWh/ year of electricity, enabling the mill to reduce its dependency on fossil fuels. The project is estimated to reduce emissions by 55,798 tCO_2e/year through 1) avoidance of methane production from POME in open lagoon and 2) substitution of fossil fuel-based electricity. It contributes to the mill's carbon footprint reduction by about 65%. Considering savings from electricity and CER revenue, the investment was projected to have a payback period of less than four years.

FELDA Serting Hilir POME Biogas Power Plant Project at Negeri Sembilan, Malaysia

[22] Reducing Operational Emissions from Palm Oil Production – A compilation of case studies, Eco-Ideal Consulting Sdn. Bhd, RSPO, 2013.

Similar to the project in Musim Mas, Felda developed a methane capture facility and converted the produced biogas into electricity. The generated electricity is used on site (300 kW) and sold to the grid (500 kW). This project was developed in two stages: methane capture in 2008 and power generation system in 2010, with a total investment of USD $3.34 million. Considering savings from electricity and CER revenue, the investment was projected to have a payback period of 5 years.

Biomass-fired Boiler in Lahad Datu, Sabah, Malaysia

LDEO Energy Sdn. Bhd. is a refinery company producing edible oils. It developed a biomass steam and power plant with boiler capacity of 35 MT/hour and produced electricity of 81 MWh/year for refinery captive use. LDEO invested about USD $2.6 million and was projected to have a payback period of 8 years. The boiler combusts about 57,000 ton solid waste (EFB, Mesocarp Fiber, and Palm Kernel Shell) supplied by a nearby mill. Emission reductions are estimated to be approximately 40,000 tCO2eq/year, achieved through 1) the displacement of fossil fuels that used to generate steam, 2) the substitution of electricity from the local grid and a fossil fueled generator set, and 3) the avoidance of methane production from decaying EFB is solid waste disposal site.

An overview of each of the case studies examined is presented below. For each case study we looked at why the initiative was started, an overview of the technologies used, the GHG emissions expected, and any lessons learned. The full case studies can be found in the Annex.

Case study 1: Peat rehabilitation at PT. AMNL, Sinarmas

a. Why and how the initiative started

PT SMART Tbk, a subsidiary of Golden Agri Resources (GAR), established the oil palm plantation PT AMNL (Agro Lestari Mandiri) in 2009 with total area 19,000 hectares (ha). The plantation is situated in the Sub-District of Nanga Tayap, District of Ketapang, Province of West Kalimantan.

The peat rehabilitation project is within the PT AMNL property and covers about 2,600 ha of conservation area (mostly peat soil) that was affected by devastating fire occurrences during strong El Niño season in 2015. The primary motivation for implementing the peat rehabilitation was to reduce the risk of fires and the damages these fires cause in the concession and in local area. Another motivator was the Indonesian government's push to restore and protect peatlands.

There are two important elements of this project: biophysical restoration and local community involvement. These build upon the fire management work that PT AMNL already had in place. As part of GAR, PT AMNL already adheres to the zero burning policy discussed in the previous section and has emergency response team personnel and equipment ready in the event of a fire. The justification for the biophysical restoration of peatlands is that they are much less vulnerable to fires than degraded peatlands. Local community involvement is also important since many locals still engage in slash and burn agriculture which can lead to wildfires.

b. Technical description of the initiative and its impacts

As mentioned above, there are two key aspects of this project: biophysical restoration and local community engagement.

Biophysical restoration

The following steps were conducted to carry out the peatland restoration:

1) Determined the status/condition of the area for rehabilitation by carrying out conservation area and biodiversity surveys;
2) Engaged the community in the rehabilitation and conservation efforts;
3) Restored the hydrology of the peat area by controlling drainage canals and maintaining a high water table;
4) Selected important native species to restore as much species diversity as possible as well as the physical appearance of the forest stand.
5) Established nurseries to build the stock of plants for planting out in the area.
6) Collected seeds and seedlings of selected plants.

Community engagement

The development of community empowerment for fire prevention was designed to improve local awareness of peat fires. A pilot program Desa Siaga Api involving 17 villages prone to fires near the concession was launched in 2016, which focused on fire prevention. In this program, villagers were motivated to maintain fire free areas through rewards in the form of social infrastructure development aid. The program trained villagers and provided them with the proper equipment to prevent and combat fire. The villages also had direct access to GAR emergency response team and fire response equipment, and conduct join regular patrol. The program provided technical assistance to villagers on how to clear land without fire and worked with schools to raise awareness about forest conservation and how to prevent forest fires.

In 2017, Desa Siaga Api was followed by the broader program Desa Makmur Peduli Api which also included conservation and food security activities. In addition to the components of Desa Siaga Api, the villagers receive training on integrated ecological farming to improve local food security and allow them to sell excess produce.

c. Projected GHG emission reductions

For the peat restoration project in PT AMNL, baseline emissions and potential emissions reduction are still being developed by the appointed consultant. Even though the emissions estimates are not known yet, implementation of peat restoration project in PT. AMNL could lead to significant GHG emissions reduction from avoided peat decomposition and fires.

d. Lessons learned

This peat rehabilitation and community engagement project has been a labor intensive, high cost investment. As a result, smaller companies could likely not engage in a project of this scale. It is important to note, however, that a key factor of the success of this effort has been the involvement and collaboration of the different stakeholders including local communities and academics. Because local communities play an important role in helping to prevent wildfires, different aspects of the community engagement work, such as education on fire prevention, could be applicable to all companies with plantations to help prevent wildfires and maintain good relations between these communities and the company.

Case study 2: Carbon stock assessments in Gabon, Olam Group

a. Why and how the initiative started

Olam Palm Gabon was established in 2011 as a joint venture (JV) between the Olam Group and the government of the Republic of Gabon (60:40 share) to develop oil palm plantations in the country. When Olam Palm Gabon was initially established seven years ago, the primary focus of the design was to ensure compliance with RSPO and Olam's Palm Policy. However, from its beginning, it was also committed to protecting ecosystem integrity and biodiversity by not developing on primary forests and High Conservation Value forests.

Olam Palm Gabon has committed to be carbon neutral or net carbon positive over the first 25 years and to achieve its goal, the low carbon policies and sustainable growth strategies is implemented. In doing so, carbon stock assessments are included in the land use planning as one of the efforts to minimize carbon emissions from oil palm operation. Olam is the first company that was tested by the Technical Committee of HCS+ in Mouila plantation.

b. Technical description of the initiative and its impacts

To comply with its Palm Policy, Olam first conducted extensive data collection within proposed concession areas. These were used to inform the needed ESIA (Environmental and Social Impact Assessments) and HCV assessments. Olam's scientific team developed its own methodological approach to assess the current land cover and uses and, with this, identified any areas of intact, or high carbon stock forests. With this combination of studies, Olam Palm Gabon was able to determine the areas within the concessions which would be developed into oil palm plantations. In particular, in order to exclude high carbon stock forests, Olam only develops plantations on lands classified as savannah, scrub, woody pioneer vegetation or logged-over forest , all of which have lower carbon stocks.

c. Projected GHG emission reductions

Olam has estimated the net carbon balance of two of their plantations, Awala and Mouila Lot 1, using the RSPO GHG calculator. In 2017, the Awala plantation had a net carbon balance of -36,648 tCO2e or -5.64 tCO2e per hectare. In 2017, Mouila Lot 1 had a net carbon balance of -182,996 tCO2e or -11.52 tCO2e per hectare. All Olam sites achieve net sequestration over one palm cycle due to selective low carbon area and protection of large conservation areas for biodiversity and local traditional use.

d. Lessons learned

As part of the "HCS Science Study" commissioned by the signatories of the Sustainable Palm Oil Manifesto, Olam offered its plantations in Gabon to help assess the feasibility of applying the HCS+ methodology in a forest-rich nations such as Gabon.

In this study, one of the biggest challenges identified was applying thresholds to identify high carbon stock areas to exclude from plantation development. Olam Palm Gabon does not have a current carbon stock threshold to differentiate between high carbon stock areas and everything else, it only develops oil palm plantations on lands considered to be degraded such as scrub and logged-over forest. In contrast, the HCS+ methodology applies an aboveground biomass (AGB) carbon stock threshold of 75 t C ha-1 (i.e., no land with AGB carbon stock greater than 75 t C ha-1 can be developed). The study found that the application of the HCS+ threshold would significantly reduce the area of the development in the two concessions, and the application of the HCS Approach threshold (35 t of C ha -1) would reduce it even more.

Despite this challenge of identifying HCS thresholds, the study found that Olam's plantations are carbon positive when HCV and HCS areas are protected from development using Olam's current carbon stock assessment practice, since oil palm plantations capture more carbon than the previously degraded, low carbon land uses stored.

Case study 3: Methane Capture at Terusan Mill, Wilmar International

a. Why and how the initiative started

Terusan Palm Oil Mill is owned and operated by PPB Oil Palm Berhads, a subsidiary of Wilmar International Ltd (Wilmar). It has a processing capacity of 60 tons of FFB per hour. Wilmar has implemented various policies to ensure continuous improvements in the sustainability of its existing plantations and mills, including reductions in emission footprint, as well as transparent and clear reporting of verifiable operational data to identify GHG emissions within the supply chain.

Methane capture is part of Wilmar's strategic focus to reduce emissions in its palm oil production. By end of 2016, Wilmar had 17 operating methane capture plants, with 8 more under construction. Terusan Palm Oil Mill developed its methane capture facility, a Covered In-Ground Anaerobic Reactor (CIGAR), in 2015, and it became operational in 2016.

b. Technical description of the initiative and its impacts

Taking into consideration the site condition, soil type, and suitability of technology to Terusan mill, the Covered In-Ground Anaerobic Reactor (CIGAR) or membrane covered lagoon was selected for the site. The total area used for the methane capture facility is about 4 ha and located within Terusan mill's compound.

In Terusan mill's methane facility, POME generated by the mill goes to a cooling pond to lower the temperature before entering the methane recovery facility. At an average COD level of 38,900 ppm, the effluent treated in CIGAR system could generate 10,000 to 14,000 Nm3 biogas per day. Biogas is treated in the chiller and scrubber to remove the moisture and H2S. The biogas engine converts the biogas into electricity to supply the mill, which subsequently distributes to employee housing. Flaring equipment is fitted for gas flaring whenever there are is excess or unutilized biogas (e.g. during biogas engine maintenance). With COD removal efficiency at about 92%, the CIGAR system lowered the COD level from 38,900 ppm to 3,000 ppm. Treated effluent from the methane recovery is channeled to the existing aerobic ponds where effluent is further treated to meet BOD standards for land irrigation.

Methane capture & utilization has enabled the Terusan Mill to provide continuous electricity supply to more than 330 houses in the Terusan housing complex. Electricity generated from methane capture has displaced electricity generated from diesel generator by almost 70%. It has reduced biomass consumption as a fuel source for boiler-turbine system, thus making more biomass available for sale and providing an additional source of revenue. Fossil fuel savings and revenues from biomass sale could potentially provide the Terusan Mill with an additional monetary benefit of more than USD 120,000 per year.

c. Projected GHG emission reductions

Using the RSPO PalmGHG Calculator and 2016 data as the baseline, methane capture and biogas utilization for electricity contributes to an estimated methane reduction of 1,011 tCH4 or an equivalent of 28,308 tCO2e per year. As a result, it reduces the overall GHG emission footprint of CPO production in Terusan Mill.

d. Lessons learned

- During the planning phase, selecting the suitable methane capture technology will depend on the specific conditions of the site including the topography, soil type, availability of space, assessments on existing and future power consumptions, POME characteristic, and utilization scenario. Therefore, a thorough assessment of the site is key to ensuring the success of the project.
- Throughout the planning, construction, and operations phase, Terusan Mill faced challenges in procuring the necessary machinery and equipment within the estimated budget and transporting it to the site. Adequate, timely planning that anticipates these difficulties is imperative for the long-term success of the project.
- Another limitation was finding qualified contractors. The Wilmar Group worked with several contractors on the construction of their methane capture facilities, and avoided engaging with just one

major contractor for all projects to reduce construction risks. In terms of project management, the planning committee for the Terusan Mill engaged the same team of consultants and contractors assisting Wilmar on previous projects. Engaging one set of consultants and team of contractors on a long-term basis helps to mitigate the risk of project delays since the contractors are already familiar with Wilmar.

- To ensure that personnel have the required skill and capacity, Terusan Mill in particular and the Wilmar Group provide them training to operate the methane capture facility and biogas utilization plant.
- Methane within the biogas generated is a valuable fuel for electricity generation or other means of energy generation and significantly influences the economic viability of a project. Therefore, only excess biogas generated that cannot be fully utilized for electricity generation should be flared.
- Involvement and support of senior management of Wilmar Group is key to expediting project implementation.

Case study 4: Filter Belt Press, KLK Berhad

a. Why and how the initiative started

A major issue that all palm oil mills are faced with is how to manage their palm oil mill effluent (POME), the liquid waste produced from the processing of fresh fruit bunches. POME consists of 4-5% suspended and dissolved solids. The presence of these solids in the conventional open pond treatment system contributes to the production of methane. Furthermore, as these solids accumulate, the ponds begin to fill in and, therefore, dredging is required. Removing these solids from POME entering pond systems at palm oil mills can be burdensome as it requires a large area for dredging, and mill operations have to periodically shut down to perform the dredging. To address this issue in its mills, Kuala Lumpur Kepong Berhad (KLK) installed a Filter Belt-Press system to remove solids from the POME before it enters treatment ponds.

b. Technical description of the initiative and its impacts

The filter belt-press (FBP) is a device used to chemically enhance the separation of POME into a filtrate (i.e., wastewater) and a solid press cake (i.e., solid organic matter). The FBP system continuously removes solids from the pond system. By removing the solids, the formation of methane gas is reduced. The system enables the mill to reduce and better manage palm oil waste. The solid removed is converted into organic fertilizer that can then be applied to plantations. The water extracted from the system is also recycled for cleaning purpose.

Solid-liquid separation is obtained by passing filtering cloths and belts through a system of rollers. The system takes sludge, effluent or slurry as a feed and separates them into a filtrate and a solid press cake.

c. Projected GHG emission reductions

Beginning in 2016, KLK partnered with Neste, International Sustainability and Carbon Certification (ISCC) and IDH Sustainable Trade Initiative to estimate methane emission reductions from the use of FBP in palm oil mills. The study found that emissions from the pond receiving wastewater from a FBP system was 50% lower than emissions from a conventional open pond. The filter belt-press reduced the mill's daily emissions by 20.6 tonnes of CO2e. This is equivalent to a reduction of 0.13 kg of CO2e per 1 kg of CPO produced.

Methane emissions from the use of FBP in a given mill will depend on the amount of belt filter cake produced and the carbon content of this cake.

d. Lessons learned

The fact that the filter belt-press does have a relatively low cost, little additional power demand, and leads to high emission reductions indicates that this technology could be a good option for mills of any size with low limited financing options or no additional power demand.

Case study 5: Composting, Sime Darby

a. **Why and how the initiative started**

Sime Darby Plantations is currently implementing initiatives on methane avoidance through composting. Sime Darby is also implementing 11 methane capture and biogas projects, some of which are already operating and some of which are in still in development. Both of these initiatives were started by the Research and Development Department to help achieve zero discharge mills, although GHG emission reductions were also a primary driver. This case study focuses on co-composting.

b. **Technical description of the initiative and its impacts**

The composting system uses a combination of mechanical and biological methods to convert POME and EFB, boiler ash, and decanter cake into organic fertilizer. EFB is first shredded and then is mixed with boiler ash and decanter cake. The mixture is then stacked in 1.5 meters windrows, which are left to degrade naturally during a 6 to 7 week period. To ensure that the process in fully aerobic at all times, the windrows are sprayed daily with POME (where COD levels are approximately 50-55 kg COD/m3) and then turned every third day. The most important part of the process is turning and aerating which maintains the oxygen levels in the compost thus ensuring that aerobic decomposition takes place. The resulting compost produced from this process is transported to the oil palm plantations and applied as fertilizer in oil palm plantations.

c. **Projected GHG emission reductions**

In the composting process, methane emissions are reduced since a portion of POME is channeled to be applied to the EFB instead of going to the open anaerobic and aerobic ponds before being discharged in rivers. The ideal ratio of EFB:POME determines the amount of carbon emissions avoided. On average, Sime Darby Plantation was able to apply between 1-1.5 tonnes of POME for every ton of EFB which means 20-30% of POME produced at the mill was able to be used for the compost process instead of remaining in wastewater ponds.

As of 2015, Sime Darby's composting projects in Malaysia have successfully reduced carbon emission intensity by 6.5% when compared to the 2009 baseline. Carbon intensity gradually decreased from 1.06 tCO2e/mt CPO in 2009 to 1.02 tCO2e/mt CPO by 2015. On average, the 22 compost plants have been able to generate a reduction of approximately 200,000 MT of CO2e per year with average EFB:POME ratio of 1:1.5.

These estimates only consider GHG reductions from mill operations. It is important to mention that, while not quantified, further GHG reductions will occur in plantations since the application of this compost will lead to reduced application of chemical fertilizers

d. **Lessons learned**

Methane avoidance via composting is a medium to high cost investment depending on the technology and equipment used. The pre-requisite of turning and aeration can be done via simple machinery such as shovel and backhoe or with proper equipment such as a turner.

Typically 20% of POME utilization or at EFB:POME ratio of 1:1 is the comfortable level as a higher POME intake will affect the moisture content of the final product or prolong the processing time to greater than 100 days. The compost can be further enhanced by fortifying it with inorganic fertilizer that is pelletized for easy application and handling. In this way, the usage of inorganic fertilizer can be reduced and the application can be spread to larger areas.

Case study 6: SNV Indonesia work with palm oil smallholders

a. Why and how the initiative started

SNV has been working on household biodigesters since 2009 and has been assisting farmers in building more than 12,000 units of biogas reactors in Indonesia. Currently, communities use stoves fueled by woods or LPG for cooking. POME is a potentially abundant source of alternative energy, but most mills are located far from communities. SNV is currently working with palm oil smallholders in Muaro Jambi, Jambi Province, to promote the use of small POME biodigesters. Further, SNV is organizing trainings for 4,000 smallholders over 9 months about different best agricultural practices. In addition to the GHG reductions these practices could lead to, there could be a host of other benefits including improved soil and water quality and biodiversity. The construction of small POME biodigester and smallholders trainings are funded by MCA-I.

b. Technical description of the initiative and its impacts

The small biodigester is powered by POME and cow dung and built in the smallholders' communities located about 6 km from the mill where the POME is sourced. POME used in the biodigester is taken from third pond of the mill's open ponds, hence it contains minimal solids and grease. POME is transported using a truck with two 2,000 liter plastic tanks in alternate days to supply a feeding rate of 15 liter per m3. Nine local masons were trained by SNV to assist local communities in the construction and operation of digesters.

