Chapter 5

A Case Study for Application of the “Decision Support Tool”

Sustainability Assessment of Biomass Utilisation in East Asia Working Group

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CHAPTER 5

A Case Study for Application of the "Decision Support Tool"

1. Introduction

Over the last decade, the interest in biomass as a renewable resource has grown rapidly, for both energy and material applications. Biomass for energy has been a primeval practice, where woody plants served as firewood for fuel. Today, modern uses of biomass as fuel or bioenergy adopt various technologies that convert biomass to briquettes, pellets or a gaseous mixture known as "synthesis gas", commonly abbreviated to "syngas", to enhance their calorific value and thus combustion efficiency. An example is the need to transform whole Empty Fruit Bunches (FFB) to a form of energy carrier to enhance their efficiency of conversion to energy, which has been reported to be around 20% (15-25%) when EFBs are directly combusted in boilers to produce heat and steam (Rahman, *et al.* 2004).

Although the sector where biomass use has been widely discussed at the global level is energy, biomass is also a renewable feedstock for product development in biomaterials and bio-chemicals. Bio-composites production, comprising biomass fibers bound in synthetic or in-situ natural polymeric resins, is a well-established industrial process producing wood polymer composites for building materials and furniture making. Research is ongoing towards commercial-scale bioprocesses to transform biomass into biochemicals such as polylactic acid, polyhydroxyalkanoates and polyamides. These would be competing uses of biomass.

The National Biomass Strategy of Malaysia (AIM, 2011) has projected that by year 2020, there will be an additional 20 million tons of palm biomass to be exploited. Through concerted efforts by government agencies and private companies in realizing the biomass potential as feedstock for biomaterials, bioenergy and biochemicals, it is estimated that the biomass value chains will enhance the Malaysian Gross National Income (GNI) by 30 billion Malaysian Ringgit (MYR) or

4.7 billion US dollar (USD) (using the approximate currency conversion rate of 1 USD = 6.4 MYR) and in tandem, support new employment of 40,000 high skill and 27,000 low skill workers.

Palm biomass, like all biomass, is hence a renewable feedstock with two established applications and one up-coming potential application in the forms of bioenergy, biomaterials and biochemicals. For a given biomass feedstock, decision makers in both the public and private sectors will be presented with options such as type of utilization and technology systems. At the same time, for a given end-use, there are multiple options on the type of biomass feedstock to be mass produced.

The objective of the case study is to apply the sustainability assessment methodology developed under ERIA to identify the most sustainable utilization of oil palm biomass (EFB) as biomaterial or bioenergy, as against the existing practice of in-situ or on-site fertilization, based on life cycle assessment (LCA) and socio-economic benefit using indicators to represent social impact, economic impact and environmental impact (specifically climate change).

2. Biomass from the Palm Oil Industry

The palm oil industry not only provides palm oil and palm kernel oil for food, industrial and consumer products utilization. The industry also generates a huge amount of biomass from its agriculture and milling activities. The importance of biomass in the palm oil industry is reflected by the fact that oil is only 10% of the total produce of an oil palm plantation. The rest is biomass, comprising predominantly oil palm wastes from milling such as oil palm shells (OPS), mesocarp fibers (MF) empty fruit bunches (EFB), and residues left in the field during replanting, namely oil palm fronds (OPF) and oil palm trunks (OPT). EFB is the residue left after oil is extracted from fresh fruit bunches (FFB).

Although OPF and OPT are good sources of woody biomass and have been used for animal feed and as logs for furniture, these two sources of woody biomass are still relatively untapped due to limited accessibility in terms of transporting them to processing sites. EFB on the other hand is a milling residue generated at all palm oil mills and poses a disposal problem that can be overcome by using this accumulated agro-waste for commercial applications such as bioenergy or biomaterials. Most palm oil mills that are located in close proximity to oil palm plantations will send a certain portion of the EFB back to the plantations for mulching. EFB is an agro-residue with many choices of utilization. This biomass is a good material to apply the sustainability assessment methodology to, evaluating the various options in a holistic approach.

3. Properties of EFB

For every ton of FFB that is processed, about 22% of its weight is left as EFB. The average yield of FFB in the typical oil palm plantation in Malaysia is 20 ton FFB/ha or 4.4 ton EFB/ha. In 2009, Malaysia had a total oil palm plantation of 4,691,160 ha (MPIC, 2010), which means that for that particular year, about 21 million ton of EFB was produced in the country.

