Improving sustainability and circularity of palm oil by anaerobic digestion of empty fruit bunch, mesocarp fibre, and palm oil mill effluent, enabling selfsufficient energy production from biogas

Biomass Conversion for Bioenergy

Voogt, J.A.; Barrera Hernandez, J.C.; Groenestijn, J.W.; Elbersen, H.W.; Garcia-Nunez, J.A.

https://doi.org/10.5071/29thEUBCE2021-2CV.3.9

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IMPROVING SUSTAINABILITY AND CIRCULARITY OF PALM OIL BY ANAEROBIC DIGESTION OF EMPTY FRUIT BUNCH, MESOCARP FIBRE, AND PALM OIL MILL EFFLUENT, ENABLING SELF-SUFFICIENT ENERGY PRODUCTION FROM BIOGAS

J.A. Voogt[1], J.C. Barrera Hernandez[2], J.W. van Groenestijn[1], H.W. Elbersen [1], J.A. Garcia-Nunez[2]
[1]Wageningen Food & Biobased Research, P.O. Box 17, 6700 AA Wageningen, The Netherlands
[2]Colombian Oil Palm Research Centre, Cenipalma, Bogotá, Colombia
julien.voogt@wur.nl

ABSTRACT: The sustainability and circularity of the production of palm oil can be improved by anaerobic digestion of EFB, MF, and POME. Anaerobic digestion experiments with untreated and steam treated EFB and MF were performed. It was experimentally proven that steam treatment of EFB and MF improves the anaerobic digestibility of these residues. Alternative conceptual palm oil mill set-ups, including anaerobic digestion, were analysed on techno-economic, environmental, and circularity aspects. The biogas from the EFB, MF, and POME can provide enough energy to be self-sufficient in steam and electricity. If the steam boiler runs on biogas instead of biomass, no cyclone and electrostatic filter are required for emission control, which equalizes the fixed capital costs related to a biogas system. Preventing methane emission from open POME ponds drastically decreases GHG emission. Besides, extra revenues can be obtained from surplus electricity. Moreover, the nutrients and recalcitrant organic matter are preserved in the sludge and effluent, which can be returned to the soil of the plantation.

Keywords: anaerobic digestion, palm oil, residues, economics, greenhouse gases (GHG), circular economy

1 INTRODUCTION

Colombia is the largest palm oil producer outside of Asia. To expand the sales market, it is important to improve the sustainability and circularity of palm oil production.

1.1 Palm oil production

An oil palm reaches a stable production at seven years [1]. The productive cycle of an oil palm is around 25 years, where palms are eradicated due to the difficulty of harvesting the fruits due to the height of the palm [2]. The harvested fresh fruit bunches (FFB) form the raw material, which are used in palm oil mills (POM) to extract the two main commercial products: crude palm oil (CPO) and palm kernel oil. During this process, residues are generated including empty fruit bunch (EFB), mesocarp fibre (MF), palm kernel shell, and palm oil mill effluent (POME).

The FFB entering the POM passes through sterilization vessels with the aim to stop the effect of the lipase on the oil acidification. Additionally, the thermal action dehydrates the biomass structures facilitating the detachment of the fruits, the liberation of the encapsulated oil and the drying of the nuts to facilitate its separation [3]. The EFB is obtained as a by-product in the de-fruiting process, where a stripping drum is used to separate the loose fruits from the EFB. The EFB comprises 21% of the weight of the FFB and comes out with a moisture of 66% [2]. The loose fruits are digested and pressed, generating two streams: a liquid phase (press liquor) and a solid phase (press cake). The press liquor is mainly composed of CPO with some impurities. The press liquor is clarified, where the CPO is separated, dried and stored for commercialization [4]. The press cake composed of the MF impregnated with oil and the palm nuts is separated using winnowing columns, taking advantage of the difference in density of these materials. Between 13% of the FFB weight belongs to MF with an average moisture of 35%. [5]. The recovered nuts from the press cake are dried in silos with hot air at controlled temperature. The nuts are milled to obtain the kernel (5% of the FFB) and the shell (5% of the FFB) [6].