A cylindrical concrete dome digester of 50 m3 capacity was designed and installed with an investment cost of USD 5,500 per unit. Initial feeding was 30% cow dung and 70% was POME. Gas production started 10 days after the initial feeding with an average yield of 19.5 liters of biogas per liter POME. The biogas generated by the small POME digester is used for cooking purposes. Fifteen houses connect to the digester through pipelines and consume about 975 liters of biogas per day. On average, households use their stoves 3 hours per day. The slurry produced by digesters is used as liquid fertilizer for vegetable production, crop production, and palm tree growth. Slurry from cow and manure biodigesters is proven to be a good organic fertilizer for crop and vegetable, yet quality of fertilizer from POME and cow slurry is still unknown.

c. Projected GHG emission reductions

This is a pilot effort to evaluate whether biodigesters can sustainably meet the energy needs of smallholder communities. The use of these biodigesters will help reduce firewood and fossil fuel use by smallholders, thereby reducing GHG emissions. GHG reductions were estimated by SNV and will be provided on later stage. It needs to be evaluated if the RSPO PalmGHG calculator can be applied to this small-scale biodigester.

d. Lesson learned

Lesson learned from the pilot POME bio-digester construction:

- The mill was initially reluctant to supply POME for communities, whereas purchasing POME for biogas would make the digester less economically feasible. Partnering with local government and local organizations, SNV educated the mill owner on the benefit of POME utilization for biogas for local communities.
- Transporting POME regularly can be costly for local communities. SNV recommended that they transport POME using trucks that deliver EFB to mill and usually return empty.
- A business model, developed by a local committee, a private company, or a farmer cooperative, is required to ensure the sustainability of POME transport to local communities on a daily basis.
- Operating small biodigesters could be a potential business source for the mill with respect to national and local regulation on energy and electricity.

Comparison of practices

Each of the BMPs examined has some GHG emission reduction potential, however, the magnitude varies (Figure 28). Since the number of different BMPs that could be initiated is quite large, the main attributes of each BMP is summarized below (Figure 28, Figure 29, Appendix A). In addition, a decision tree for all mill BMPs (Appendix B) was developed that guides companies to help companies evaluate how to get started.

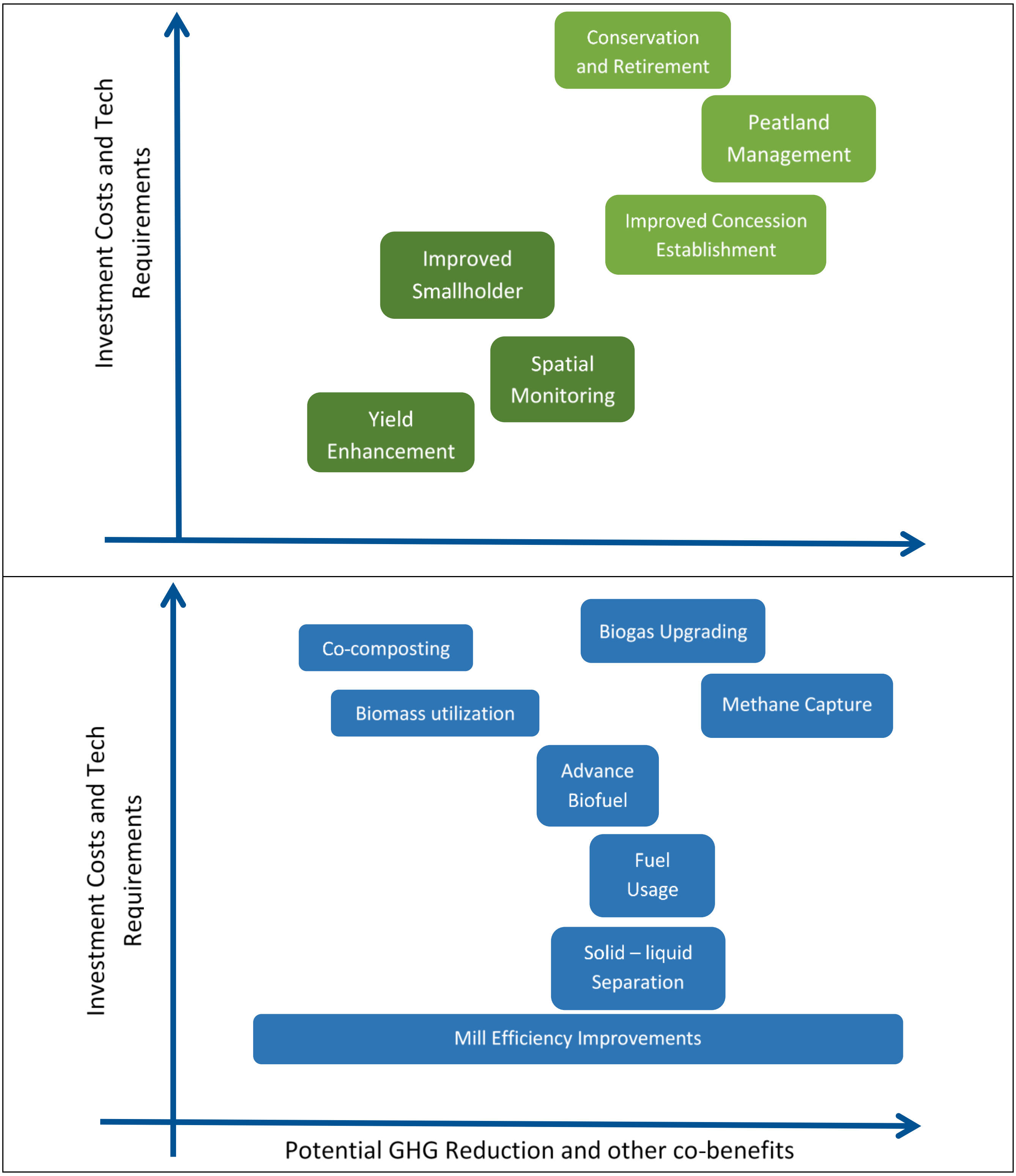

Figure 28. Comparison investment and technical requirements to potential GHG reduction and other co-benefits of the BMPs examined

	RESOURCE REQUIREMENTS	BENEFITS
Concession Establishment	H – Potentially high costs due to reduced area under production	H – High GHG emission reduction potential and co-benefits
Spatial Monitoring	M – Low cost, but technologies changing rapidly	M – Improved yields ► reduced PO product emission intensity
Yield Enhancement	L – Low investment cost	M – Improved yields ► reduced PO product emission intensity
Peatland management	H – Significant investment costs	H – Extremely large annual GHG emission reduction potential
Improved smallholder production	H – Significant investment costs	M – Improved yields ► reduced PO product emission intensity
Integrated Pest Management	L – Low investment cost	M – Improved yields ► reduced PO product emission intensity
Fuel Usage	H – High initial investment cost, rapid return	M – High GHG emission reduction potential
Improved concession management	H – Potentially high costs due to reduced area under production	H – High GHG emission reduction potential and co-benefits
Efficiency improvements	L – Low investment costs and low tech skills needed	V – GHG reductions dependent on technology
Methane Capture and POME-to-Biogas Electricity	H – High investment costs	H – Very high GHG reduction
Co-composting	H – High investment costs; only requires low tech skills	M – Replaces use of inorganic fertilizer
Solid Liquid Separation	L – Lower investment compared to methane	H – High GHG emission reduction potential
Biomass Waste Utilization	M – Medium investment cost, low technical skill	M – Products can be sold and add revenue for companies
Biogas Upgrading	H – High investment cost	H – High GHG emission reduction potential and fossil fuel replacement
Advanced Biofuel Production	M – Medium investment cost	H – High GHG emission reduction potential and fossil fuel replacement

H – High **M** – Medium **L** – Low **V** – Varies

Figure 29. Summary of main considerations for each BMP examined

For a number of BMPs at the plantation level, the GHG emissions on a per hectare level may not change significantly, but instead will result in improved yields per hectare, and thus improve the GHG efficiency of the PO produced. This includes various yield enhancement techniques such as pest management, fertilizer usage, improved smallholder production, and remote-sensing approaches to improve management. Although these BMPs do require capital investment, since overall yields are increased, the long term financial returns will likely be larger than the investments needed.

The other main category at the plantation stage was related to the design of plantation establishment and replanting. It has become increasingly common during the plantation design stage to conduct an analysis across the proposed concession to identify HCS, HCV, and peatland locations, and conserve those areas as natural ecosystems. In addition, during replanting, areas of low productivity, riparian buffers, and peatland areas can be restored instead of being replanted. These commitments will result in removing areas from existing or potential future production, however, and thus will have direct financial implications. Nonetheless, many companies have committed to policies that will result in the increased sustainability of palm oil production despite these policies' potentially negative impact on the companies' bottom line.

The action with the most significant GHG emission reduction potential for any palm oil plantations grown on peatlands would be to either retire the area, or improve the water table management to result in reduced annual emissions. It is recommended that additional piloting and research take place to identify the most cost-effective water table management technologies for installation across peatland areas and evaluate the impact on yields.

At the mill level, methane capture offers the highest emission reduction potential. Although the initial investments can be high, installation costs can be recouped relatively rapidly. Additional guidance is presented in Appendix B the steps to take to determine the feasibility of methane capture at a specified mill. The technology behind solid-liquid separation techniques has recently advanced beyond the pilot stage, and thus offers a very attractive option, especially in locations where the space for methane capture is less available. Co-composting and biomass utilization offer relatively cheaper investment cost with considerable environmental and social co-benefits. For example, pallet and briquette can be sold and serve as an additional source of revenue for the companies. Emerging technologies such as biogas upgrading and advance biofuel production can be the most appropriate option for companies focused on reducing fossil fuel consumption in plantation and mill. Similar to methane capture, these technologies require higher investment costs with more advance technical and operational capacity.

Concluding thoughts

When considering potential best management practices to reduce GHG emissions in its production process, each company needs to carefully evaluate the different options available. This report is designed to serve a resource for palm oil companies during this evaluation process by providing an overview of the different practices currently being implemented in the sector and a coarse assessment of their financial requirements and benefits, GHG reduction potential, technical and operational challenges, environmental and social co-benefits, and replicability. It is important to note that the exact costs, emission reductions, challenges, etc will depend on the particular circumstances where the BMPs will take place. Nonetheless, companies can use this report to focus their search on a selection of practices that are most likely to fit their needs. This in turn supports companies in meeting the RSPO principles and criteria and ultimately in helping to mitigate the threat of global climate change by reducing greenhouse gas emissions.

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Appendix A. Summary of Best Management Practices

Plantation Establishment and Management:

Criteria	Financial evaluation	Technical and operational challenge	GHG reduction potential	Environment and Social co-benefits	Replicability
Concession Establishment	H	M	H	H	H
	May result in significant areas not under production. Significant initial analysis costs	Technologies exist	If prevent intact forest conversion or peatland drainage, emissions reductions very high	Protection of biodiverse habitats and other ecosystem services	Recommended for all new concessions
Spatial Monitoring	L	M	M	M	H
	Variable. Using products such as Global Forest Watch have minimal costs. Use of aerial imagery will have medium level costs	Standardized approaches are still in development, however drone based technologies offer low cost potential	Improving productivity can reduce the GHG intensity of PO ; Fire prevention is significant reduction source	Reducing smoke from fires and preventing encroachment have extensive co-benefits	The use of products such as Global Forest Watch will allow all types of concessions to monitor forests and encroachment
Yield Enhancement	M	M	L	M	M-H
	Investment costs low, however, where additional fertilizer is required costs will increase	Significant research is required to identify improved seeds.	Increasing productivity reduces the GHG intensity of PO	Reducing fertilizer use has significant environmental co benefits	Most plantations have the potential to increase yield, thus any improvements to seeds or fertilizer management are widely replicable

Criteria	Financial evaluation	Technical and operational challenge	GHG reduction potential	Environment and Social co-benefits	Replicability
Peatland management	H	M-H	H	M	H
	Significant upfront investment required to install improved drainage systems	Research still required	Significant and permanent annual GHG emissions for all hectares	Reduced fire risk, increased fish biodiversity	Will be more cost effective for larger operations
Improved smallholder production	M	M	M	H	H
	High upfront cost to initiate financing scheme and coordinate with related stakeholders in the supply chain	Good knowledge of best agricultural practice is needed	Avoided land use change by smallholder/ intensification can lead to high GHG emission reduction	Avoided unsustainable practices, environmental risks, and danger for deforestation. Improve farmers' livelihood	Can be implemented by all scale of plantation.
Integrated Pest Management	L	L	L	M	H
	Low investment and maintenance costs	Yet it requires knowledge and skill to maintain the balance.	Relatively L when compared to total GHG emissions	Avoided adverse impacts of pesticide application, maintain natural ecosystem.	Can be implemented by all scale of plantation.
Fuel Usage	H	M	H	H	M
	Significant investment costs to install	Technicians must install; personnel will need training on use	Biofuel replaces fossil-fuel use in vehicle and machinery	Improved air quality	High investment costs may pose barriers
Improved concession management	H-M	M	M	H	H
	Removing areas from production, rewetting, and conservation	High fire risk may continue; Rewetting dams and protection	Rewetting or preventing drainage will	Improved water eco-services,	High costs, but highly preplicable

Criteria	Financial evaluation	Technical and operational challenge	GHG reduction potential	Environment and Social co-benefits	Replicability
	result in ongoing costs	will required ongoing costs	result in high GHG emissions	reduced fire risk	

Mill Management:

Criteria	Financial evaluation	Technical and operational challenge	GHG reduction potential	Environment and Social co-benefits	Replicability
Efficiency improvements	Low	Low	Low to high	Medium	High
	Low investment and maintenance costs	No additional skills needed	Highly depends on the utilization scenario. Biomass combustion generates negligible net GHG emissions, however GHG reduction can be significant when electricity is used to replace fossil-based electricity generation. Supplying electricity to grid can lead to GHG emission reduction beyond CPO production boundary.	Potentially provides excess energy or biomass for use elsewhere in production	Technically feasible for many mills
	High	Medium	High	High	Medium

Criteria	Financial evaluation	Technical and operational challenge	GHG reduction potential	Environment and Social co-benefits	Replicability
Methane Capture and POME-to-Biogas Electricity	Investment cost USD 1.5 to 2 million per MWe for methane capture and RE utilization	Mill personnel needs to be trained to operate the facility, Service contract with provider could ensure smooth operation.	Potentially reduce about 50% of mill's emission	Cleaner air, RE generation, improving access to electricity, supporting national target in GHG reduction.	Technically replicable, yet utilization scenario and financing could be determining factors for small and medium company group.
	Medium	Low	Medium	Medium	High
Co-composting	Starting from USD 650,000	Does not require highly skilled workers	Bulk GHG saving to be evaluated based on replacement of inorganic fertilizer and fossil fuel combustion for transportation of compost product.	Organic fertilizer can be produced, minimizing POME discharge	Technically applicable in almost all mills
	Medium	Low	High	Medium	High
Solid Liquid Separation	Starting from USD 165,000. It is a lower investment when compared to methane capture.	Does not require highly skilled workers	About 50% of the baseline or higher. Unfortunately, study or quantitative data on GHG reduction of this BMP are still limited at this moment.	Decanter cake can be used for fertilizer, water can be recycled, and overall lower methane release	Technically viable for any sized company
	Low	Low	Low - Medium	Medium	High

Criteria	Financial evaluation	Technical and operational challenge	GHG reduction potential	Environment and Social co-benefits	Replicability
Biomass Waste Utilization	Some investment costs, but creates sellable product	Does not require high skilled workers	Avoids landfilling, and replaces fossil fuel use	Provides renewable energy source	Technically viable for any sized company
Biogas Upgrading	High	High	High	Medium	Medium
	High investment costs	Training required for operations	Potentially reduces 50% of mill emissions	Provides renewable energy source	Technically replicable, but financing could be barrier to small companies
Advanced Biofuel Production	Medium	Medium	High	Medium	Medium
	Investment costs needed	Training required for operations	Potential to significantly reduce fossil fuel emissions	Provides renewable energy source	Technically replicable, but financing could be barrier to small companies

Appendix B. Guidance on evaluating appropriateness of mill BMPs

The range of BMPs that can be initiated are quite varied and require weighing priorities, determining the GHG emission target, availability of investment capital, current and future power demands, and other factors. To assist in these efforts, guidance has been developed in the form of a decision tree. This hopes to serve as a guideline for companies in deciding the best management practice (BMP) based on the companies' needs and resources in mill management. This decision tree covers BMPs that directly and indirectly reduce GHG emission in the mill.

The recommendation of BMP might not be the only options that companies can choose as there might be other external or internal factors that cannot be covered in the decision tree. However, it is hoped that this assists companies in thinking about what they want to prioritize, and what the goals are of implementing a given BMP.

Step 1: General information of your mill

Compile the important information needed to use the decision tree. This will be help companies to choose the appropriate BMP based on their resources.

Mill	
Parent company	
Capacity (FFB Ton/Hour)	
GHG emission reduction target (%)	
Investment capital (possible to raise, externally and internally)	
Power demand (Y/N)	
Space/area available to build BMP facility (ha)	
Time constraint? (Y/N)	
Intention to generate additional revenue (Y/N)	
Distance to existing national grid (km)	

Step 2: Electrical supply and demand assessment

In a palm oil mill, the new electricity generation needs to be synchronized with the existing electricity sources within the palm oil mill to meet the total electricity demand in the electricity network. The existing electricity sources in the palm oil mill normally include a biomass power plant and diesel generators. It is recommended that a mill take an electrical supply and demand assessment to understand the mill's current power status and gaps.

Step 3: Decision Tree

Follow the questions along in the below decision tree. Each question will lead to further inquiry about your mill and BMPs that can be applied according to your needs and resources. Each BMP circle is colored according to their potential to reduce GHG emission:

Orange: low potential
Green: medium potential
Blue: high potential

It is therefore important to match this with your current GHG emission reduction target as written in **Step 1**.

Detailed criteria and information of each BMP can be found in section 3 of this report. If you the decision tree recommends the installation of a POME Biogas Power Plant, please see **Step 4**. A similar feasibility analysis would need to take place for any BMPs a mill is considering initiating.

