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Supporting Low Emission Development by Generating Electricity from Biogas from Palm Oil Mill Effluent: Costs, Benefits, and the Potential for Replication

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March 2019

In this paper, the RALI team presents lessons learned from efforts undertaken in Indonesia to recover biogas methane (CH_4) from palm oil mill effluent (POME) to produce electricity and reduce greenhouse gas (GHG) emissions from palm oil mills. The team also identifies the potential benefits of replicating these efforts at additional mills.

The Millennium Challenge Account-Indonesia (MCA-I) implemented the Green Prosperity (GP) Project from 2013 to 2018 with the support of the Millennium Challenge Corporation (MCC), a U.S. foreign aid agency that provides countries with grants to fund initiatives to reduce poverty through sustainable economic growth. Among many positive outcomes of the GP Project, MCA-I demonstrated the feasibility of reducing GHG emissions from palm oil mills by generating renewable electricity from POME. Most significantly, Musim Mas, a global company with activities across the palm oil supply chain, and MCC co-financed projects that involved installing equipment and facilities at three of Musim Mas's Indonesian mills to generate electricity from recovered biogas produced by anaerobic digestion of the mills' POME. In this manner, each of the three mills produces more than 8.5 gigawatt hours (GWh) of electricity and reduces its GHG emissions by nearly 55,000 metric tons (MT) of carbon dioxide equivalent (CO_2e) every year.[1]

If 100 more palm oil mills (13.5 percent of the 742 mills in Indonesia in 2015) recovered biogas from palm oil mill effluent (POME), annual net power generation could conservatively exceed 400 GWh, enough to meet the annual electricity needs of 240,000 Indonesian households, and contribute to annual GHG emission reductions approaching 2.6 MMT CO_2e.

The potential contribution of recovery of biogas from POME to Indonesia's renewable energy mix is noteworthy. If 100 more palm oil mills (13.5 percent of the 742 mills in Indonesia in 2015) recovered biogas from POME, annual net electricity generation could conservatively exceed 400 GWh – enough to meet the needs of approximately 240,000 Indonesian households – and annual GHG emission reductions could approach 2.6 million metric tons (MMT) CO_2e. Turning POME into renewable electricity, a demonstrably profitable practice that has been widely adopted across Southeast Asia, could make a significant contribution to Indonesia's efforts to achieve its Nationally Determined Contribution (NDC) to reducing GHG emissions. External financing for such POME generation facilities, from the Green Climate Fund (GCF), Global Environment Facility (GEF),[2] or other sources may further incentivize this activity.

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[1] These POME projects were part of a larger collaboration between MCC, Musim Mas, and the International Finance Corporation to strengthen independent smallholder oil palm producers in the palm oil supply chain through farmer training and certification efforts. Funding from MCC for the POME methane capture and electricity generation system component of the projects was contingent upon the agreement of the grant recipient to work with its independent smallholder supply base.

[2] The GEF has previously supported a Malaysian palm oil industry biomass power generation project, as well as other agro-biogas projects in Brazil, Guinea, Tanzania, Botswana, and Chile.

BACKGROUND

Three of the projects supported by the MCA-I GP Project involved palm oil mills. These mills process fresh fruit bunches (FFBs) from oil palm trees into crude palm oil and palm kernel oil. A waste product of the milling activity is POME, of which 0.6–0.7 percent is palm oil and 4–5 percent is solids, the remainder being water. For every metric ton of crude palm oil produced, a mill will release approximately 2.5 MT of POME into a lagoon system wherein anaerobic decomposition produces GHGs that are emitted into the atmosphere. From a climate change perspective, this source of GHGs is significant in the case of Indonesia because it is the world's leading producer of palm oil (Irvan, 2018), producing nearly 31.3 MMT of crude palm oil and 6.3 MMT of palm kernel oil in 2015 (Directorate General of Estate Crops, Ministry of Agriculture, 2015). Also in 2015, the country's 742 palm oil mills produced almost 74 MMT of POME (Hambali & Rivai, 2017).

One way to reduce the GHG emissions from POME is to install an anaerobic digester, biogas conditioning and cleanup equipment, and a biogas engine/generator, or "genset." The digester converts 80 percent or more of the Chemical Oxygen Demand (COD) in the POME to biogas, which is typically 50–75 percent methane[3] (Rahayu, et al., 2015). Subsequently, biogas conditioning equipment removes hydrogen sulfide and moisture from the biogas. Lastly, the biogas is combusted in a genset to produce electricity (Rahayu, et al., 2015). The palm oil mill may directly consume electricity from the biogas generation facility to reduce the mill's energy costs,[4] or sell the electricity to the grid to increase revenues. If the mill sells the electricity to the grid, this transaction reduces the quantity of fossil fuel that a non-renewable-fuel power plant would otherwise need to produce an equal quantity of electricity.

Approximately 13 percent of the GHG emission reductions from the three Musim Mas projects come from displacing fossil fuel combustion in this manner. The remaining GHG emission reductions arise from capturing and combusting the POME-derived biogas (i.e., CH_4), as opposed to allowing it to enter the atmosphere. The combined emission reductions of the three Musim Mas projects total approximately 162,000 MT CO_2e annually.[5] Assuming a project lifetime of 20 years, each of the three mills could produce GHG emission reductions approaching 1.1 MMT CO_2e, or nearly 3.3 MMT CO_2e across the three mills.

