Study on the Potential of Using Agricultural Wastes as Fuel for Power Generation in Sarawak

N. Abdul Rahman, M.F. Atan, P. Igam, R. Baini, N.F. Che Mat and S.F. Salleh

Abstract

Agricultural wastes could cause serious environmental problem. Thus, it should be disposed sustainably and, preferably, the selected disposal method generates addition income such as fuel for power generation. This solution is in line to the urgent needs of finding the alternative for the depleting fossil fuels. For Sarawak, a Malaysian state, the availability of hydropower potential is enormous that the exploitation of other energy resources such as biomass from agricultural industries is practically unknown. Therefore, the main aim of this study is to investigate agricultural biomass wastes potential for power generation in Sarawak. The study found that Sarawak power generation potential from four selected plantation crops in 2010 is 5.09 GW which is more than 3 times the current installed capacity in Sarawak. If all the available biomass is used as substitution fuel for coal power plant, Sarawak could save about 40.1 Mtonnes of CO_2 emission in 2010.

Keywords: Agricultural Wastes, Alternative Fuel, Carbon Saving

1. INTRODUCTION

Sarawak is the largest state in Malaysia which occupies 12.33 million hectares of land in Borneo Island [1] and in 2010 about 1.35 million hectares of this area are dedicated for agricultural activities [2]. In term of commercial crop, oil palm plantation dominates the land area for plantation in Sarawak in which accounted 68.1% of the total agricultural area in 2010. The other major plantation crops are rubber, paddy, sago and coconut which occupy 11.9%, 9%, 4.4%, and 1.6% of agricultural area respectively [2]. Despite being quite significant in term of the land area occupied by agricultural plantations in Sarawak, the potential of power generation from biomass wastes produced from agricultural industry have not being put into ample consideration toward the development for Sarawak Corridor of Renewable Energy or commonly known as SCORE. SCORE is an initiative taken by the state government to develop Sarawak central region economic by developing 10 priorities industries which have the highest economic impact to the state. The priorities include energy intensive industries such as aluminium, glass, and steel processing [3, 4]. The main driver for establishing these energy intensive industries are due to the abundant of indigenous energy resources in this region particularly hydropower (28,000 MW), coal (1.46 billion tonnes), and natural gas (40.9 trillion square cubic feet) [4]. As such, the main aim of this study is to investigate the potential of utilising agricultural biomass wastes as fuel for power generation in Sarawak. This, apparently, would diversify the energy resources availability for SCORE. In addition, as mentioned by Ong et al. [5], the biggest challenge of utilising biomass in Malaysia is ensuring sufficient continuous supply of biomass.

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As such, this study also provides some insights of the impending biomass supply from agricultural residues in Sarawak. Due to the fact that there is no published academic research has been found in exploring the potential of biomass waste for power generation in Sarawak, the following objectives have been devised in order to achieve the said aim which are (i) to estimate the quantity of biomass waste produced from agricultural industries in Sarawak suitable for power generation, (ii) to calculate the power generation potential deriving from the estimated biomass waste production, (iii) to identify the suitable locality for establishing biomass wastes power generation industry derive from agricultural wastes, and (iv) to determine CO_2 saving due to agricultural wastes substitution as fuel in the coal power plant.

2. METHODOLOGY

The methodology in this study is divided into four parts, namely, (i) agricultural biomass waste estimation, (ii) power generation potential, (iii) suitable location for biomass power generation, and (iv) carbon savings.

2.1. AGRICULTURAL BIOMASS WASTE ESTIMATION

The estimation of biomass waste generated is made by calculating the amount of the residue generated (ARG) [6, 7]. In which, it is calculated based on the residue to product ratio (RPR) as depicted by (1)**.** The data for agricultural plantation area is obtained from Department of Agriculture, Sarawak whereas residue to product ratios are taken from various published literatures.

$$ARG = A \times AH \times RPR \quad (1)$$

Where,

ARG	the amount of residue generated annually (t/yr)	AH	annual harvest of the crop or product (t/ha/yr)
A	the area of crop plantation (ha)	RPR	residue production ratio (dimensionless)

2.2. POWER GENERATION POTENTIAL

In Malaysia, it has been estimated that 1PJ of biomass potential can be converted to 46 MW of electrical energy with 21% electrical conversion efficiency [8, 9]. The estimation of potential power generated from agricultural wastes is calculated based on the amount of the residue generated (ARG) as shows by (2) and (3)**.**

$$EP_{residue} = ARG \times SAF \times LHV_{residue} \quad (2)$$

Where,

$EP_{residue}$	total energy potential of residue (J/t)	SAF	surplus availability factor (dimensionless)
ARG	the amount of a residue generated annually (t/yr)	$LHV_{residue}$	lower heating value of residue (J/t)

$$PP_{residue} = EP_{residue} \times (4.6 \times 10^{-8}) \quad (3)$$

Where,

$PP_{residue}$	total amount electrical power potential annually (W/yr)	$EP_{residue}$	total energy potential of residue (J/t)

2.3. SUITABLE LOCATION FOR BIOMASS POWER GENERATION

In this study, the determination of suitable locality for biomass waste power generation is in accordance to government administration division in Sarawak. In which, the decision is based on total potential power generation generated by the division as depicts by (4).

$$TEP_{division} = \sum_{i} (EP_i) \quad (4)$$

Where,

$TEP_{division}$ total energy potential of biomass waste (J/t)

EP_i total energy potential of residue (J/t)

2.4. CARBON SAVINGS.

Nowadays, typically large subcritical coal-fired utility plants produce around 900 kgCO_2 per MWh of electricity generated [10]. Assuming that the coal plants are operating all year round with no CO_2 capture, the emission of CO_2 can be calculated as in (5).

$$EM_{CO_2} = MW \times 7884 \quad (5)$$

Where,

EM_{CO2} CO_2 Emission annually (tonne/yr)

MW Plant power generation capacity (MW)

3. RESULT AND DISCUSSION

The result and discussion from this study are divided into few sections as follow;

3.1. CURRENT AND FUTURE ENERGY DEMAND IN SARAWAK

In 2010, Sarawak has 1,315 MW installed power generation capacity in which 609 MW is derived from natural gas fuelled power generation, 480 MW from coal power plants, 108 MW from hydroelectric and the rest are diesel and oil power plants as depicted by Table 1. Currently, Sarawak has 270 million tonnes of coal reserves in which 262.7 million tonnes are located in Kapit and Mukah division and the rest are located in Sri Aman division [5]. Corresponding to SCORE development, the state government is planning to develop a number of newer power generation projects, as shown by Table 2, in which include two new coal power plants. The first new coal power plant which has the rated capacity of 900 MW is to be built in Balingian, Mukah division in 2019. This plant is established within a close vicinity to Mukah coalfield which has been estimated to have a proven mineable reserve of 48.24 million metric tonnes of Sub-Bituminous "B" coal [11]. The second coal power plant with a rated capacity of 600 MW will be located in Nanga Merit, Kapit division, and the construction of this coal power plant is expected to commence in 2022. Upon the completion of these two coal power plants, Sarawak installed power generation capacity deriving from coal is projected to be 1,980 MW [12].

Table 1 Existing Power Plant Capacity in Sarawak, August 2010 [12]

No.	Plant Name	Installed Capacity (MW)	Fuel Type
1	Biawak Power station	114	Diesel and Natural Gas
2	Batang Ai Hydroelectric power station	108	Hydroelectric
3	Bintulu Power Station	510	Natural Gas

4	Distributed Generation (Various locations)	4	Diesel and Oil
5	Miri Power Station	99	Natural Gas
6	Mukah Coal Power Station	270	Coal
7	Sejingkat Coal Power Station	210	Coal
	Total	**1315**	

Table 2 Hydroelectricity and Coal Fired Facilities to be part of SCORE [12]

No.	Project	Rated Capacity (MW)	Type	Date of Commencement of Construction	Date Operational
1	Batang Ai	108	Reservoir	1981	1985
2	Bakun	2400	Reservoir	1994	2011
3	Murum	944	Reservoir	2008	2013
4	Belaga	230	Reservoir	2014	
5	Pelagus	411	Reservoir	2015	
6	Baram	1212	Reservoir	2015	
7	Limbang 1	45	Run of River	2018	
8	Limbang 2	200	Reservoir	2018	
9	Baleh	1400	Reservoir	2019	
10	*Balingian*	*900*	*Coal-fired*	*2019*	
11	*Merit*	*600*	*Coal-fired*	*2022*	
12	Punan Bah	130	Run of River	After 2022	
13	Lawas	105	Reservoir	After 2022	
14	Limbang 3	50	Reservoir	After 2022	
15	Linau	290	Reservoir	After 2022	
16	Tutoh	160	Reservoir	After 2022	
17	Belapeh	140	Reservoir	After 2022	
18	Ulu Ai	54	Reservoir	After 2022	
	Total	**9379**			

3.2. IDENTIFICATION OF SUITABLE AGRICULTURAL CROP WASTES FOR POWER GENERATION

According to plantation annual statistics published by Department of Agriculture Sarawak, there are ten major crops planted in Sarawak in which the main crops are oil palm, rubber, sago, fruit trees, coconut, pepper, cocoa and spices. Figure 1 and 2 show the estimated area and percentage distribution of crop in Sarawak for 2006 and 2010 respectively.

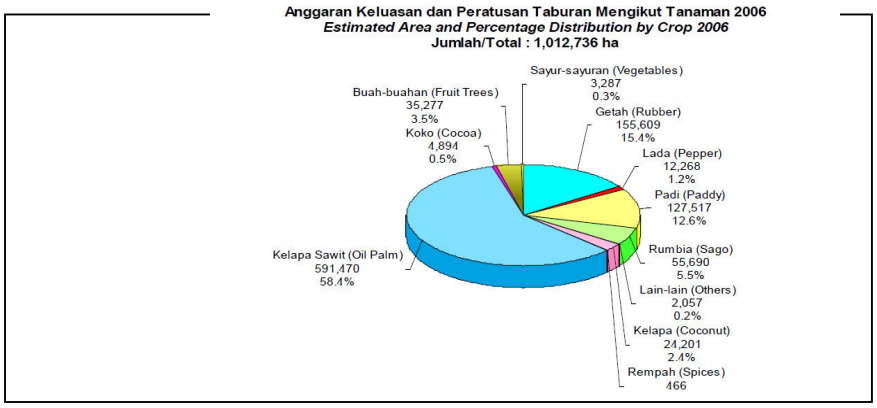

Figure 1 Estimated Area and Percentage Distribution by Crop 2006 in Sarawak [13]

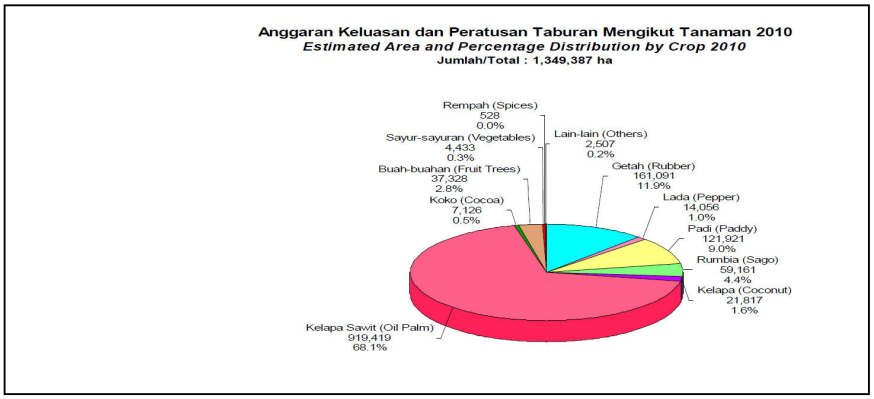

Figure 2 Estimated Area and Percentage Distribution by Crop 2010 in Sarawak [14]