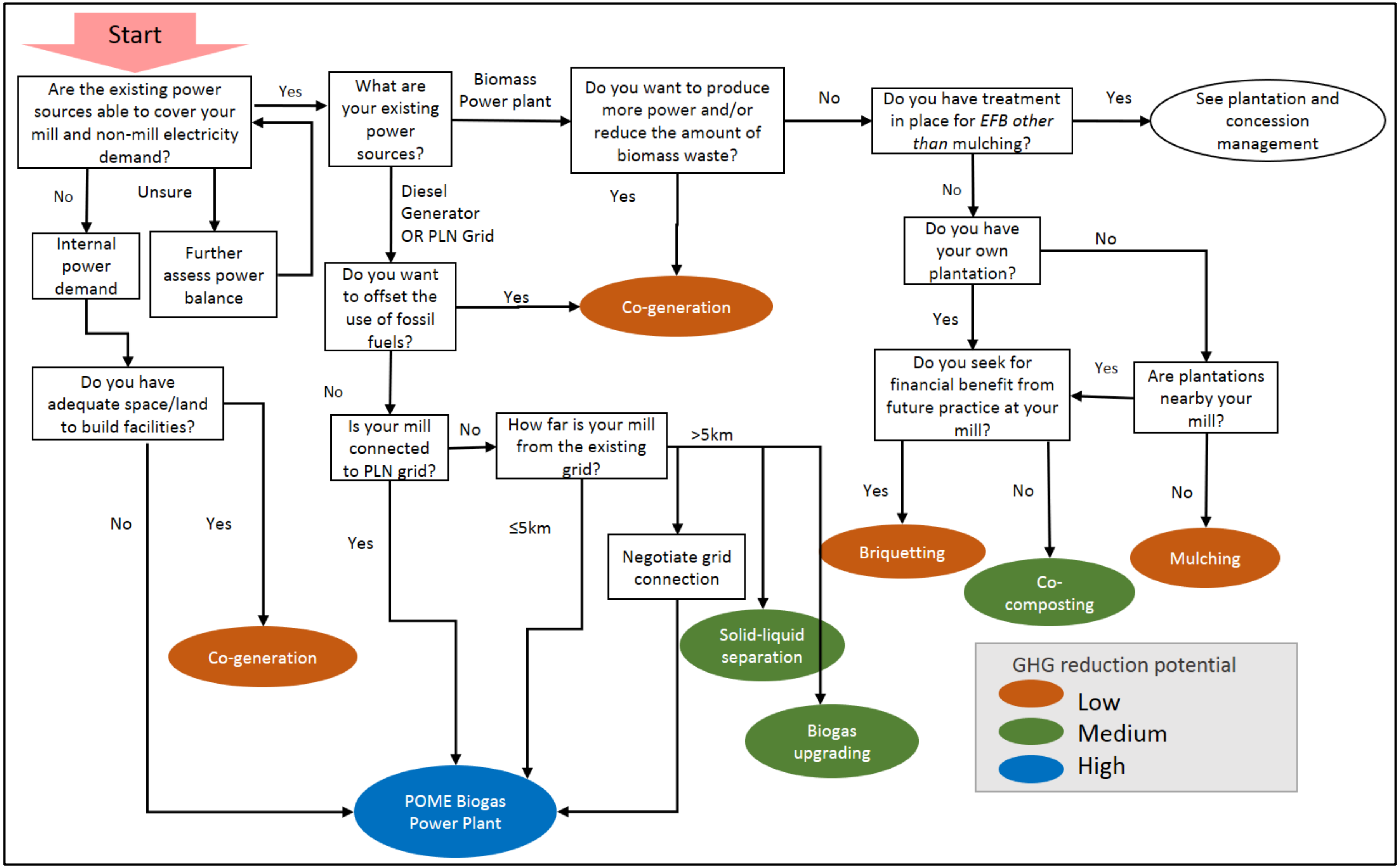

Figure 30. Decision tree to evaluate appropriateness of BMP

Step 4: POME Biogas: Analyzing your mill's potential

If you are considering installing a biogas plant in a palm oil mill, you will want to conduct a feasibility study to evaluate your mill's potential. To help get you started, below is the typical power potential estimate for each mill capacity (Table 32).

Table 32. Typical power potential based on mill capacity

Mill capacity (Ton FFB/Hour)	POME produced		Potential power (MWe)
	m3/ hour	m3/day	
30	21	400	1.1
45	31.5	600	1.6
60	42	800	2.1
90	63	1200	3.2

If you are considering installing a biogas plant in a palm oil mill, you will want to conduct a feasibility study to evaluate your mill's potential. Flowchart below outlines the recommended steps. With such a study, a company will be in position to have a strong understanding of the investment costs along with expected GHG and other co-benefits.

Desktop Analysis

- Technical Questionnaire
- Data Collection
  - Production Data
  - Power Monitoring
  - Diesel consumption
  - POME data (COD and flowrate)
  - POM Flow Chart
  - Detailed WWTP P&ID
  - Site Plant Drawing
  - Soil test analysis of biogass plant location
  - Rainfall Data
  - Topographical data
  - Water Consumption
- Output:
- Pre-feasiblity study site visit

Pre-feasibility Study

- Wastewater sampling using 'grab sampling' method
- Site survey: process and electrical
- Data Verification
- Output:
- Estimated power generation and in-depth feasibility study

In-depth Feasibility Study

- Wastewater sampling using 'compost sampling method'
- Site survey: process, electrical, civil, and mapping
- Data verfication
- Output:
  - Design basis
  - Estimated power generation, electricity sold to PLN and/or internal consumption and diesel saving
  - Conceptual process flow diagram
  - Conceptual biogas plant layout
  - Map of future electrical network and transmission line
  - Estimated CAPEX and OPEX
  - Bidding document

Annexes: Detailed Case Studies

Case study 1: Peat Rehabilitation Program and other Best Management Practices to Reduce GHG Emissions of Golden Agri Resources

Background

Golden Agri Resources (GAR) is one of the leading integrated palm oil plantation companies in the world with primary activities ranging from cultivating and harvesting oil palm trees, processing FFB into CPO and PK, refining CPO into industrial and consumer products such as cooking oil, margarine, biodiesel, as well as merchandising palm products. GAR has been listed in Indonesia Stock Exchange and Singapore Exchange since 1992 and 1999, respectively. 96% of GAR plantations are at a mature stage and located in Indonesia, dominantly in West Kalimantan, South Kalimantan, East Kalimantan, Central Kalimantan, Papua, Riau, South Sumatra, North Sumatra, Jambi, Lampung, Bangka and Belitung islands.

GAR Facts in 2016	
Cultivation area	488,252 ha in Indonesia
Estates	169 (79% nucleus, 21% plasma)
FFB yield	19.04 MT/ha
Number of mills	45 mills
Production	12.8 MT CPO and PK in 2016

As discussed in the Chairman's statement in GAR's 2016 Sustainability Report[23], its strategic focus is to "maintain its position as a leading sustainable palm oil producer by applying best agronomic practices." Its Social and Environmental Policy identifies its sustainability priorities which include four major areas: Environmental Management, Social and Community Engagement, Marketplace and Supply Chain, and Work Environment and Industrial Relations (Figure 31). It is also committed to helping meet the UN Sustainable Development Goals (SDGs). One of its key sustainability commitments is to report and reduce greenhouse gas emissions, although many of its other key commitments also help reduce emissions such as no development of and the conservation of HCS forests and peat land of any depth and develop strategies for long-term rehabilitation of peatlands.

Figure 31. GAR Social and Environmental Policy priority areas[24]

Comprehensive GHG emission reduction BMP Portfolio

GAR has implemented BMPs which reduce GHG emissions throughout the value chain process as discussed below and summarized in Table 33. It has integrated standards from RSPO, ISPO and ISCC into its practices. The implementation of BMPs in GAR is motivated by its commitment to sustainability. Unlike some other BMPs, assessing the economic feasibility of the activity is unnecessary as the initial financial investment of the

[23] GAR. "Delivering on Our Commitment. Realising sustainable policies in practices. Sustainability Report 2016" https://goldenagri.com.sg/pdfs/Sustainability/2016/golden-agri-resources-sr2016.pdf.

[24] https://goldenagri.com.sg/sustainability/

implemented BMP is not easily translated to financial returns. Instead, it is GAR's commitment as a sustainability leader that motivates the company to carry out these BMPs (Table 33).

Table 33. BMPs implemented by GAR that reduce GHG emissions[25]

BMP category	BMP
Plantation	Zero burning policy
	Zero new development on peatlands and conservation of peatlands
	High Conservation Value (HCV) and High Carbon Stock Approach (HSCA)
	Peatland restoration
	Fire prevention and community engagement
	More efficient fertilizer application
	Integrated pest management
	Continuous yield improvement
	Research in ways to reduce nitrous oxide (N_2O) emissions from nitrogen fertilizers application
Mill	Waste recycling and reuse
	Methane capture
Downstream	Reduce plastic packaging waste

Plantation BMPs

GAR adopted a commitment to no burning for new plantings, replantings, or any other development in 1997 as well as a commitment to no new development on peatlands regardless of depth in 2010. Following the adoption of the Forest Conservation Policy in 2011, GAR also has carried out High Conservation Value (HCV) and High Carbon Stock (HCS) assessments on all lands prior to development. As of 2016, 72,000 hectares were identified for conservation. As will be discussed in detail in this case study, GAR is also involved in a peatlands restoration project, which includes fire prevention and community engagement.

In addition, it has implemented a comprehensive mineral nutrition management system to minimize the quantity of fertilizers applied to reduce nutrient run-off and reduce the risk of soil degradation. Standard operating procedures (SOPs) in fertilizer application have been established with some adjustment to each plantation. Palm fronds and other organic products are applied in the plantation to increase the fixing capacity of soils.

An integrated pest management IPM approach is applied across its plantations by combining cultural, mechanical, biological and chemical methods to control pests while minimizing the economic, public health and environmental risks. GAR uses beneficial plants that attract parasitoids to control pests, pathogens or bacteria, and natural predators; supplemented with handpicking and mechanical traps. Barn owls are bred on estates to control the rat population; flora, beneficial plants and pheromones are used to control leaf-eating caterpillars and rhinoceros

[25] Each of these are discussed in detail in GAR's 2016 Sustainability Report. https://goldenagri.com.sg/pdfs/Sustainability/2016/golden-agri-resources-sr2016.pdf.

beetles. The costs of barn owls for biological control is estimated to be US$ 2 to 4 ha^{-1} yr^{-1} and the costs of small carnivores (e.g., wild cats) is US$ 1.6 ha^{-1} yr^{-1} respectively[26].

The Research and Development (R&D) division of GAR, SMARTRI, spearheads efforts to improve yields, thereby reducing the pressure to clear more land and the risk of soil degradation through oil palm cultivation. SMARTRI has been working on a conventional breeding and tissue culture program to selectively breed clones with 20-20% higher yield. This, in turn, reduces pressure on new land development without increased use of chemical pesticides and fertilisers.

SMARTRI has also started looking at nitrous oxide (N_2O) emissions from nitrogen fertilizers application. Field measurements and testing of new methods are performed in plantations to explore potential methods to reduce N_2O emissions. It is working on identifying the best quantity of biochar added to the beginning of EFB composting to minimize N_2O emissions.

Mill BMPs

Under GAR's Zero Waste Policy, solid and liquid waste from the CPO production process are reused, recovered and recycled for fuel and organic fertilizer. Fiber and shells are used for combustion fuel in boiler and turbine, EFB are processed in co-composting facilities for organic fertilizer, and 100% of the final treated POME is used for land application.

GAR has developed 7 methane capture facilities in Central Kalimantan, Jambi and Riau. Six facilities –Hanau, Sungai Rungau, Perdana, Sei Pelakar and Semilar mills- use covered lagoons, while the other two in Libo and Rama-Rama mills use tank digesters. The generated biogas is used as an alternative energy source, generating electricity for the mill's operation. The installation of methane capture facilities has reduced 40-55% operational GHG in those mills.

Downstream activities

Plastic packaging in the downstream activities can lead to waste and other environment impact. GAR has been reducing the material thickness or weight of the packaging material to maximize space when loading containers. The initiative has helped reduce almost 300 tons of plastic packaging waste in 2016. It led to lower costs, lower energy consumption and reduced carbon emissions, since plastic production and the incineration of plastic waste lead to emissions.

Conclusions

The range of best management practices that GAR is engaged in illustrates its commitment to reaching its sustainability goals and, in particular, the goal of reducing greenhouse gas emissions in its operations. Estimates of total reductions of GHG emissions from implementation of all these BMPs have not been calculated, reductions from certain activities have been calculated. For instance, seven methane capture facilities have been set of in GAR's palm oil mills leading to reduction of 40-55% of each mill's GHG emissions. GAR is also working on improving its measurement of GHG emissions from plantations.

In addition to GHG reductions, the BMPs mentioned above lead to a variety benefits for GAR as well as for society. These include improvements in biodiversity, improvements in local community livelihoods, fire risk reduction, improvements in soil conditions, substitution of fossil fuel use for renewable energy sources, among other benefits. Some of these BMPs, such as R&D on yield improvement and peatland restoration, require high investment without short or medium economic payback, and therefore are not easily replicable by small or medium-sized companies.

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[26] Caliman, J.P. (2017) Scientific Insights and development in sustainable palm oil production. European Palm Oil Conference 2017. https://www.palmoilandfood.eu/en/news/epoc-2017-european-food-industry-used-60-certified-sustainable-palm-oil

Other of these BMPs, however, have smaller upfront investment costs, such as more efficient fertilizer application and integrated pest management, are more accessible to any companies of any size.

The Initiative

PT SMART Tbk, a subsidiary of Golden Agri Resources (GAR), established the oil palm plantation PT AMNL (Agro Lestari Mandiri) in 2009 with total area 19,000 hectares (ha). The plantation is situated in the Sub-District of Nanga Tayap, District of Ketapang, Province of West Kalimantan. PT AMNL is a RSPO-certified oil palm plantation since March 31, 2011. This company conducted an HCV assessment in 2011 and received ISPO certification in 2015.

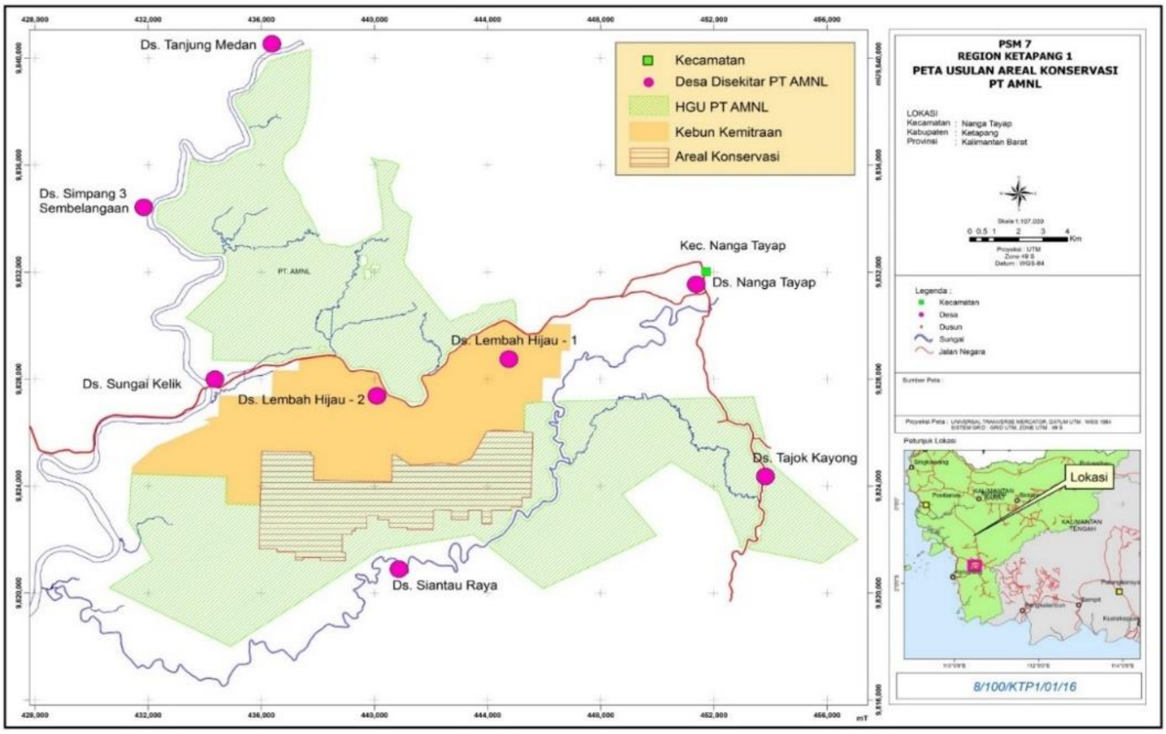


Figure 32. Map of Peat Habilitation Area in PT AMNL[27]

The peat rehabilitation project is within the PT AMNL property and covers about 2,600 ha of conservation area (mostly peat soil). that were affected by devastating fire occurrences during strong El Niño season in 2015.

The two key components of the project are peat restoration and community engagement for fire prevention. GAR is using ecological approaches to restore degraded peatlands including: determining the status and condition of the area to be rehabilitated; conducting hydrological restoration by constructing canal blocking and thus raising the water level of the surrounding area; and revegetating using selected native species. Since the project has started, 500 hectares (ha) have been established as a demonstration plot and will be expanded to 1000 ha. A restored patch of peatland will take 25 to 30 years to reach maturity, although it can never be completely restored to its natural state prior to conversion.

[27] Source: https://www.smart-tbk.com/en/berkelanjutan/konservasi-hutan/rehabilitasi-gambut/

Motivation

The primary motivation for implementing the peat rehabilitation program was to reduce the risk of fires and the damages these fires cause in the concession and in local area. This was spurred by the El Niño fires of 2015 which led major haze pollution causing respiratory illnesses and low visibility.

Figure 33. Fires and hotspots on PT AMNL's concession

Figure 33 shows the fires and hotspot areas on PT AMNL's concession area in 2015. Another motivator was the Indonesian government's push to restore and protect peatlands.