The nutrient contents of EFB, although variable, are significant. The nitrogen content has been reported to range between 0.34 – 0.66%, with a mean of 0.54%; phosphorus 0.03-0.10% with a mean of 0.06%; potassium 1.20 - 2.40% with a mean of 2.03%; and magnesium 0.17-0.20% with a mean of 0.19% (Heriansyah, 2011). Hence EFB is a good source of organic matter and plant nutrients.

The most prevalent practice at the palm oil mills is to send some of the EFBs back to the oil palm plantations for mulching. Mulching is the practice of applying biomass such as EFB on the soil surface to reduce temperature and conserve moisture, in addition to supplying varying amounts of nutrients as they degrade. It has been reported that EFB mulching at about 27 ton/ha is equivalent to current practices of applying mineral (inorganic) fertilizers (Loong *et al.*, 1987).

Tables 1 and Table 2 illustrate the importance of EFB in improving soil condition and productivity (Mannan, 2012).

Table1: Fertilizer Equivalence of 1 ton EFB

Type of Fertilizer	Equivalent quantity of nutrient
Urea	3.8 kg
Rock phosphate	3.9 kg
Muriate of potash	18.0 kg
Kieserite	9.2 kg

Table 2: Nutrient Equivalence of 1 ton EFB

Type of Nutrient	Composition as a percentage of dry matter
Nitrogen (N)	0.44
Phosphorous (P)	0.144
Potassium (K)	2.24
Magnesium (Mg)	0.36
Calcium (Ca)	0.36

Aside from agricultural applications, including use in animal feed supplement, EFBs are also increasingly used for bioenergy. One of the main reasons for the inability to use all of the EFBs for mulching in the plantations is the transportation distance. It is not economic to move the EFBs to plantations beyond a certain distance.

Non-agricultural applications of EFB include conversion to biomaterials for the following end-products:

- a material for composite wood-based products (particle boards, medium density fiberboards, biofiber composite profiles)
- pulp & paper
- filler material for pipes and conduits

Feedstock for conversion into bioenergy existing in various forms of energy carriers such as:

- Pellets
- Bioethanol
- Syngas

One of the unique properties of EFB, even when converted into fibrous material, is the presence of lignin with an adhesive property. It has been reported that biofiber materials, and pellets produced from fibrous EFB, do not need external adhesive to bind the fibers. Appropriate heating is able to just melt the lignin to take on the adhesive function.

4. Sustainability Assessment Methodology

The past case studies conducted by the ERIA WG have shown the viability of using the sustainability assessment methodology to evaluate the utilization of biomass for fuel or bioenergy. It is the intention of this case study to test the suitability of the assessment methodology to evaluate the utilization of a biomass feedstock for applications in two different domains i.e. bioenergy and biomaterials.

Sustainability assessment methodology on the utilization of woody biomass will be based on life cycle GHG emissions for environmental impact, job creation for social impact, and total value addition for economic impact for the two different domains.

The production and utilization of any form of biomass as energy carrier or as material for further downstream applications as in furniture or building materials cover three major stages, namely:

- feedstock supply
- processing
- conversion

EFB is generated as long as crude palm oil is produced. The supply of EFB is therefore dependent on the yield at the plantation, irrespective of its subsequent utilization. Although many types of EFB utilizations are reported or known, EFB is still considered as a form of agro-waste and does not fetch a good price in the unprocessed form. The processing of EFB includes removal of residual oil, shredding and desizing to short fine fibers, and these processes are common for both bioenergy and biomaterial applications.

The increasingly popular form of EFB biofuel is in the form of pellets, while EFB can also be converted to boards or profiles for use in furniture-making. In assessing the sustainability of the two routes of utilization for the same feedstock, the divergence occurs only from the conversion stage onwards. The sustainability assessment to evaluate utilization of EFB as pellets for fuel or as biomaterials will have similar input for the two stages of feedstock supply and processing as illustrated in Figures 5-1 and 5-2. As there are many types of biomaterials, the specific type that will be described in this study is the biofiber wood composite profiles produced from extrusion of a mixture of EFB-fiber and resins using a typical extruder (hereinafter referred to as biofiber composite profiles).

Figure 1: System Boundary for Conversion of EFB to Pellets for Use as Fuel.