As the most important crop, oil palm plantations occupy more than half of all the plantation area in Sarawak in which it accounted 58.4% in 2006 and 68.1% in 2010. Rubber plantations witness a significant reduction in term of area percentage despite the expansion in plantation area. In 2006, this crop occupied 15.4% of the total agricultural land in Sarawak whereas in 2010 it only accounted about 12%. There are two types of paddy plantation in Sarawak, namely, wet and hill paddy. The total area percentage occupied by paddy plantation deceased by 4.4% from 127,517 hectares in 2006 to 121,921 hectares which is 9% of the agricultural area in 2010. On the other hand, sago plantation area has increased by 3,471 hectares in 2010 from 55,690 hectares in 2006 in which on average it accounted almost 5% of the total agricultural area in Sarawak. Fruit trees plantations in Sarawak occupy an average of 3.0% from the total plantation area in Sarawak. Meanwhile, coconut plantations in Sarawak are mainly concentrated at the southern region of the state accounted only 2.4% and 1.6 % of total plantation area in Sarawak in 2006 and 2010 respectively. Cocoa and other spices occupy less than 1% of the area. Despite being a major pepper producer in the world, pepper plantations also occupied less than 1% of total agricultural area in Sarawak. With regard to the area percentage of crop plantations in Sarawak, it is found that there are six potential crops in which their biomass waste can be exploited as fuel for power generation in Sarawak. These crops are the oil palm, rubber, paddy, sago, fruit trees and coconut. Due to the nature of rubber and fruit trees plantations, which hardly required any regular pruning and barely produce any biomass wastes during harvesting, both crops are omitted in this study. As such, in this study, four types of agricultural plantation wastes are further investigated namely palm oil, paddy, coconut and sago. This selection is predominantly driven to the fact

that biomass wastes from those plantations could be feasibly gathered and utilised as fuel for power generation.

3.3. AGRICULTURAL BIOMASS WASTE ESTIMATION AND POTENTIAL POWER POTENTIAL

The specific types of biomass wastes produced by the selected crops which are suitable to be used as fuel are identified from various literature review conducted. The data for agricultural plantation areas are obtained from Department of Agriculture Sarawak whereas residue to product ratios are also taken from various published literatures. The parameters for the calculation of agricultural biomass wastes generation and power generation are summarised by Table 3.

3.3.1 OIL PALM AGRICULTURAL WASTE

For oil palm industry, the biomass wastes can be categorised into two groups, namely, the plantation and processing mill wastes. From oil palm plantation, three type of wastes are available which are the oil palm trunk, frond and male bunches [15]. However, palm oil trunks are only available if the trees are dead or the old and unproductive trees are cut for replanting purposes. As such, the supply of oil palm trunk as source for biomass fuel are irregular and estimation in term of annual production would be complicated. The other biomass wastes available from oil palm plantation, frond and male bunch, are the products of regular pruning at the plantation. As such, the amount of these wastes can be estimated directly and, in addition, both wastes can be gathered and transported without much difficulty from the plantation. To date, no known economic utilisation has been observed for both oil palm frond and male bunch in Sarawak. The biomass wastes from palm oil processing mill are empty fruit bunch (EFB), fibre and shell. Currently, most of the EFB produced are returned to the plantation and some palm oil mills in Sarawak mulch this waste into organic fertiliser which is then mostly also returned to the plantation as partial substitution for chemical fertiliser. Only a small fraction of EFB is used as fuel for the mill boilers. The fibre from palm oil mill is mostly used a fuel for mill boiler and in the event when the fibre supply is insufficient, the mill will include some oil palm shell into their boiler fuel mix [6, 7, 15-23]. Therefore, it can be deduced that the suitable biomass wastes from palm oil industry are the oil palm frond, male bunch, empty fruit bunch (EFB), fibre and shell. The moisture content, residue production ratio, surplus availability and calorific value of these biomass wastes are taken from other published literatures which are then compiled in Table 3.

Table 3 RPR and Calorific Values of Selected Agricultural Residues

Crop	Yield	Residue	Moisture (%)	Residue Production Ratio (dimensionless)	Surplus Availability Factor	Calorific Value (MJ/Kg)
Palm Oil	The production varies annually from 2.62 to 3.10 tonnes crude palm oil per hectare [24]	Empty Fruit bunch	8.81[7]	0.428[7]	0.584[7]	16.44[7]
		Fibre	10.11[7]	0.147[7]	0.134[7]	16.19[7]
		Shell	13.00[7]	0.049[7]	0.370[7]	17.00[7]
		Frond	48.34[7]	2.604[7]	1.000[a]	7.97[7]
		Male bunches	13.82[7]	0.233[7]	1.000[a]	14.86[7]

Paddy	Wet paddy yields vary annually from 1.662 to 3.03 tonnes per hectare [25]. Hill paddy yields vary annually from 0.654 to 0.759 tonne per hectare [25]	Husk	8.83[7]	0.25[26]	0.469[7]	12.85[7]
		Straw	8.17[7]	1.50 [26]	0.684[7]	8.83[7]
Coconut	The production is estimated to be 1.1 tonnes copra per hectare per year [27].	Husk	12.53[7]	0.36[28]	0.595[7]	14.71[7]
		Shell	11.79[7]	0.20[28]	0.378[7]	16.48[7]
		Empty bunches	13.03[7]	0.049[7]	0.843[7]	13.94[7]
		Frond	11.21[7]	0.234[29]	0.809[7]	14.55[7]
Sago	Sago starch production is in the range of 10 to 25 tonnes starch per hectare [30]. As such average value of 17.5 tonnes per hectare is used.	Bark	10.00[31]	0.500[32]	1.000[b]	16.15[31]
		Hampas	8.00[31]	3.000[32]	1.000[b]	13.17[31]
		Frond	19.00[33]	1.470[33]	1.000[b]	13.05[33]
		Sucker	19.00[33]	0.675[33]	1.000[b]	13.05[33]

Note: [a] Estimated - no known economic utilisation of both palm oil frond and male bunches observed in Sarawak.

[b] Estimated – utilisation of sago wastes in Sarawak are insignificant.

In Sarawak, the palm oil plantation areas are expanding significantly. Within the period of 2005 to 2010, oil palm plantation areas in Sarawak have enlarged almost 60% from 543,396 to 919,418 hectares respectively [24, 34]. The estimated oil palm plantation area by division in Sarawak from 2005 to 2010 is as depicted by Table 4. However, in order to estimate the biomass waste produced, the study only considered the hectarage of mature oil palm plantation area. This is done by taking the ratio of mature plantation area to total plantation area as in Table 5. The estimated mature plantation area by division in Sarawak is shown by Table 6. The annual production of crude palm oil, as in Table 7, is calculated by multiplying the yields of crude palm oil in Table 5 with the calculated mature oil palm plantation areas in Table 6. The differences of the calculated values to the actual production as reported by Department of Agriculture Sarawak are in the range of 1.88 to 4.7% only. As such, it can be assumed that it is possible to estimate the production of oil palm by means of mature oil palm plantation area.

Table 4 Total Oil Palm Plantation (hectare) in Sarawak for 2005 to 2010 [24]

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	35,034	36,423	37,881	40,216	41,417	41,210
2	Sri Aman	15,277	15,155	22,766	23,922	29,606	37,121
3	Sibu	37,091	41,276	49,396	57,590	63,706	76,773
4	Miri	190,807	210,241	222,372	238,073	257,832	266,236
5	Limbang	12,127	12,114	12,553	12,553	12,451	14,473
6	Sarikei	3,876	4,206	4,848	5,140	5,735	6,837
7	Kapit	18,876	31,540	34,631	34,993	45,376	52,060
8	Samarahan	36,647	42,060	50,634	60,335	64,679	73,913
9	Bintulu	116,123	117,714	133,822	147,683	158,869	165,390
10	Mukah	57,959	60,306	76,490	104,111	130,991	152,055
11	Betong	19,582	20,431	21,033	19,755	29,086	33,351
	Total	**543,399**	**591,466**	**666,426**	**744,371**	**839,748**	**919,419**

Table 5 Mature, Immature and Yield of Oil Palm Plantation in Sarawak for 2005 to 2010 [24]

Year	**Mature (hectare)**	**Immature (hectare)**	**Total (Hectare)**	**Ratio mature to total**	**Yield (tonne/hectare)**
2005	439537	103862	543399	**0.81**	**3.17**
2006	471029	120441	591470	**0.80**	**3.33**
2007	515120	151306	666426	**0.77**	**3.3**
2008	569195	175176	744371	**0.76**	**3.41**
2009	646002	193746	839748	**0.77**	**3.24**
2010	716586	202833	919419	**0.78**	**3.1**

Table 6 Mature Oil Palm Plantation in Sarawak for 2005 to 2010 [24]

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	28,338	29,006	29,280	30,752	31,861	32,119
2	Sri Aman	12,357	12,069	17,597	18,292	22,775	28,932
3	Sibu	30,002	32,871	38,181	44,037	49,008	59,836
4	Miri	154,337	167,430	171,884	182,046	198,345	207,502
5	Limbang	9,809	9,647	9,703	9,599	9,578	11,280
6	Sarikei	3,135	3,350	3,747	3,930	4,412	5,329
7	Kapit	15,268	25,118	26,768	26,758	34,907	40,575
8	Samarahan	29,643	33,495	39,138	46,136	49,756	57,607
9	Bintulu	93,928	93,744	103,439	112,928	122,215	128,903
10	Mukah	46,881	48,026	59,124	79,610	100,769	118,510

11	Betong	15,839	16,271	16,258	15,106	22,375	25,993
	Total	**439,537**	**471,026**	**515,120**	**569,195**	**646,002**	**716,586**

Table 7 Crude Palm Oil Production (tonne) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	89,831	96,591	96,626	104,864	103,231	99,568
2	Sri Aman	39,172	40,190	58,071	62,377	73,792	89,688
3	Sibu	95,105	109,460	125,998	150,167	158,785	185,492
4	Miri	489,249	557,541	567,219	620,778	642,638	643,255
5	Limbang	31,095	32,125	32,020	32,732	31,034	34,968
6	Sarikei	9,938	11,154	12,366	13,403	14,294	16,519
7	Kapit	48,400	83,641	88,336	91,245	113,098	125,783
8	Samarahan	93,967	111,539	129,155	157,324	161,210	178,582
9	Bintulu	297,752	312,167	341,348	385,085	395,976	399,600
10	Mukah	148,613	159,926	195,108	271,470	326,491	367,381
11	Betong	50,210	54,181	53,650	51,511	72,496	80,580
	Total	**1,393,332**	**1,568,516**	**1,699,896**	**1,940,955**	**2,093,046**	**2,221,417**
	Actual Production [a]	**1,336,638**	**1,503,122**	**1,634,882**	**1,864,372**	**1,994,780**	**2,179,601**
	Differences (%)	**4.07**	**4.17**	**3.82**	**3.95**	**4.69**	**1.88**

Note: [a] Taken from [24]

The available palm oil biomass wastes for power production are calculated by multiplying the crude oil production with respective residues production ratio and surplus availability as mentioned in Table 3. The available empty fruit bunch, fibre, shell, frond and male bunch for power generation in Sarawak from 2005 to 2010 are shown by Table 8, 9, 10, 11 and 12 respectively. As depicted in Table 8, the available empty fruit bunch in Sarawak in 2010 is 555 ktonnes which is 1.6 times more than the available empty fruit bunch in 2005. The availability of oil palm fibre within the 5 years period is in the range of 27 to 44 ktonnes while for shell the range is 25 and 40 ktonnes for 2005 and 2010 respectively. The lower availability of both fibre and shell are due to the fact that their productions are small and, as mentioned earlier, both are commonly used as fuel for mill boiler. The ignored biomass wastes from the plantation are undoubtedly have the highest potential which are in the range of 3,628 to 5,785 ktonnes for frond and 324 to 518 ktonnes for male bunch for 2005 and 2010 respectively.