The financial benefits of the projects are also significant. Expenses include 121.5 billion Indonesian Rupiah (IDR) (8.4 million USD) for project development and installation costs. The three projects received a combined grant of 60.7 billion IDR (4.2 million USD) from MCA-I to offset some of the project development and installation costs. Ongoing operation and maintenance, and labor expenses, are expected to cost 6.79 billion IDR (470,000 USD) annually.[6] Additionally, for all three projects, the gensets are expected to require replacement after 10 years, that is, at the midpoint of the projects' lifespans, for a cost of 22.8 billion IDR (1.58 million USD). Revenue accrues from the sale of electricity to Indonesia's national grid operator, Perusahaan Listrik Negara (PLN) at the rate of IDR 850/kWh (0.058 USD/kWh) for two projects and IDR 1,120/kWh (0.077 USD/kWh) for the third project, and is expected to total 24.1 billion IDR (1.7 million USD) annually. Again assuming a project lifetime of 20 years, and a discount rate of 12 percent, the total net present value (NPV)[7] of the three projects is estimated to be approximately 62.5 billion IDR (4.3 million USD), and the payback period[8] is expected to be 3.5 years.[9] Without the grant from MCA-I, the NPV would have been 1.8 billion IDR (126,000 USD), and the payback period 7 years, so it is evident that the grant significantly improves the financial viability of the Musim Mas projects.

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[3] Methane has a global warming potential 25 times that of carbon dioxide (CO_2) (IPCC, 2007).

[4] Normally, palm oil mills are self-sufficient in energy use even without POME capture because they burn palm kernel shells and FFB husks in boilers to generate steam and electricity.

[5] The plants at each Musim Mas project site have a processing capacity of 45 MT of FFBs per hour, or 202,500 MT per year, assuming they operate for 15 hours per day and 300 days per year.

[6] Cost and price increases over time are not applied in the analysis.

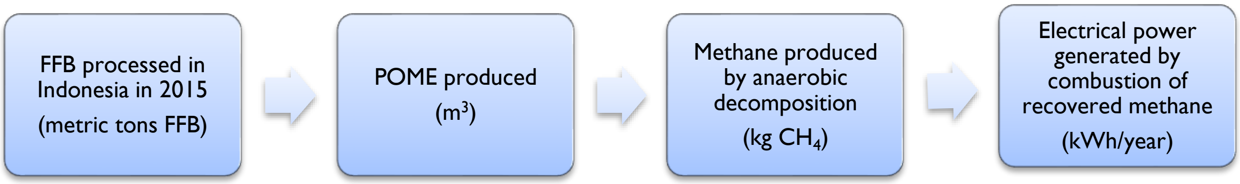
[7] NPV is the difference between the present value of cash inflows and the present value of cash outflows over a period, discounted to the present time using a selected discount rate. NPV is used in capital budgeting to analyze the profitability of an investment.

[8] The payback period is the length of time required to recover the cost of an investment. The payback period of a given investment or project is an important determinant of whether to undertake the position or project, as longer payback periods are typically not desirable for investment positions. The payback period ignores the time value of money, unlike other methods of capital budgeting such as NPV.

[9] All currency conversions were performed on July 26, 2018, using the currency conversion calculator at www.xe.com. The currency conversion rate at that time was 14,460.04 IDR/USD.

THE BENEFITS OF SCALING UP

The substantial GHG emission reductions and financial benefits of Musim Mas's three projects demonstrate that generating electricity from biogas from POME is an effective means of supporting low emission development, and warrant a close look at the potential impacts of scaling up this strategy. To determine the GHG emission reductions that could arise in the event that additional POME-to-biogas renewable generation projects took place at other mills, we use a methodology similar to the one we used to determine the GHG impacts of the Musim Mas projects, adjusting several assumptions to represent the typical POME-to-biogas power plant in Indonesia. The methodology starts with the known quantity of total fresh fruit bunches (metric tons FFB) that palm oil mills in Indonesia processed in 2015, and proceeds in the manner illustrated below.



From the quantity of methane produced and the electrical power generated, the methodology estimates the potential GHG emission reductions from both (1) directly avoided methane emissions and (2) displacing fossil fuels that would otherwise be used to generate power. It also calculates the equivalent number of households in Indonesia that POME renewable generation projects could serve. Table 1 presents these benefits in detail. The Appendix presents a comprehensive explanation of the methodologies used.

Table 1. Three scenarios showing the estimated benefits if additional mills in Indonesia implement POME-to-biogas renewable energy projects

Scenario	Number of mills that convert biogas from POME into electrical power	Gross electricity generation (MWh/year)	Net electricity delivered to households (MWh/year)[10]	Number of households for which POME could supply electricity	**Annual GHG emission reductions (MT CO_2e/year)**
1	1	4,575	4,117	2,383	25,507
2	100	457,484	411,735	238,311	2,550,744
3	742	3,394,530	3,055,077	1,768,271	18,926,523

In addition to the significant benefits enumerated in Table 1, capturing biogas from POME could help Indonesia meet its nationally determined contribution (NDC) commitments under the Paris Agreement. In its first NDC, Indonesia commits to unconditionally reduce its GHG emissions by 29 percent against the business-as-usual scenario by 2030 (Republic of Indonesia, 2016). Indonesia anticipates that in this scenario, emissions in 2030 will be approximately 2,869 MMT CO_2e, meaning that a reduction by 29 percent would be approximately 830 MMT CO_2e. The estimated annual GHG emission reductions of Scenario 3 in Table 1, which involves all 742 mills in Indonesia in 2015 capturing and utilizing methane from POME, comes to 18.9 MMT CO_2e, or 2.3 percent of the unconditional reduction. This makes Scenario 3 a potentially valuable part of the country's GHG emission mitigation strategy.