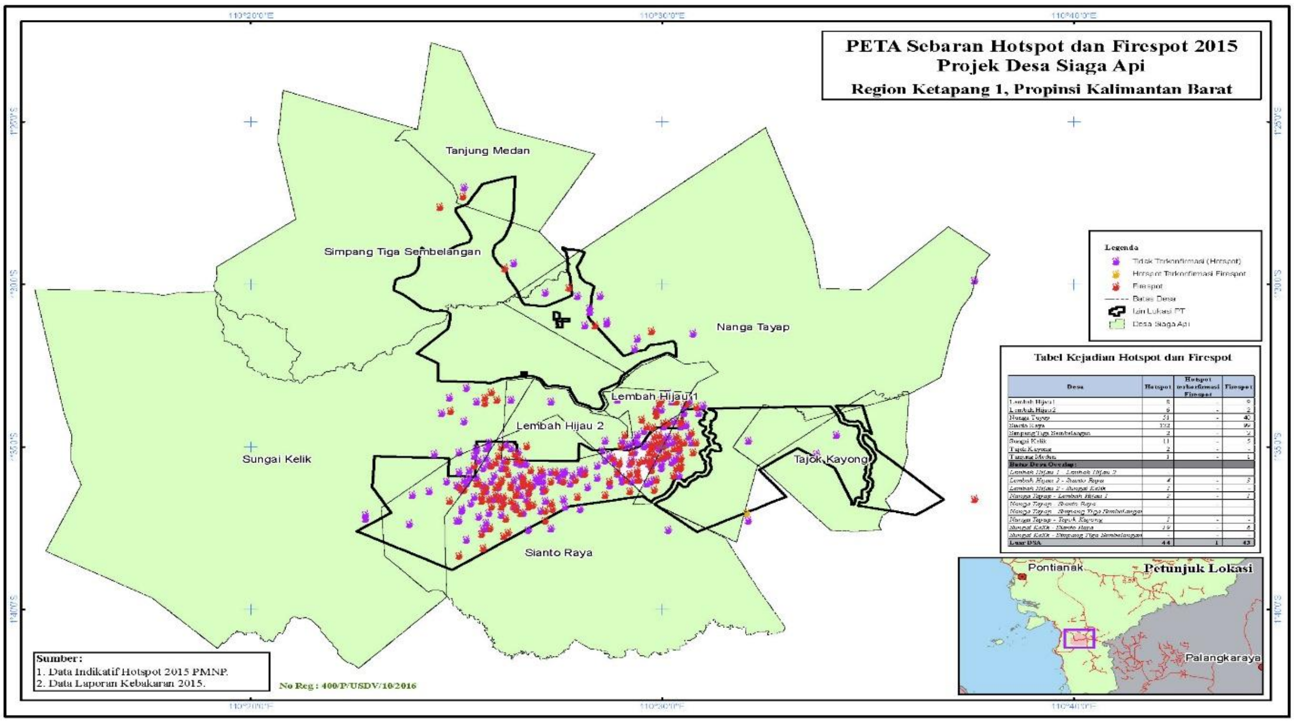


Figure 33. Fires and hotspots on PT AMNL's concession[28]

Project execution

GAR identified two important elements of peatland rehabilitation monitoring, as described below: biophysical restoration and local community involvement. These two elements build upon the fire management work that PT AMNL already have in place. As part of GAR, PT AMNL already adheres to the zero burning policy discussed in the previous section and has emergency response team personnel and equipment ready in the event of a fire. The justification for the biophysical restoration of peatlands is that they are much less vulnerable to fires than degraded peatlands. Local community involvement is also important since many locals still engage in slash and burn agriculture which can lead to wildfires.

Biophysical restoration

In order to gain local support for the project, PT SMART held a series of consultations with community leaders. As shown in Figure 34, the initial phase activities were peat mapping and conducting a biodiversity inventory to determine priority areas for rehabilitation. Based on the biodiversity inventory, more than 300 species of flora and 170 species of fauna were recorded in this area. The project also collaborated with a local institution, Tanjung Pura University, to conduct the inventory of the area.

The second phase involved hydrological restoration using the canal blocking strategy to raise the water level. GAR engaged with the environmental consultancy Malaysia Environmental Consultants (MEC) to determine the hydrological status using unmanned aerial vehicles (UAVs) (i.e, drones) of the 2000 ha of the project area. Restoring

[28] Source: http://www.eco-business.com/news/how-a-palm-oil-company-is-fighting-slash-and-burn-culture/

hydrological condition by increasing water table depth to at least 40 cm is required to prevent occurrence fires (Jaenicke et al. 2010)[29]. Therefore, GAR blocked the drainage canals to control the water level in the peatlands and prevent peat oxidation from drained ecosystem. Native species are being grown in a nursery, established by MEC, for revegetation which occurs after the hydrological restoration. The species that will emerge naturally in the restored area will tested in an area with new revegetated native species to see what thrives, then a mosaic of plant species will be gradually introduced across a wider area.

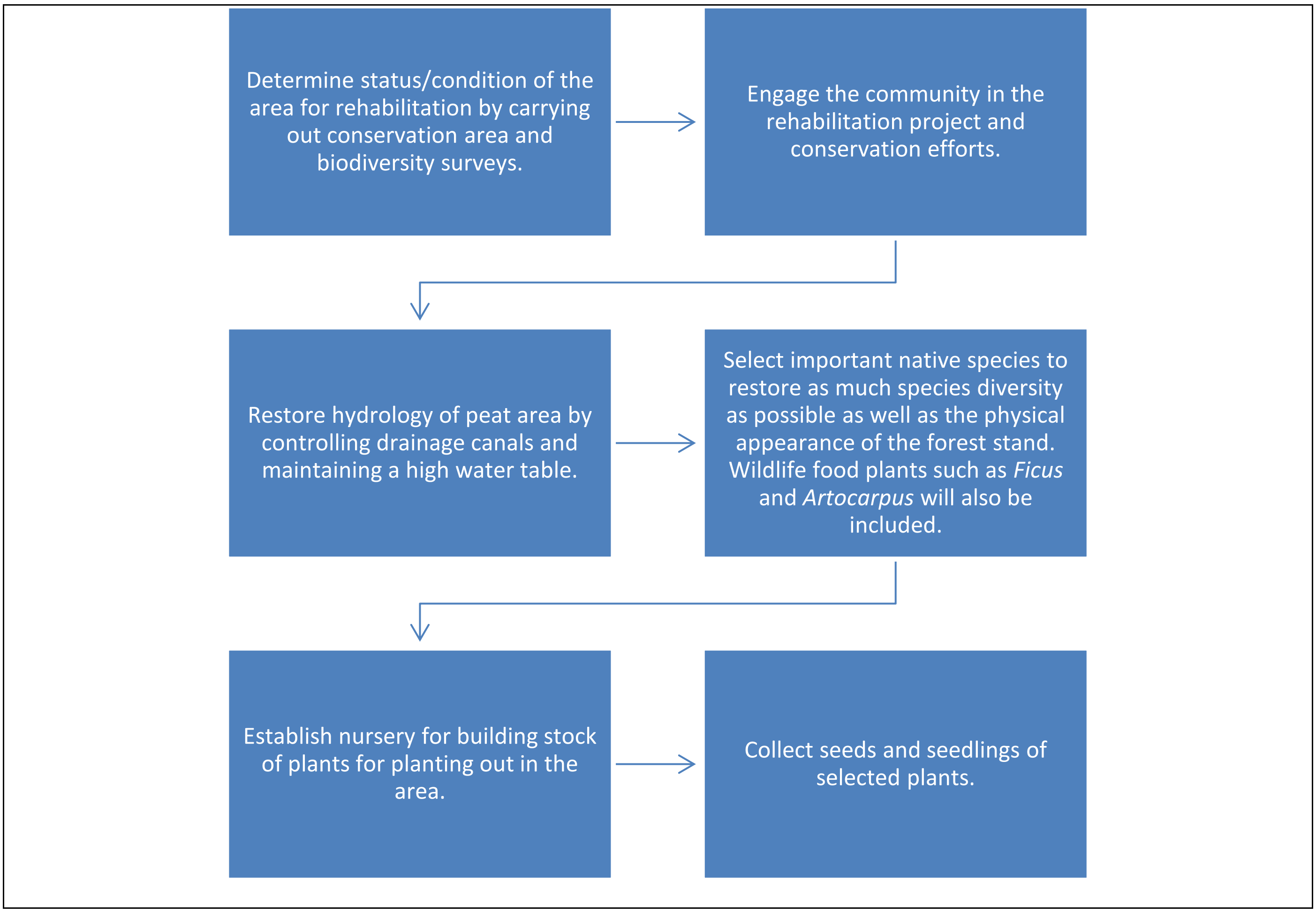


Figure 34. Stages in the biophysical restoration activity[30]

Community engagement on fire prevention

Education and community engagement are crucial to enable local people to understand the key issues and the benefits of the project for them. The three objectives of the project's community engagement efforts are fire prevention, conservation, and food security. The community engagement component of the project aims to establish a fire prevention program as well as to provide improved alternative livelihood opportunities for local people.

[29] Jaenicke, J., Wösten, H., Budiman, A., & Siegert, F. (2010). Planning hydrological restoration of peatlands in Indonesia to mitigate carbon dioxide emissions. Mitigation and Adaptation Strategies for Global Change, 15(3), 223-239.

[30] Modified from Golden Agri-Resources Ltd (GAR) and PT Sinar Mas Agro Resources and Technology Tbk (PT SMART Tbk). Peat Ecosystem Rehabilitation Project. https://goldenagri.com.sg/pdfs/Sustainability/GAR-Peat-Ecosystem-Rehabiliation-Project.pdf.

The development of community empowerment for fire prevention is designed to improve local awareness of peat fires. A pilot program Desa Siaga Api involving 17 villages prone to fires near the concession was launched in 2016, which focused on fire prevention. In 2017, Desa Siaga Api was followed by the broader program Desa Makmur Peduli Api which also included conservation and food security activities.

In the Desa Siaga Api program, villagers were motivated to maintain fire free areas through rewards in the form of social infrastructure development aid. The program trained villagers and provided them with the proper equipment to prevent and combat fire. The villages also had direct access to GAR emergency response team and fire response equipment, and conduct join regular patrol. The program provided technical assistance to villagers on how to clear land without fire and worked with schools to raise awareness about forest conservation and how to prevent forest fires. Because each participating village were fire free the following dry season, each was rewarded US$7,480[31]. This program was also supported by the local and regional government. Three out of 17 villages are established as national pilot model villages by the Coordinating Ministry for Economic Affairs.

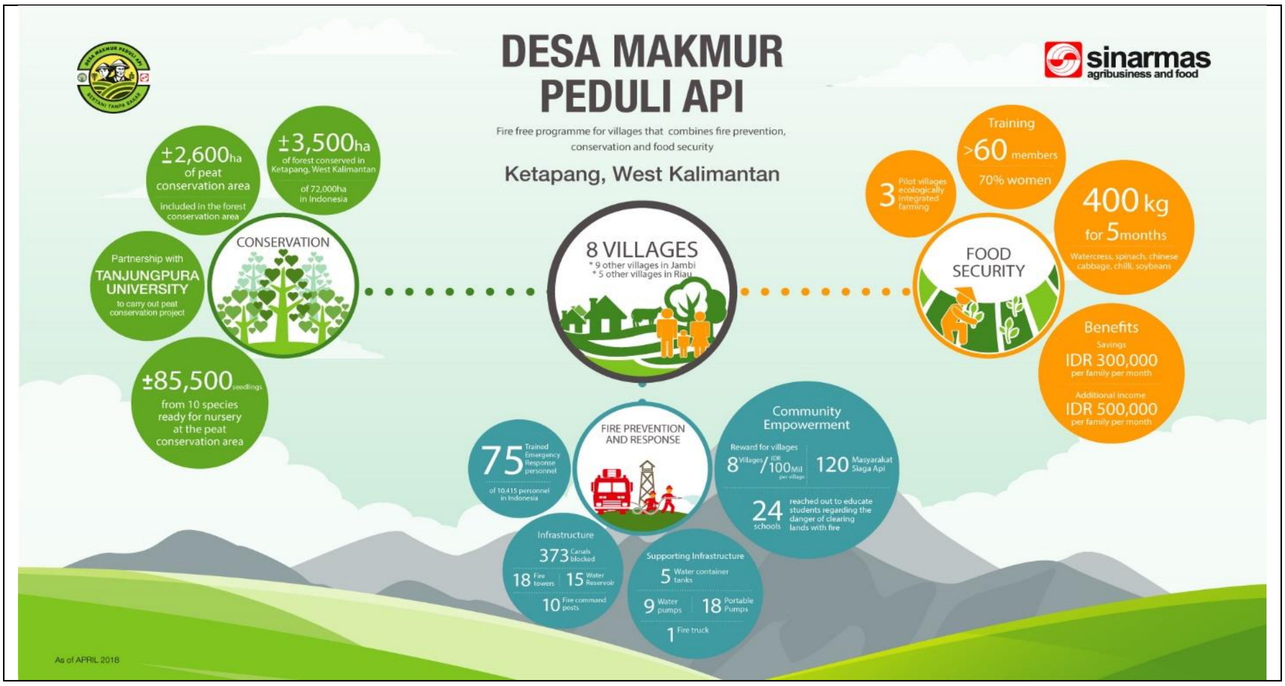
Figure 35. Fire prevention training for Desa Siaga Api personnel

In Desa Makmur Peduli Api, in addition to the components of Desa Siaga Api, the villagers receive training on integrated ecological farming to improve local food security and allow them to sell excess produce. As an example, as part of Desa Makmur Peduli Api, the Learning garden or Sekolah Lapangan implemented in Lembah Hijau 2 village is teaching villagers how to clear and cultivate land without burning it. This activity provides local farmers with expert knowledge on managing plant nurseries, shown how to make and apply organic fertilizer as a substitute to chemical fertilizers, how to cultivate food crops such as chilli, mustard and kale using sustainable farming techniques.

[31] http://www.eco-business.com/news/how-a-palm-oil-company-is-fighting-slash-and-burn-culture/

Figure 36. Farmers harvesting vegetables in learning garden

The different components of the Desa Makmur Peduli Api program in Ketapang, West Kalimantan[32] can be found in Figure 37.



[32] The program also exists in villages in Jambi and Riau

Figure 37. Desa Makmur Peduli Api program in Ketapang, West Kalimantan [33]

These community engagement programs have been deemed successful at reducing fire risks. In 2015, a year before Desa Siaga Api began, the number of hotspots and firespots were 423 and 217 respectively; in 2016, they fell to 25 hotspots and 7 firespots; in 2017, there were 13 hotspots and 9 firespots[34].

Resource requirements

Financial requirement

The total costs associated for the project were not available. For the revegetation portion (including nursery, planting, and maintenance), costs were between 500 to 550 USD per hectare. For each hectare restored, approximately 480 seedlings are grown. Of these 480, 400 seedlings are initially planted. Another 80 seedings were prepared, assuming a survival rate of 80% for the original 400 planted. The Indonesia Peat Restoration Agency (BRG) calculation estimates that peat restoration costs approximately USD 900 and USD 750 per hectare for hydrology restoration and revegetation program, respectively[35].

Technical expertise

Ecological and hydrological expertise is necessary to ensure success of the restoration project. Furthermore, to facilitate the community engagement aspect, expertise on fire prevention is also necessary.

Stakeholder involvement

Various stakeholders are involved in this restoration project. As discussed above, the involvement of local community stakeholders is pivotal to this project. They were consulted in the development of the restoration project and have been given training on fire prevention and organic farming, as well as financial rewards for their success in preventing fires.

GAR also engaged with the environmental experts to implement the restoration including the consultancy Malaysia Environmental Consultants (MEC) and Tanjungpura University. The consultancy South Pole Carbon is working on estimating the expected GHG emissions from the project.

Projected GHG emission reductions

Peat fires, included in land use change and forestry (LUCF) sector, is one of major contributors of GHG emissions in Indonesia. According to Indonesia's INDC[36], land use change and peat and forest fires account for 63% of the countries emissions of 400 $MtCO_2e$. Emissions from oil palm on peat is estimated to be between 18 to 73 $tCO2_e$/ha per year (Brinkmann Consultancy, 2009)[37], the largest contributor to GHG emissions in the CPO supply chain. Under

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[33] Yang, S (2018). PROSPEROUS FIRE FREE VILLAGE/DESA MAKMUR PERDULI API (DMPA): Partnership between Corporate and Community to prevent Fire and to develop Community Welfare. International Conference on Palm Oil and Environment, April 25th -27th 2018, Bali -Indonesia. https://icope-series.com/programme/conferences/

[34] https://www.prnewswire.com/news-releases/sinar-mas-agribusiness-and-food-expands-its-fire-prevention-programme-to-improve-community-welfare-300599315.html

[35] http://www.antaranews.com/en/news/103948/agency-to-restore-over-800-thousand-hectares-of-peatland-areas

[36] http://www4.unfccc.int/submissions/INDC/Published%20Documents/Indonesia/1/INDC_REPUBLIC%20OF%20INDONESIA.pdf

[37] Brinkmann Consultancy. (2009). Greenhouse gas emissions from palm oil production. Prepared for RSPO. http://rspo.org/sites/default/files/RSPO-GHG-WG-FinalReport-Nov09.pdf.

the business as usual scenario, emissions resulting from drainage and development of peatleads are expected to be 1.2 Gt CO_2e[38] by 2030[39].

For the peat restoration project in PT AMNL, baseline emissions and potential emissions reduction are still being developed by the appointed consultant. Even though the emissions estimates are not known yet, implementation of peat restoration project in PT. AMNL could lead to significant GHG emissions reduction from avoided peat decomposition and fires.

Other Impacts and Benefits

As discussed previously, the primary purpose of this peatland rehabilitation project was to reduce risk of fires and the haze pollution that the fires produce. A World Bank study found that the Indonesian economy lost more than US$16 billion due to the fires in 2015[40]. This project, therefore, to prevent fires could have significant, wide-reaching benefits.

Further, the rehabilitation of the peat ecosystem could have a variety of positive impacts include increasing local biodiversity, reducing the rate of soil subsidence, and improving soil structure. The community engagement element also benefits local communities by improving food security and additional income from the integrated ecological knowledge on plant varieties for own consumption and selling.

Lessons Learned

This peat rehabilitation and community engagement project has been a labor intensive, high cost investment. As a result, smaller companies could likely not engage in a project of this scale. It is important to note, however, that a key factor of the success of this effort has been the involvement and collaboration of the different stakeholders including local communities and academics. Because local communities play an important role in helping to prevent wildfires, different aspects of the community engagement work, such as education on fire prevention, could be applicable to all companies with plantations to help prevent wildfires and maintain good relations between these communities and the company. Local engagement is a long-term process. Community involvement will be most effective and sustainable through long-term collaboration, assistance and adequate knowledge sharing.

Acknowledgements

Winrock thanks Desti Hertanti and Gotz Martin of Golden Agri-Resources for reviewing and providing feedback on the report.