Table 8 Available Empty Fruit Bunch for Power Generation (Tonne) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	22,453	24,143	24,152	26,211	25,803	24,887
2	Sri Aman	9,791	10,046	14,515	15,591	18,444	22,418
3	Sibu	23,772	27,360	31,493	37,534	39,689	46,364
4	Miri	122,289	139,358	141,777	155,165	160,629	160,783
5	Limbang	7,772	8,030	8,003	8,181	7,757	8,740
6	Sarikei	2,484	2,788	3,091	3,350	3,573	4,129
7	Kapit	12,098	20,906	22,080	22,807	28,269	31,440
8	Samarahan	23,487	27,880	32,283	39,323	40,295	44,637
9	Bintulu	74,424	78,027	85,321	96,253	98,975	99,881
10	Mukah	37,146	39,974	48,768	67,855	81,607	91,828
11	Betong	12,550	13,543	13,410	12,875	18,121	20,141
	Total	**348,266**	**392,054**	**424,892**	**485,146**	**523,161**	**555,248**

Table 9 Available oil palm fibre for power generation (tonne) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	1,769	1,903	1,903	2,066	2,033	1,961
2	Sri Aman	772	792	1,144	1,229	1,454	1,767
3	Sibu	1,873	2,156	2,482	2,958	3,128	3,654
4	Miri	9,637	10,982	11,173	12,228	12,659	12,671
5	Limbang	613	633	631	645	611	689
6	Sarikei	196	220	244	264	282	325
7	Kapit	953	1,648	1,740	1,797	2,228	2,478
8	Samarahan	1,851	2,197	2,544	3,099	3,176	3,518
9	Bintulu	5,865	6,149	6,724	7,585	7,800	7,871
10	Mukah	2,927	3,150	3,843	5,347	6,431	7,237
11	Betong	989	1,067	1,057	1,015	1,428	1,587
	Total	**27,446**	**30,897**	**33,485**	**38,233**	**41,229**	**43,757**

Table 10 Available Oil Palm Shell for Power Generation (Tonne) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	1,629	1,751	1,752	1,901	1,872	1,805
2	Sri Aman	710	729	1,053	1,131	1,338	1,626
3	Sibu	1,724	1,985	2,284	2,723	2,879	3,363
4	Miri	8,870	10,108	10,284	11,255	11,651	11,662
5	Limbang	564	582	581	593	563	634
6	Sarikei	180	202	224	243	259	299
7	Kapit	877	1,516	1,602	1,654	2,050	2,280
8	Samarahan	1,704	2,022	2,342	2,852	2,923	3,238
9	Bintulu	5,398	5,660	6,189	6,982	7,179	7,245
10	Mukah	2,694	2,899	3,537	4,922	5,919	6,661
11	Betong	910	982	973	934	1,314	1,461
	Total	**25,261**	**28,437**	**30,819**	**35,190**	**37,947**	**40,274**

Table 11 Available Oil Palm Frond for Power Generation (Tonne) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	233,920	251,522	251,613	273,065	268,813	259,275
2	Sri Aman	102,003	104,654	151,216	162,429	192,155	233,549
3	Sibu	247,654	285,035	328,098	391,034	413,477	483,021
4	Miri	1,274,005	1,451,836	1,477,037	1,616,505	1,673,431	1,675,037
5	Limbang	80,971	83,654	83,379	85,234	80,812	91,058
6	Sarikei	25,880	29,045	32,201	34,900	37,222	43,015
7	Kapit	126,034	217,802	230,026	237,601	294,508	327,538
8	Samarahan	244,689	290,449	336,321	409,672	419,792	465,027
9	Bintulu	775,345	812,883	888,871	1,002,761	1,031,122	1,040,559
10	Mukah	386,988	416,448	508,061	706,909	850,183	956,661
11	Betong	130,748	141,088	139,705	134,136	188,780	209,829
	Total	**3,628,237**	**4,084,416**	**4,426,529**	**5,054,247**	**5,450,293**	**5,784,569**

Table 12 Available Oil Palm Male Bunch for Power Generation (Tonne) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	20,931	22,506	22,514	24,433	24,053	23,199
2	Sri Aman	9,127	9,364	13,530	14,534	17,194	20,897
3	Sibu	22,160	25,504	29,357	34,989	36,997	43,220
4	Miri	113,995	129,907	132,162	144,641	149,735	149,878
5	Limbang	7,245	7,485	7,461	7,627	7,231	8,148
6	Sarikei	2,316	2,599	2,881	3,123	3,331	3,849
7	Kapit	11,277	19,488	20,582	21,260	26,352	29,307
8	Samarahan	21,894	25,989	30,093	36,657	37,562	41,610
9	Bintulu	69,376	72,735	79,534	89,725	92,262	93,107
10	Mukah	34,627	37,263	45,460	63,253	76,072	85,600
11	Betong	11,699	12,624	12,501	12,002	16,892	18,775
	Total	**324,646**	**365,464**	**396,076**	**452,243**	**487,680**	**517,590**

As shown by Table 13, the total available oil palm biomass wastes for power generation in Sarawak are in the range of 4,353 to 6,941 ktonnes for 2005 to 2010 period. Miri division has the highest available oil palm biomass wastes of 2,226 ktonnes in 2010 in which corresponding to almost 29% of total available oil palm biomass waste in Sarawak. Bintulu and Mukah division are the second and third highest divisions with available oil palm biomass wastes in Sarawak in which account 18% and 17% respectively of the total

available oil palm biomass waste in 2010. Overall, Miri, Bintulu and Mukah divisions hold about 65% of total available oil palm biomass waste for power generation in Sarawak.

Table 13 Total Available Palm Oil Industry Biomass Waste for Power Generation (tonne) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Miri	1,528,796	1,742,192	1,772,434	1,939,794	2,008,104	2,010,031
2	Bintulu	930,408	975,454	1,066,639	1,203,306	1,237,338	1,248,663
3	Mukah	464,383	499,734	609,670	848,286	1,020,213	1,147,986
4	Sibu	297,183	342,039	393,715	469,237	496,169	579,622
5	Samarahan	293,625	348,536	403,582	491,603	503,747	558,029
6	Kapit	151,240	261,361	276,029	285,119	353,407	393,043
7	Kuching	280,702	301,824	301,933	327,676	322,573	311,128
8	Sri Aman	122,403	125,584	181,458	194,914	230,584	280,256
9	Betong	156,896	169,304	167,645	160,962	226,534	251,794
10	Limbang	97,165	100,384	100,055	102,281	96,974	109,268
11	Sarikei	31,056	34,854	38,641	41,880	44,667	51,618
	Total	**4,353,857**	**4,901,267**	**5,311,801**	**6,065,057**	**6,540,310**	**6,941,438**

Power generation potential estimations for palm oil industry residues are as in Table 14, 15, 16, 17, and 18 for palm oil empty fruit bunch, fibre, shell, frond and male bunch respectively. The results show that oil palm empty fruit bunch, frond, and male bunch are the preeminent palm oil residues to be exploited for power generation. The utilisation of frond as fuel for power generation could generate 1,330 MW in 2005 and 2,120 MW in 2010. If fully utilised, oil palm frond could meet the current power generation, which is 1,315 MW, as in Table 1. The study also observed that power generation potential from oil palm empty fruit bunch and male bunch, which are 419.90 MW and 353.80 MW respectively in 2010, surpass the installed capacity of the currently operating two coal power generation plants in Sarawak as in Table 1. As expected, the power generation from available oil palm fibre and shell are comparatively small as compare to other oil palm residues. This is due to the fact that both of oil palm residues are commonly used by palm oil processing mills as fuel for their boiler.

Table 14 Empty Fruit Bunch Potential Power Generation (MW) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	16.98	18.26	18.26	19.82	19.51	18.82
2	Sri Aman	7.40	7.60	10.98	11.79	13.95	16.95
3	Sibu	17.98	20.69	23.82	28.39	30.01	35.06
4	Miri	92.48	105.39	107.22	117.34	121.47	121.59
5	Limbang	5.88	6.07	6.05	6.19	5.87	6.61
6	Sarikei	1.88	2.11	2.34	2.53	2.70	3.12
7	Kapit	9.15	15.81	16.70	17.25	21.38	23.78
8	Samarahan	17.76	21.08	24.41	29.74	30.47	33.76
9	Bintulu	56.28	59.01	64.52	72.79	74.85	75.53
10	Mukah	28.09	30.23	36.88	51.31	61.71	69.44

11	Betong	9.49	10.24	10.14	9.74	13.70	15.23
	Total	**263.37**	**296.49**	**321.32**	**366.89**	**395.64**	**419.90**

Table 15 Fibre Potential Power Generation (MW) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	1.32	1.42	1.42	1.54	1.51	1.46
2	Sri Aman	0.57	0.59	0.85	0.92	1.08	1.32
3	Sibu	1.40	1.61	1.85	2.20	2.33	2.72
4	Miri	7.18	8.18	8.32	9.11	9.43	9.44
5	Limbang	0.46	0.47	0.47	0.48	0.46	0.51
6	Sarikei	0.15	0.16	0.18	0.20	0.21	0.24
7	Kapit	0.71	1.23	1.30	1.34	1.66	1.85
8	Samarahan	1.38	1.64	1.89	2.31	2.36	2.62
9	Bintulu	4.37	4.58	5.01	5.65	5.81	5.86
10	Mukah	2.18	2.35	2.86	3.98	4.79	5.39
11	Betong	0.74	0.79	0.79	0.76	1.06	1.18
	Total	**20.44**	**23.01**	**24.94**	**28.47**	**30.70**	**32.59**

Table 16 Shell Potential Power Generation (MW) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	1.27	1.37	1.37	1.49	1.46	1.41
2	Sri Aman	0.56	0.57	0.82	0.88	1.05	1.27
3	Sibu	1.35	1.55	1.79	2.13	2.25	2.63
4	Miri	6.94	7.90	8.04	8.80	9.11	9.12
5	Limbang	0.44	0.46	0.45	0.46	0.44	0.50
6	Sarikei	0.14	0.16	0.18	0.19	0.20	0.23
7	Kapit	0.69	1.19	1.25	1.29	1.60	1.78
8	Samarahan	1.33	1.58	1.83	2.23	2.29	2.53
9	Bintulu	4.22	4.43	4.84	5.46	5.61	5.67
10	Mukah	2.11	2.27	2.77	3.85	4.63	5.21
11	Betong	0.71	0.77	0.76	0.73	1.03	1.14
	Total	**19.75**	**22.24**	**24.10**	**27.52**	**29.67**	**31.49**