In fact, the unconditional mitigation scenario described in Indonesia's NDC includes capturing and utilizing methane from POME to reduce emissions from the industrial liquid waste sub-sector. In that scenario, year 2030 emissions from the waste sector are anticipated to be 285 MMT CO_2e, representing a reduction of 11 MMT CO_2e, or 3.7 percent, from the business-as-usual scenario waste sector emissions of 296 MMT CO_2e. If Indonesia scaled up its adoption of methane capture and utilization to 100 mills per Scenario 2 in Table 1, this would result in annual GHG emission reductions of approximately 2.6 MMT CO_2e, or 23.2 percent of the planned 11 MMT CO_2e reduction. The GHG emission reductions

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[10] Net electricity delivered to households equals gross electricity generation reduced according to an availability factor that accounts for engine downtime and distribution losses.

from Scenario 3 would be 172 percent of the planned 11 MMT CO_2e reduction. Table 2 summarizes how Scenarios 2 and 3 could contribute to Indonesia's efforts to achieve its unconditional GHG emission reductions.

Table 2. Potential impact of Scenarios 2 and 3 on achieving the unconditional mitigation scenario GHG emission reductions described in Indonesia's Nationally Determined Contributions

Scale	Unconditional mitigation scenario emission reductions (MMT CO_2e)	Scenario 2 emission reductions as % of the unconditional mitigation scenario emission reductions	Scenario 3 emission reductions as % of the unconditional mitigation scenario emission reductions
All sectors	830	0.3%	2.3%
Waste sector	11	23.2%	172.1%

Regarding the potential financial benefits of replicating the Musim Mas projects at additional mills, we estimate the potential project costs, revenue, NPV, and payback period by first determining the generation capacity the typical mill[11] would need in order to produce 4,117 MWh per year (see the "Net electricity generation delivered to households" column in Table 1). By comparing this capacity to the size of one of Musim Mas's projects, we derive a ratio by which to adjust the upfront installation costs of those projects to what the owner of the typical mill might incur. Thus, the project development and installation costs are expected to total 26 billion IDR (1.8 million USD) for the "average" mill. The costs of ongoing operation and maintenance, and labor expenses, are expected to be approximately 5–9 percent of installation costs (Rahayu, et al., 2015). Here, we use the midpoint of 7 percent of installation costs. As a result, the ongoing operation and maintenance, and labor expenses are estimated to amount to 1.83 billion IDR (126,000 USD) annually.

To estimate the potential NPV and payback period of the "average" mill scenario, RALI included no grant in our calculations, and use a feed-in tariff based on *Decree No. 1772 K/20/MEM/2018 on the Amount of Cost Generation Provision of PLN in 2017*. This tariff is calculated by selecting the higher of two values, being the national average cost to PLN of procuring power from the different systems/sub-subsystems listed in Decree No. 1772, or 85 percent of the cost of procuring power in the system/sub-system in which the project is occuring. Most of the palm oil mills in Indonesia are located in Kalimantan and Sumatra. To determine what the feed-in tariff might be for these regions, we average the cost of procuring power within them and multiply the result by 85 percent. This produces a feed-in tariff of IDR 1,140/kWh (0.079 USD/kWh), which is greater than the national average cost of procuring power, and therefore the tariff we use to estimate revenue. Assuming that the mill's biogas engine produces 4,346 MWh net per year,[12] this leads to an annual revenue of 4.96 billion IDR (343,000 USD) per project. Assuming a project lifetime of 20 years, and a discount rate of 12 percent, the total NPV of the typical project would thus come to approximately negative 2.70 billion IDR (negative 187,000 USD), with a payback period of 8.3 years, as seen in Table 3. Hence, the average mill case is not financially viable because the feed-in tariff is too low. That said, each project would receive a different feed-in tariff based on the system/sub-system in which it is located. To be financially viable, the "average" mill must be located in a system/sub-system that yields a feed-in tariff of at least IDR 1,224/kWh (0.85 USD/kWh), or receive external funding, such as a grant, to make up for the shortfall in revenue due to tariffs below that threshold. Additionally, as the national and system/sub-system costs of power production are published yearly, project developers may choose to sign a power purchase agreement at a time when the feed-in tariff is highest, thereby increasing the revenue stream. Otherwise, these projects will have negative NPVs.

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[11] For this paper, the "typical mill" is defined by Scenario 1 in Table 1. That is, it is the theoretical mill that will generate a quantity of electricity and GHG emission reductions equivalent to the average of the 742 palm oil mills in Indonesia in 2015.

[12] The power purchase agreement (PPA) will determine where the sale of electricity takes place in relation to the location of the buyer and the seller. In this analysis, the delivery point of the electricity is assumed to be on-site, i.e., prior to the occurrence of any distribution losses. According to (Rahayu, et al., 2015), an availability factor ranging from 90–98 percent should be applied to gross electrical power generation to account for engine downtime and distribution losses. RALI uses 90 percent to be conservative, and multiplies gross by 95 percent, effectively halving the factor that accounts for downtime alone, and thereby estimate net electrical power generation prior to distribution losses, this being the quantity of electricity the buyer would purchase assuming the delivery point is on-site. Per Table 1, the "average" mill is assumed to deliver 4,117 MWh per year of net electricity to households. According to the estimate methodology described, the quantity of electricity the buyer would purchase, assuming the delivery point is on-site, is 4,117 / 0.95 = 4,346 MWh per year.