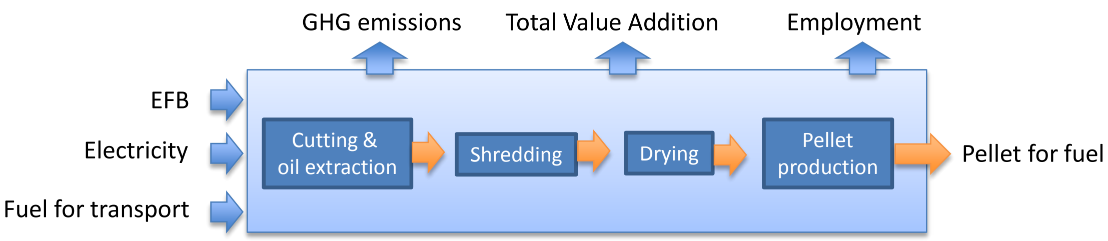
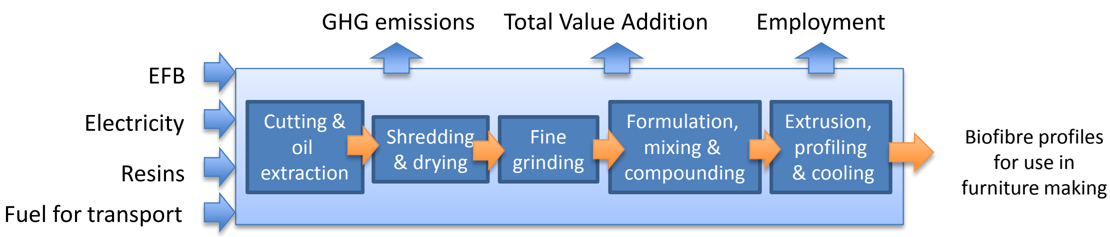


Figure 2: System Boundary for Conversion of EFB to Biofiber Composite Profiles (Wood Plastic Composite Containing 70% Biofiber) for Use in Furniture Making.



4.1. Environmental Indicator

For this study, the environmental indicator for the sustainability assessment of EFB is the life cycle greenhouse gas profile. The surge in interest in biomass has been attributed largely to the perception that it is not only a renewable resource but also contributes to a reduction in greenhouse gases based on the concept of carbon neutrality at the point of combustion. However, from the life cycle perspective, there are net emissions related to land-use change, agricultural practices, logistics, processing and conversion of the biomass to different forms of bioenergy.

Although EFB has been used for diverse applications, it is still considered an agro-waste in the production of crude palm oil and palm kernel oil. EFB is therefore not allocated any environmental burden from the upstream processes in the life cycle system boundary (land use change, oil palm cultivation, transportation of FFB and palm oil milling). In other words, EFB as a raw material by itself does not carry any CO_2eq burden. The emission associated with the use of EFB will come mainly from transportation of the material from point of generation to the point of use and subsequent processing.

Based on this background scenario, the life cycle inventory analysis of EFB for the two routes of application is tabulated in Table 3.

Table 3: Life Cycle Inventory Analysis for Conversion of EFB to Pellets and Biofiber Composite Profiles.

Parameter	Description
Goal of study	To establish the greenhouse gas emission of two different EFB-based products. The greenhouse gas emissions of the two EFB-based products will be compared with respect to the EFB consumed and used for a specific utilization.
Function	• Pellets produced from EFB for use as fuel – for the system boundary illustrated in Figure 5-1 • Biofiber composite profiles produced from EFB for furniture making - for the system boundary illustrated in Figure 5-2
Functional Unit	1 ton of EFB consumed to produce the specific product (pellets or biofiber composite profiles).
System Boundary	Pretreatment of EFB to fibrous material and conversion to different forms as pellets and biofiber composite profiles. The system boundaries are shown in Figures 5-1 and 5-2.

4.2. Economic Indicator

Based on the latest version of the ERIA WG methodology presented in ERIA Research Project Report 2010, No. 22 (November 2011), the economic assessment can be presented by two levels of indicators: a master indicator and a few sub-indicators.

The master economic indicator to calculate the economic impact of a particular form of biomass utilization is the Total Value Addition (TVA), while the sub-indicators are: employment, net profits and tax revenues.