[38] 1 Gigatonne (Gt) = 1 billion tonnes

[39] Golden Agri-Resources Ltd (GAR) and PT Sinar Mas Agro Resources and Technology Tbk (PT SMART Tbk). Peat Ecosystem Rehabilitation Project. https://goldenagri.com.sg/pdfs/Sustainability/GAR-Peat-Ecosystem-Rehabiliation-Project.pdf.

[40] Ibid.

Case study 2: Improved Plantation Establishment through exclusion of High Carbon Stock Forests - Olam Palm Gabon

Background

Olam Palm Gabon was established in 2011 as a public-private partnership between the Olam Group and the government of the Republic of Gabon (60:40 share) to develop oil palm plantations in the country. Four new plantations located in Kango and Mouila were established and an existing plantation was acquired from SIAT located in Makouke in 2016. Olam and the government of Gabon worked together to identify potential concession locations that would meet Gabon's objectives while fulfilling Olam's Palm Policy Criteria. Olam planted 50,000 hectares of industrial plantations ending in 2017 (and an additional 6,000 ha of planted area in Makouke)[41]. RSPO certified the Kango plantation in August 2016, and the Mouila plantation was certified in December 2017[42]. These areas were converted from secondary, degraded or logged over forests and savannah ecosystems. In the next phase, smallholder plantation schemes will be developed[43].

Table 34. Olam Palm Gabon Facts

Olam Palm Gabon	
JV partners:	Olam Group: 60% Republic of Gabon: 40%
Land bank:	144,000 ha
Planted area:	56,000 ha (including plantations acquired in Makouke) by 2017
Location and acreage:	Awala: 6,822 ha; Mouila: 43,217 ha
Expected FFB yield:	Up to 24 MT/ha
Expected CPO yield:	5.2 MT/ha
Capital expenditure:	US$600 million

Figure 38. Olam Palm Gabon plantation lot

Since 2011, Olam Palm Gabon fully complied with the RSPO New Planting Procedure and complied to the High Conservation Value (HCV) Resource Network's quality control process from 2015. The company applied Free Prior

[41] Palm Quarterly Dashboard – April 2018: http://49tmko49h46b4e0czy3rlqaye1b.wpengine.netdna-cdn.com/wp-content/uploads/2018/05/PalmQuarterlyDashboard-_Apr2018.pdf

[42] http://olamgroup.com/news/olam-achieves-second-rspo-certification-palm-plantations-gabon/#_ftn2

[43] https://www.rspo.org/certification/new-planting-procedures/public-consultations/sotrader-societe-gabonaise-de-transformation-agricol

and Informed Consent (FPIC) principles, Environmental and Social Impact Assessments (ESIA), and RSPO Principles and Criteria prior oil palm establishment. The partnership is in line with the key pillars of the "Green Gabon" National Development Strategy[44]. In addition, in 2014 Olam invited the international "High Carbon Stock Study Group"[45] to conduct a pilot application of the HCS+ methodology in a forest-rich nation such as Gabon (Box 4). The following case study provides an overview of the analysis Olam conducted to determine the location for plantation establishment and presents the results of the HCS+ pilot study.

Olam's GHG emission reduction BMP portfolio

As part of the Olam Sustainable Palm Oil Policy[46], Olam Palm Gabon is committed to implementing a range of best management practices which reduce emissions including the following:

- No deforestation of protected area, high conservation value forests and ecosystems, and high carbon stock forests;
- Zero burning including no use of fire during land preparation, planting or replanting;
- No development on peatland regardless of depth;
- Application of CPO byproducts as fertilizer in plantations
- Fronds are stacked to improve soil in plantations
- In the future, Olam is planning to construct methane capture facilities.

Box 4. About Olam Group

Olam International is a global agribusiness that has been established in 1989 and is now expanding in 66 countries. Olam, which means 'Transcending Boundaries', started in Nigeria exporting raw cashew nuts to India. Currently, Olam is headquartered in Singapore and has been listed in the Singapore Exchange since 2005. It is also recorded in component stock in the Straits Times Index (STI), the S&P and the DAX global Agribusiness Indices. Olam is producing 47 agricultural products from various segments including: edible nuts, spices and vegetable ingredients, confectionery and beverage ingredients, food staples and package foods, industrial raw materials, and commodity financial services. The company is based in more than 66 countries supplying agricultural raw materials and food ingredients across 18 platforms to over 22,000 customers worldwide.

Olam Facts in 2016

Owner: Temasek Holdings (52.2%)
& Mitsubishi corporation (20.3%)
Cultivation area: 2.46 million ha
Processing plants: 210
Production capacity: 22.5 million MT
Revenue : 26.27 billion SGD
Employee : 72,000 pe

The only oil palm plantations that the Olam has are located in Gabon. It also obtains crude palm, palm kernel, palm kernel oil from third party suppliers. As an oil palm grower and buyer from third party suppliers, Olam follows **RSPO Principles and Criteria as the basis for its sustainability practices. In addition,** Olam developed its own 'palm oil policy' in 2011 which was updated in 2018. This policy states Olam's commitment to the RSPO standard, protection of high conservation value forests and ecosystems, high carbon stock forests, peatland, and improving the livelihood of rural communities. The policy also includes a roadmap to sustainable and traceable third party sourcing.

[44] http://visiongabon.com/our-masterplan/

[45] http://www.carbonstockstudy.com/

[46] http://49tmko49h46b4e0czy3rlqaye1b.wpengine.netdna-cdn.com/wp-content/uploads/2018/01/Olam-Sustainable-Palm-Oil-Policy-January-2018.pdf

The Initiative

Olam Palm Gabon has served as a pioneer in improving the sustainability of oil palm production. During the plantation design phase, along with application of RSPO's new planting procedures, a HCV assessment, a ESIA, and FPIC, the company was one of the first committed to not developing plantations in **high carbon stock forests**. Along with maintaining intact forest areas, through this design, Olam's greenhouse gas emissions associated with plantation establishment were significantly reduced. In fact, all of Olam's plantation sites have been identified as being carbon positive (i.e., they sequester more greenhouse gases from atmosphere than they emit). The studies required for this analysis took place in 2011, prior to the establishment of either the first version of the HCS Approach toolkit[47] or the HCS Study[48].

Motivation

When Olam Palm Gabon was initially established seven years ago, the primary focus of the design was to ensure compliance with RSPO and Olam's Palm Policy. However, from its beginning, it was also committed to protecting ecosystem integrity and biodiversity by not developing on primary forests and High Conservation Value forests. To comply with its Palm Policy, Olam first conducted extensive data collection within proposed concession areas. These were used to inform the needed ESIA (Environmental and Social Impact Assessments) and HCV assessments. Olam's scientific team developed its own methodological approach to assess the current land cover and uses and, with this, identified any areas of intact, or high carbon stock forests. With this combination of studies, Olam Palm Gabon was able to determine the areas within the concessions which would be developed into oil palm plantations.

Execution of the Plantation Design by Oil Palm Gabon

As stated, prior to selecting the chosen location for potential plantation establishment, Olam conducted an overall assessment to determine if it would likely meet Olam's Palm Policy. Once the concession boundaries were established, a thorough and extensive study took place during the design phase of the Kango and Mouila plantations. Field and remote sensing based data was collected across the area, including:

- Wall-to-wall LiDAR data collection on topography and canopy height;
- Field data collection on biodiversity. This includes a flora assessment based on forest and savannah plots, a mammal fauna assessment using transect sign counts followed by camera trapping, and sampling of fish, aquatic invertebrates, and insects;
- Assessment of the hydrological regime, water quality, soils and soil chemistry;
- Socioeconomic surveys and full participatory mapping.

This information was used to complete both the Environmental and Social Impact Assessments, its HCV assessments, and identify locations of relatively undisturbed forest. All HCV, ecologically sensitive, and/or high carbon stock forest areas were mapped for exclusion from palm oil development. In particular, in order to exclude high carbon stock forests, Olam only develops plantations on lands classified as savannah, scrub, woody pioneer vegetation or logged-over forest[49], all of which have lower carbon stocks.

All of the data results are publicly shared on Olam's website and directly with local NGOs and community members. In addition, Olam also engaged with all affected communities following FPIC guidelines. Based on the FPIC negotiations, Olam signs Social Contracts with each community which clarify the conditions and compensations

[47] http://highcarbonstock.org/the-hcs-approach-toolkit-version-1-0/

[48] http://www.carbonstockstudy.com/

[49] Olam Sustainable Palm Oil Policy. Available at http://olamgroup.com/wp-content/uploads/2014/01/16053-Palm-Policy-template_English_Screen.pdf

that communities require to grant them access to traditionally used lands. If a community refuses to grant Olam access, that community's area will be removed altogether from any plantation development.

Figure 39. Aerial view of one of Olam Palm Gabon's concessions

Box 5. Pilot Study – Feasibility study of the HCS+ methodology in Olam Palm Gabon plantations

The "HCS Science Study"[50] was commissioned by the signatories of the Sustainable Palm Oil Manifesto[51]. Its goal was to help define high carbon stock forests and establish thresholds for what can and cannot be developed as palm oil plantations based on environmental, socio-economic, and political considerations. Olam offered its plantations in Gabon to help the HCS Science Study assess the feasibility of applying the HCS+ methodology in a forest-rich nation such as Gabon. While Olam had already developed its land use plans for each concession in the study, the study looked how land use decisions would have changed if the HCS+ methodology has been applied.

In comparison to other carbon stock assessment approaches, which focus only on identifying high carbon stock forests and soils, the HCS+ methodology also places importance on local biodiversity and socio-economic conditions. There are 3 pillars that govern the HCS+ methodology: 1) land conversion for oil palm must maintain critical ecosystem services; 2) oil palm development must ensure socio-economic benefits for local communities; and 3) oil palm development must be economically viable. Figure 40 summarizes the steps of the HCS+ methodology.

[50] http://www.carbonstockstudy.com/

[51] http://www.ioigroup.com/Content/S/S_PalmOil

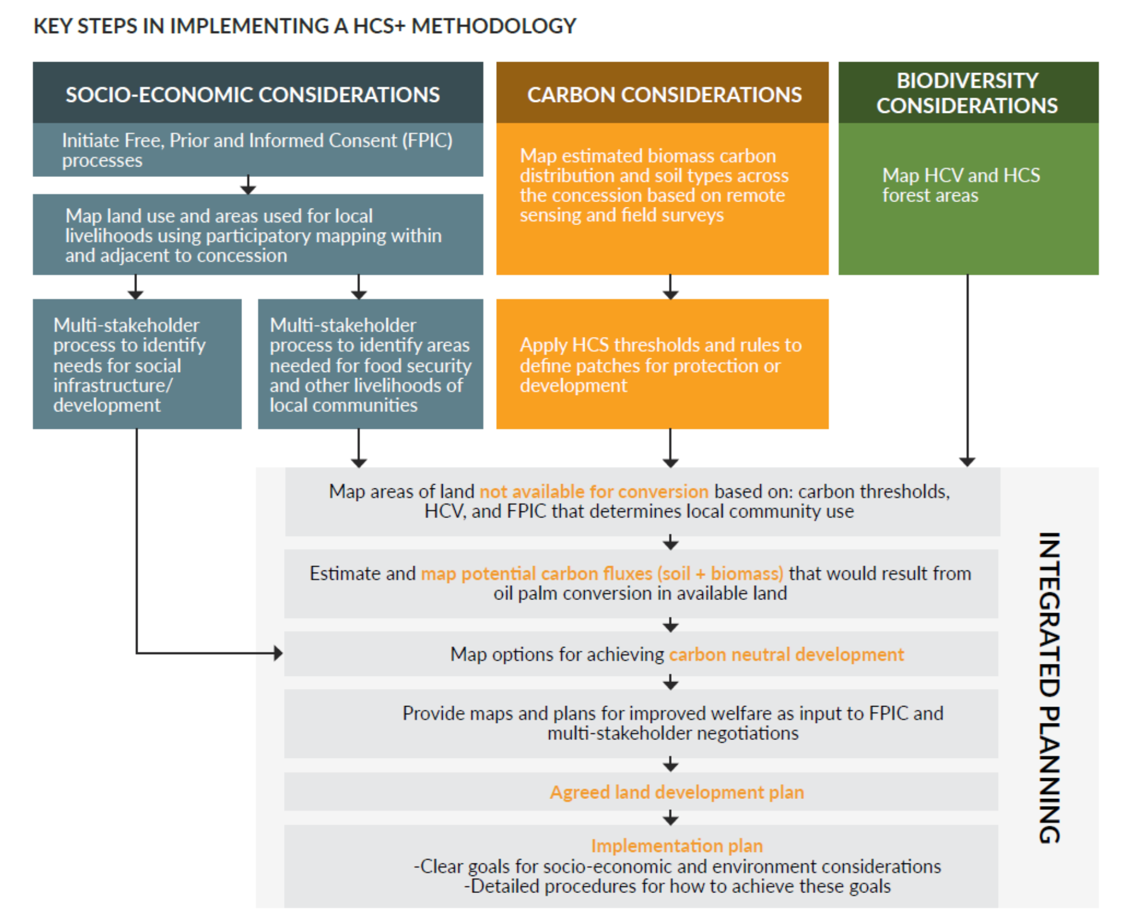

Figure 40. Key Steps in Implementing a HCS+ Methodology[52]

When implementing carbon stock assessment approaches, an area of debate is what is considered high carbon stock. While Olam Palm Gabon does not have a current carbon stock threshold to differentiate between high carbon stock areas and everything else, it only develops oil palm plantations on lands considered to be degraded such as scrub and logged-over forest. This approach of excluding high carbon stock areas by only developing on degraded lands requires access to land use spatial data and the technical expertise to analyze these data. In contrast, the HCS+ methodology applies an aboveground biomass (AGB) carbon stock threshold of 75 t C ha^{-1} (i.e., no land with AGB carbon stock greater than 75 t C ha^{-1} can be developed).

The HCS+ methodology requires a significant amount of resources and technical expertise, including access to high-resolution optical remote sensing images like RapidEye to map vegetation and land, the capacity to conduct on-the-ground biomass estimates, as well as the biodiversity and socio-economic surveys required as part of the approach.

The study in the Olam lands (in particular, in 2 of its concessions in the Mouila plantation) found that the application of the HCS+ threshold of 75 t C ha^{-1} for aboveground biomass would significantly reduce the area of the development in the two concessions, and the application of the HCS methodology threshold (35 tonnes of C ha^{-1}) would reduce it even more.

Despite this challenge of identifying thresholds to identify forests with high carbon stock, the study found that Olam's plantations are carbon positive when HCV and high carbon stock areas are protected from development using Olam's current carbon stock assessment practice, since oil palm plantations capture more carbon than the previously degraded, low carbon land uses stored.

[52] Taken from Figure 5 in the 2015 High Carbon Stock Science Study available at https://www.tfa2020.org/wp-content/uploads/2017/09/HCS-Technical-report-with-Gabon-Case-Study.pdf.

Stakeholder involvement

As partners in Olam Palm Gabon, Olam and the Government of Gabon work together on the development and operation of the plantation area. At the national level, civil society actors and the Institut Gabonais d'aide au Developpement (IGAD) were extensively engaged. As discussed above, Olam Palm Gabon goes through a thorough engagement process to ensure they have their free, prior, and informed consent in developing land for cultivation. This included engagement with all potentially affected communities. In addition, during the plantation establishment and during ongoing operations, Olam prioritizes providing employment for the community members surrounding the plantation areas.

Resource requirements

The completion of the field and remote sensing data collection and analysis prior to plantation establishment required significant resources, including engagement with specialized technical consultants. At the time, and even to this day, a limited number of organizations have developed the specialized skills required for conducting LiDAR data collection and analysis.

Olam Group invests in different sustainability actions, in which HCV and carbon stock assessment criteria are non-negotiable policies. It is difficult to gauge the yield and economic benefits at this stage. Olam sees this as a way to demonstrate that palm oil plantation can be established in sustainable way. Investment is USD 600 million or about USD 10,000/ha. This figure accounts for land preparation, nursery, planting and upkeep, fixed asset, overhead and various studies/ assessment, investment related to social contracts realization and others

Estimated GHG emission reductions

Olam has estimated the net carbon balance of two of their plantations, Awala and Mouila Lot 1, using the RSPO GHG calculator. In 2017, the Awala plantation had a net carbon balance of -36,648 tCO_2e or -5.64 tCO_2e per hectare. In 2017, Mouila Lot 1 had a net carbon balance of -182,996 tCO_2e or -11.52 tCO_2e per hectare. All Olam sites achieve net sequestration over one palm cycle due to selective low carbon area and protection of large conservation areas for biodiversity and local traditional use.

If Olam were to implement the HCS+ methodology, emission reductions would increase even more, although less land would be available for development.

A 2017 study (Burton et al 2017)[53] looked at how Gabon could promote a national palm oil policy that is carbon neutral. The study estimated that palm oil companies operating in logged forests would need to set aside approximately 2.6 hectares of forests for every one hectare converted to plantation and recommended an upper threshold for development on lands with 118 t C per hectare. With this threshold applied, plantation development could only occur in the lowest quartile of forest carbon densities in Gabon.

Other Impacts and Benefits

Incorporating a carbon stock evaluation during the design of the plantation also has additional benefits. Firstly, this development approach support's the governments overall goal of sustainable growth and assists in meeting multiple Sustainable Development Goals. In addition, by including these areas within the concession but excluding them from development serves to protect that forested area and thus the ecosystem services this area provides including biodiversity, cultural significance, and local water supplies. Taking into consideration the needs and desires of the local communities also helps ensure good relationships between these communities and the palm oil companies.

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[53] Burton, M. E., Poulsen, J. R., Lee, M. E., Medjibe, V. P., Stewart, C. G., Venkataraman, A., & White, L. J. (2017). Reducing carbon emissions from forest conversion for oil palm agriculture in Gabon. Conservation Letters, 10(3), 297-307.

There are some notable negative impacts associated with this approach. Every hectare protected on a company's land means there is one less hectare available for development of plantations. Companies need to carefully weigh the costs and benefits of implementing carbon stock assessment approaches, and further evaluate its relevance in high forest cover landscape or application for smallholder development.

Lessons learned

In the HCS+ assessment study done on Olam's land, one of the biggest challenges identified was applying thresholds to identify high carbon stock areas to exclude from plantation development. Applying a threshold of 75 tonnes of carbon (high carbon stock areas > 75) per hectare reduced the area Olam could develop substantially. Deciding upon a threshold could have implications to the entire country, as this decision will affect what lands can be converted to agriculture.