Table 3. Potential costs, revenue, NPV, and payback period for the "average" mill in Indonesia undertaking a POME-to-biogas renewable energy project[a]

Variable	Unit	Value
Project development, installation	IDR (USD) (one time)	26 Bln (1.8 Mln)
Ongoing operation and maintenance, and labor expenses	IDR (USD) (annually)	1.8 Bln (0.13 Mln)
Revenue from sale of electricity to PLN	IDR (USD) (annually)	5.0 Bln (0.34 Mln)
NPV	IDR (USD)	-2.7 Bln (-0.19 Mln)
Payback period	Years	8.3

[a] For a comprehensive explanation of the methodology used to develop these estimates, see Table 12 in the Appendix.

It is important to note that in estimating each of the varied benefits of scaling up, we used the most conservative value of nearly every range involved. Table 4 presents these ranges and the values selected. If in practice any of the variables in Table 4 were found to be higher than the values indicated, then the benefits would be greater. Significantly, if the quantity of electricity generated was 6 percent higher, the "average" mill case would be financially viable.

Table 4. The conservative values used to estimate the benefits of scaling up

Variable	Use	Range	Value used in calculations
POME discharged per metric ton of FFBs processed (m^3)	To estimate the potential daily methane production for Indonesia (see Table 5 in the Appendix)	0.7–1	0.7
Chemical Oxygen Demand (COD) loading (kg/m^3)		15–100[a]	55
COD removal efficiency (percent of COD that will be converted to CH_4)		80–95%	80%
Average electrical efficiency	To estimate the potential annual electrical power generation for Indonesia based on annual methane production (see Table 6 in the Appendix)	38–42%	38%
Electricity availability factor	To estimate the number of Indonesian households the electricity of which could come from POME (see Table 11**Error! Not a valid result for table.** in the Appendix)	90–98%	90%

[a] *POME-to-Biogas Project Development in Indonesia* (Rahayu, et al., 2015) indicates a range of 15–65 kg/m^3, but the POME from the mills in the Musim Mas-MCC co-financed projects had a COD of 100 kg/m^3. Therefore, we suggest a range of 15–100 kg/m^3. In our calculations, we used 55 kg/m^3 per the methodology in *POME-to-Biogas Project Development in Indonesia* (Rahayu, et al., 2015) to estimate the projected potential power from POME.

In addition to the values in Table 4, several other variables help ensure that the estimate of the potential daily methane production for Indonesia will be conservative. For instance, following CDM methodology *AMS-III.H: Methane recovery in wastewater treatment* (CDM, 2017), the quantity of methane from POME is further reduced by a methane correction factor of 0.8 and a model correction factor of 0.89 (see Table 5).

THE EXPERIENCES OF MALAYSIA AND THAILAND

Implementing POME-to-biogas renewable energy projects at the magnitude of 100 or more mills in Indonesia would be an ambitious undertaking, but there are precedents. Malaysia and Thailand provide relevant case studies because of their proximity to Indonesia and the scale of their palm oil industries.

Both countries have employed proven, scalable POME-to-biogas technology to increase domestic access to renewable energy, and reduce the environmental impact of their palm oil sectors while increasing their economic competitiveness. By examining the pathways Malaysia and Thailand followed to achieve their successes in this domain, it is possible to glean promising strategies to expand POME-to-biogas renewable energy in Indonesia. Figure 1 provides a summary of Thailand, Malaysia, and Indonesia POME achievments and goals.

Thailand

In 2016, Thailand had 137 palm oil mills, and produced 11.2 MMT of oil palm and approximately 2 MMT of crude palm oil (Petchseechoung, 2017). In that same year, Malaysia's 453 palm oil mills processed 85.8 MMT of fresh fruit bunches into 17.3 MMT of refined palm oil and 57.5 MMT of POME (Loh, 2017).

In 2007, the Royal Thai Government created the conditions for POME-to-biogas projects to flourish when the Ministry of Energy (MoE) streamlined and simplified the regulations of its Very Small Power Producer (VSPP) program, which purchases renewable energy from sources not exceeding 10 MW (Greacen, 2013). Since then, the opportunity for VSPPs to enter into long-term contracts that guarantee their sale of electricity to the grid at a set tariff for a predetermined period prompted most palm oil mills in Thailand to install biogas systems (Greacen, 2013). Further incentivizing this move, the government replaced the prior feed-in premium scheme in 2014 when it implemented a new scheme that increased the feed-in tariff available to renewable energy producers. While this scheme ascribes lower tariffs to POME-to-biogas projects than to some other renewable technologies, the tariffs are still greater than what is available to non-renewable electricity producers.

In addition, the MoE actively promotes POME biogas as a key resource to help Thailand achieve its Alternative Energy Development Plan, which has a target of 30 percent renewable energy (out of total energy consumption) by 2036 (Achawangkul, 2018). In 2012, 5 years after MoE's simplification of the VSPP program, the Institute for Industrial Productivity found that, "All major [palm oil mills in Thailand had] a [biogas] system installed or under development, and a biogas system is more or less seen as a must in terms of competitiveness and efficiency" (Siteur, 2012).

Malaysia

In Malaysia, a combination of similar government interventions and market forces has spurred the rapid growth of biogas renewable energy (Loh, 2017). The country's *Economic Transformation Programme: A Roadmap for Malaysia*, released in 2010, describes how Malaysia plans to develop the 12 National Key Economic Areas (NKEAs) announced in its 10th National Plan, one of which pertains to the palm oil industry. To address this NKEA, the *Economic Transformation Programme* describes a series of entry point projects (EPPs). According to EPP 5: Developing biogas at palm oil mills, biogas plants would be developed at the country's 500 mills by 2020,[13] and of these, 250 would supply electricity to the national grid, 233 would capture biogas for their own boilers, and the remaining 17 would perform both of these functions (Performance Management and Delivery Unit (PEMANDU), Prime Minister's Department, 2010). In support of these ends, the Malaysian Palm Oil Board mandated that effective January 1, 2014, all new mills or existing mills applying for throughput expansion would need to implement full biogas capture or methane avoidance (Loh, 2017).