Table 17 Frond Potential Power Generation (MW) in Sarawak for 2005 to 2010

No	Division	2005	2006	2007	2008	2009	2010
1	Kuching	85.76	92.21	92.25	100.11	98.55	95.06
2	Sri Aman	37.40	38.37	55.44	59.55	70.45	85.62
3	Sibu	90.79	104.50	120.29	143.36	151.59	177.09
4	Miri	467.08	532.27	541.51	592.64	613.51	614.10
5	Limbang	29.69	30.67	30.57	31.25	29.63	33.38
6	Sarikei	9.49	10.65	11.81	12.80	13.65	15.77
7	Kapit	46.21	79.85	84.33	87.11	107.97	120.08
8	Samarahan	89.71	106.48	123.30	150.19	153.90	170.49
9	Bintulu	284.26	298.02	325.88	367.63	378.03	381.49
10	Mukah	141.88	152.68	186.27	259.17	311.69	350.73
11	Betong	47.93	51.73	51.22	49.18	69.21	76.93
	Total	**1330.18**	**1497.43**	**1622.85**	**1852.99**	**1998.19**	**2120.74**

Table 18 Male Bunch Potential Power Generation (MW) in Sarawak for 2005 to 2010

No	Division	2005	2006	2007	2008	2009	2010
1	Kuching	14.31	15.38	15.39	16.70	16.44	15.86
2	Sri Aman	6.24	6.40	9.25	9.93	11.75	14.28
3	Sibu	15.15	17.43	20.07	23.92	25.29	29.54
4	Miri	77.92	88.80	90.34	98.87	102.35	102.45
5	Limbang	4.95	5.12	5.10	5.21	4.94	5.57
6	Sarikei	1.58	1.78	1.97	2.13	2.28	2.63
7	Kapit	7.71	13.32	14.07	14.53	18.01	20.03
8	Samarahan	14.97	17.76	20.57	25.06	25.68	28.44
9	Bintulu	47.42	49.72	54.37	61.33	63.07	63.64
10	Mukah	23.67	25.47	31.07	43.24	52.00	58.51
11	Betong	8.00	8.63	8.54	8.20	11.55	12.83
	Total	**221.92**	**249.82**	**270.74**	**309.13**	**333.36**	**353.80**

The total power generation from available oil palm biomass waste in 2010 is almost 3,000 MW as depicted by Table 19. This value exceeds significantly the planned total installed power generation capacity of 1,980 MW coal generations for SCORE. In fact, in the future, power generation potential from palm oil industry is likely to be augmented due to the enlargement of palm oil plantation in Sarawak as the state government aspired to double the plantation area to 2 million hectares by 2020 [35].

Table 19 Total Palm Oil Wastes Potential Power Generation (MW) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Miri	651.59	742.54	755.43	826.76	855.88	856.70
2	Bintulu	396.55	415.75	454.61	512.86	527.37	532.20
3	Mukah	197.93	212.99	259.85	361.55	434.83	489.29
4	Sibu	126.66	145.78	167.81	199.99	211.47	247.04
5	Samarahan	125.15	148.55	172.01	209.53	214.70	237.84
6	Kapit	64.46	111.40	117.65	121.52	150.63	167.52
7	Kuching	119.64	128.64	128.69	139.66	137.48	132.61
8	Sri Aman	52.17	53.53	77.34	83.07	98.28	119.45
9	Betong	66.87	72.16	71.45	68.60	96.55	107.32
10	Limbang	41.41	42.79	42.64	43.59	41.33	46.57
11	Sarikei	13.24	14.86	16.47	17.85	19.04	22.00
	Total	**1855.67**	**2088.98**	**2263.95**	**2585.00**	**2787.56**	**2958.53**

3.3.2 PADDY AGRICULTURAL WASTE

As mentioned earlier, there are two types of paddy planted in Sarawak, namely, wet paddy and hill paddy. Wet paddy is normally planted in the low flat land on the coastal region of the state and the annual yields vary from 1.662 to 3.03 tonnes per hectare [25]. Hill paddy required less water during its growing period therefore it is mostly planted at hilly but fertile terrain such in Kapit division and the interior of Miri and Bintulu divisions. Hill paddy annual yields vary from 0.654 to 0.759 tonne per hectare [25]. There are two main types of biomass waste available for power generation from paddy plantation, namely, paddy straw and husk [7, 26]. The residue production ratio, surplus availability and calorific values of paddy residues used in this study are shown by Table 3. The hectarage for both type of paddy are depicted by Table 20 and 21.

Table 20 Wet Paddy Plantation (hectare) in Sarawak for 2005 to 2010 [36]

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	2,469	2,352	2,474	2,514	2,435	3,194
2	Sri Aman	11,160	11,035	10,664	10,320	9,350	9,371
3	Sibu	6,136	8,077	6,311	6,262	6,484	6,233
4	Miri	7,929	7,656	6,595	6,545	6,990	7,116
5	Limbang	2,310	2,331	2,287	1,990	2,032	2,232
6	Sarikei	2,234	2,916	2,371	3,076	3,224	3,237
7	Kapit	529	501	501	503	545	575
8	Samarahan	10,649	10,197	9,453	9,710	10,236	11,972
9	Bintulu	4,092	3,863	3,786	3,869	4,027	4,104
10	Mukah	6,507	6,487	7,384	7,213	6,822	6,736
11	Betong	7,146	6,924	6,926	6,743	6,208	6,194
	Total	**61,161**	**62,339**	**58,752**	**58,745**	**58,353**	**60,964**

Table 21 Hill Paddy Plantation (Hectare) in Sarawak for 2005 to 2010 [36]

No	Division	2005	2006	2007	2008	2009	2010
1	Kuching	4,539	4,475	3,816	3,602	4,156	4,456
2	Sri Aman	8,306	8,342	8,650	8,399	8,010	8,060
3	Sibu	5,901	5,882	5,993	5,957	6,876	6,851
4	Miri	5,437	4,984	4,742	4,518	4,512	4,332
5	Limbang	2,370	2,369	2,216	1,838	1,874	2,269
6	Sarikei	8,551	8,621	9,028	8,472	9,691	8,595
7	Kapit	18,871	18,733	12,159	12,668	12,744	12,683
8	Samarahan	3,939	3,948	4,673	4,821	4,842	5,642
9	Bintulu	3,539	3,230	3,083	2,725	2,815	2,776
10	Mukah	376	366	346	390	390	569
11	Betong	4,230	4,228	4,087	3,809	4,735	4,724
	Total	**66,059**	**65,178**	**58,793**	**57,199**	**60,645**	**60,957**

In this study, it is considered that the wet paddy yields to be an average of 3.0 tonnes per hectare and hill paddy yield to be 0.75 tonne per hectare. As such, the estimated total paddy production in Sarawak is as shown in Table 22. The differences of the estimated paddy production to the actual production are less than 7% except for 2009 which is about 19%. This significant difference is due to natural disaster event in which in 2009 Sarawak experienced major floods in most divisions [37]. As such, it can be presumed that the estimated yields can be used to estimate future available biomass wastes for power generation in Sarawak.

Table 22 Estimated Total Paddy Production (tonne) in Sarawak for 2005 to 2010

No	Division	2005	2006	2007	2008	2009	2010
1	Kuching	10,811	10,412	10,284	10,244	10,422	12,924
2	Sri Aman	39,710	39,362	38,480	37,259	34,058	34,158
3	Sibu	22,834	28,643	23,428	23,254	24,609	23,837
4	Miri	27,865	26,706	23,342	23,024	24,354	24,597
5	Limbang	8,708	8,770	8,523	7,349	7,502	8,398
6	Sarikei	13,115	15,214	13,884	15,582	16,940	16,157
7	Kapit	15,740	15,553	10,622	11,010	11,193	11,237
8	Samarahan	34,901	33,552	31,864	32,746	34,340	40,148
9	Bintulu	14,930	14,012	13,670	13,651	14,192	14,394
10	Mukah	19,803	19,736	22,412	21,932	20,759	20,635
11	Betong	24,611	23,943	23,843	23,086	22,175	22,125
	Total	**233,027**	**235,901**	**220,351**	**219,134**	**220,543**	**228,610**
	Actual Production [a]	**231,487**	**243,881**	**207,574**	**209,912**	**185,346**	**229,063**
	Differences (%)	0.67	-3.27	6.16	4.39	18.99	-0.20

Note: [a] Taken from [24]

From Table 23, the available paddy husks for power generation from 2005 to 2010 are in the range of 21 to 27 ktonnes. While for paddy straw, the available biomass for power generation are in the range of 190 to 250 ktonnes as depicted by Table 24. As shown by Table 25, total paddy biomass waste available for power generation in Sarawak is about 279 ktonnes in 2006 and 262 ktonnes in 2010. Even in 2009, as Sarawak experienced a major natural disaster, the available paddy biomass waste is significant at about 212 ktonnes. In 2010, Samarahan, Sri Aman and Betong divisions are the top three producers of available paddy biomass waste in Sarawak in which account 19.4, 18.5 and 12.8 % from the state total respectively. All three divisions are located in the southern region of Sarawak and, if Kuching division is included, the four southern divisions produced about 58% of all available paddy biomass waste in Sarawak.

Table 23 Available Paddy Husk for Power Generation (tonne) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	1,198	1,164	1,152	1,171	1,227	1,658
2	Sri Aman	5,183	5,336	4,848	4,749	4,318	4,969
3	Sibu	2,589	2,730	2,178	1,691	1,549	1,989
4	Miri	2,403	3,395	3,275	2,638	1,914	3,082
5	Limbang	1,322	1,382	1,155	1,098	860	1,126
6	Sarikei	998	1,232	1,180	1,696	1,731	1,818
7	Kapit	2,260	2,276	1,250	1,305	1,336	1,296
8	Samarahan	3,635	3,441	3,355	3,404	3,519	5,213
9	Bintulu	1,497	1,531	1,081	1,139	1,007	1,118
10	Mukah	2,381	2,294	2,333	2,438	1,352	1,152
11	Betong	3,676	3,816	2,530	3,283	2,920	3,436
	Total	**27,142**	**28,595**	**24,338**	**24,612**	**21,732**	**26,858**

Table 24 Available Paddy Straw for Power Generation (tonne) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	10,484	10,186	10,078	10,245	10,737	14,512
2	Sri Aman	45,357	46,689	42,425	41,554	37,785	43,478
3	Sibu	22,653	23,889	19,060	14,798	13,550	17,408
4	Miri	21,025	29,706	28,658	23,084	16,744	26,970
5	Limbang	11,570	12,089	10,105	9,604	7,524	9,856
6	Sarikei	8,734	10,778	10,329	14,841	15,148	15,905
7	Kapit	19,774	19,914	10,937	11,418	11,691	11,341
8	Samarahan	31,811	30,113	29,359	29,791	30,796	45,620
9	Bintulu	13,099	13,395	9,460	9,968	8,808	9,782
10	Mukah	20,834	20,070	20,416	21,337	11,831	10,081
11	Betong	32,164	33,392	22,143	28,730	25,550	30,065
	Total	**237,506**	**250,222**	**212,971**	**215,370**	**190,165**	**235,019**

Table 25 Total Available Paddy Biomass Waste for Power Generation (tonne) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Samarahan	35,446	33,554	32,714	33,195	34,316	50,833
2	Sri Aman	50,541	52,025	47,273	46,303	42,102	48,446
3	Betong	35,840	37,208	24,674	32,013	28,470	33,501
4	Miri	23,427	33,101	31,933	25,722	18,658	30,053
5	Sibu	25,242	26,619	21,238	16,489	15,099	19,398
6	Sarikei	9,732	12,010	11,509	16,537	16,879	17,723
7	Kuching	11,682	11,350	11,230	11,415	11,964	16,170
8	Kapit	22,034	22,189	12,187	12,723	13,027	12,637
9	Mukah	23,215	22,363	22,750	23,775	13,183	11,234
10	Limbang	12,892	13,471	11,260	10,702	8,383	10,982
11	Bintulu	14,596	14,926	10,541	11,107	9,815	10,900
	Total	**264,648**	**278,817**	**237,309**	**239,982**	**211,897**	**261,876**

The estimated power generation potential for paddy residues are as in Table 26 and 27 for paddy husk and straw respectively. Paddy husk power generation is in the range of 12.85 to 16.9 MW within the period of 2005 to 2010. Within the same period, paddy straw shows a much higher power generation potential which is in the range of 77.24 to 101.64 MW. The estimated total power generation potential from paddy residues are in the range of 90.09 MW in 2009 to 118.54 MW in 2006 as in Table 28. In 2010, paddy residues power generation potential is 111.34 MW. This potential is comparable to the installed capacity of Batang Ai Hydroelectric power station which is the first hydroelectric plant in Sarawak. The power generation potential from paddy residues is also expected to be significantly increased in the future as the government has considered to develop Sarawak as the second rice bowl of Malaysia [38] in which the paddy plantation in Sarawak are expected to be enlarged considerably.