Having support from the government, as Olam Palm Gabon does, could help in not just defining the HCS threshold but also in the implementation of the carbon stock assessment approach. As discussed in the background section of this case study, these types of initiatives can help countries meet their green development strategies. This government buy-in could help smaller companies, which might not otherwise have the resources, carry out carbon stock assessment approaches to plantation planning as well. It also may help ensure that the carbon stock assessment approaches done within countries are standardized and effective. For instance, implementing advanced technology such as LiDAR for estimating aboveground carbon stocks is highly recommended by Olam for a comprehensive landscape level assessment. This is difficult to do without some government support.

In addition to government support, it is also important to mention that the local stakeholder consultation processes were also key to gain the local buy-in and support of the local communities when developing the plantations.

Acknowledgements

Winrock thanks Audrey Lee and Christopher Stewart of Olam for their input in developing and finalizing this case study.

Case study 3: Reducing GHG Emissions through POME Methane Capture in Terusan Mill, Sabah, Malaysia

Background

Terusan Palm Oil Mill is owned and operated by PPB Oil Palms Berhad, a subsidiary of Wilmar International Limited (Wilmar). Wilmar has implemented various policies to ensure continuous improvements in the sustainability of its existing plantations and mills, including reductions in emission footprint, as well as transparent and clear reporting of verifiable operational data to identify GHG emissions within the supply chain. Wilmar monitors and reports its GHG reduction efforts using GHG Protocol and the RSPO PalmGHG Calculator. According to its 2016 Sustainability Report, the three biggest GHG emission sources in Wilmar's palm oil production are land use change (43.4%), peat oxidation (25.7%), and POME (17.2%).

Figure 41. Methane Capture Facility at Terusan Mill

Wilmar's GHG emission reduction BMP portfolio

Wilmar is involved in a range of activities that result in a reduction in its total GHG portfolio. In 2013, it adopted a No Deforestation, No Peat, No Exploitation Policy governing its sustainability policy as shown in Figure 42. The practices include commitments to not engage in future development on High Carbon Stock (HCS) areas, High Conservation Value (HCV) areas, and peatlands as well as to engage in no-burn approaches in land preparation and development.

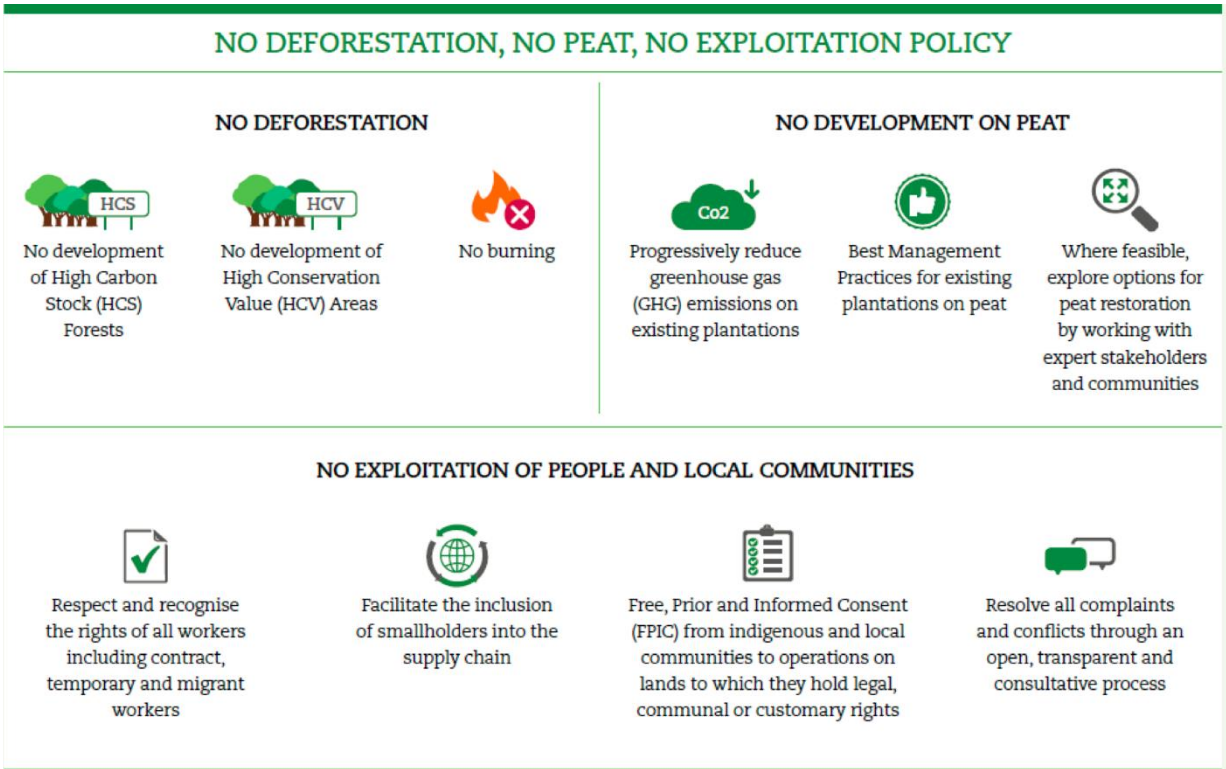

Figure 42. The principles of Wilmar's No Deforestation, No Peat, No Exploitation Policy [54]

In addition to committing to reduce emissions from its plantations, methane capture is a strategic focus for Wilmar in its efforts to reduce emissions in its palm oil production. As of the end 2016, Wilmar had 17 operating methane capture plants, with 8 more under construction, using either tank or covered lagoon technologies. Wilmar developed and started operating the first two methane capture facilities in Malaysia using tank digesters in 2011.

About Wilmar International

Wilmar International Limited (Wilmar) is a leading agribusiness group founded in 1991 and ranked amongst the largest listed companies in market capitalization on the Singapore Exchange in 2015 and 2016. The business activities include palm oil production, sugar milling and refining, biodiesel and fertilizer production, as well as flour and rice milling. With over 500 manufacturing plants and an extensive global distribution network, Wilmar operates in more than 50 countries with a total workforce of about 90,000 people.

Wilmar manages both upstream and downstream palm oil businesses in countries like Indonesia, Malaysia and Africa with its operations in plantations, mills, and refineries. Wilmar has signed the United Nations (UN) Global Compact and the Tropical Forest Alliance (TFA) 2020, as well as co-founded the Fire-Free Alliance community program. Wilmar also has various voluntary certifications (e.g. RSPO, ISCC) supporting sustainable products.

Wilmar Facts in 2016

Cultivation area	241,892 ha
FFB yield	19.0 MT/ha/year
Number of mills	43 mills
OER	20.0%

The Initiative

Terusan Palm Oil Mill developed its methane capture facility, a Covered In-Ground Anaerobic Reactor (CIGAR), in 2015, and it became operational in 2016. Terusan Palm Oil Mill is located about 160 km from Sandakan town, Sabah, Malaysia (Figure 43), with a designed processing capacity to process 60 tons of FFB per hour. Terusan Mill has been in operation since 1995 and is supplied by its own plantation with a total area of 6,788.46 ha. The estates were first

[54] Source: http://www.wilmar-international.com/sustainability/

planted in 1989 and were fully established by 2005 and have obtained RSPO and ISCC certifications. No peat land was planted on in these estates. Its replanting program is currently underway and scheduled till 2020.

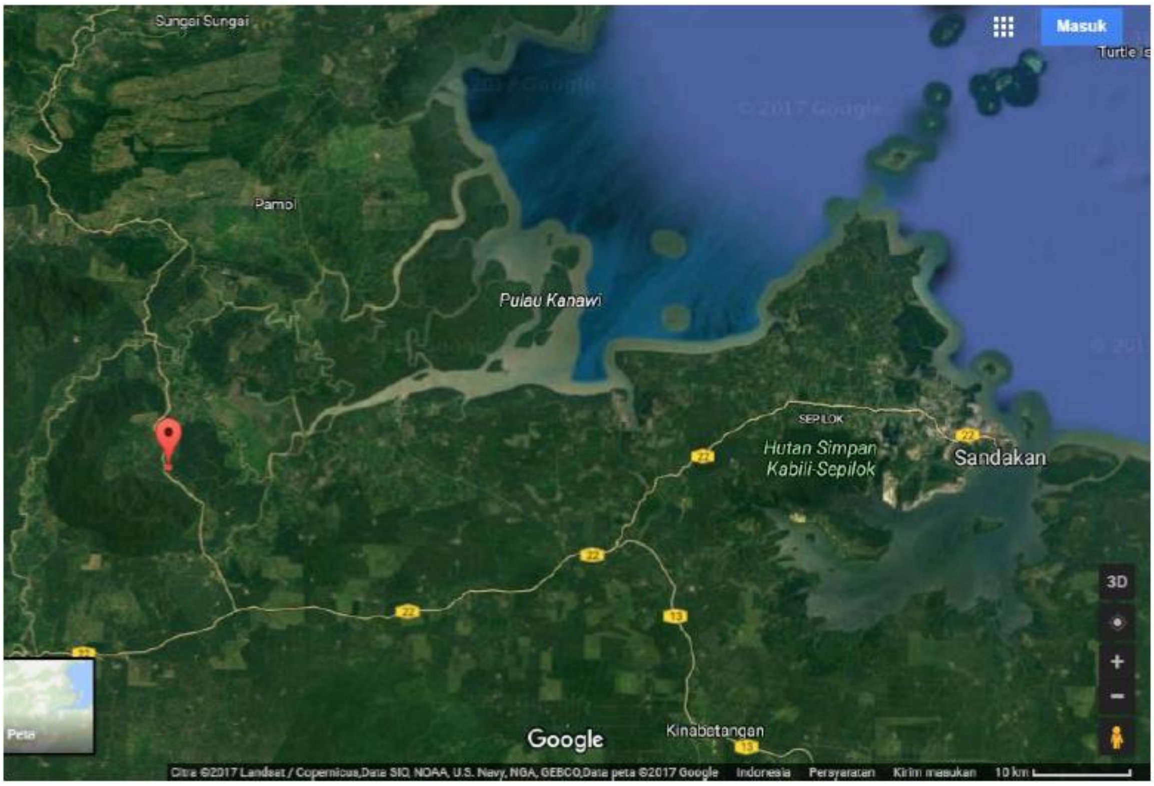

Figure 43. Location of Terusan Palm Oil Mill

Motivation

The methane capture facility at Terusan Mill was developed as part of Wilmar's effort to reduce its GHG emission footprint from mills due to POME generation. The initiative is supported by the company's No Deforestation, No Peat, No Exploitation policy which commits to progressively reducing the GHG emissions on existing plantations.

Terusan Methane Capture	
Mill Capacity	60 ton/hour
Average inlet COD level	38,900 ppm
Annual operating hours	7,500 hours
Daily biogas production	10,000-14,000 Nm^3/day
Installed power capacity	0.5 MWe
Annual power generation	2,400 MWh
Investment costs	USD 1.5 million
O&M costs (0.09 RM/kWh or 0.02 US$/kWh)	

Wilmar had existing tank digesters (continuous stirred tank reactors - CSTRs) and membrane covered lagoon (CIGAR) projects in other mills, which allowed them to easily compare the pros and cons of the two technologies. The membrane covered lagoon technology was selected because it was easier and less expensive to construct as well as easier to operate and maintain.

Another important consideration for constructing the methane capture facility was the additional benefit of using biogas to generate electricity.

Planning and execution of the initiative

The budgeting and development plan for the methane capture plant in Terusan Mill was approved in 2014, followed up by construction in 2015 and 2016. The methane capture plant started operating and producing electricity in 2016.

The planning and development phases of methane capture in Terusan Mill involved the Wilmar Group and Mill management and occurred in close coordination with the purchasing and contract departments. A consultant was hired to design and assist in the planning of the methane capture facilities. In the construction phase, the Group

Mill Manager directly supervised and managed the project in coordination with the Mill Manager and Mill Engineer. The Mill Engineer was responsible for liaising with the contractors, while Group Mill Manager liaised with the local authorities for permits and licenses.

During the operation phase, the Mill Engineer is in charge of overseeing daily operations with support from a senior staff member who is also the mill electrical engineer (in charge of electrical operations). Operators work in shifts to ensure the smooth operation of the methane capture plant. Terusan Mill recruits personnel with high academic qualifications and licenses to operate internal combustion engines (ICE). Figure 44 describes the phases and all the parties involved in the implementation of a methane capture project in Wilmar mills in general, including the Terusan Mill. The mill also engages a biogas engine supplier to provide contract services for routine checks, trouble-shooting, and major maintenance works.

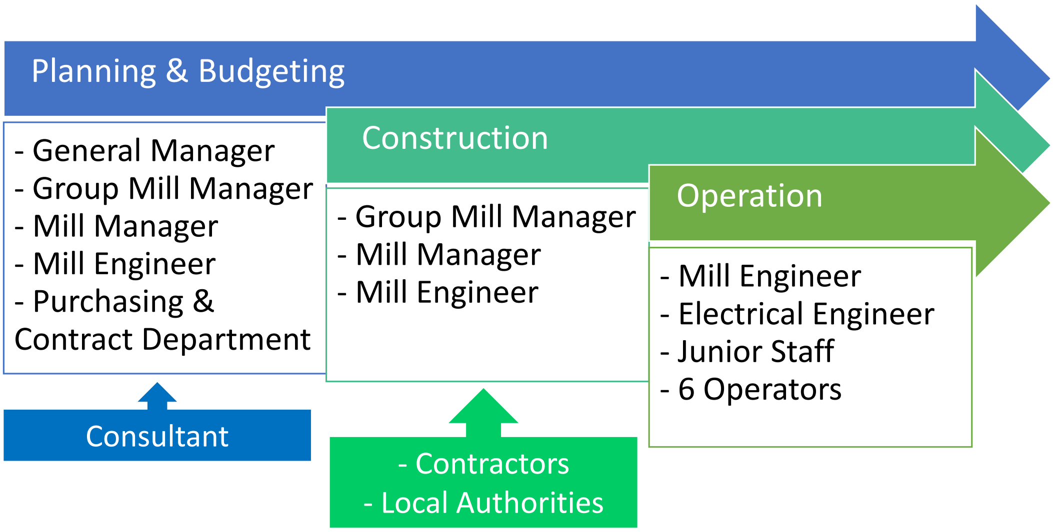

Figure 44. Methane Capture Development Process in Terusan Mill

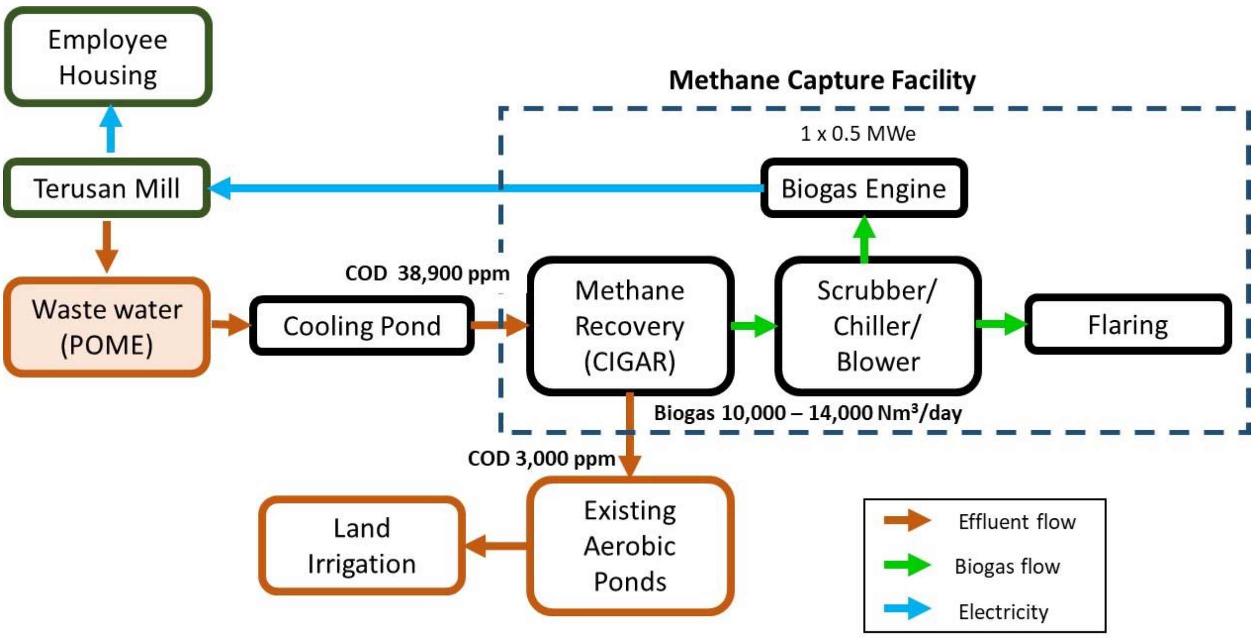

Figure 45. Diagram of Methane Capture and Biogas Plant

Figure 45 depicts the components and flow process in methane capture/biogas plant in Terusan Mill. POME generated by mill goes to a cooling pond to lower the temperature before entering the methane recovery facility. At an average COD level of 38,900 ppm, the effluent treated in CIGAR system could generate 10,000 to 14,000 Nm^3 biogas per day. Biogas is treated in the chiller and scrubber to remove the moisture and H_2S. The biogas engine converts the biogas into electricity to supply the mill, which subsequently distributes to employee housing. Flaring equipment is fitted for gas flaring whenever there is excess or unutilized biogas (e.g. during biogas engine maintenance). With COD removal efficiency at about 92%, the CIGAR system lowered the COD level from 38,900 ppm to 3,000 ppm. Treated effluent from the methane recovery is channeled to the existing aerobic ponds where effluent is further treated to meet BOD standards for land irrigation.

Figure 46. Aerial View of Methane Capture and Biogas Plant Site during Construction

Figure 47. Left: Construction of lagoon, Right: Biogas engine

Resource requirements

Resource requirements for developing and implementing the methane capture plant in Terusan Mill included:

- Sufficient, adequate space for constructing the lagoon. The site conditions need to be appropriate as well, including absence of peat soils and land of appropriate slope. Total area used for methane capture is about 4 ha and located within the mill's compound;
- Competent contractors and personnel to construct and operate the plant;
- Adequate budget. Table 35 shows the breakdown of capital expenditures for the methane capture facility with earthwork and civil work making up the largest portion at 25% followed by costs associated with covered lagoon and piping at 20% and costs associated with gas engine and associated equipment at 20%;

Table 35. Components of Capital Expenditure for the Terusan Mill methane capture facility

Components	% of Capex	Amount (in USD)
Earthwork & Civil Work	25%	375,000
Covered Lagoon and Piping	20%	300,000
Gas Engine & Associated Equipment	20%	300,000
Mechanical Installation	10%	150,000
Electrical & Wiring	15%	225,000
Dewatering Plant	10%	150,000
Total	100%	1,500,000

- Compliance with local and national regulations;
- To take into consideration the suitability of the technology for providing sufficient electricity. A unit of biogas engine with a capacity of 0.5 MWe operates on average 7,500 hours per year to produce electricity for the mill and the employee housing complex. The mill management plans to increase the installed capacity to 1 MWe in the future, if feasible. Since current installed capacity is sufficient to meet the electricity demand of the housing complex, the additional power produced will be used in the mill to supplement electricity produced by steam turbines with boilers to reduce biomass consumption as boiler fuel. Final treated effluent is discharged for land irrigation in accordance to mill's license from the authorities.