The POME that considers the moisture of the FFB, the remaining water of the steam sterilization of the FFB, and the water added in the process to facilitate the separation of CPO. The POM produces approximately 670 m^3 POME per tonne FFB [7]. This effluent is mainly composed of organic material with a level of total solids of approximately 9% of the FFB.

1.2 Process improvements

Recently some emerging technologies have been development to improve the efficiency of palm oil processing. These technologies improve the oil recovery and the energy and water consumption.

EFB pressing is an additional process that is used in some POMs. The aim of this process is recovery a portion of the oil impregnated in the EFB. Usually, a screw press is used to press the EFB.

According to [8], it is feasible improve the steam consumption in POM using energetic integration or pinch analysis. Up to 60% of the steam consumption is required for the sterilization and the digestion. It is possible to reduce the steam consumption by upgrading the operation conditions using the residual heat from streams like POME. Reducing steam consumption also results in water savings.

Steam and water consumption can also be saved by using dynamic clarification, which is an alternative process for static clarification [4]. The dynamic clarification process uses a decanter that separates the press liquor in three phases. In the first phase the CPO is recovered, the other two phases are a liquid and solid sludge. It was identified that the dilution required for dynamic clarification was 1.8 oil/water compared to a dilution of 1.4 oil/water for static clarification, which represents a 30% decrease of overall water consumption of the POM.

1.3 Use of residual biomass and alternatives

MF and shell are generally used as solid fuel in biomass boilers to generate the steam required for the POM. Ash from the biomass boilers can be used as fertilizer in the plantation. The EFB is usually returned to the plantation and used as mulch. POME is generally treated in open ponds and facultative lagoons before the effluent is discharged [9–13].

The treatment of POME in open ponds causes a high methane emission. An obvious measure to prevent this methane emission, which currently only is applied at a limited number of Colombian POMs [14], is turning the open POME ponds into covered lagoons. This not only prevents methane emission, but the captured biogas can be used to generate electricity.

Once a covered lagoon is available, also other residues can be anaerobically digested. Anaerobic digestion of EFB, MF and POME can be beneficial. The biogas from these three residues can provide enough energy for a POM to be self-sufficient in both steam and electricity. Furthermore, if the steam boiler runs on biogas instead of biomass, no cyclone and electrostatic filter are required for emission control. Besides, extra revenues can be obtained from surplus electricity and the export of shell. Moreover, the nutrients (N, P, and K) and recalcitrant organic matter (lignin) are preserved in the sludge and effluent, which can be returned to the soil of the plantation.

To improve the biogas yield and to increase the speed of the anaerobic digestion of lignocellulosic material like EFB and MF, the biomass can be steam treated for a few minutes at a temperature of approximately 200°C. In this study, anaerobic digestion experiments of untreated and steam treated EFB and MF were performed.

A scenario analysis was performed to investigate the efficiency of the alternative residue use. Four POM set-ups were defined and analysed. The composition and size of the input and output streams were determined and for all set-ups the mass, mineral, and energy balances were obtained. The analysis included a techno-economic analysis, GHG emission performance, and circularity performance.

2 SCENARIO DEFINITION

Four POM set-ups were defined:

- Base case: Combustion of MF (and 13% of shell) for steam generation, electricity from the grid, EFB is returned to plantation as mulch, POME is treated in open ponds and the sludge and effluent are returned to the plantation.
- Case 1: Same as the Base case except POME is anaerobically digested in covered lagoons and the collected biogas is used to generate electricity.
- Case 2a: Besides POME, also EFB and MF are anaerobically digested in covered lagoons and the collected biogas is used to produce both steam and electricity.
- Case 2b: Same as Case 2a except the EFB and MF are steam treated before they are anaerobically digested.

In this study, processing the kernel into palm kernel oil is not considered. Both the CPO and kernel are assumed to be final products of the POM.

For all the cases, the EFB is pressed, as described in the introduction.