TVA in the ERIA WG methodology is calculated per unit mass of biomass production as shown in Equation (5-1):

$$\begin{aligned} TVA &= \textit{Output value} \text{ (or } \textit{Gross revenue}) - \textit{Cost of intermediates} \\ &= \sum \textit{Price} \times \textit{Output quantity} - \textit{Cost of intermediates} \qquad \text{(5-1)} \end{aligned}$$

- Gross revenue applies to income from the main products (pellets and biofiber composite profiles) and by-products (none for both system boundaries)
- Intermediates include goods and services, other than assets used as inputs in the production of pellets and biofiber composite profiles namely whole EFBs from the mills, and EFB fibers, additives and utilities.
- Total returns of primary output and by-products will be based on market sale prices e.g. current market price for pellets and biofiber composite profiles.
- Total cost of intermediates will be based on market sales prices of input materials and utilities.

The sub-indicators include:

- Labor income
- Net profit
- Tax revenues

- Foreign exchange earnings

Capital costs, although a significant component of any investment will be reported but not included as an indicator.

The eventual TVA and sub-indicator values are reported as per unit of EFB consumed instead of per unit of pellets or biofiber composite profiles produced. This is because both end-products require different amount of EFB, comparison based on the same amount of EFB consumed will refer to the same baseline.

The parameters where information is required to calculate TVA and sub-indicators for both types of EFB utilizations, are listed in Table 4.

Table 4: Data Required for Calculating TVA and Sub-indicators of EFB Utilisations.

Parameter	Pellets	Biofiber Composite Profiles
Gross Revenue		
Sales of primary output	Pellets	Profiles (for furniture assembly)
Sales of by-products	None	None
Cost of Intermediates		
Materials input (cost is at ex-factory gate for whole EFB and EFB fibers)	Whole EFB	Whole EFB
	EFB Fibers	EFB Fibers
		Polypropylene
		Additive
Services input	Electricity	Electricity
	Transport	Transport
Labor income (wages)		
Labor costs (only for converting EFB to fibrous material, pellets, fiber boards and furniture)	Monthly wages of manual workers + production engineer	Monthly wages of manual workers + production engineer
Net Profit = Total Returns – Total Costs (overhead included on top of cost of intermediates and labor income)		
Overhead costs (only for stages in the value chain relevant to conversion of EFB to specific end-product)	25% of direct cost of pellets (20% for corporate tax and 5% for duties, interest and depreciation)	30% of direct cost of profiles (20% for corporate tax and 5% for duties, interest and depreciation)
Tax Revenues		
Taxable income	Taxable income (profit) from sales of pellets at tax rate of 25% of net profit	Taxable income (profit) from sales of profiles (exclude furniture as the range of furniture possible is too broad) at tax rate of 25% of net profit
Foreign Exchange Earnings (not included in this study)		
Export (earnings)	Export of pellets	Export of profiles
Savings (import substitution)	None	None

4.3. Social Indicator

The social Indicator will be based mainly on job creation analyzed as follows:

- Number of jobs created compared to "business-as-usual" scenario i.e. current handling and usage of EFB
- Number of jobs that are applicable to both sexes
- Type of jobs created, whether increase at operator or professional level

5. A Case Study - Processing of EFB to Target End-Products

5.1. Scenario Setting

As this study is going to compare two forms of utilization of EFB, it is important to define clearly the common activities in their respective production, and the point where the processed EFB material will divert to different routes. The stages in the value chain production of pellets and biofiber composite profiles for use in furniture making are summarized in Table 5 together with hardware and material inputs.

The following assumptions are made in setting the scenario for eventual comparison:

- The EFB produced in a year by the generic palm oil mill will be consumed either for producing pellets, or biofiber composite profiles for furniture-making (as EFB is required for mulching in most plantations, only half of what is produced at the mill will be consumed for bioenergy or biomaterials).
- The pre-treatment of EFB to fibrous material that serves as raw material for pellets and biofiber composite profiles for furniture assembly will be carried out at the mill. This is a logical approach as transportation of wet and unprocessed EFB incurs high transportation cost.
- Transportation impact will be considered only from the mill to the factories that are converting the fibrous EFB material to pellets or biofiber composite profiles. The transportation distance from mill to the respective destination for conversion to pellets or biofiber composite profiles is assumed the same.