Stakeholder involvement

As discussed in the previous section, the methane capture plant was designed (with inputs from a consultant), developed, and implemented by an in-house team (see Figure 44). This team, however, did have to work with local authorities to get approval for the project. They also worked with contractors on construction and commissioning.

Estimated GHG emission reductions

GHG emissions are estimated using the RSPO PalmGHG calculator; a European Union-recognized calculator for ISCC certification; and Wilmar's own COD tabulation on digester efficiency. Actual emissions fluctuate based on POME production and biogas generation, which are influenced by various factors like crop processing, weather and microbial processes. Therefore, actual emission reductions are subject to the mill's operation; the baseline could serve as a guide, but never the rule.

Using the RSPO PalmGHG Calculator and 2016 data as the baseline, methane capture and biogas utilization for electricity contributes to an estimated methane reduction of 1,011 tCH_4 or an equivalent of 28,308[55] tCO_2e per year. As a result, it reduces the overall GHG emission footprint of CPO production in Terusan Mill.

[55] Global Warming Potential used is 28 for Methane. IPCC (2013). Climate Change 2013: The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report (AR5) of the IPCC. Chapter 8: Anthropogenic and Natural Radiative Forcing. See : https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf

Other Impacts and Benefits

Operational impacts

Additional manpower is required to operate the methane capture plant with proper supervision and maintenance efforts. However, the plant has allowed the mill to more effectively manage final discharge to better comply with regulations.

Financial impacts

Prior to the initiative, Terusan Mill supplied electricity to its mill and housing complex using steam turbines powered by biomass boilers during processing hours, and diesel generators during non-processing hours (particularly from 12 AM to 4 AM). Methane capture & utilization has enabled the Terusan Mill to provide continuous electricity supply to more than 330 houses in the Terusan housing complex. Electricity generated from methane capture has displaced electricity generated from diesel generator by almost 70%. It has reduced biomass consumption as a fuel source for boiler-turbine system, thus making more biomass (about three times as much) available for sale and providing an additional source of revenue. Fossil fuel savings and revenues from biomass sale could potentially provide the Terusan Mill with an additional monetary benefit of more than USD 120,000 per year (Table 36).

Table 36. Annual Fuel Saving Benefits

Fuels	Amount & unit	Amount (MYR)	Amount (USD)
Diesel oil savings	179,400 liter	147,100	34,226
Biomass savings	2,400 ton	375,700	87,377
Total		522,800	121,602

Impacts on Company image and staff morale

Wilmar International has also benefited from the methane capture facility, as it has been identified as enhancing the company's good image and reputation in sustainability efforts as well as boosting staff morale. The project has been discussed in Wilmar's Annual Reports, Sustainability Reports, CDP programs, and its Sustainability Dashboard.

> ***"The operation of methane capture plant is found to be a morale booster for the Terusan Mill and its personnel. We are proud of being a part of this green initiative with benefits to the environment. It enhances the positive perception towards our workplace."***
>
> ***Mr. Lo Yee Hang, Group Mill Manager***

Lessons learned

During the methane capture facility development, the Wilmar Group, and in particular the Terusan Mill, faced different challenges and identified different ways to overcome these challenges as discussed below.

Technology selection

During the planning phase, selecting the suitable methane capture technology will depend on the specific conditions of the site including the topography, soil type, availability of space, assessments on existing and future power consumptions, POME characteristic, and utilization scenario. See Table 37 for consideration of technology selection. Therefore, a thorough assessment of the site is key to ensuring the success of the project.

Table 37. Considerations for Technology Selection

Items	Continuous Stirred Tank Reactor (CSTR)	CIGAR/ Membrane Covered lagoon
Space requirement	Smaller space requirement	Larger space requirement
Electricity utilization	Suitable for large and continuous demand (i.e. grid connection,	Suitable for captive power and power supply to the grid

Items	Continuous Stirred Tank Reactor (CSTR)	CIGAR/ Membrane Covered lagoon
	large domestic electricity demand)	
Capital expenditure	Higher investment cost	Moderate investment cost

Procuring and transporting the necessary equipment

Throughout the planning, construction, and operations phase, Terusan Mill faced challenges in procuring the necessary machinery and equipment within the estimated budget and transporting it to the site. The closest city is 160 km away from Terusan Mill, thus transporting the necessary machinery and equipment required significant time and costs. Adequate, timely planning that anticipates these difficulties is imperative for the long-term success of the project.

Qualified contractors

Another key limitation was finding qualified contractors. These contractors are crucial to ensure timely construction, high quality installation, and avoid cost-overrun. The Wilmar Group worked with several contractors on the construction of their methane capture facilities, and avoided engaging with just one major contractor for all projects to reduce construction risks.

Wilmar Group set up the following evaluation criteria to ensure successful implementation of methane capture project:

1. Available technology and its safety features
2. Cost of project and selected technology
3. Maintenance of the available technology
4. Power demand for domestic usage and mill application
5. Availability of distribution or transmission line
6. Backup services from the local supplier
7. Location and available footprint

In terms of project management, the planning committee for the Terusan Mill engaged the same team of consultants and contractors assisting Wilmar on previous projects. Engaging one set of consultants and team of contractors on a long-term basis helps to mitigate the risk of project delays since the contractors are already familiar with Wilmar . This also allowed for better work coordination and optimization of budget. For mills developing their individual projects, it is advisable to work with a technology provider, consultant, as well as contractor(s) with good experience and track record.

Skilled personnel retention

To ensure that personnel have the required skill and capacity, Terusan Mill in particular and the Wilmar Group provide them training to operate the methane capture facility and biogas utilization plant. Working with POME, which has an unpleasant smell, and being in a remote location can be challenging for some personnel. Terusan Mill learned that job enrichment can support retaining personnel. For example, an operator of the biogas plant has been promoted to work in the mill’s composting facility and be in charge for overall mill waste management.

Biogas flaring

Methane within the biogas generated is a valuable fuel for electricity generation or other means of energy generation and significantly influences the economic viability of a project. Therefore, only excess biogas generated that cannot be fully utilized for electricity generation should be flared.

Involvement of senior management

In addition to the success factors presented above, the senior management of Wilmar Group played an important role in expediting project implementation through:

1. Full support of the project implementation

2. Giving timely guidance on the implementation process
3. Monitoring closely of project schedule and issues faced to ensure timely implementation.

Acknowledgements

Winrock thanks Lee Kok Vui and Foo Siew Theng of Wilmar for their input in developing and finalizing this case study.

Case study 4: Reducing GHG Emission through Filter Belt-Press Systems within Palm Oil Mill – Kuala Lumpur Kepong

Background

A major issue that all palm oil mills are faced with is how to manage their palm oil mill effluent (POME), the liquid waste produced from the processing of fresh fruit bunches. POME consists of 4-5% suspended and dissolved solids. The presence of these solids in the conventional open pond treatment system contributes to the production of methane. Furthermore, as these solids accumulate, the ponds begin to fill in and, therefore, dredging is required. Removing these solids from POME entering pond systems at palm oil mills can be burdensome as it requires a large area for dredging, and mill operations have to periodically shut down to perform the dredging. To address this issue in its mills, Kuala Lumpur Kepong Berhad (KLK) installed a Filter Belt-Press system to remove solids from the POME before it enters treatment ponds.

KLK's GHG emission reduction BMP portfolio

KLK is committed to reducing GHG emissions across its production system. This includes a commitment to no development on areas classified as having potential high carbon stocks, following the HCS approach, as well as to no new development on peat[56]. In 2016, it achieved its target of reducing emissions in its palm oil mills by 50%[57]. The two main approaches that KLK has implemented in its mills are the installation of methane capture facilities and employing the use of the filter belt-press system. Four methane capture facilities are in operation and supplying electricity to the national grid, and another two are in the construction stage. A group-wide program to install filter belt-press (FBP) systems is now being carried out across the KLK group mills as an additional approach to reduce GHG emissions in CPO production. Twenty-nine FBPs have been developed in Malaysia and Indonesia, whereas another two are in construction.

Box 6. About KLK Group

KLK Facts in 2016

Plantation area: 270,000 ha
FFB yield: 3.5 million MT/ha/year
Number of mills: 24 mills
OER: 22.28% (source: 2016 Annual Report)

Kuala Lumpur Kepong Berhad ("KLK") is a palm oil company managing upstream and downstream business. KLK was established more than 101 years ago and is listed on the Main Market of Bursa Malaysia Securities Berhad with a market capitalization of about MYR 26.5 billion, or US$ 6.7 billion[58] as of mid-June 2017. KLK has been identified as one of the largest plantation companies, with land banks spread across Malaysia, Indonesia, and Liberia. Pursuing best sustainability practice for CPO production, KLK launched its sustainability policy in 2014 that included no development on peatlands, conservation of peatlands, and stakeholder engagement. All its operating centers in Malaysia have been RSPO certified since 2015. It is aiming to have all its operating centers in Indonesia certified by 2019. Its commitment to sustainability has been strengthened through the formation of the Sustainability Steering Committee chaired by KLK's CEO. Further, KLK is implementing a traceability program that provides product traceability to palm oil mills, refineries and kernel crushing plants. GPS coordinates of its POMs are also available on the corporate website (http://www.klk.com.my/sustainability/palm-oil-mills/).

[56] www.klk.com.my/sustainability/environmental-stewardship

[57] http://www.klk.com.my/wp-content/uploads/2017/04/KLK-Sustainability-Report-2016.pdf

[58] 1 RM = 0.253 US $

The Initiative

The filter belt-press (FBP) is a device used for the separation of POME into a filtrate (i.e., wastewater) and a solid press cake (i.e., solid organic matter). Chemicals are used to improve the flocculation (i.e., clumping together) of solids. The FBP system continuously removes organic matter from the pond system. By removing the solids, the formation of methane gas is reduced. The system enables the mill to reduce and better manage palm oil waste. The solid removed can be used as organic fertilizer and applied to plantations. The water extracted from the system is also recycled for irrigation and technical cleaning purpose.

Solid-liquid separation is obtained by passing filtering cloths ("belts") through a system of rollers as shown in Figure 48. The system takes sludge ("effluent" or "slurry") as a feed between these cloths and separates them into a filtrate and a solid press cake.

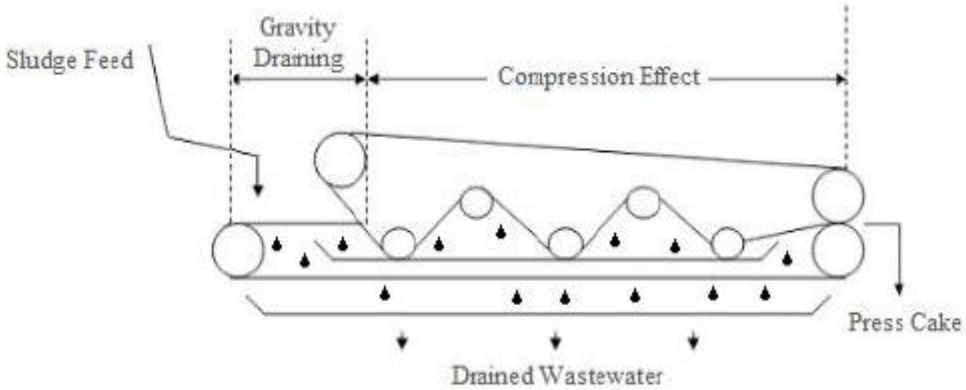

Figure 48. Diagram of the Filter Belt Press System[59]

Motivation

The filter belt press system in KLK mills was initially installed to avoid the need to open a large area in the mill property to perform dredging. However, KLK subsequently realized the application of the technology could also reduce methane emissions, therefore, this provided further incentive to develop and maintain the initiative.

Execution of the initiative

The initiative was started by the Production Division with an approval from the KLK headquarters. The development of the system in each mill requires involvement by a range of staff, including the Production Director, the Mill Advisor, the Mill Manager, the Purchasing Unit, the Supplier and Contractor. The Purchasing Unit is responsible for procuring the belt-press machine and accessories, whereas construction and commissioning are done by the Operating Centre. During the construction, the Mill Manager supervises the civil and mechanical works done by appointed contractor.

The construction of the filter belt-press in KLK mills takes about one year. The filter belt press (FBP) should be located close to mill and the existing wastewater treatment ponds. Prior to commissioning the work, a permit needed to be obtained from the Department of Environment. Normally, additional personnel are hired by KLK to operate the FBP where they receive training to equip them with specific required skills.

[59] Figure from presentation "GHG reduction with solid separation in POME ponds: Introducing new emission factors for alternative CH_4 reduction techniques" by Annamari Enstrom of Neste. https://www.iscc-system.org/wp-content/uploads/2017/08/2.-Reducing-the-Impact-of-Methane-Emissions-2.pdf.

Figure 49. Filter Belt Press at one of KLK's mills[60]

Stakeholder involvement

As indicated in the section above, in the process of constructing the filter belt-press, KLK worked with both outside consultants as well as the appropriate government ministry to get the correct permits to do the work.

Resource requirements

Investment in one filter belt press system with a capacity to process 25 m^3 of wastewater per hour costs about US$ 177,000, financed by the KLK Group and the individual mill. The civil and mechanical works and filter belt press machines are the largest cost components, 45.8% and 39.3% of investment costs respectively, as shown in Table 38.

Table 38. Components of Capital Expenditure

Components	% of total costs	Amount (in US$)
Civil structures & mechanical works	45.8%	81,042
Piping	0.6%	972
Cable and switch board (including installation)	7.1%	12,567
Centrifugal pump	0.7%	1,166
Submersible mixer	6.5%	11,486
Filter Belt Press machine	39.3%	69,575
Total	100%	176,808

Estimated GHG emission reductions

Beginning in 2016, KLK partnered with Neste, Meo Carbon and IDH Sustainable Trade Initiative to estimate methane emission reductions from the use of FBP in palm oil mills.

Methane (CH_4) emission measurements were conducted at a mill located in peninsular Malaysia which processed 730 tonnes of FFB per day, produced over 156 tonnes of CPO per day, and whose FBP generated 27.3 tonnes of belt press cake per day. The study was conducted to find a simple method for determining the reduction in CH_4 emissions at the palm oil mills that companies utilizing solid-liquid separation in the palm oil industry could apply, rather than having to engage in complicated and expensive on-site measurements. In the study, it was found that

[60] Photo from presentation "Improving Palm Oil Mill Performance – Ways towards Low Carbon Palm Oil" by https://www.iscc-system.org/wp-content/uploads/2017/05/KLK_Improving-palm-oil-mill-performance_240315.pdf

the achieved reduction in methane emissions correlates to the methane formation potential of the organic carbon in the belt press cake produced from the FBP[61].

The emissions from the pond implementing a FBP system was 50% lower than emissions from a parallel conventional open pond[62]. The study found that the filter belt-press reduced the mill's daily emissions by 20.6 tonnes of CO_2e. This is equivalent to a reduction of 0.13 kg of CO_2e[63] per 1 kg of CPO produced. While the study did not come up with one universal emission factor number that could be applied to other facilities, it did come up with an equation. The emission factor of a given mill is dependent on the amount of belt filter cake produced and the organic carbon content of this cake[64]. The equation for calculating the emission factor is in Equation 1 where 23.1 is the conversion factor from carbon to CO_2e.

This study and result are also presented in a peer-reviewed article Enström et al 2018, Introducing a new GHG emission calculation approach for alternative methane reduction measures in the wastewater treatment of a palm oil mill in the journal Environment, Development and Sustainability at: https://link.springer.com/epdf/10.1007/s10668-018-0181-4?author_access_token=-F7xEddWHKoltVNCDhhaW_e4RwlQNchNByi7wbcMAY4CFydja1QQGlej9TeEMWE08qlop71asPsVDM2iVm_9gTCRdlx04jQy4bcjAFeKrGzJdBBhgPT9P9tckO7LRKgoAcQrE-JwM_UcpvxXXZZv9Q%3D%3D

Equation 1[65]

$$EF_{belt\ press}\left(\frac{kg\ CO_{2e}}{kg\ CPO}\right) =$$

$$EF_{open\ ponds}\left(\frac{kg\ CO_{2e}}{kg\ CPO}\right) - \frac{Carbon\ content_{Belt\ press\ cake} * annual\ average\ belt\ press\ cake\ production\ (t)}{annual\ average\ CPO\ production\ (t)} * 23.1$$

In addition to the GHG emission reductions of the wastewater treatment, organic fertilizer is also produced. The application of such fertilizer reduces the need for chemical fertilizers, further reducing total operation level greenhouse gas emissions.

The implications of these findings are significant, as it provides evidence of the technology's potential to serve as a cost-effective way of reducing emissions. FBP has the potential to reduce emissions in CPO production at lower cost when compared to methane capture.

Other Impacts and Benefits

The use of filter belt-presses provide the following additional benefits to mills and plantations:

[61] GHG reduction with solid separation in POME ponds: Introducing new emission factors for alternative CH_4 reduction techniques" by Annamari Enström of Neste. https://www.iscc-system.org/wp-content/uploads/2017/08/2.-Reducing-the-Impact-of-Methane-Emissions-2.pdf.

[62] Neste. March 2, 2018. "Neste-lead project verified 50% methane emission reduction at palm oil mills." https://www.neste.com/en/neste-lead-project-verified-50-methane-emission-reduction-palm-oil-mills.

[63] 1 kg of CO_2 = 0.001 tonnes of CO_2

[64] GHG reduction with solid separation in POME ponds: Introducing new emission factors for alternative CH_4 reduction techniques" by Annamari Enstrom of Neste. https://www.iscc-system.org/wp-content/uploads/2017/08/2.-Reducing-the-Impact-of-Methane-Emissions-2.pdf.

[65] Ibid.

