Environmental and Economic Impact of Using Logging Residues as Bioenergy: The Case of Malaysia

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The potential use of residues from the logging process was evaluated for electrical energy generation by direct combustion. The findings were based on logging residues accrued from 1990 to 2015 and were enumerated using a 43% residue recovery rate. The available logging residues were insufficient to supply the primary electrical energy demand as well as reduce the emission of carbon dioxide. However, when coupled with other agricultural residues, the potential energy generation from biomass was significant and could not only lead to reduced fossil fuel demand, but also improve the carbon credit and provide additional employment opportunities in the bioenergy sector.

Keywords: Logging residues; Electrical energy; Biomass; Energy consumption; Carbon dioxide

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INTRODUCTION

The expansion in manufacturing and transportation since the industrial revolution in the early eighteenth century has led to the extensive use of fossil fuels for energy generation. However, the dependence on fossil fuels for economic development has negatively impacted the environment. As a result, there is a global concern about climate change due to the increasing concentration of carbon dioxide (CO_2) and other greenhouse gases (GHGs), such as methane (CH_4) and nitrogen oxide (N_2O), in the atmosphere. Numerous studies have reported on the possible exhaustion of fossil fuels and the resultant global warming (Malinen *et al.* 2001; Gan and Smith 2006; Sathre and Gustavsson 2011; Whittaker *et al.* 2011; Shafie *et al.* 2012; Mekhilef *et al.* 2014).

The depletion of fossil fuels and the consequence of their contribution to global warming cannot be overlooked. As a result, different types of renewable energy sources are being explored throughout the world. Some of the common sources of renewable energy are solar, wind, biomass, and hydropower. Gan and Smith (2006) suggested that countries should select the appropriate renewable energy source based on its geographical location, climate, and availability.

Malaysia has several sources of renewable energy, namely solar, wind, biomass, and hydropower. Among all of the renewable energy sources, Tock *et al.* (2010) highlighted that biomass may have the greatest potential to be exploited as a renewable energy source (Table 1); several other researchers agree (Chuah *et al.* 2006; Shafie *et al.* 2012; Mekhilef *et al.* 2014; Ratnasingam *et al.* 2015a). According to Sathre and Gustavsson (2011), biomass is a promising candidate for renewable energy because solar energy is captured and stored as energy in the plants and trees. Generally, biomass can be converted into different energy forms. In fact, Shafie *et al.* (2012) highlighted that biomass is important for electrical energy generation in many developing countries. It is well known that Malaysia has several different types of available biomass from sectors such as forestry and agriculture (Chuah *et al.* 2006).

Table 1. Types and Quantities of Biomass Produced Annually in Malaysia

Types	Quantities (ktonnes)	Source	Source (ktonnes)	Moisture Content (wt.%)	Dry Weight (ktonnes)
Oil palm fronds	46,837	Oil palm fresh fruit bunch	81,920	60	18,735
Oil palm empty fruit bunches	18,022			65	6308
Oil palm fibres	11,059			42	6414
Oil palm shells	4506			7	4190
Oil palm trunks	10,827			75.9	2609
Paddy straw	880	Replanting paddy	-	11	783
Rice husk	484		2375	9	440
Banana residues	530	Banana	265	10.7	473
Bagasse	234	Sugarcane	730	50	117
Coconut husk	171	Coconut	505	11.5	151
Pineapple waste	48	Pineapple for factories	69	61.2	19
Logging residues	2649	Logs	2649	12	2331
Plywood residues	2492	Plywood	2492	12	2193
Sawmill residues	1160	Sawn timber	1418	12	1021
Source: Mekhilef *et al.* (2014)					

Apart from agricultural residues, forestry and resultant logging residues should also be given attention as an important source of biomass. Malaysia produces a significant amount of logging residues from harvesting forests annually. Although Malaysia practices sustainable forest management (SFM) to manage its forest resources, the allowable annual coup (AAC) that stipulates the extent of harvesting activities allowed often produces a large amount of residues. Noridah *et al.* (2014) described logging residues as the unused portion of growing stock trees left in the forest. Material left unutilized due to excessive stump height, excessive minimum top-diameters, damage to harvested and other trees during felling, skidding damage to logs and other trees, unused secondary species, and unused small-diameter trees are classified as logging residues. However, the cited report did not provide sufficient insights into the different logging residues and mill waste in estimating the potential energy generation from such residues, as different types of biomass often have different energy contents or calorific values (Repo *et al*. 2015). In fact, the data presented in the cited report is far from satisfactory due to the inaccuracy of data compiled from secondary sources, as acknowledged by Noridah *et al.* (2014).