Table 26 Paddy Husk Potential Power Generation (MW) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	0.71	0.69	0.68	0.69	0.73	0.98
2	Sri Aman	3.06	3.15	2.87	2.81	2.55	2.94
3	Sibu	1.53	1.61	1.29	1.00	0.92	1.18
4	Miri	1.42	2.01	1.94	1.56	1.13	1.82
5	Limbang	0.78	0.82	0.68	0.65	0.51	0.67
6	Sarikei	0.59	0.73	0.70	1.00	1.02	1.07
7	Kapit	1.34	1.35	0.74	0.77	0.79	0.77
8	Samarahan	2.15	2.03	1.98	2.01	2.08	3.08
9	Bintulu	0.88	0.90	0.64	0.67	0.59	0.66
10	Mukah	1.41	1.36	1.38	1.44	0.80	0.68
11	Betong	2.17	2.26	1.50	1.94	1.73	2.03
	Total	**16.04**	**16.90**	**14.39**	**14.55**	**12.85**	**15.88**

Table 27 Paddy Straw Potential Power Generation (MW) in Sarawak for 2005 to 2010

No	Division	2005	2006	2007	2008	2009	2010
1	Kuching	4.26	4.14	4.09	4.16	4.36	5.89
2	Sri Aman	18.42	18.96	17.23	16.88	15.35	17.66
3	Sibu	9.20	9.70	7.74	6.01	5.50	7.07
4	Miri	8.54	12.07	11.64	9.38	6.80	10.95
5	Limbang	4.70	4.91	4.10	3.90	3.06	4.00
6	Sarikei	3.55	4.38	4.20	6.03	6.15	6.46
7	Kapit	8.03	8.09	4.44	4.64	4.75	4.61
8	Samarahan	12.92	12.23	11.93	12.10	12.51	18.53
9	Bintulu	5.32	5.44	3.84	4.05	3.58	3.97
10	Mukah	8.46	8.15	8.29	8.67	4.81	4.09
11	Betong	13.06	13.56	8.99	11.67	10.38	12.21
	Total	**96.47**	**101.64**	**86.50**	**87.48**	**77.24**	**95.46**

Table 28 Total Paddy Wastes Potential Power Generation (MW) in Sarawak for 2005 to 2010

No	Division	2005	2006	2007	2008	2009	2010
1	Samarahan	15.07	14.27	13.91	14.11	14.59	21.61
2	Sri Aman	21.49	22.12	20.10	19.69	17.90	20.60
3	Betong	15.24	15.82	10.49	13.61	12.10	14.24
4	Miri	9.96	14.07	13.58	10.94	7.93	12.78
5	Sibu	10.73	11.32	9.03	7.01	6.42	8.25
6	Sarikei	4.14	5.11	4.89	7.03	7.18	7.53
7	Kuching	4.97	4.83	4.77	4.85	5.09	6.87
8	Kapit	9.37	9.43	5.18	5.41	5.54	5.37
9	Mukah	9.87	9.51	9.67	10.11	5.60	4.78
10	Limbang	5.48	5.73	4.79	4.55	3.56	4.67
11	Bintulu	6.21	6.35	4.48	4.72	4.17	4.63
	Total	**112.51**	**118.54**	**100.89**	**102.03**	**90.09**	**111.34**

3.3.3. Coconut Agricultural Waste

For coconut plantation, there are four types of biomass waste available which are suitable for power generation, namely, husk, shell, empty bunch and frond [7, 27, 28]. In Sarawak, only coconut shell is known to have some economic values in which the shells are processed into activated charcoal [39] and some coconut husks are also used by the locals as fuel for cooking. The frond and male bunch have no known commercial values and are normally disposed or burned at the plantation. Table 29 shows the hectarage for mature coconut plantation in Sarawak.

Table 29 Mature Coconut Plantation (Hectare) in Sarawak for 2005 to 2010 [40, 41]

No	Division	2005	2006	2007	2008	2009	2010
1	Kuching	2,127	2,126	2,073	2,005	1,959	1,884
2	Sri Aman	50	50	53	53	53	55
3	Sibu	0	0	0	0	0	1
4	Miri	300	296	296	296	299	299
5	Limbang	551	545	518	518	519	493
6	Sarikei	0	0	0	0	0	0
7	Kapit	0	0	0	0	0	0
8	Samarahan	13,934	13,661	13,687	13,521	13,725	11,853
9	Bintulu	579	591	591	628	629	681
10	Mukah	1,692	1,696	1,740	1,826	1,826	1,587
11	Betong	2,417	2,323	2,320	2,321	2,248	2,266
	Total	**21,649**	**21,288**	**21,278**	**21,278**	**21,258**	**19,119**

According to Novarianto and Warokka [27], the average copra production in South East Asia is about 1.1 tonnes copra per hectare of coconut plantation. This value is used as the basis for the calculation of available coconut biomass wastes production in this study in which it is assumed that all the coconut produced from the coconut plantations in Sarawak are processed into copra. Therefore, a direct comparison to actual production of copra cannot be made as the data reported by Department of Agriculture Sarawak is a mixture of various coconut products. Table 30 shows the potential of production of copra in Sarawak is in the range of about 21 to 24 ktonnes. In which, most coconut production are located at Samarahan division.

Table 30 Copra Production (tonne) in Sarawak for 2005 to 2010

No	Division	2005	2006	2007	2008	2009	2010
1	Kuching	2,339	2,339	2,280	2,206	2,155	2,072
2	Sri Aman	55	55	58	58	58	61
3	Sibu	0	0	0	0	0	1
4	Miri	330	326	326	326	329	329
5	Limbang	607	600	570	570	571	542
6	Sarikei	0	0	0	0	0	0
7	Kapit	0	0	0	0	0	0
8	Samarahan	15,327	15,027	15,056	14,873	15,098	13,038
9	Bintulu	637	650	650	691	692	749
10	Mukah	1,861	1,866	1,914	2,009	2,009	1,746
11	Betong	2,659	2,555	2,552	2,553	2,473	2,493
	Total	**23,814**	**23,417**	**23,406**	**23,285**	**23,384**	**21,031**

The estimated available coconut husk, shell, empty bunch, and frond are shown by Table 31, 32, 33 and 34 respectively. It is observed that due to the reduction of coconut mature plantation area the coconut husk availability is reduced from 5.1 to 4.5 ktonnes in 2005 and 2010 respectively. Coconut shell production is in the range of 1.8 ktonnes to 1.56 ktonnes while the empty fruit bunch is about 1 ktonnes to 0.9 ktonnes, and frond from 4.5 ktonnes to 4 ktonnes.

Table 31 Available Coconut Husk for Power Generation (tonne) in Sarawak for 2005 to 2010

No	Division	2005	2006	2007	2008	2009	2010
1	Kuching	501	501	488	472	462	444
2	Sri Aman	12	12	12	12	12	13
3	Sibu	0	0	0	0	0	0
4	Miri	71	70	70	70	70	70
5	Limbang	130	128	122	122	122	116
6	Sarikei	0	0	0	0	0	0
7	Kapit	0	0	0	0	0	0
8	Samarahan	3,283	3,219	3,225	3,186	3,234	2,793
9	Bintulu	136	139	139	148	148	160
10	Mukah	399	400	410	430	430	374
11	Betong	569	547	547	547	530	534
	Total	**5,101**	**5,016**	**5,014**	**4,988**	**5,009**	**4,505**

Table 32 Available Coconut Shell for Power Generation (tonne) in Sarawak for 2005 to 2010

No	Division	2005	2006	2007	2008	2009	2010
1	Kuching	177	177	172	167	163	157
2	Sri Aman	4	4	4	4	4	5
3	Sibu	0	0	0	0	0	0
4	Miri	25	25	25	25	25	25
5	Limbang	46	45	43	43	43	41
6	Sarikei	0	0	0	0	0	0
7	Kapit	0	0	0	0	0	0
8	Samarahan	1,159	1,136	1,138	1,124	1,141	986
9	Bintulu	48	49	49	52	52	57
10	Mukah	141	141	145	152	152	132
11	Betong	201	193	193	193	187	188
	Total	**1,800**	**1,770**	**1,769**	**1,760**	**1,768**	**1,590**

Table 33 Available Coconut Empty Bunch for Power Generation (tonne) in Sarawak for 2005 to 2010

No	Division	2005	2006	2007	2008	2009	2010
1	Kuching	97	97	94	91	89	86
2	Sri Aman	2	2	2	2	2	2
3	Sibu	0	0	0	0	0	0
4	Miri	14	13	13	13	14	14
5	Limbang	25	25	24	24	24	22
6	Sarikei	0	0	0	0	0	0

7	Kapit	0	0	0	0	0	0
8	Samarahan	633	621	622	614	624	539
9	Bintulu	26	27	27	29	29	31
10	Mukah	77	77	79	83	83	72
11	Betong	110	106	105	105	102	103
	Total	**984**	**967**	**967**	**962**	**966**	**869**

Table 34 Available Coconut Frond for Power Generation (tonne) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	443	443	432	418	408	392
2	Sri Aman	10	10	11	11	11	11
3	Sibu	0	0	0	0	0	0
4	Miri	62	62	62	62	62	62
5	Limbang	115	113	108	108	108	103
6	Sarikei	0	0	0	0	0	0
7	Kapit	0	0	0	0	0	0
8	Samarahan	2,901	2,845	2,850	2,816	2,858	2,468
9	Bintulu	121	123	123	131	131	142
10	Mukah	352	353	362	380	380	330
11	Betong	503	484	483	483	468	472
	Total	**4,508**	**4,433**	**4,431**	**4,408**	**4,427**	**3,981**

As depicted by Table 35, about 84% of 10.945 ktonnes of the total available coconut biomass waste for power generation in 2010 is located in the southern region of Sarawak. Samarahan division accounts 62% of the total available coconut biomass waste. Betong and Kuching division contribute about 13 and 12 % respectively of the total available coconut biomass wastes.