3 STEAM TREATMENT AND ANAEROBIC DIGESTION OF PALM OIL MILL RESIDUES

Anaerobic digestion experiments with untreated and steam treated EFB and MF were performed. The anaerobic digestion experiments lasted 2 months. The EFB and MF were steam treated at approximately 200°C for approximately 20 minutes. The results of the anaerobic digestion experiments are shown in Table I.

The assumed biogas production from POME is based experimental data from Colombian POMs and expert knowledge of Cenipalma.

Table I: Experimentally determined and assumed biogas production of EFB, MF, and POME

		Untreated		Steam treated	
	POME	EFB	MF	EFB	MF
DW	9%	44%	65%	44%	65%
Moisture	91%	56%	35%	56%	35%
Experimentally determined					
OM removal		56%	35%	66%	46%
Biogas production (m3/tonne OM in)		350	260	475	360
Increased production				36%	38%
CH4 content		54%	59%	54%	59%
Assumed in scenario analysis					
Increased OM removal		10%	20%	10%	20%
OM removal	85%	62%	42%	73%	55%
Biogas production					
(m3/tonne OM in)	538	385	312	523	432
(m3/tonne FW)	39	161	197	219	272
CH4 content	65%	54%	59%	54%	59%

Both the untreated EFB and MF produced a significant amount of biogas. The steam treatment of EFB and MF improved the anaerobic digestibility of these residues. Both the organic matter (OM) removal and biogas production were increased. The steam treatment also increased the speed of the anaerobic digestion.

These biogas yields were determined in laboratory scale biodigesters that were inoculated with sludge that never had converted EFB and MF before. It is likely that in practice, the bacteria in the sludge of a biodigester will adapt to the new substrate within months by natural selection. Because of this effect the biogas yield will gradually increase. It is assumed that compared to the experimentally determined values, the OM removal and biogas production will increase 10% for EFB and 20% for MF. These assumed values were used in the scenario analysis.

4 ASSSUMPTIONS

The assumptions regarding the scenario analysis are based on literature. The main sources were [6,14,15] , which were complemented with the sources in the introduction [1–13] and [16–29]. Furthermore, experimental data from Colombian POMs, quotes from Colombian equipment suppliers, and expert knowledge of Cenipalma and Wageningen Food and Biobased Research was used.

4.1 General assumptions

Each scenario is designed as hypothetical POM with an average capacity (i.e. medium size) for Colombia. The POM has a capacity of processing 30 tonnes FFB per hour, with 5,000 production hours annually, it will serve a plantation of approximately 8200 ha. It produces 6.4 tonnes CPO and 1.8 tonnes kernel per hour.

The POM has a steam consumption of 400 kg per tonne of FFB assuming an efficient heat exchange network and dynamic clarification process. Water consumption is assumed to be 313 kg of water per tonne of FFB. In the Base case and Case 1, the steam is generated in a biomass boiler using all the MF and a small fraction of the shell (13% of total available). The efficiency of the biomass boiler is assumed to be 60%. In Case 2a and 2b, the steam is generated in a biogas boiler with an efficiency of 87%.

The steam treatment of the EFB an MF in Case 2b requires 0.3 tonnes steam per tonne biomass of which 50% is assumed to be recovered.

The electricity consumption in the Base case and Case 1 is 22 kWh per tonne FFB. In Case 2a and 2b, the electricity consumption is corrected for the cyclone and electrostatic filter (which are not required) and the biogas system. A biogas generator is assumed to have an efficiency of 35%.

The general assumptions regarding the scenarios are summarized in Table II.

Table II: General assumptions regarding the scenarios

Throughput	30	tonnes FFB/h
Annual throughput	150	ktonnes FFB/y
Oil extraction rate	21.4%	t CPO/t FFB
Output	6.4	tonnes CPO/h
Annual output	32	ktonnes CPO/y
Plantation area	8200	ha
Annual production hours*	5000	h/y
Steam consumption	400	kg/tonne FFB
Water consumption	313	m3/tonne FFB
Electricity consumption		
- Base case POM	22	kWh/tonne FFB
- Cyclone & electr. filter	4.5	kWh/tonne FFB
- Biogas system	0.2	kWh/m3 biogas
Steam treatment	0.3	t steam/t biomass
Steam recovery	50%	
Energy content CH_4	10	kWh/m3 CH_4
Biogas leakage	3%	
Biomass boiler efficiency	60%	
Biogas generator efficiency	35%	
Biogas boiler efficiency	87%	

*Flows for ponds & lagoons are also scaled to 5000 h/y

4.2 Size and composition of input and output streams

The sizes (Table III) and composition (Table IV) of the input and output streams of the POM are determined.