- As discussed previously, FBP produces belt-press cakes that can be used as organic fertilizer in plantations thereby reducing the amount of chemical fertilizer that needs to be applied.
- The separation of sludge and wastewater also reduces the need for dredging and the need to shut down operations to do the dredging.
- Space is freed up which otherwise would be needed for dredging.
-

Lesson learned

A major challenge KLK is addressing is how to improve the efficiency of their FBP systems. To do this, they are improving the design of the Horizontal Filtration System to recover wastewater which is enriched with polymers and used to clean the FBP system. They are also working to improve the production of belt-press cake by introducing a submerged mixer. This mixer helps get more of the settled sludge into the pump towards belt press without constantly having to move the pump itself. This, in turn, slows down the dilution of pumped slurry.

The fact that the filter belt-press does have a relatively low cost, little additional power demand, and leads to high emission reductions indicates that this technology could be a good option for mills of any size with low limited financing options or no additional power demand.

Acknowledgements

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Case study 5: Reducing GHG Emissions through Co-composting and Methane Capture, Sime Darby

Background

Sime Darby Plantation (SDP) is committed to implementing various best management practices to reduce its GHG emissions in both its plantations and its mills, as well as to increasing the bar on sustainability standards. SDP has set a target to reduce GHG emissions intensity by 40% by 2020 or reduce to 0.64 tCO_2e/tonnes CPO (based on a baseline of 1.01 tCO2e). The company initiated the GHG monitoring in 2012 using 2009 data to establish the baseline using GHG Protocol methodology for Scope 1 and 2 emissions[66] only. Sime Darby has committed to implementing key green initiatives as part of its Carbon Reduction Strategy[67] through which the company will meet its GHG emissions reduction target.

Further, Sime Darby Group affirmed its commitment though the Responsible Agriculture Charter (RAC) launched in 2016 to address challenges around no-deforestation, no-peat and no-exploitation[68]. The Charter will be applicable to its entire oil palm operations, extended in phases to third party palm oil suppliers and other agricultural suppliers in the supply chain.

SDP's GHG emission reduction BMP portfolio

To meet these GHG reduction commitments and other sustainability commitments (e.g., forest conservation), SDP's BMP practices include both practices associated with plantation establishment and management and during mill production. As shown below, some of these are company-wide policies/practices while others are specific to certain plantations or mills.

- Zero burning replanting techniques;
- No new plantings on peatlands;
- No deforestation
- Integrated pest management
- Development of higher yield seeds to reduce pressure to expand plantations;
- Co-composting (discussed in detail below);
- Methane capture;
- Replacement of Light Fuel Oil with natural gas at one refinery (Nuri Edible Oil refinery).

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[66] Scope 1 emissions are direct emissions from owned or controlled sources. Scope 2 emissions are indirect emissions from the generation of purchased energy. http://www.ghgprotocol.org/sites/default/files/ghgp/standards_supporting/FAQ_0.pdf.

[67] http://demoweb11.simedarby.com/sustainability_2015/case-studies/biogas

[68] http://www.simedarbyplantation.com/sustainability/beliefs-progress/practices-key-initiatives/responsible-agriculture-charter

Box 7. About Sime Darby

Sime Darby Plantation (SDP) is the largest division of Sime Darby Group, a conglomerate group listed in Malaysia. It is one of the founding members of RSPO and is now one of the largest global sustainable palm oil producers. Producing more than 2 million tonnes of CSPO and almost a half million tonnes of SCPK, certified sustainable palm oil account for 98% of total production[69]. Sime Darby Plantation operates in 18 countries, encompassing more than 254 estates and 71 mills. The business spans upstream and downstream palm oil value chain, from oil palm cultivation to refineries. Plantation areas are located in Malaysia, Indonesia, Liberia, Papua New Guinea, and Solomon Islands.

SDP has set a target to reduce GHG emissions intensity by 40% by 2020 or 0.64 tCO_2e/tonnes CPO[70]. Participating and committing to United Nations Global Compact (UNGC) Traceability Taskforce, Sime Darby launched the Open Palm Traceability Dashboard to provide information on the traceability of its supply chain. 78.9% of CPO and 85.8% of PK produced by Sime Darby are now traceable to the plantations.

Sime Darby Facts in 2016

Land banks	988,599 ha
Cultivation area	628,995 ha
Number of mills	71 mills
CPO production	2.4 million tonnes/yr

Methane Capture at Sime Darby

Sime Darby has a long-held commitment to efficient use of resources. For example, Sime Darby first installed methane capture back in the late 1980's in mills such as Bukit Rajah, Chan Wing and Tennamaram. Among the most successful projects was at the Tennamaram mill, where biogas was used for power generation and piped to an adjacent facility to power a ceramic drying furnace. In 2010, Sime Darby Plantation decided to re-evaluate the potential of methane capture and formulated a Biogas Masterplan. Under this plan, methane capture serves as the centerpiece of Sime Darby Plantation's emission reduction initiatives. To date, Sime Darby Plantation has 7 fully active biogas plants with another 6 in various stages of planning and commissioning. Under its methane capture initiatives, Sime Darby also found GHG emission reductions. Depending on the size and technology post methane capture (flaring, co-firing, FIT or Bio-CNG), SDP's biogas plants are designed for around 50-100% utilization of total POME produced by the mill and capable of reducing around 13,000 - 33,000 Mt CO_{2-e}/year per plant.

This then translates to a 28-73% reduction of the mills' annual emissions (0.5 - 1.3% reduction of SDP's annual emissions). Thus, methane capture stands out as one of the largest and most effective approaches to GHG emission reductions at SMP Mills.

The Initiative

Sime Darby Plantations is currently implementing initiatives on methane avoidance through composting. Sime Darby is also implementing 11 methane capture and biogas projects, some of which are already operating and some of which are in still in development. This case study will discuss the co-composting and methane capture initiative implementation in Sime Darby, with more emphasis placed on co-composting since another case study focuses on methane capture. The case study will highlight how these two BMPs can significantly reduce the bulk GHG emissions in the CPO supply chain.

Motivation

Sime Darby's co-composting project was initiated by the Research and Development Department to help achieve zero discharge mills, although GHG emission reductions were also a primary driver for both co-composting and methane capture efforts.

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[69] http://www.simedarbyplantation.com/corporate/overview/about-us

[70] Greenhouse Gas Emission Reduction via Composting: Sime Darby's Perspective: https://www.iscc-system.org/wp-content/uploads/2017/05/Devi_Nair_Sime_Darby_TC_SEA_Jakarta_120815.pdf.

Execution

Sime Darby Plantation began piloting composting as a mill waste management initiative in 2004 initially with 5 plants, of which 4 were registered under the Clean Development Mechanism under the Kyoto Protocol that allowed developed countries to invest in developing countries for the purpose of financing carbon emission reduction projects. For the first four projects, Sime Darby worked with a third party vendor on a build-operate-transfer (BOT) basis. In 2009, the BOT model was migrated to a concession scheme with third party vendors. Project implementation was led by the upstream plantation division and coordinated by the sustainability department.

The carbon reductions from these composting projects belonged to Denmark via an Emission Reduction Purchase Agreement (ERPA) with the Danish Ministry of Climate and Energy. The 4 composting projects generated Certified Emission Reductions (CERs) from 2010 to the end of 2012, culminating in the delivery of more than 180,000 CERs to Denmark. The four successful projects were among the first of their kind in Asia to achieve issuance of CERs. The projects continue to be in operation as part of Sime Darby's Carbon Reduction Strategy, along with 18 other composting plants constructed since 2010, making up a total of 22 compost plants that produce about 500,000 mt of compost per year. Considering infrastructure, resources, and anticipated challenges, this first phase of development is focused in Malaysia.

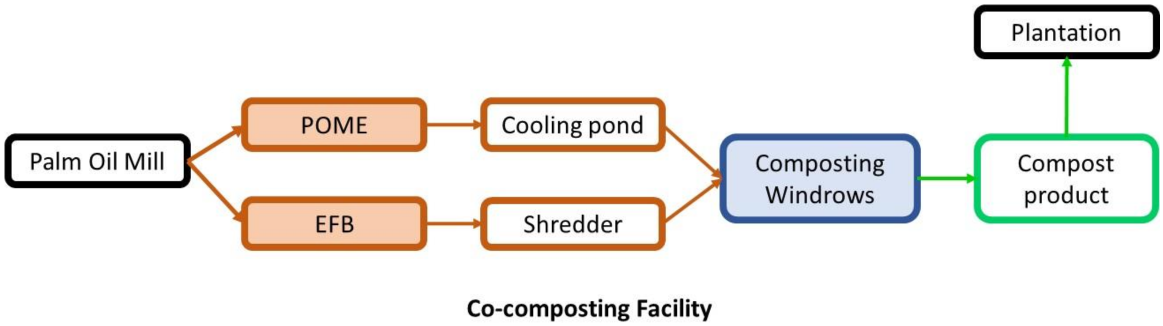

Figure 50. Schematic Diagram of Co-composting process

Figure 51. Co-composting Process in Sime Darby Plantation Mills[71]

The composting system uses a combination of mechanical and biological methods to convert POME and EFB, boiler ash, and decanter cake into organic fertilizer. As shown in Figure 51, EFB is first shredded and then is mixed with boiler ash and decanter cake. The mixture is then stacked in 1.5 meters windrows, which are left to degrade naturally during a 6 to 7 week period. To ensure that the process in fully aerobic at all times, the windrows are sprayed daily with POME (where COD levels are approximately 50-55 kg COD/m^3) and then turned every third day. The most important part of the process is turning and aerating which maintains the oxygen levels in the compost thus ensuring that aerobic decomposition takes place. The resulting compost produced from this process is transported to the oil palm plantations and applied as fertilizer.

In the composting process, methane emissions are reduced since a portion of POME is channeled to be applied to the EFB instead of going to the open anaerobic and aerobic ponds before being discharged in rivers.

The ideal ratio of EFB:POME determines the amount of carbon emissions avoided. On average, Sime Darby Plantation was able to apply between 1-1.5 tonnes of POME for every ton of EFB which means 20-30% of POME produced at the mill was able to be used for the compost process instead of remaining in wastewater ponds. Sime Darby Plantations' R&D has been working on improving the POME utilization on composting to achieve 40% POME utilization, out of total POME volume in the mill; at the ratio of 1:2 EFB:POME.

Box 8. Composting Facility at Pekaka Palm Oil Mill

The Pekaka palm oil mill of Sime Darby (previously Golden Hope), is located in Bintulu, Sarawak, Malaysia. The composting facility at Pekaka started operating in 2005 and was registered as a

[71] Taken from the presentation "Greenhouse Gas Emission Reduction via Composting: Sime Darby's Perspective"

CDM project in 2007. The composting plant can process about 60,000 ton EFB per year and can use up to 50% of the POME produced by the mill or about 86,000 m^3/year. The COD level of the POME is 53.6 kg COD/m^3. The plant produces 25,000 – 30,000 ton of compost per year. The average annual GHG emissions reduction is 22,364 tCO_2e/year.
EFB are stacked in 1.5 meters windrows and sprayed daily with POME. The windrows are left to degrade aerobically and aerated by turning if the oxygen level is low. Shredding is carried out either between days 20 – 40 of the composting process or after 6-7 weeks, depending on the POME spraying pattern and nutrient content. Shredding enables the mill to apply additional POME. This additional POME application, in turn, not only reduces mill waste but it makes the composting process more efficient since higher moisture promotes microbial activity. The compost will go through a curing stage for a week or more and then be delivered to the estates. The compost product reaches maturity after 6-7 weeks. With the curing stage, it takes about 8-10 weeks to deliver compost to estates.

The operation of the composting plant at Pekaka mill is performed by a 3rd party operator working under a concession contract. The investment cost for the composting plant is RM 3.41 million or about USD 780,000. The operation and maintenance costs consist of labor, maintenance, chemical (inoculant), electricity and diesel oil to run heavy equipment. The total operation and maintenance costs are about MYR 1.8 million or about USD 410,000 per year.

It is extremely important to note that this project was initiated to address solid waste in the Pekaka mill and achieve a zero waste mill. Reviewing the capital expenditure, annual O&M costs, and compost selling price, this project is not considered financially attractive without the carbon revenues.

Figure 52. Composting Facility at Sime Darby's mill

Figure 53. Heavy Equipment is employed to turn Windrows

Box 9. Composting & Biogas Case study at the Flemington Oil Mill

The Flemington Oil Mill, with a 60 tonnes per hour (tph) capacity, is one of the first of SDP's oil mills to incorporate both methane avoidance and capture in its operations. Its compost plant started operating in 2011 as part of SDP's expansion of the composting projects from 5 to 22 plants. In 2013, the Flemington compost plant was turned into an R&D plant mainly aimed at improving both the quality of the final product and the efficiency of the composting process. The compost plant currently produces 10,000Mt of compost annually with an average emission reduction of 5,000Mt CO_2e/year.

December 2016 marked the start of full-scale operations of Flemington Biogas plant, a joint venture project between SDP and Tenaga Nasional Bhd (TNB). The biogas plant is capable of utilizing an average of 80% of the mill's annual POME produced, in which the resulting biogas is used for electricity generation and sold back to the grid through the national feed-in tariff (FIT) mechanism. In 2017, the plant utilized 113,000Mt of POME which generated 6.5GWh of electricity and an estimated emission reduction of 29,000Mt CO_2e; a 64% reduction of the mills emissions. Co-composting and methane capture in Flemington oil mill has led to total emission reductions of about 75% of the mill's emissions.

Resource requirements

The investment to start a co-compost plant can range from about USD 1.3 million to USD 2.3 million, depending on the infrastructure and machineries used. Operation and maintenance costs typically consist of salary, maintenance, and fuel costs to run the equipment. The plant can be operated as part of the mill operations or be outsourced to 3rd party vendors. Plant supervisors lead the plant operation and supervise 10-15 semi-skilled workers and qualified heavy machinery drivers. Alternatively, the operations component of manpower management can be outsourced.

Stakeholder involvement

SDP worked with third party vendors to construct and operate the composting plants. All composting projects is approved by Department of Environment as the initiative is recognized as part of mill waste managing process.

Estimated GHG emission reductions

As of 2015, composting projects in Malaysia have successfully reduced carbon emission intensity by 6.5% when compared to the 2009 baseline. Carbon intensity gradually decreased from 1.06 tCO_2e/mt CPO in 2009 to 1.02 tCO_2e/mt CPO by 2015.

Under CDM guidance, the project falls under AMS-III.F.ver 3 - Avoidance of methane production from biomass decay through composting. The key data collected for this emission includes FFB produced, EFB generated, POME uptake, chemical oxygen demand analysis records of POME, oxygen level readings, diesel consumption records, POME runoff volume and COD analysis.

On average, the 22 compost plants have been able to generate a reduction of approximately 200,000 MT of CO_2e per year with average EFB:POME ratio of 1:1.5. However, the percentage reduction is less than 10% of total emission intensity, per ton of CPO. Data are monitored and collected to calculate GHG emission reductions of composting projects using the CDM methodology. Sime Darby had adopted GHG Protocol before the RSPO Palm Oil GHG Calculator was introduced. Both GHG Protocol and RSPO GHG Calculator are now used to calculate the emissions from the overall supply chain, whereas AMS-III.F ver 3 is still applied to calculate GHG emissions reduction from the composting projects.

These estimates only consider GHG reductions from mill operations. It is important to mention that, while not quantified, further GHG reductions could possibly occur due to the displacement of synthetic N fertilizer application. The IPCC 2006 guidelines[72] do not differentiate between organic and synthetic N on the basis of their potential to generate N_2O per unit of N applied. However, if an organic N fertilization regimen permits a reduction in total N applied per hectare when compared to synthetic N, this change would be expected to produce a reduction in N_2O roughly proportional to the reduction in applied N. If N application rates remain consistent between synthetic and organic sources, a reduction in N_2O is still possible, but would depend on a complex and site-specific interaction between soil conditions, biota, and management practice, that are not yet captured in IPCC guidelines.

Other Benefits

In addition to GHG emissions reduction purpose, composting and methane capture as best management practices provides multiple benefits to the overall CPO production as identified in Table 39.

Table 39. Other benefits of co-composting and methane capture

Benefits	Co-composting	Methane Capture
Reduce solid and liquid wastes in mill, thus improve the air quality and aesthetic of mill area	√	√
Compost application could improve soil conditions	√	
Cost savings from not applying inorganic fertilizer	√	
Energy generation from biogas conversion		√

Lessons learned and recommendations

Methane avoidance via composting is a medium to high cost investment depending on the technology and equipment used. The pre-requisite of turning and aeration can be done via simple machinery such as shovel and backhoe or with proper equipment such as a turner.

> *"The composting project serves as a stepping stone for Sime Darby Plantation in its emission reduction strategy."*
>
> Mr. Tang Men Kon, Head of PSQM

Typically 20% of POME utilization or at EFB:POME ratio of 1:1 is the comfortable level as a higher POME intake will affect the moisture content of the final product or prolong the processing time to greater than 100 days. The compost can be further enhanced by fortifying it with inorganic fertilizer that is pelletized for easy application and

[72] IPCC 2006 v. 4 ch. 11, equation 11.1

handling. In this way, the usage of inorganic fertilizer can be reduced and the application can be spread to larger areas. In the process of co-composting development, Sime Darby faced different challenges in each stage of development (Table 40).

Table 40. Lessons Learned

Phases	Challenges	Sime Darby's solution
Preparation & budgeting	Sourcing for the right technology and infrastructure as there a range of technology providers that provide from simple to high tech systems	To choose a technology that is effective in ensuring easy maintenance and minimum breakdown.
Construction	Meeting the project schedule and avoid cost overrun	Monitoring the project progress and working with reputable vendors with experience
Operation	Training and retaining local workers	Outsourcing the job to contract workers is more effective
	The EFB uptake and compost evacuation can be hindered by poor weather which leads to backlog of EFB and compost.	Planning and dedicated evacuation team is essential, preferably mechanized application but is limited to flat terrain.
	Consistently maintain the POME –EFB ratio without affecting the compost quality – nutrient content and moisture content	Regular testing and having a monitoring mechanism is essential

While inclusion of both methane avoidance and capture is ideal environmentally, the implementation and operation of the said setup will likely be costly. Because of this costliness, exploring scenarios of biogas utilization is an important step that the mill needs to carry out. Biogas utilization will depend on the specific needs and location of the project site be it profit-bearing in more accessible areas (e.g. FIT, Bio-CNG) or cost reduction for electricity generation for more rural areas.

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The RSPO is an international non-profit organization formed in 2004 with the objective to promote the growth and use of sustainable oil palm products through credible global standards and engagement of stakeholders.

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