While not requiring mill operators to necessarily install biogas engines, the regulation may have a synergistic effect with market forces. These forces take the form of multiple monetary incentives, including income tax exemptions; import duty and sales tax exemptions on machinery, equipment, and materials; and investment tax allowances (Malaysian Palm Oil Board, 2014). For example, the Promotion of Investment Act 1986 provides tax incentives (Loh, 2017), and the Green Technology Financing Scheme, which the Malaysian Green Technology Corporation (GreenTech Malaysia), under the purview of the Ministry of Energy, Green Technology and Water, launched in 2010, provides a guarantee of 60 percent "for the green cost of the financed amount" to reduce the risk for financial institutions funding POME-to-biogas infrastructure (Green Bank Network, 2018). Finally, the Renewable Energy Act of 2011 raised the applicable feed-in tariff, effective from 2014, to Malaysian Ringgit (RM) 0.40/kWh (0.099 USD/kWh) (up to RM 0.47/kWh (0.12 USD/kWh) with "bonuses") from the previous feed-in tariff of RM 0.32/kWh (0.79 USD/kWh) (Loh, 2017).[14]

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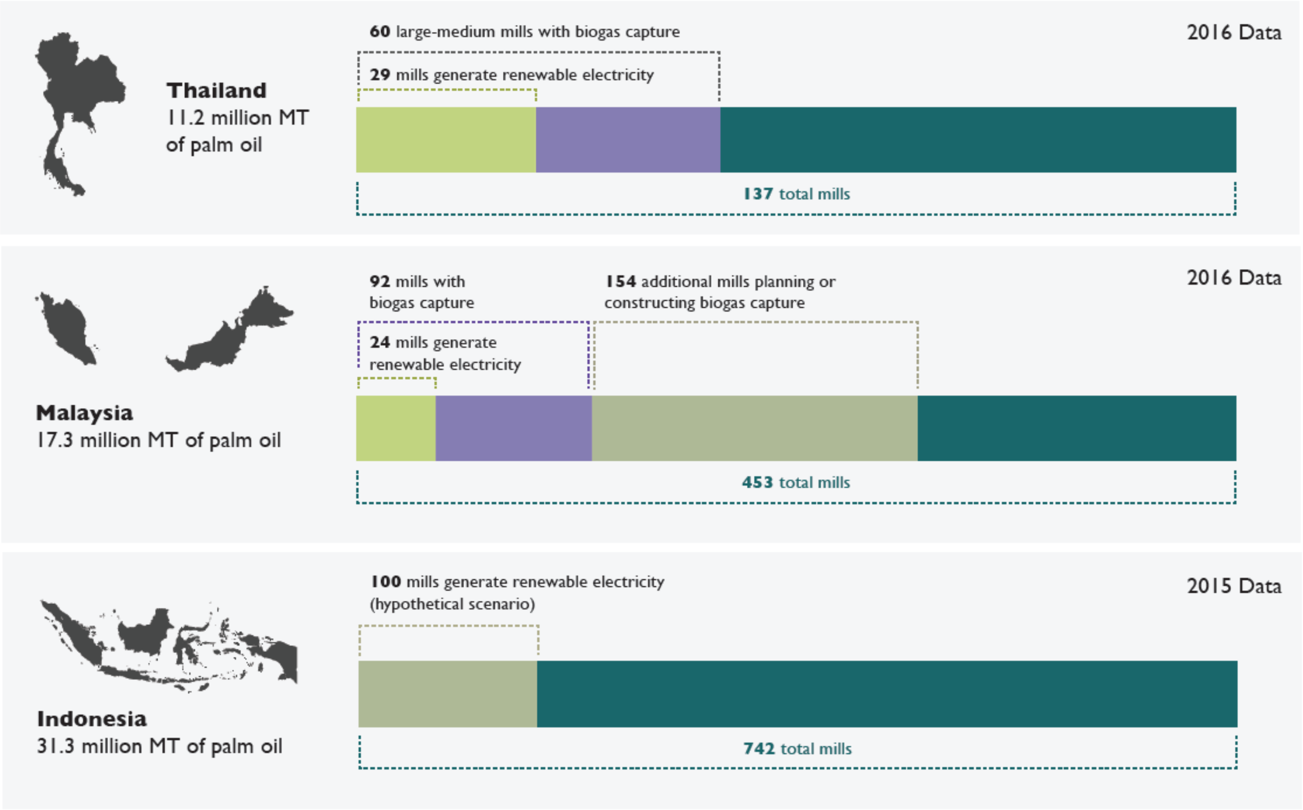
[13] *Economic Transformation Programme: A Roadmap for Malaysia*, the source of this estimate of the number of mills Malaysia will have by 2020, is roughly consistent with the data from Loh (2017) that indicate 453 POME mills are presently in the country.

[14] All currency conversions were performed on July 26, 2018, using the currency conversion calculator at www.xe.com. The currency conversion rate at that time was 0.24718 RM/USD.