Table III: Size (relative to FFB) and DW of input and output streams of a POM

		Fraction of FFB (% of FW)	(% of DW)	DW (kg/kg)
Input	FFB	100%	100%	55%
	Steam	40%		
	Water	31%		
Output	CPO	21%	39%	100%
	EFB	19%	15%	44%
	MF	13%	16%	65%
	Shell	6%	9%	85%
	Kernel	6%	11%	95%
	POME	67%	10%	8%
	Vapor	39%		

Due to varieties in the composition and characteristics of the residues through reports and literature, the sizes and composition of the streams are based on adapted values from a large number of sources. Undefined organic matter (Und. OM) is included in the composition of the streams, which makes the composition of each individual stream add up to 100%. The composition of the FFB is calculated based the composition of the output streams.

Table IV: Composition of input and output streams of a POM

	Input	**Output**				
	FFB	EFB	MF	Shell	Kernel	POME
Oil	46%	3.2%	1.4%	1.0%	50%	11%
Fibre	39%	88%	88%	91%	38%	
- Lignin	12%	20%	25%	49%	5.5%	
- Cellulose	14%	36%	33%	20%	17%	
- Hemicell.	13%	33%	30%	22%	15%	
Protein	2.7%	4.1%	3.8%	2.7%	8.5%	3.2%
Und. OM	8.5%	0.2%	3.8%	4.0%	1.5%	71%
Ash	3.1%	4.5%	3.1%	1.3%	2.3%	15%
N	0.6%	0.7%	0.6%	0.4%	3.0%	0.5%
P	0.1%	0.1%	0.1%	0.0%	0.6%	0.1%
K	0.6%	1.6%	0.3%	0.3%	0.9%	1.5%

4.3 Techno-economic analysis

The assumption regarding the economics and fertilizer prices are shown in Table V and Table VI respectively. The revenues from electricity are close to half the costs of electricity. Revenues from shell and MF are based on their energy content when used as solid fuel in a biomass boiler. Fertilizer and nutrient prices are based on 50 kg bags delivered at the plantation.

Table V: Assumptions regarding the economics

Costs		
FFB	76	$/tonne
Electricity (from grid)	0.13	$/kWh
Water preparation	0.16	$/m3
POME handling	0.22	$/m3
EFB, Sludge, Effluent handling	4.32	$/tonne
Labour & Management	716	k$/y
Maintenance	2.5%	of fixed capital/y
Fixed capital scaling power	0.6	
Revenues		
Crude palm oil	445	$/tonne
Palm Kernel	264	$/tonne
Shell	16	$/tonne
MF	8	$/tonne
Electricity (to grid)	0.06	$/kWh
Prevented CO2 eq emission	5	$/tonne

Table VI: Assumptions regarding the fertilizer and nutrient prices

Fertilizer	Urea	Rock phosphate	Muriate of potash
Content	N	P2O5	K2O
(kg/kg fertilizer)	46%	30%	60%
Content	N	P	K
(kg element/kg fert.)	46%	13%	50%
Price ($/kg fertilizer)	0.76	0.44	0.64
($/kg element)	1.7	3.4	1.3

4.4 GHG emission performance

The parameters regarding the CO_2 eq emission estimation are shown in Table VII. The CO_2 eq emission from electricity from the grid is based on Colombian electricity generation from coal and gas only, assuming electricity from biomass and biogas will replace electricity from these carbon sources.

Table VII: Parameters regarding the CO_2 eq emission

Parameter	Value	Unit
CH_4	25	kg CO_2 eq/kg CH_4
N_2O	298	kg CO_2 eq/kg N_2O
Coal combustion	98	kg CO_2 eq/GJ
Electricity from grid (from coal and gas)	0.76	kg CO_2 eq/kWhe

Prevented emissions of fertilizer replacement and emissions of biomass and biogas combustion, and transport of EFB, sludge and effluent were also included in the analysis, but were negligible and are therefore not shown.