Secondary data will be obtained and used for the input-output approach as shown in Table 5-5. The modeling will be done on a 60 ton/hour capacity plant operating 280 days/year for an average of 16 hours per day. The plant will generate ~54,000 ton EFB/year at dry weight or ~162,000 ton EFB/year containing 70% moisture.

It should also be noted the plant capacities, in particular the designated capacities at the conversion stage, are not realistic. For comparison, it is assumed that the plant is designed to handle half the daily production of the total EFB produced at the 60 ton/hour capacity palm oil mill, which will be consumed either as bioenergy or biomaterial. Some capital goods, especially key equipment, are included to enable estimation of operational cost and operational emissions, for example from electricity. Construction of plant and all other civil structure requirements to house the production plants are not considered.

Table 5: Stages in the Value Chain Production of Biofiber Composite Profiles and Pellets[1]

No.	Parameters	Biofiber Composite Profiles	Pellets
1.	Feedstock Supply (as whole EFB with ~70% moisture)		
	Source:	Palm Oil Mill	Palm Oil Mill
	Amount /year (half of total produced at mill):	80,640 ton	80,640 ton
	Price/ton (market price):	20 MYR/ton	20 MYR/ton
	Cost of raw material/year	1.613 million MYR (0.25 million USD)	1.613 million MYR (0.25 million USD)
2.	Production of EFB fiber (30,000 ton/year capacity) at the mill		
2.1	Final form required: Conversion of EFB to EFB fiber requires two different items of equipment (*based on system supplied by Muar Ban Lee Sdn. Bhd. of Malaysia* (Muar Ban Lee Sdn. Bhd., 2012))	Shredded of size <1/2", 15% moisture content	Shredded of size<1/2 " 15% moisture content
	Single Barrel Press to reduce moisture content from 70% to 50%	Number of machines: 1 Capacity: 12 Mton/hour	Number of machines: 1 Capacity: 12 Mton/hour
	EFB Shredder (Size reduction break cutter) which includes screening and recycling system to reduce size of EFB to below ½" and 45% moisture	Number of machines: 4 Capacity: 6 Mton/hour	Number of machines: 4 Capacity: 6 Mton/hour
	Dryer using biomass as fuel to reduce moisture content to 15%	Number of dryers: 1	Number of dryers: 1
	Total capital investment inclusive of all ancillary parts and components for pre-treatment and desizing of EFB to form fiber	[2]3.3 million MYR (0.52 million USD)	3.3 million MYR (0.52 million USD)

[1] The values are estimated on annual production that varies in work schedule e.g. it can be 8-10 hour/day and 5-6 days/week for 52 weeks

[2] All prices given are approximate values and are provided as a general guide and for the purpose of the study

No.	Parameters	Biofiber Composite Profiles	Pellets
2.2	Total power consumption for producing EFB fiber	Power: 2,386 MWh	Power: 2,386 MWh
2.3	Waste (residual oil) generation: (Sold as low quality palm oil at 1/3 current price of crude palm oil (CPO), assume 1% recovery from EFB)	1,300 ton/year 1,000 MYR (156 USD)/ton residual oil	1,300 ton/year 1,000 MYR (156 USD)/ton residual oil
2.4	Jobs created (to mobilize, operate pre-treatment machinery, shredders and dryer) No. of persons (not part of mill)	15 technicians for 3 shifts and 1 supervisor	15 technicians for 3 shifts and 1 supervisor
	Gross salary/year	211,200 MYR (33,000 USD)/year	211,200 MYR (33,000 USD)/year
	Output - Weight of EFB fiber -[3]15% moisture content	40,000 ton/year	40,0000 ton/year
	Selling price of EFB fiber: MYR/ton (USD/ton) Million MYR/year (Million USD/year)	 120 (18.8) 3.415 (0.53)	 120 (18.8) 3.415 (0.53)
3.	Conversion to final form for target use		
3.1	Transportation distance to conversion site using 5 ton lorry:	50 km	50 km
	Number of trips/year	5,700 trips/year	5,700 trips/year
	Cost of transportation of 5 ton/truck travelling 100 km on 2-way trip @ 350 MYR (54.7 USD)/trip and diesel consumption @ 5km/liter	1.755 million MYR (0.27 million USD)/year	1.755 million MYR (0.27 million USD)/year
3.2	Production process	Fine grinding, compounding and extrusion to produce extruded profiles4	Processing, pelletizing and cooling to produce pellets for fuel5
	Equipment required for plant capacity to handle 40,000 ton/year. (details not provided as part of confidentiality agreement with operating entities)	Equipment for compounding and extrusion line	Equipment for automated pelletization processing line with pollution controls
	Capital investment (million MYR(USD)): Capacity (ton/year:) Total power consumption (MWh/year):	226 (3.4) 40,000 1250	10 (1.6) 40,000 3600
3.3	Consumables:	Polypropylene: 12,860 ton/year Additive: 900 ton/hour	None
	Total Cost (million MYR(USD)/year):	84.7 (13.2)	None
3.4	Wastes	Process residue (10% feedstock lost as process waste)	None