Table 35 Total Available Paddy Biomass Waste for Power Generation (tonne) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Samarahan	7,976	7,820	7,835	7,740	7,857	6,785
2	Betong	1,384	1,330	1,328	1,329	1,287	1,297
3	Kuching	1,217	1,217	1,187	1,148	1,121	1,079
4	Mukah	968	971	996	1,045	1,045	908
5	Bintulu	332	338	338	360	360	390
6	Limbang	316	312	297	297	297	282
7	Miri	172	169	169	169	171	171
8	Sri Aman	29	29	30	30	30	31
9	Sibu	0	0	0	0	0	1
10	Sarikei	0	0	0	0	0	0
11	Kapit	0	0	0	0	0	0
	Total	**12,393**	**12,186**	**12,181**	**12,118**	**12,169**	**10,945**

Table 36, 37, 38 and 39 show the power generation potential of husk, shell, empty bunch and frond respectively for coconut plantation residues in Sarawak. Power generation potential from coconut residues is insignificant as compare to oil palm and paddy residues. The total power generation derived from coconut

residues are less than 10 MW as show by Table 40. In most divisions, coconut residues power generation potential is less than 1 MW. Meanwhile for Samarahan division, the biggest producer of coconut products in Sarawak has the power generation potential in the range of 4.63 MW to 5.45 MW only for 2010 and 2005 respectively. As such, it can be deduced that coconut plantation residues are not suitable to be exploited as fuel for power generation in Sarawak due to its inconsequential contribution for the purposes. However, the small portion of coconut plantation residues availability of in Samarahan division could be used to supplement other types of plantation wastes as fuel for power generation.

Table 36 Coconut Husk Potential Power Generation (MW) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	0.34	0.34	0.33	0.32	0.31	0.30
2	Sri Aman	0.01	0.01	0.01	0.01	0.01	0.01
3	Sibu	0	0	0	0	0	0
4	Miri	0.05	0.05	0.05	0.05	0.05	0.05
5	Limbang	0.09	0.09	0.08	0.08	0.08	0.08
6	Sarikei	0	0	0	0	0	0
7	Kapit	0	0	0	0	0	0
8	Samarahan	2.22	2.18	2.18	2.16	2.19	1.89
9	Bintulu	0.09	0.09	0.09	0.10	0.10	0.11
10	Mukah	0.27	0.27	0.28	0.29	0.29	0.25
11	Betong	0.39	0.37	0.37	0.37	0.36	0.36
	Total	**3.45**	**3.39**	**3.39**	**3.37**	**3.39**	**3.05**

Table 37 Coconut Shell Potential Power Generation (MW) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	0.13	0.13	0.13	0.13	0.12	0.12
2	Sri Aman	0	0	0	0	0	0
3	Sibu	0	0	0	0	0	0
4	Miri	0.02	0.02	0.02	0.02	0.02	0.02
5	Limbang	0.03	0.03	0.03	0.03	0.03	0.03
6	Sarikei	0	0	0	0	0	0
7	Kapit	0	0	0	0	0	0
8	Samarahan	0.88	0.86	0.86	0.85	0.87	0.75
9	Bintulu	0.04	0.04	0.04	0.04	0.04	0.04
10	Mukah	0.11	0.11	0.11	0.12	0.12	0.10
11	Betong	0.15	0.15	0.15	0.15	0.14	0.14
	Total	**1.36**	**1.34**	**1.34**	**1.33**	**1.34**	**1.21**

Table 38 Coconut Empty Bunch Potential Power Generation (MW) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	0.06	0.06	0.06	0.06	0.06	0.05
2	Sri Aman	0	0	0	0	0	0
3	Sibu	0	0	0	0	0	0
4	Miri	0.01	0.01	0.01	0.01	0.01	0.01
5	Limbang	0.02	0.02	0.02	0.02	0.02	0.01
6	Sarikei	0	0	0	0	0	0
7	Kapit	0	0	0	0	0	0
8	Samarahan	0.41	0.40	0.40	0.39	0.40	0.35
9	Bintulu	0.02	0.02	0.02	0.02	0.02	0.02
10	Mukah	0.05	0.05	0.05	0.05	0.05	0.05
11	Betong	0.07	0.07	0.07	0.07	0.07	0.07
	Total	**0.63**	**0.62**	**0.62**	**0.62**	**0.62**	**0.56**

Table 39 Coconut Frond Potential Power Generation (MW) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	0.30	0.30	0.29	0.28	0.27	0.26
2	Sri Aman	0.01	0.01	0.01	0.01	0.01	0.01
3	Sibu	0	0	0	0	0	0
4	Miri	0.04	0.04	0.04	0.04	0.04	0.04
5	Limbang	0.08	0.08	0.07	0.07	0.07	0.07
6	Sarikei	0	0	0	0	0	0
7	Kapit	0	0	0	0	0	0
8	Samarahan	1.94	1.90	1.91	1.88	1.91	1.65
9	Bintulu	0.08	0.08	0.08	0.09	0.09	0.09
10	Mukah	0.24	0.24	0.24	0.25	0.25	0.22
11	Betong	0.34	0.32	0.32	0.32	0.31	0.32
	Total	**3.02**	**2.97**	**2.97**	**2.95**	**2.96**	**2.66**

Table 40 Total Coconut Wastes Potential Power Generation (MW) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Samarahan	5.45	5.34	5.35	5.29	5.37	4.63
2	Betong	0.95	0.91	0.91	0.91	0.88	0.89
3	Kuching	0.83	0.83	0.81	0.78	0.77	0.74
4	Mukah	0.66	0.66	0.68	0.71	0.71	0.62
5	Bintulu	0.23	0.23	0.23	0.25	0.25	0.27
6	Limbang	0.22	0.21	0.20	0.20	0.20	0.19

7	Miri	0.12	0.12	0.12	0.12	0.12	0.12
8	Sri Aman	0.02	0.02	0.02	0.02	0.02	0.02
9	Sibu	0	0	0	0	0	0
10	Sarikei	0	0	0	0	0	0
11	Kapit	0	0	0	0	0	0
	Total	**8.46**	**8.32**	**8.32**	**8.28**	**8.31**	**7.48**

3.3.4. Sago Agricultural Waste Availability in Sarawak.

Similar to palm oil industry, the biomass wastes from sago industry can be divided into two categories, namely, processing and plantation biomass wastes. The processing wastes are the sago bark and hampas. Bark is produced after the debarking process of sago trunk prior to rasping of the pith while hampas is the leftover pith fibre after starch being extracted from the grinded pith [30, 32, 42, 43]. From the plantation, two types of biomass are produced which in the form of frond and sucker [33]. Currently, most of the sago wastes produced are not utilised in which most ends up being disposed by dumping within the vicinity of the sago processing mill or into natural waterways. The total sago plantation areas in Sarawak are showed by Table 41. As in the case of oil palm plantation, only the mature plantation areas are considered toward the calculation of available sago biomass wastes. The mature sago areas are depicted by Table 42. From both tables, sago plantations are concentrated mainly in Mukah division and some are located in Betong, Sarikei and Sibu divisions.

Table 41 Total Sago Plantation (hectare) in Sarawak for 2005 to 2010 [44, 45]

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	2	2	2	2	2	2
2	Sri Aman	42	42	42	42	42	42
3	Sibu	1,188	1,188	1,187	1,187	1,187	1,053
4	Miri	1	1	1	1	1	1
5	Limbang	0	0	0	0	0	0
6	Sarikei	1,752	1,383	1,433	1,433	1,433	1,433
7	Kapit	0	0	0	0	0	0
8	Samarahan	0	0	0	0	0	0
9	Bintulu	386	386	386	381	381	342
10	Mukah	41,008	45,259	46,591	48,029	49,058	49,330
11	Betong	7,384	7,429	7,274	7,012	6,794	6,958
	Total	**51,763**	**55,690**	**56,916**	**58,087**	**58,898**	**59,161**

Table 42 Mature Sago Plantation (hectare) in Sarawak for 2005 to 2010 [44, 45]

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	2	2	2	2	2	2
2	Sri Aman	42	42	42	42	42	42

3	Sibu	713	713	752	752	752	684
4	Miri	1	1	1	1	1	1
5	Limbang	0	0	0	0	0	0
6	Sarikei	711	561	561	561	561	561
7	Kapit	0	0	0	0	0	0
8	Samarahan	0	0	0	0	0	0
9	Bintulu	261	261	261	271	271	232
10	Mukah	23,323	25,741	25,759	25,689	26,748	26,895
11	Betong	3,729	3,752	4,674	4,436	4,236	4,622
	Total	**28,782**	**31,073**	**32,052**	**31,754**	**32,613**	**33,039**

According to Ishizaki [46], a 25 tonnes of sago starch per hectare plantation is under development in Sarawak. However, for most cultivated sago plantation in Sarawak the production is in the range of 10 to 25 tonnes per hectare [30]. Therefore, in order to ease the calculation, a production average of 17.5 tonnes per hectare is used in this study. As such, the estimated annual sago starch productions in Sarawak are as depicted in Table 43. Corresponding to the plantation area, the sago starch production in Sarawak is in the range of 503 to 578 ktonnes in 2005 and 2010 respectively. Mukah division production of 470 ktonnes in 2010 accounts more than 80% of the total sago starch production in Sarawak for that year. Similar to coconut, direct comparison of sago estimation to the data obtained from Department of Agriculture Sarawak cannot be made as the data reported is in the form of various products.

Table 43 Sago Starch Production (tonne) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	35	35	35	35	35	35
2	Sri Aman	735	735	735	735	735	735
3	Sibu	12,478	12,478	13,160	13,160	13,160	11,970
4	Miri	18	18	18	18	18	18
5	Limbang	0	0	0	0	0	0
6	Sarikei	12,437	9,818	9,818	9,818	9,818	9,818
7	Kapit	0	0	0	0	0	0
8	Samarahan	0	0	0	0	0	0
9	Bintulu	4,568	4,568	4,568	4,743	4,743	4,060
10	Mukah	408,157	450,468	450,783	449,558	468,090	470,663
11	Betong	65,262	65,660	81,795	77,630	74,130	80,885
	Total	**503,689**	**543,778**	**560,910**	**555,695**	**570,728**	**578,183**

Detail estimations for sago bark, hampas, frond, and suckers production are showed by Table 44, 45, 46, and 47 respectively. The available sago bark biomass for power generation is in the range of 251 ktonnes in 2005 to 289 ktonnes in 2010. For sago hampas, the generated biomass is much higher which is in the range of 1,511 ktonnes in 2005 and 1,734 ktonnes in 2010. For sago plantation wastes, frond production in 2005 and 2010 are 740 and 850 ktonnes respectively, whereas, for sucker, it is in the range of 340 to 390 ktonnes in 2005 and 2010 respectively.