5 SCENARIO ANALYSIS

5.1 Mass, mineral and energy balance

For each case a conceptual process is designed. Based on these conceptual process designs and the assumptions in the previous chapter, the mass, mineral, and energy balances are determined (Table VIII).

Table VIII: Mass, mineral and energy balance

	Base case	**Case 1**	**Case 2a**	**Case 2b**
Input (ktonnes/y)				
FFB	150	150	150	150
Water	107	107	107	114
Output (ktonnes/y)				
Crude palm oil	32	32	32	32
Palm kernel	9	9	9	9
Shell	8	8	9	9
EFB	28	28		
Ash	0.4	0.4		
Effluent	88	88	5	31
Sludge	6	6	124	95
To plantation (ktonnes/y)				
Lignin	2440	2440	5635	5635
N	125	125	202	202
P	27	27	27	27
K	368	368	366	366
Biogas (Mm3/y)	3.9	3.9	12.3	15.4
Methane content	65%	65%	59%	59%
Electricity (MWh/y)				
- produced from biogas		8880	7010	10609
- use biogas system		781	2461	3082
- use POM	3300	3300	2625	2625
- to grid		4799	1924	4901
CO2 eq emission (ktonnes/y)	31	-16	-14	-16

An obvious difference between the cases is the amount of produced biogas. As in Case 2a and 2b, besides the POME, also the EFB and MF are anaerobically digested, the biogas production is 3 to 4 times larger compared to Case 1.

In Case 2a and 2b the largest part of the biogas is used to generate steam. The remaining biogas is converted into electricity, which is used by the POM including the biogas system. Surplus electricity is sold to the grid.

Because in Case 2a and 2b EFB and MF are also anaerobically digested, the amount of undigested matter in the covered lagoons increases. As a result, much more sludge compared to effluent is generated, which effects the options of bringing back the residue streams to the plantation. Although the sludge is assumed to be pumpable, it is unsuitable for fertigation systems. A mixture of effluent and sludge is likely to be distributed in the plantation using slurry tanks.

5.2 Techno-economic analysis

The fixed capital investment is assumed to be for a grass roots plant and includes equipment, installation, design and engineering, and infrastructure. The fixed capital investment is estimated based on the required equipment and relevant size (Table IX).

Table IX: Required equipment and fixed capital in M$

	Base case	**Case 1**	**Case 2a**	**Case 2b**
POM	20.0	20.0	20.0	20.0
Biomass boiler	0.6	0.6		
Cyclone	0.1	0.1		
Electrostatic filter	0.3	0.3		
POME ponds	0.4			
Covered lagoon		0.5	0.6	0.6
Biogas treatment		0.3	0.6	0.7
Biogas generator		0.3	0.3	0.3
Biogas boiler			0.5	0.6
Steam treatment				1.4
Total fixed capital	**21.4**	**22.1**	**22.0**	**23.6**

The fixed capital investment of the different case is very comparable. The capital costs of a biomass boiler are comparable to a biogas boiler, the capital costs of a covered lagoon are slightly higher compared to POME ponds, and the capital costs of the biogas treatment are slightly higher compared to a cyclone and electrostatic filter. Only the steam treatment in Case 2b makes a significant difference in the fixed capital investment.

Economic indicators are after tax and based on a 10-year period. The interest rate is assumed to be 2%, the tax rate is assumed to be 32%, and the depreciation method is 10-year straight line (Table X).