Recent statistics on the extent of biogas capture at Malaysia's palm oil mills reveal that this industry is indeed transforming there. In 2016, the number of Malaysia's palm oil mills that captured biogas increased 30 percent from 2014, from 71 to 92 plants. Of the 92 plants, 12 combusted the biogas in boilers for onsite use, 24 generated renewable electricity, 54 flared the biogas, and 2 produced thermal energy for onsite use. Also in that year, an additional 154 mills were planning or contructing biogas capture systems. In 2017, 17 plants were connected to the national grid, and 3 to local grids furnishing electricity to external users in the area of the mills. By 2019, 29 additional plants are expected to connect to the national grid (Loh, 2017).

Figure 1. Summary of Thailand, Malaysia, and Indonesia POME Achievements and Goals



The cases of Thailand and Malaysia just described reveal several means of using market forces and government regulation to promote biogas capture and biogas-to-energy at palm oil mills. While not all means are necessarily transferrable from one country to another given differences in national circumstances, Thailand and Malaysia provide instructive and relevant examples of the potential for government intervention to drive economically, environmentally, and socially positive change in the palm oil industry.

The preceding discussion does not suggest that Indonesia lacks relevant laws and regulations. In fact, *POME-to-Biogas Project Development in Indonesia* (Rahayu, et al., 2015) lists several. However, these laws and regulations promote renewable energy in general rather than provide specific opportunities for the palm oil industry or POME-to-biogas projects as found in Thailand and Malaysia.

LESSONS FROM MUSIM MAS PROJECTS

The projects that Musim Mas implemented under the MCA-I GP Project provide guidance for the project implementer and other key participants in Indonesia. Consequently, to facilitate the success of efforts to implement POME-to-biogas renewable energy projects at additional palm oil mills in Indonesia, we summarize the strategies that Musim Mas employed during the MCA-I GP Project and offer the following recommendations:

- Employ a proven technology and a standard design for multiple projects to reduce the cost per project and increase the chance of success significantly. Custom, one-off designs are more expensive and, consequently, unproven or non-commercial designs should be avoided. In the case of Musim Mas, its mills use a standard digester system design that Musim Mas developed with an anaerobic digestion technology company over the course of constructing about a dozen previous projects. The three Musim Mas projects that MCA-I co-financed were all essentially the same design and used the same equipment.
- Co-financing could help accelerate projects similar to the Musim Mas POME capture projects, and thereby help scale them up.
- If co-financing will be involved, the co-financier (e.g., donor, investor, or lender) should:
    - Thoroughly evaluate the project developer before making an award, noting that large, successful companies that have already installed digesters at their mills are particularly promising.
    - Establish a memorandum of understanding, contract, or other agreement with the project developer at the onset of the project, and assign appropriate people to monitor the project during design and construction. Documenting arrangements or agreements after the commencement of the project can limit inspection and compromise the documentation of costs and other critical aspects of the project.
    - Engage pre-qualified Environmental and Social (E&S) contractors, or have an approved E&S contractor, to facilitate the E&S activities that project developers may have planned.
        - Adopt internationally-recognized standards such as the International Finance Corporation's *Performance Standards on Environmental and Social Sustainability*, which should streamline projects like this and make them easier and faster to carry out (in comparison to developing custom E&S standards/guidelines, which may delay projects and introduce unnecessary costs).
        - Establish a technical and E&S advisory group or similar to help project developers succeed and ensure that deliverables are satisfactory; and ensure that the people assigned to this group are capable of providing practical technical review and quality control of project design and construction.
- If the project implementer has corporate social responsibility goals, then it may consider the Community Benefit Sharing plans that Musim Mas developed for each of its three palm oil mills involved in the GP Project. According to these plans, Musim Mas committed to share approximately 10 percent of the revenue from electricity sales with local communities over 20 years. Musim Mas would share these proceeds in two ways. First, it would establish community oil palm estates that would be owned and managed by the communities, with profits from the sale of fresh fruit bunches going to the community benefit sharing committee. Second, Musim Mas would provide direct financial support to the community benefit sharing committee to help them implement community priorities.

CONCLUSION

In Thailand and Malaysia, there is clear evidence of the successful widespread adoption of POME capture and utilization for generating renewable energy. This has also started to occur in Indonesia, as demonstrated by the three MCA-I and Musim Mas co-financed POME-to-biogas renewable energy projects. In each of these cases – Thailand, Malaysia, and the emergence of a similar trend in Indonesia – the potential to generate clean energy and reduce GHG emissions from the palm oil industry is evident. To support future POME-to-electricity projects, the Government of Indonesia may wish to reevaluate its incentive policies around renewable energy. Were the country to take steps to accelerate this trend, it could help address energy access and meet the GHG emission reduction targets defined in its NDC. Palm oil companies, in coordination with the national government, could seek funding for expansion from multilateral climate finance sources such as the Green Climate Fund and the Global Environment Facility. Indonesia is an eligible country to both funds, and POME biogas projects address core objectives of both funding bodies.

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Published March 2019
Prepared by ICF and MCC under the USAID Resources to Advance LEDS Implementation activity. Visit: climatelinks.org/projects/rali
Period of Performance: 2014–2019

REFERENCES

Achawangkul, Y. (2018, July 25). *Thailand's Alternative Energy Development Plan.* Retrieved from United Nations ESCAP: https://www.unescap.org/sites/default/files/MoE%20_%20AE%20policies.pdf

CDM. (2017). *AMS-III.H: Methane recovery in wastewater treatment.* UNFCCC.

Directorate General of Estate Crops, Ministry of Agriculture. (2015). *Tree Crop Estate Statistics of Indonesia 2014-2016.* Jakarta: Directorate General of Estate Crops.