[3] MS 1408 :1997 (P) - Specification for oil palm empty fruit bunch fiber.

[4] Data modeled from a pilot plant producing wood polymer composite (WPC) furniture using rice husk, EFB fiber replaces rice husk in the study (Syed Mustafa Syed Jamaludin, 2012)

[5] Data modeled from a private operating entity involved in the pelletizing business using diverse biomass feedstock supply (Builders Biomass Sdn. Bhd., 2012)

[6] For the sake of comparison, an unrealistic plant capacity of 40,000 ton WPC compounding mix/year was designed for the study in order to make a fair comparison with the alternative usage for pellets that has also been assigned a production capacity of 40,000 ton/year

No.	Parameters	Biofiber Composite Profiles	Pellets
3.5	Jobs created		
	No. of person months:		
	Type of Job and Salary (MYR (USD)/person month)	12 technicians @ 1,500 (234)	3 technicians @ 1500 (234)
	Type of Job and Salary (MYR (USD)/person month)	3 line leaders and 2 QA@ 2,800 (438)	1 line leader and 1 QA @ 2,800 (438)
	Type of Job and Salary (MYR (USD)/person month)	6 engineers @ 3,300 (516)	2 engineers @ 3,300 (516)
	Gross salary (thousand MYR (USD)/year):	Total: 620 (97)	Total: 200 (31)
3.6	Output: Product	22,000 ton extruded profiles (ready to be used for furniture assembly)	27,000 ton Pellets (CV>4,500 kcal/kg)
	Selling price of product:	4,000 MYR (625 USD)/ton extruded profiles	400 MYR (64 USD)/ton pellets

5.2. Findings of Study

The estimated values of the three sustainability indicators were calculated using the material, monetary and human resource input and output, and are summarized in Table 6.

Table 6: Indicator Values for Conversion of EFB to Biofiber Composite Profiles vs Pellets

	Sustainable Indicator	Biofiber Composite Profiles	Pellets
Environmental	GHG emissions for end-product	752 kg CO_2/ton profile	84 kg CO_2/ton pellet
	GHG emissions for 1 ton EFB consumed to make a target end-product	203 kg CO_2/ton of EFB consumed	27 kg CO_2/ton of EFB consumed
Economic.	Main indicator: Total Value Addition (TVA)	687 MYR (107 USD)/ton profile 186 MYR (29 USD)/ton EFB consumed to produce profile	86 MYR (13 USD)/ton pellet 28 MYR (4.4 USD)/ton FFB consumed to produce pellet
	Sub indicators: Labor income:	43 MYR (6.7 USD)/ton profile 12 MYR (1.9 USD)/ton EFB-consumed	12 MYR (1.9 USD)/ton profile 4 MYR (0.6 USD)/ton EFB-consumed
	Net profit:	643 MYR (100 USD)/ton profile 174 MYR (27 USD)/ton EFB-consumed	74 MYR (11.6 USD)/ton profile 24 MYR (3.8 USD)/ton EFB-consumed
	Tax revenue:	161 MYR (25 USD)/ton profile 43 MYR (6.7 USD)/ton EFB-consumed	18 MYR (2.8 USD)/ton profile 6 MYR (0.9 USD)/ton EFB-consumed

	Sustainable Indicator	Biofiber Composite Profiles	Pellets
Social	Job Creation[7]	30 new jobs compared to business-as-usual i.e. sending some proportion of EFB back to the field. Due to manual handling of large volume of materials, the production is expected to employ mostly males. Ratio of executive to operator level is 30:70. Indirect employment such as transportation of EFB fibers is not included.	11 new jobs created compared to business-as-usual i.e. EFB sent to field for mulching. Due to manual handling of large volume of materials, the production is expected to employ mostly males. Ratio of graduates to operator level is 20:80. Indirect employment such transportation of EFB fibers is not included.