Table X: Economic indicators

	Base case	**Case 1**	**Case 2a**	**Case 2b**
Average cash flow (M$/y)	3.4	4.1	4.1	4.2
Simple pay-back period (y)	6.2	5.4	5.4	5.6
Net present value (M$)	9.6	15.0	14.7	14.5
Internal rate of return	10%	14%	13%	13%

The main contributor to the costs is the costs for the

FFB. This contribution ranges from 83% to 86% for the different cases. The main contributors to the revenues are the CPO (ranges from 78% to 81%) and the kernel (ranges from 13% to 14%). Compared to the Base case, no clear extra costs are required, but also no clear cost savings or extra revenues are made in the alternative POM set-ups. Only purchasing electricity from the grid in the Base case compared to selling electricity in the other cases, makes a significant difference in the average cash flow. This results in a slightly longer pay-back period and a lower net present value and internal rate of return.

5.3 GHG emission performance

The main items which determine the CO_2 eq emission and prevented CO_2 eq emission of the different case are shown in Figure 1.

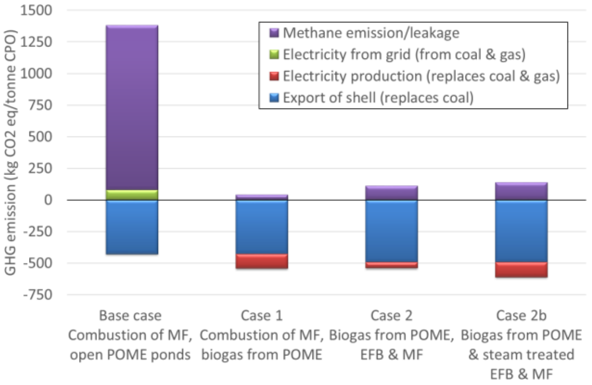

Figure 1: GHG emission performance of the defined cases

The methane emission from the open POME ponds in the Base case is by far the largest contributor to the GHG emission. By using covered lagoons and capturing the biogas, the GHG emission of the POM is drastically reduced. Because of the larger biogas production in Case 2a and 2b compared to Case 1, the related leakage is also larger.

Generating electricity from biogas (Case 1, 2a, and 2b) has, compared to getting electricity from the grid in the Base case, a relatively small effect on the GHG emission performance.

The export of shell, which replaces coal, has a significant contribution to the prevented CO_2 eq emission. However, the amount of exported shell is in the Base case and Case 1 only 13% lower compared to Case 2a and 2b, which makes the effect on the overall GHG emission performance small.

5.4 Circularity performance

The circularity performance is based on the useful components in the residue streams, which are brought back to the plantation. In the study the lignin is considered recalcitrant organic matter which is assumed to improve the texture and water holding capacity of the soil. The N, P, and K in the residue streams are nutrients for the plantation, which replace mineral fertilizers.

For the Base case and Case 1, the residue streams and their composition are the same. The lignin and nutrient content of the combined sludge and effluent of Case 2a and 2b are also the same. The lignin and nutrients which are returned to the plantation are expressed as percentage of the component in the FFB and are shown in Figure 2.

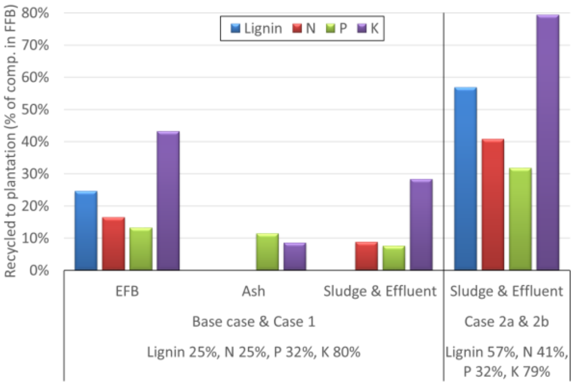

Figure 2: Circularity performance, the totals are given below the X-axes

In the Base case and Case 1, the mulched EFB, ash from the biomass boiler, and sludge and effluent are used as fertilizer in the plantation. In Case 2a and 2b the sludge and effluent are the only residue streams which are used as fertilizer in the plantation.

The main difference in the circularity performance is caused by the use of MF in the biomass boiler in the Base case and Case 1. By burning the MF, the lignin and N cannot be recovered. By anaerobic digestion, in Case 2a and 2b, the lignin and N are preserved in the sludge and effluent.