Greacen, S. T. (2013). An assessment of Thailand's feed-in tariff program. *Renewable Energy*, 439-445.

Green Bank Network. (2018, January 22). *Malaysia Green Technology Corporation*. Retrieved July 25, 2018, from Green Bank Network: https://greenbanknetwork.org/malaysia-green-technology-corporation/

Hambali, E., & Rivai, M. (2017). The Potential of Palm Oil Waste Biomass in Indonesia in 2020 and 2030. *IOP Conf. Ser.: Earth Environ. Sci., 65*.

Institute for Global Environmental Strategies (IGES). (n.d.). *IGES List of Grid Emission Factors.* Retrieved July 2, 2018, from Institute for Global Environmental Strategies: https://pub.iges.or.jp/pub/iges-list-grid-emission-factors

IPCC. (2007). *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Geneva: IPCC.

Irvan. (2018). Processing of palm oil mill wastes based on zero waste. *IOP Conf. Ser.: Mater. Sci. Eng.*(309).

Loh, S. K. (2017). Biogas Capture - A Means of Reducing Greenhouse Gas Emissions from Palm Oil Mill Effluent. *Oil Palm Bulletin*(75), 27-36.

Malaysian Palm Oil Board. (2014). *Biogas Capture and CDM Project Implementation for Palm Oil Mills.* Retrieved from mpob.gov: http://www.mpob.gov.my/images/stories/pdf/2014/2014_nkea.pdf

Performance Management and Delivery Unit (PEMANDU), Prime Minister's Department. (2010, October 26). *Economic Transformation Programme: A Roadmap for Malaysia.* Performance Management and Delivery Unit (PEMANDU), Prime Minister's Department. Retrieved from https://policy.asiapacificenergy.org/sites/default/files/ETP.pdf

Petchseechoung, W. (2017). *Thailand Industry Outlook 2017-2019: Oil Palm Industry.* Krungsri Research.

Rahayu, A. S., Karsiwulan, D., Yuwono, H., Trisnawati, I., Mulyasari, S., Rahardjo, S., . . . Paramita, V. (2015). *POME-to-Biogas Project Development in Indonesia.*

Republic of Indonesia. (2016). *First Nationally Determined Contribution.*

Siteur, J. (2012). *Rapid Deployment of Industrial Biogas in Thailand: Factors of Success.* Institute for Industrial Productivity.

World Energy Council. (n.d.). *Energy Efficiency Indicators.* Retrieved April 16, 2018, from World Energy Council: https://wec-indicators.enerdata.net/xls/Indonesia.xls

APPENDIX

The following tables present the methodologies employed to determine the potential GHG emission reductions (MT CO_2e/year), and the number of households that recovered biogas from POME could provide electricity to if all 742 of Indonesia's palm oil mills in 2015 implemented POME-to-biogas power.

Table 5. Potential daily methane production, based on total fresh fruit bunches (FFB) for Indonesia in 2015

Variable	Fresh fruit bunches (FFB)	POME	Chemical Oxygen Demand (COD) loading	COD removal efficiency	Methane correction factor	Methane producing capacity of effluent	Model correction factor	Methane produced	Methane produced, minus fugitive emissions
Unit	MT/year	m^3/day	Kg COD/day	%	N/A	kg CH_4/kg COD	N/A	kg CH_4/day	kg CH_4/day
Letter	A	B	C	D	E	F	G	H	I
Formula/ Value	N/A	A * 0.7 / 365 days/year	B * 55 Kg COD/m^3	80%	0.8	0.25	0.89	C * D * E * F * G	H * 90%
Result	130,351,275	249,989	13,749,381	N/A	N/A	N/A	N/A	1,957,912	1,762,121
Assumption	N/A	For every metric ton of FFBs processed, a mill will discharge 0.7–1 m^3 of POME; 0.7 is used to be conservative.	Untreated POME has a COD of 55 kg/m^3 (55,000 mg/l).	COD that will be converted to CH_4 ranges from 80–95%; 80% is used to be conservative.	Most lagoons in Indonesia are anaerobic and deeper than 2 meters. Hence, the methane correction factor is 0.8.	0.25 kg of CH_4 is produced per kg of COD removed from POME.	This accounts for inherent uncertainties in the model.	N/A	Capture efficiency of the biogas recovery equipment in the POME treatment system is 90%.
Source	(Hambali & Rivai, 2017)	(Rahayu, et al., 2015)			(CDM, 2017)			(CDM, 2017), (Rahayu, et al., 2015)	(CDM, 2017)

Table 6. Potential annual electrical power generation, based on annual methane production in 2015

Variable	Methane energy content	Average electrical efficiency	Generated power capacity	Gross electrical power generation	Net electrical power generation (gross reduced by downtime)
Unit	MJ/kg	%	MW	kWh/year	kWh/year
Letter	J	K	L	M	N
Formula/Value	50	38%	(I * J * K) / (24 hours/day * 60 min/hour * 60 sec/min)	L * 24 hours/day * 365 days/year * 1,000	M * 0.95
Result	N/A	N/A	388	3,394,529,693	3,224,803,208
Assumption	CH_4 energy value is 50 MJ/kg (converted from 35.7 MJ/m^3).	Typical electrical efficiency ranges from 38–42%; 38% is used to be conservative.	N/A	N/A	An availability factor is applied to gross electrical power generation to account for engine downtime and distribution losses. The factor has a range of 90–98%. RALI uses 90% to be conservative, and multiplies gross by 95%, effectively halving the factor that accounts for downtime alone. InTable 7, we use this net electrical power generation value to estimate emission reductions from displacing grid electricity. RALI does not use 90% for this purpose because the mill's biogas engine will offset the emissions from the *actual* power generation of conventional fossil fuel-powered grid-connected plants, i.e., their net generation prior to distribution losses. Consistent with this, it is necessary to estimate the biogas engine's net electrical power generation prior to distribution losses.
Source	(Rahayu, et al., 2015)				