Table 44 Available sago bark for power generation (tonne) in Sarawak for 2005 to 2010

No	Division	2005	2006	2007	2008	2009	2010
1	Kuching	18	18	18	18	18	18
2	Sri Aman	368	368	368	368	368	368
3	Sibu	6,239	6,239	6,580	6,580	6,580	5,985
4	Miri	9	9	9	9	9	9
5	Limbang	0	0	0	0	0	0
6	Sarikei	6,218	4,909	4,909	4,909	4,909	4,909
7	Kapit	0	0	0	0	0	0
8	Samarahan	0	0	0	0	0	0
9	Bintulu	2,284	2,284	2,284	2,371	2,371	2,030
10	Mukah	204,078	225,234	225,391	224,779	234,045	235,331
11	Betong	32,631	32,830	40,898	38,815	37,065	40,443
	Total	**251,844**	**271,889**	**280,455**	**277,848**	**285,364**	**289,091**

Table 45 Available sago hampas for power generation (tonne) in Sarawak for 2005 to 2010

No	Division	2005	2006	2007	2008	2009	2010
1	Kuching	105	105	105	105	105	105
2	Sri Aman	2,205	2,205	2,205	2,205	2,205	2,205
3	Sibu	37,433	37,433	39,480	39,480	39,480	35,910
4	Miri	53	53	53	53	53	53
5	Limbang	0	0	0	0	0	0
6	Sarikei	37,311	29,453	29,453	29,453	29,453	29,453
7	Kapit	0	0	0	0	0	0
8	Samarahan	0	0	0	0	0	0
9	Bintulu	13,703	13,703	13,703	14,228	14,228	12,180
10	Mukah	1,224,471	1,351,403	1,352,348	1,348,673	1,404,270	1,411,988
11	Betong	195,787	196,980	245,385	232,890	222,390	242,655
	Total	**1,511,066**	**1,631,333**	**1,682,730**	**1,667,085**	**1,712,183**	**1,734,548**

Table 46 Available sago frond for power generation (tonne) in Sarawak for 2005 to 2010

No	Division	2005	2006	2007	2008	2009	2010
1	Kuching	51	51	51	51	51	51
2	Sri Aman	1,080	1,080	1,080	1,080	1,080	1,080
3	Sibu	18,342	18,342	19,345	19,345	19,345	17,596
4	Miri	26	26	26	26	26	26
5	Limbang	0	0	0	0	0	0
6	Sarikei	18,282	14,432	14,432	14,432	14,432	14,432
7	Kapit	0	0	0	0	0	0
8	Samarahan	0	0	0	0	0	0
9	Bintulu	6,714	6,714	6,714	6,971	6,971	5,968
10	Mukah	599,991	662,187	662,650	660,850	688,092	691,874
11	Betong	95,936	96,520	120,239	114,116	108,971	118,901
	Total	**740,422**	**799,353**	**824,538**	**816,872**	**838,969**	**849,928**

Table 47 Available sago sucker for power generation (tonne) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	24	24	24	24	24	24
2	Sri Aman	496	496	496	496	496	496
3	Sibu	8,422	8,422	8,883	8,883	8,883	8,080
4	Miri	12	12	12	12	12	12
5	Limbang	0	0	0	0	0	0
6	Sarikei	8,395	6,627	6,627	6,627	6,627	6,627
7	Kapit	0	0	0	0	0	0
8	Samarahan	0	0	0	0	0	0
9	Bintulu	3,083	3,083	3,083	3,201	3,201	2,741
10	Mukah	275,506	304,066	304,278	303,451	315,961	317,697
11	Betong	44,052	44,321	55,212	52,400	50,038	54,597
	Total	**339,990**	**367,050**	**378,614**	**375,094**	**385,241**	**390,273**

Total sago biomass waste available for power generation in Sarawak are in the range of 2,843 ktonnes in 2005 to 3,264 ktonnes in 2010 as in Table 48. Mukah division produces about 2,304 ktonnes of sago wastes in 2005 and 2,657 ktonnes in 2010. These values account more than 80% of the total sago biomass waste available for that five years duration. Apart from Mukah division, Betong division contributes about 14% of the total available sago biomass wastes for power generation.

Table 48 Total Available Sago Biomass Waste for Power Generation (tonne) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Mukah	2,304,045	2,542,889	2,544,667	2,537,752	2,642,368	2,656,890
2	Betong	368,406	370,651	461,733	438,221	418,464	456,596
3	Sibu	70,435	70,435	74,288	74,288	74,288	67,571
4	Sarikei	70,206	55,420	55,420	55,420	55,420	55,420
5	Bintulu	25,784	25,784	25,784	26,771	26,771	22,919
6	Sri Aman	4,149	4,149	4,149	4,149	4,149	4,149
7	Kuching	198	198	198	198	198	198
8	Miri	99	99	99	99	99	99
9	Limbang	0	0	0	0	0	0
10	Kapit	0	0	0	0	0	0
11	Samarahan	0	0	0	0	0	0
	Total	**2,843,322**	**3,069,624**	**3,166,337**	**3,136,898**	**3,221,757**	**3,263,840**

The power generation potentials from sago residues are as tabulated in Table 49, 50, 51 and 52 for sago bark, hampas, frond, and sucker respectively. The highest power potential for sago biomass waste is derived from sago hampas which is in the range of 915.43 MW to 1050.82 MW in 2005 to 2010 period. Sago frond power potential is within 444 MW to 510 MW for the same interval while sago sucker potential is from 204.10 MW to 234.28 MW. The smallest, but by no means insignificant, sago bark power generation potential is from 187MW to 214 MW for the 2005 and 2010 period. As depicted by Table 53, the total estimated power generation potential from sago industry in Sarawak is the range of 1751.1 MW in 2005 to 2010.08 MW in 2010. These values are comparable to the oil palm power generation potential in Sarawak as mentioned previously. Mukah division alone generates about 1418.98 MW power potential in 2005 and

1636.28 MW in 2010. Despite being significantly lower, Betong division estimated power generation from sago residues is in the range of 226.89 MW in 2005 to 281.20 MW in 2010.

Table 49 Sago Bark Potential Power Generation (MW) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	0.01	0.01	0.01	0.01	0.01	0.01
2	Sri Aman	0.27	0.27	0.27	0.27	0.27	0.27
3	Sibu	4.63	4.63	4.89	4.89	4.89	4.45
4	Miri	0.01	0.01	0.01	0.01	0.01	0.01
5	Limbang	0	0	0	0	0	0
6	Sarikei	4.62	3.65	3.65	3.65	3.65	3.65
7	Kapit	0	0	0	0	0	0
8	Samarahan	0	0	0	0	0	0
9	Bintulu	1.70	1.70	1.70	1.76	1.76	1.51
10	Mukah	151.61	167.33	167.44	166.99	173.87	174.83
11	Betong	24.24	24.39	30.38	28.84	27.54	30.04
	Total	**187.10**	**201.99**	**208.35**	**206.41**	**212.00**	**214.77**

Table 50 Sago Hampas Potential Power Generation (MW) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	0.06	0.06	0.06	0.06	0.06	0.06
2	Sri Aman	1.34	1.34	1.34	1.34	1.34	1.34
3	Sibu	22.68	22.68	23.92	23.92	23.92	21.75
4	Miri	0.03	0.03	0.03	0.03	0.03	0.03
5	Limbang	0	0	0	0	0	0
6	Sarikei	22.60	17.84	17.84	17.84	17.84	17.84
7	Kapit	0	0	0	0	0	0
8	Samarahan	0	0	0	0	0	0
9	Bintulu	8.30	8.30	8.30	8.62	8.62	7.38
10	Mukah	741.81	818.71	819.28	817.05	850.73	855.41
11	Betong	118.61	119.33	148.66	141.09	134.73	147.01
	Total	**915.43**	**988.29**	**1019.43**	**1009.95**	**1037.27**	**1050.82**

Table 51 Sago Frond Potential Power Generation (MW) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	0.03	0.03	0.03	0.03	0.03	0.03
2	Sri Aman	0.65	0.65	0.65	0.65	0.65	0.65
3	Sibu	11.01	11.01	11.61	11.61	11.61	10.56
4	Miri	0.02	0.02	0.02	0.02	0.02	0.02
5	Limbang	0	0	0	0	0	0
6	Sarikei	10.97	8.66	8.66	8.66	8.66	8.66
7	Kapit	0	0	0	0	0	0
8	Samarahan	0	0	0	0	0	0
9	Bintulu	4.03	4.03	4.03	4.18	4.18	3.58
10	Mukah	360.17	397.51	397.79	396.71	413.06	415.33
11	Betong	57.59	57.94	72.18	68.50	65.42	71.38
	Total	**444.48**	**479.85**	**494.97**	**490.37**	**503.63**	**510.21**

Table 52 Sago Sucker Potential Power Generation (MW) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Kuching	0.01	0.01	0.01	0.01	0.01	0.01
2	Sri Aman	0.30	0.30	0.30	0.30	0.30	0.30
3	Sibu	5.06	5.06	5.33	5.33	5.33	4.85
4	Miri	0.01	0.01	0.01	0.01	0.01	0.01
5	Limbang	0	0	0	0	0	0
6	Sarikei	5.04	3.98	3.98	3.98	3.98	3.98
7	Kapit	0	0	0	0	0	0
8	Samarahan	0	0	0	0	0	0
9	Bintulu	1.85	1.85	1.85	1.92	1.92	1.65
10	Mukah	165.39	182.53	182.66	182.16	189.67	190.71
11	Betong	26.44	26.61	33.14	31.46	30.04	32.77
	Total	**204.10**	**220.34**	**227.28**	**225.17**	**231.26**	**234.28**

Table 53 Total Sago Wastes Potential Power Generation (MW) in Sarawak for 2005 to 2010

No	**Division**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
1	Mukah	1418.98	1566.07	1567.17	1562.91	1627.34	1636.28
2	Betong	226.89	228.27	284.36	269.88	257.72	281.20
3	Sibu	43.38	43.38	45.75	45.75	45.75	41.61
4	Sarikei	43.24	34.13	34.13	34.13	34.13	34.13
5	Bintulu	15.88	15.88	15.88	16.49	16.49	14.11
6	Sri Aman	2.56	2.56	2.56	2.56	2.56	2.56
7	Kuching	0.12	0.12	0.12	0.12	0.12	0.12
8	Miri	0.06	0.06	0.06	0.06	0.06	0.06
9	Limbang	0	0	0	0	0	0
10	Kapit	0	0	0	0	0	0
11	Samarahan	0	0	0	0	0	0
	Total	**1751.10**	**1890.47**	**1950.03**	**1931.90**	**1984.16**	**2010.08**

3.3.5. Total Available Agricultural Biomass and Power Generation Potential in Sarawak.

As depicted in Table 54 and 55, biomass availability from agricultural wastes for power generation and potential power generated in Sarawak are increasing significantly annually. In 2005, approximately 7.5 Mtonnes of biomass waste from selected agricultural plantations are available for utilisation for power generation in Sarawak. Correspondingly, such biomass could generate about 3.73 GW of electricity. In 2010, about 10.5 Mtonnes of biomass are available for power generation which able to generate 5.09 GW of electricity. This is a staggering increase of about 37% for both biomass availability and power potential in Sarawak within five years of duration. The considerable increase is predominantly due to large expansion of palm oil plantation area in Sarawak especially in Miri, Bintulu and Mukah division. In term of power generation potential, it is proven that, as in Table 56, if all the available biomass wastes from selected agriculture are destined for power generation, it would not only exceeding the installed capacity of the four coal power plants planned for SCORE but it has the potential to suffice the current total installed capacity in Sarawak. In fact, if only half of the available biomass wastes from agricultural industry are retrievable it still able to meet the current total demand for power generation. However, to date no known biomass power plant exists nor planned in Sarawak. For palm oil and sago industry, most biomass generated is either

disposed within the processing mill site or returned to the plantation and both solutions do not generate any addition income to the industry. In addition, such disposal methods are not sustainable and potentially causing environmental hazardous through open burning and emission of methane to the atmosphere during biomass waste uncontrolled decomposition. Per volume, the methane is more potent than CO_2 in term of its contribution to global warming.