It should be recognized that the large amount of timber harvested from the natural forest generates a sizable amount of residues that could be recovered and used for bioenergy production and/or other purposes. The timber resources from the natural forests are often converted into sawn timber before being exported overseas, particularly to Japan, South Korea, India, and the European Union. In the case of Sarawak, however, 40% of the logs produced from the natural forests are exported primarily to East Asia, while the balance 60% is meant for domestic consumption, usually in the form of sawn timber. Logs have been banned from export in Peninsular Malaysia since 1992 (Lim *et al.* 2016).The harvesting methods, using chain-saws and crawler tractors for winching and skidding of the logs to the storage area, are the usual methods of harvesting employed throughout the country. It has been reported that under such harvesting methods, the logging residue left behind is often around 35% (Kong 2000). In a recent report by Lim *et al.* (2016) it was suggested that for the common commercial timber species harvested presently, such as Meranti, (*Shorea* spp.), Kelat (*Eugenia* spp.), and Keruing (*Dipterocarpus* spp.), the harvesting residue of 35% was acceptable. Nevertheless, studies about logging residues as a biomass for potential electrical energy generation have been limited in the subject country and their arguments have been difficult to generalize. Therefore, this study aims to estimate the recoverable logging residues from the natural forests and the amount of electrical energy that could potentially be generated from this biomass. Further, the co-benefits of logging residues for electrical energy generation will also be examined in terms of their economic and environmental aspects.

METHODOLOGY

The potential electricity generation from logging residues during the period from 1990 to 2015 was calculated based on the annual harvesting records from the Forestry Departments of Peninsular Malaysia, Sabah and Sarawak (Table 2). Although the data were compiled from published information from the respective Forestry Departments, efforts were taken to ensure that the logging data used in this study were accurate by verifying the logging activities with the Pre-Felling and Post-Felling inventory records available at the Forestry Departments. As suggested by Ratnasingam and Ioras (2006), the Pre-Felling and Post-felling inventories are useful tools in monitoring and controlling the logging activities as prescribed under the Sustainable Forest Management (SFM) system.

Table 2. Annual Log Production from the Natural Forests in Malaysia

Year	Log Production (mil m^3)
1990	40.10
1992	43.51
1994	35.67
1996	30.09
1998	21.67
2000	23.08
2001	18.92
2002	20.65
2003	21.53
2004	22.04
2005	22.36
2006	21.89
2007	22.05
2008	20.26
2009	18.31
2010	17.80
2011	16.17
2012	15.89
2013	14.30
2014	14.58
2015	13.62

As Malaysia practices the Sustainable Forest Management (SFM) system, the total annual harvesting area is regulated by the respective Forestry Departments, ensuring that only the stipulated logging area is harvested by the contractor or concession holder. The trees to be harvested are marked and tagged, and the felling-direction is indicted by the Forestry Department, which ensures that only the selected species were harvested. In most instances, 12 to 14 trees are tagged per hectare (Lim *et al.* 2016). Such a practice ensures that there is minimal damage to the stand and sufficient regeneration in the residual stand.

Recoverable Logging Residues

Logging residues produced from harvesting activities are generally difficult to capture due to their location, geographical distances, and the variable quality of the standing stock in the forest. Consequently, a logging residue recoverability factor is used to determine the quantity of logging residues produced annually. In this study, the volume of logging residues was established in accordance with the recovery rate suggested by Kong (2000), who reported that 43% of the total tree volume is left behind in the forest after the logging operation using the conventional chain-saw and crawler-tractor method. The timber species felled were predominantly Meranti (*Shorea* spp.), which was very well adapted over a wide range of topography and elevations in the forests. The amount of residue produced was estimated by taking into account the waste from the felled tree, the trees damaged during the felling, as well as during the log extraction process. However, this recoverability factor is slightly higher than that suggested by the Forest Research Institute of Malaysia (1992) and Harun *et al.* (1984), where it was reported to be 30% and 34%, respectively. Noridah *et al.* (2014) suggested that this difference was possibly due to unwanted timber species that were felled intentionally or accidentally during the harvesting operation.

Gan and Smith (2006) explained that logging residues also cover growing stock and other sources, which implies that the 43% recoverability factor is the most appropriate value to be used in this study. The logging residue from growing stock is referred to as the growing stock volume, including branches and tops, which are knocked down during the harvesting activity but left on the harvest site. In the meantime, other sources were related to the wood volume knocked down or damaged during the harvesting activity. In a later study by the Forestry Department of Peninsular Malaysia (2015), it was reported that the average logging residues recoverability factor of 40% was applicable when logging between the lowland and hill forests, which inevitably lends support to the value reported by Kong (2000).