From Table 6, it can be inferred that:

- EFB consumed as pellets produce less GHG compared to biofiber composite profile, due mainly to the inclusion of propylene and additive to produce the biomaterial (biofiber composite profiles).
- EFB consumed as pellets gave lower TVA compared to biofiber composite profiles. Although a higher TVA is achieved for biofiber composite profiles, the specific utilization of EFB fiber require higher CAPEX (Capital Expenditure) and OPEX (Operational Expenditure) compared to pellet production.
- EFB consumed as pellets also gave lower values for all three economic sub-indicators i.e. labor wages, net profit and tax revenue.

5.3. Conclusion and Recommendations

It must be noted that the choice of another type of biomaterial that does not require the addition of plastic resins will generate a different set of results. The results generated in the case study are all modeled from existing facilities that are not exactly doing the activities described e.g. the pellet production plant uses a range of feedstocks. However, the case study assumes pellets are produced primarily from EFB fibers. The same applies to biofiber composite profiles where the modeling is based on a pilot plant using rice husks. Hence the figures produced from the

[7] "Jobs created" relates only to full employment for a specific activity in the value chain of the target product and do not include administrative staff of the company or, transportation, logistics, laboratories and machine maintenance employees of other companies.

calculations are not necessarily precise, but are sufficiently comprehensive to give a representative picture.

In using the sustainability assessment methodology for ex-ante studies, the following pre-requisites should be carefully considered:

- The form of the raw material should be the same at the starting point of comparison for the two different applications, in this case EFB from the palm oil mill.
- Input for utilities should be based on an annual production schedule for easier accounting. In this case study, half of the EFB generated by a mill of 60 ton/hour capacity was consumed by either forms of EFB utilization.
- The input of auxiliary materials will differ in the consumption of 1 ton of EFB for the two different routes of application, resulting in end-products that are different in weight but yet have consumed 1 ton of EFB, including losses in the particular production process.
- Assumptions are clearly defined, as the market situation changes rapidly with demand.

Ex-ante studies will have to depend on secondary information from reliable sources namely:

- Existing facilities that are involved in similar business (although not always exactly the same)
- Existing facilities involved in activities that are part of the value chain in the production of a product containing EFB
- Equipment suppliers who are able to give ball-park figures of capital and operating costs based on a known plant capacity
- Public domain information such as pricing and tariff data for electricity consumption published on the web
- Private communication with relevant stakeholders to provide general insights of the proposed project’s activities

The case study on evaluating alternative uses of EFB using the sustainability assessment methodology showed that it is possible to compare ex-ante activities by creating well-defined scenarios. Although not performed in this study, it is recommended that uncertainty and sensitivity analyses be conducted to increase the level of confidence in the results produced by the methodology.

Finally, a concern that has surfaced recently, particularly from the plantation owners, is that the removal of oil palm biomass from the field should be studied carefully with respect to maintaining the soil's organic carbon levels, preserving or enhancing productivity and reducing the impact of soil erosion before making decisions (Hashim *et al*., 2012). In this respect, the sustainability assessment methodology should still be able to address the functional unit of consumption of (1 ton) EFB for use in mulching as against its use for biomaterials or biomass utilization for energy.

Although this case study showed that ex-ante figures could be obtained by using the assessment methodology on bioenergy and biomaterials, the exercise has also raised concerns that should be investigated further to strengthen the approach. These concerns are:

- The result of the sustainability assessment indicates that biofiber composite profiles earn more social and economic benefits than pellets. On the other hand, given the magnitude of GHG emissions, biofiber composite profiles produce more emissions than pellets within the system boundary set in this study. It is to be noted that the result would give different figures and information if the system boundary or the function of the biomass-based products was set differently. It is imperative that, at the outset of the study, boundary and functions should be clearly defined so that the assessment result can provide the target of the study with appropriate information.
- Uncertainty and sensitivity analyses may also be considered to enhance the reliability of the study and the level of confidence in its result, but this would be an additional step.

Assessments on the potential utilization of EFB for bioenergy versus biomaterial usage are becoming more important as competing uses of biomass emerge, and biomass feedstock is also reducing with competing land use. More case studies should be carried out to strengthen the methodology as a decision support tool for ex-ante activities.