Table 54 Total biomass waste available for power generation (ktonne)

No	Division	2005	2006	2007	2008	2009	2010
1	Mukah	2,792.61	3,065.96	3,178.08	3,410.86	3,676.81	3,817.02
2	Miri	1,552.49	1,775.56	1,804.64	1,965.78	2,027.03	2,040.35
3	Bintulu	971.12	1,016.50	1,103.30	1,241.54	1,274.28	1,282.87
4	Betong	562.53	578.49	655.38	632.52	674.76	743.19
5	Sibu	392.86	439.09	489.24	560.01	585.56	666.59
6	Samarahan	337.05	389.91	444.13	532.54	545.92	615.65
7	Kapit	173.27	283.55	288.22	297.84	366.43	405.68
8	Sri Aman	177.12	181.79	232.91	245.40	276.87	332.88
9	Kuching	293.80	314.59	314.55	340.44	335.86	328.57
10	Sarikei	110.99	102.28	105.57	113.84	116.97	124.76
11	Limbang	110.37	114.17	111.61	113.28	105.65	120.53
	Total	**7,474.22**	**8,261.89**	**8,727.63**	**9,454.06**	**9,986.13**	**10,478.10**

Table 55 Total potential power generation available from biomass (MW)

No	Division	2005	2006	2007	2008	2009	2010
1	Mukah	1,627.44	1,789.24	1,837.37	1,935.28	2,068.49	2,130.97
2	Miri	661.73	756.79	769.19	837.88	863.99	869.65
3	Bintulu	418.86	438.21	475.21	534.32	548.27	551.21
4	Betong	309.94	317.16	367.21	353.01	367.25	403.65
5	Sibu	180.77	200.48	222.59	252.76	263.64	296.90
6	Samarahan	145.66	168.16	191.27	228.93	234.66	264.08
7	Kapit	73.83	120.83	122.83	126.93	156.17	172.89
8	Sri Aman	76.23	78.22	100.01	105.34	118.75	142.62
9	Kuching	125.56	134.42	134.39	145.42	143.46	140.34
10	Sarikei	60.61	54.09	55.49	59.01	60.34	63.67
11	Limbang	47.11	48.73	47.63	48.35	45.10	51.43
	Total	**3,727.75**	**4,106.31**	**4,323.20**	**4,627.21**	**4,870.12**	**5,087.42**

3.4. SUITABLE LOCATION FOR BIOMASS POWER PLANT

Mukah division has the highest potential in term of power generation availability. Biomass generated in that division could generate 1,789.24 and 2,130.97 MW of power in 2006 and 2010 respectively as show by

Table 56 and 57. These values are corresponding to more that 40% of total available power potential generated from agricultural biomass wastes in Sarawak. Miri is the second highest with 756.79 and 869.65 MW power potential in 2006 and 2010 respectively. The third highest is Bintulu with 438.21 and 551.21 MW in 2006 and 2010 respectively. Mukah division has enormous potential to develop biomass power generation from sago industry waste as well as a significant amount of potential from palm oil. Miri and Bintulu, on the other hand, are the two divisions with the largest palm oil plantation. As such, both divisions have the largest power potential generation from palm oil industry which accounts about 29% for Miri and 18% for Bintulu for total power generation from palm oil industry wastes in Sarawak. In term of southern division of Sarawak, Betong division has the highest power potential at 317.16 MW in 2006 and 403.65 MW in 2010. Most of those potential are deriving from palm oil and sago industry. For Samarahan division, the major contributor for power generation is from palm oil industry despite the fact that this division has the highest power potential generation from paddy and coconut in Sarawak. The other southern divisions in Sarawak, Kuching and Sri Aman, the potential are mainly derived from palm oil industry and some potential are generated from paddy. In central region of the state, Sibu and Kapit division power generation potential are derived mostly from palm oil industry. However, for both Sarikei and Limbang division, biomass waste power generation from agricultural are insignificant as compare to other divisions.

Sarawak land area is vast and the plantations are scattering all over the state. Such ordeal, causing some logistical problem for transportation of raw agricultural biomass waste to biomass power generation plant should such plant to be established in the state. In order to tackle such problem, it is suggested that biomass wastes are to be densified into pellet or briquettes forms prior to transportation of the biomass to power plant. This will not only solve the density problem but an effective moisture content control for transporting biomass wastes for long distance. With this in mind, Table 58 summarises the possible biomass power generation solution for each division in Sarawak.

Table 56 Total potential power generation available from biomass in 2006 (MW)

No	Division	Palm Oil	Paddy	Coconut	Sago	Total	Percentage (%)
1	Kuching	128.64	4.83	0.83	0.12	**134.42**	3.27
2	Sri Aman	53.53	22.12	0.02	2.56	**78.22**	1.90
3	Sibu	145.78	11.32	0.00	43.38	**200.48**	4.88
4	Miri	742.54	14.07	0.12	0.06	**756.79**	18.43
5	Limbang	42.79	5.73	0.21	0.00	**48.73**	1.19
6	Sarikei	14.86	5.11	0.00	34.13	**54.09**	1.32
7	Kapit	111.40	9.43	0.00	0.00	**120.83**	2.94
8	Samarahan	148.55	14.27	5.34	0.00	**168.16**	4.10
9	Bintulu	415.75	6.35	0.23	15.88	**438.21**	10.67
10	Mukah	212.99	9.51	0.66	1,566.07	**1,789.24**	43.57
11	Betong	72.16	15.82	0.91	228.27	**317.16**	7.72
	Total	**2,088.98**	**118.54**	**8.32**	**1,890.47**	**4,106.31**	**100.00**

Table 57 Total potential power generation available from biomass in 2010 (MW)

No	Division	Palm Oil	Paddy	Coconut	Sago	Total	Percentage (%)
1	Kuching	132.61	6.87	0.74	0.12	**140.34**	2.76
2	Sri Aman	119.45	20.60	0.02	2.56	**142.62**	2.80
3	Sibu	247.04	8.25	0.00	41.61	**296.90**	5.84
4	Miri	856.70	12.78	0.12	0.06	**869.65**	17.09
5	Limbang	46.57	4.67	0.19	0.00	**51.43**	1.01
6	Sarikei	22.00	7.53	0.00	34.13	**63.67**	1.25
7	Kapit	167.52	5.37	0.00	0.00	**172.89**	3.40
8	Samarahan	237.84	21.61	4.63	0.00	**264.08**	5.19
9	Bintulu	532.20	4.63	0.27	14.11	**551.21**	10.83
10	Mukah	489.29	4.78	0.62	1,636.28	**2,130.97**	41.89
11	Betong	107.32	14.24	0.89	281.20	**403.65**	7.93
	Total	**2,958.53**	**111.34**	**7.48**	**2,010.08**	**5,087.42**	**100.00**

Table 58 Suggestion on feasible utilisation of Biomass as power generation

No	Division	Note
1	Kuching	Possible for small scale biomass power generation, pelletisation or as substitution fuel for Sejingkat coal power plant especially for palm oil waste.
2	Sri Aman	Palm oil waste is possible for small scale biomass power generation, pelletisation or as substitution fuel for nearby Sejingkat coal power plant. Paddy waste would be suitable for small scale pelletisation which can be transported to Sejingkat coal power or used as fuel for small furnace or boiler.
3	Sibu	Possible for small scale biomass power generation, pelletisation or as substitution fuel for coal power plant in Mukah or Balingian
4	Miri	Highly recommended for Biomass Power Generation Plant establishment due to existence of enormous available palm oil biomass waste.
5	Limbang	Pelletisation or briquetting as the volume is too small.
6	Sarikei	Pelletisation or briquetting as the volume is too small.
7	Kapit	Pelletisation of briquetting due to remote location of this division in which it could be used as fuel for furnace or boiler
8	Samarahan	Possible for small scale biomass power generation, pelletisation or as substitution fuel for nearby coal power plant at Sejingkat.
9	Bintulu	Highly recommended for Biomass Power Generation Plant establishment due to existence of enormous available palm oil biomass waste.
1	Mukah	The best location for biomass power generation plant in

0		Sarawak due to massive available palm oil and sago wastes.
11	Betong	Possible for small scale biomass power generation or for pelletisation or briquetting.

3.5. CO_2 SAVING FROM UTILISATION OF BIOMASS AS FUEL FOR POWER GENERATION

If all of the available biomass wastes generated from the selected agriculture industries are used for power generation, Sarawak could save 29.4 Mtonne of CO_2 emissions in 2005 and 40.1 Mtonne in 2010 as depicted by Table 59. This assumption is considering the fact that biomass is a carbon neutral fuel and it is used to replace coal as fuel in the plant. As in Table 60, if the current and future coal power plants are capable to substitute biomass as fuel about 15.6 Mtonne of CO_2 could be saved. Such saving not only environmentally beneficial but also could also be economically advantageous due to additional income generation from disposed wastes and/or through carbon credit transfer in Clean Development Mechanism Project. Biomass power generation is also expected to induce social developments in Sarawak rural areas not only due to generation of employments in pelletisation industry but also due to possibility of being self sufficient in generating power from locally available biomass wastes.

Table 59 CO_2 saving through utilisation of biomass waste (tonne)

No	Division	2005	2006	2007	2008	2009	2010
1	Kuching	990	1,060	1,060	1,146	1,131	1,106
2	Sri Aman	601	617	789	830	936	1,124
3	Sibu	1,425	1,581	1,755	1,993	2,079	2,341
4	Miri	5,217	5,967	6,064	6,606	6,812	6,856
5	Limbang	371	384	376	381	356	405
6	Sarikei	478	426	438	465	476	502
7	Kapit	582	953	968	1,001	1,231	1,363
8	Samarahan	1,148	1,326	1,508	1,805	1,850	2,082
9	Bintulu	3,302	3,455	3,747	4,213	4,323	4,346
10	Mukah	12,831	14,106	14,486	15,258	16,308	16,801
11	Betong	2,444	2,500	2,895	2,783	2,895	3,182
	Total	**29,390**	**32,374**	**34,084**	**36,481**	**38,396**	**40,109**

Table 60 CO_2 saving through substitution of biomass wastes as fuel in coal power plant (tonne)

No	Plant	MW	CO_2 Saving (tonne)
1	Mukah Coal Power Station	270	2,128.68
2	Sejingkat Coal Power Station	210	1,655.64
3	Balingian	900	7,095.60
4	Nanga Merit	600	4,730.40
	Total	**1980**	**15,610.32**

4. CONCLUSION

Despite being ignored in SCORE development plan, the study has proven qualitatively and quantitatively that biomass waste generated from agricultural industry especially palm oil, paddy, coconut and sago have enormous potential to be developed in Sarawak. The calculated potential is more than 3 times the current

installed capacity of 1,315 MW in Sarawak. Mukah, Miri and Bintulu are the three divisions in Sarawak which have the highest potential for establishing biomass power generation plant. Other divisions such as Betong, Sibu, Samarahan, Kuching and Sri Aman also show some potential in developing biomass power plant but in much smaller scale. Kapit division have some comparable potential but due to remoteness of the locality, centralised biomass power generation would be a challenge. As such, it have been suggested that this division, along with Limbang and Sarikei, to develop pelletisation or briquetting industry in which would supplement other divisions with higher potential of biomass power generation. From carbon saving investigation, it is calculated that 15.6 Mtonnes of CO_2 could be saved should the available biomass in Sarawak are utilised sustainability to meet the current power generation capacity. Therefore, it can be concluded that Sarawak has the potential to implement biomass power generation as the availability of biomass resources from agricultural industry is enormous. However, further studies are still required in order to determine the effectiveness of implementing such project in this vast state.

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