The fact that the lignin and nutrients in the mulched EFB and the nutrients in the ash are probably less effective for fertilizer application, compared to the lignin and minerals in the sludge and effluent, is not incorporated in this study.

6 DISCUSSION

The economic advantages of applying steam treatment on EFB an MF are not distinctive. Despite a larger biogas production and electricity revenues, the steam treatment has a significant contribution to the fixed capital costs. However, if a rapid anaerobic digestion of EFB and MF is required to prevent clogging of the covered lagoons, steam treatment is probably obligated.

As the anaerobic digestion of EFB and MF increases the amount of undigested matter in the covered lagoons, much more sludge compared to effluent is generated, which reduces the options of bringing back the residue streams to the plantation. Sludge is unsuitable for fertigation systems. Distributing a mixture of sludge and effluent in the plantation using slurry tanks is an option.

The effect of the alternative POM set-ups on the performance seems limited. It should however be noted that based on the general assumptions, the palm oil mil representing the Base case is already very efficient in steam and electricity consumption. Furthermore, in this study, the recalcitrant organic matter has no economic value and the value of the nutrients, which are based on mineral fertilizer prices, are low.

The circularity performance should not only include the mass and mineral balance, but also the include the effectiveness in fertilizer applications of the different component in the different residues. Besides, not only lignin serves as functional soil organic matter, but also bacterial cell walls, present in the sludge, can improve the soil. The functionality and value of these components should be determined more accurately.

7 CONCLUSIONS

It is concluded that the sustainability and circularity of the production of palm oil can be improved by anaerobic digestion of EFB, MF, and POME. The biogas from these residues can provide enough energy to be self-sufficient in steam and electricity.

It was experimentally proven that steam treatment of EFB and MF improves the anaerobic digestibility. Both the organic matter removal and biogas production were increased. The steam treatment also increased the speed of the anaerobic digestion, which might be required to be able to anaerobically digests these residues in covered lagoons.

The techno-economic analysis showed that, if the steam boiler runs on biogas instead of biomass, no cyclone and electrostatic filter are required for emission control, which equalizes the fixed capital related to a biogas system.

In the alternative POM set-ups, no clear extra costs are required, but also no clear cost savings or extra revenues are made. A small extra profit is realized by generating the required electricity and getting revenues from surplus electricity.

From a sustainability perspective it was demonstrated that the methane emission from the open POME ponds by far is the largest contributor to the GHG emission of a POM. By using covered lagoons and capturing the biogas, the GHG emission of the POM can be drastically reduced.

Regarding the circularity performance, it was shown that are preserved in the sludge and effluent, which can be returned to the soil of the plantation.

The main difference in the circularity performance is caused by the use MF in the biomass boiler in the Base case and Case 1. By burning the MF, the lignin and N cannot be recovered. By anaerobic digestion of EFB, MF and POME, the recalcitrant organic matter (lignin) and nutrients (N, P, and K) are preserved in the sludge and effluent. Moreover, the recalcitrant organic matter and nutrients in the sludge and effluent are likely to be more effective when applied as fertilizer, compared to the recalcitrant organic matter and nutrients in mulched EFB and the nutrients in boiler ash.

If the efficiency of the utility use of a POM is further improved, the biogas from anaerobic digestion of EFB and POME might be sufficient to cover the energy demand. In that case, it is not required to anaerobically digest the MF. The MF has a high fibre and cellulose content which can be used in material applications. Valorising the MF in material applications can increase the total added value of POM products. Moreover, it will result in land sparing as it replaces biobased fibre and cellulose sources.

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9 ACKNOWLEDGEMENTS

This project has been partially financed through the BO-43-003.02-017 "Sustainable Palm Oil Colombia" project financed by the Dutch Ministry of Agriculture, Nature and Food Quality, and partially by the Colombian Oil Palm Development Fund.

A Knowledge to Knowledge (K2K) agreement is established between Wageningen University and Research (the Netherlands) and Cenipalma (Colombia). The K2K aims to boost a circular economy in the palm oil sector. It addresses efficient use of land, nutrients, and biomass. The objective is to increase circularity of resource use on the field and in the palm oil mill.

10 LOGO SPACE

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