Table 7. Emission reductions from displacing grid electricity (MT CO_2e/year)

Variable	Grid emission factor	Emissions reduced
Unit	kg CO_2e/kWh	MT CO_2e/year
Letter	O	P
Formula/Value	0.88	N * O / 1,000 kg/MT
Result	N/A	2,837,021
Assumption	Non-weighted average of ex-post emission factors of 2015 from all grids in Kalimantan and Sumatra, where most mills in Indonesia are located and therefore most indicative of the grid emissions that would be displaced.	N/A
Source	Calculated based on data from IGES	N/A

Table 8. Emission reductions from methane capture and combustion (MT CO_2e/year)

Variable	Methane global warming potential	Emissions reduced
Unit	N/A	MT CO_2e/year
Letter	Q	R
Formula/Value	25	I * Q * 365 days/year / 1,000 kg/MT
Result	N/A	16,079,351
Assumption	N/A	N/A
Source	(IPCC, 2007)	N/A

Table 9. Emission reductions from discharged wastewater (MT CO_2e/year)

Variable	Chemical Oxygen Demand (COD) loading	Methane correction factor	Methane produced	Emissions reduced
Unit	kg/day	N/A	kg CH_4/day	MT CO_2e/year
Letter	S	T	U	V
Formula/Value	B * 0.2	0.1	F * G * S * T	U * Q * 365 days/year / 1,000 kg/MT
Result	49,998	N/A	1,112	10,151
Assumption	Musim Mas uses a COD of 0.2 kg/m³ (200 mg/l).	Discharge of wastewater to sea, river, or lake is accompanied by a methane correction factor of 0.1.	N/A	N/A
Source	Data Musim Mas furnished during the MCA-I GP Project, related to its POME projects.	(CDM, 2017)	(CDM, 2017), (Rahayu, et al., 2015)	N/A

Table 10. Total annual emission reductions (MT CO_2e/year)

Variable	Total emissions reduced
Unit	MT CO_2e/year
Letter	W
Formula/Value	P + R + V
Result	18,926,523

Table 11. Number of Indonesian households the electricity of which could come from POME

Variable	Electricity availability factor	Net electrical power generation (gross adjusted to account for availability factor)	Average electricity consumption of electrified households in 2015	Number of households for which POME could supply electricity
Unit	%	kWh/year	kWh/household	households
Letter	X	Y	Z	AA
Formula/Value	90%	M * X	1,728	Y / Z
Result	N/A	3,055,076,724	N/A	1,768,271
Assumption	An availability factor is applied to gross electrical power generation to account for engine downtime and distribution losses. The factor has a range of 90–98%. RALI uses 90% to be conservative. In this table, we use this net electrical power generation value to estimate the quantity of electrical power generated (kWh/year) that may be expected to reach the consumer.	N/A	RALI estimates this value for 2015 by trend analysis using data for 2009 to 2014.	N/A
Source	(Rahayu, et al., 2015)		(World Energy Council)	N/A

Table 12. NPV calculations for an average Indonesia POME biogas generator[15]

Variable	Feed-in tariff	Installation cost of power station	O&M costs	Annual revenue	Discount rate	NPV	Payback period
Unit	IDR/kWh	IDR	IDR/year	IDR/year	%	IDR	years
Letter	BB	CC	DD	EE	FF	GG	HH
Formula/Value	1,140.13 (0.079 USD/kWh)	26,076,382,381 (1,803,341 USD)	CC * 7%	BB * N / 742 mills	12%	((EE - DD) * (1 – (1 + FF)^(-20)) / FF) – CC	CC / (EE – DD)
Result	N/A	N/A	1,825,346,767 (126,234 USD)	4,955,128,883 (342,677 USD)	N/A	-2,698,651,305 (-186,628 USD)	8.3
Assumption	Feed-in tariffs vary by region. Most of the palm oil mills in Indonesia are located in Kalimantan and Sumatra. An average of the feed-in tariffs for these regions was selected for use.	Installation cost for Musim Mas projects with a capacity of 2,137 kW was scaled based on average expected Indonesia capacity.	The annual fixed and variable O&M costs range from 5–9% of the EPC (i.e., installation) costs. A cost of 7% is assumed.	All net electricity generated over the length of the project is sold to PLN at the feed-in tariff price. The power purchase agreement (PPA) will determine where the sale of electricity takes place in relation to the location of the buyer and the seller. In this analysis, the delivery point of the electricity is assumed to be on-site, i.e., before distribution losses would occur. Therefore, this calculation relies on variable N, "Net electrical power generation (gross reduced by downtime)."	Selection of discount rate based on industry standard.	Assuming a 20-year project timeline. Entire installation cost is assumed to occur at the start of the project (i.e., year 0). Annual revenue and O&M costs are realized at the end of year 1. The calculations assume an all-equity investment, and do not include taxes.	N/A
Source	(Rahayu, et al., 2015)	(Musim Mas, 2015)	(Rahayu, et al., 2015)	N/A	N/A	(Rahayu, et al., 2015)	N/A

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[15] All currency conversions were performed on July 26, 2018, using the currency conversion calculator at www.xe.com. The currency conversion rate at that time was 14,460.04 IDR/USD.