In this study, the amount of logging residue recovered was determined using Eq. 1,

$$LR = RF \times V_y \quad (1)$$

where LR is the logging residue recovered (mil m^3), RF is the recoverability factor (%), and V_y is the volume of logs harvested during the particular time frame (year).

Energy content of logging residue

The next step is to determine the energy content of the recoverable logging residue. Noridah *et al.* (2014) reported that the energy content of biomass is normally reported as dry biomass. The enumeration of energy value in logging residue is in accordance with Eq. 2 (Gan and Smith 2006),

$$E = D \times LR \times CV \quad (2)$$

where *E* is the energy value (mil MJ), *D* is the density of the logging residues (kg/m^3), and *CV* is the calorific value of the logging residues (MJ/kg). Because the logging residues are comprised of different types of wood species, a bulk density of 294 kg/m^3 was applied in this study. The net calorific value of logging residues used was taken to be 18.41 MJ/kg (Chuah *et al*. 2006), which was the energy value of the biomass at moisture contents below 15% (or also referred to as dry biomass).

Based on the records from the Forest Department, approximately 80% of the harvested logs have an average bulk density between 250 kg/m^3 to 320 kg/m^3 (Lim *et al.* 2016), which supports the use of a bulk density of 294 kg/m^3 as suggested by Chuah *et al.* (2006). This value of bulk density was the average value of waste, splinters, shavings, and particles of the residues, which is ready to be burnt.

Potential Electrical Energy Generation from Logging Residues

To date, most research on electrical energy generation from wood biomass is focused on direct combustion methods. Tock *et al*. (2010) defined direct combustion as the burning of biomass to convert energy stored in plants into heat and electricity. The energy value of logging residue is converted into electrical energy that can be calculated based on the average energy efficiency, as shown in Eq. 3,

$$EE(MW) = (E) \times \eta \tag{3}$$

where *EE* is potential electrical energy (MW) and η is the energy efficiency. The energy efficiency differs based on the technology used during the conversion process. The conversion process used for energy generation from logging residues is direct combustion. The energy efficiency for direct combustion was taken to be 0.19 to 0.26 as reported by Shafie *et al.* (2012), which also includes biomass derived from plants and trees. Therefore, in this study, an average energy efficiency value of 0.225 was applied. In accordance to Tock *et al.* (2010), 1 PJ of biomass potential can be converted into 46 MW of electrical energy with electrical conversion efficiency.

RESULTS AND DISCUSSION

This study evaluated the potential electrical energy that could be generated from logging residues by direct combustion. Table 3 provides a summary of the recoverable logging residues, their energy content, and their potential electrical energy generation.

As can be calculated from Table 3, the total amount of logging residues for the period from 1990 to 2015 was 192.0 million m^3. It was noticeable that the availability of logging residue has gradually decreased since the 1990's as the annual logging coupe was reduced steadily to conform to the requirements of the Sustainable Forest Management (SFM) system. In fact, the total amount of logging residue has dropped 66.0% from 1990 to 2015. The decrease in log production was related to the government's efforts to preserve the environment and its biodiversity. Realizing the need to sustainably harvest the forest, to conserve the environment, and to protect the highly prized wildlife sanctuaries, the SFM system was implemented in the 1990's.

The SFM system has restricted logging activities through the allowable annual coups (AAC), which has regulated annual growth rates of the forest with the annual harvested volume. This is the main factor that contributed to the reducing availability of logging residues in the country over the years (Menon 2000).

Table 3. Recoverable, Energy Value, and Potential Electrical Energy of Logging Residues

Year	Logging Residues (mil m^3)	Energy Content of Logging Residues (mil MJ)	Electrical Generation (MW)
1990	17.2	93,300	966
1992	18.7	101,000	1,100
1994	15.3	83,000	859
1996	12.9	70,000	725
1998	9.32	50,000	522
2000	9.92	53,700	556
2001	8.14	44,000	456
2002	8.88	48,100	497
2003	9.26	50,100	519
2004	9.48	51,300	531
2005	9.61	52,000	539
2006	9.41	51,000	527
2007	9.48	51,300	531
2008	8.71	47,200	488
2009	7.87	43,000	441
2010	7.65	41,400	429
2011	6.95	37,600	390
2012	6.83	37,000	383
2013	6.15	33,300	345
2014	6.27	34,000	351
2015	5.86	32,000	328

Current Energy Consumption Pattern in Malaysia

The demand for electrical energy in Malaysia is provided by a variety of sources, predominantly through the combustion of fossil fuels, namely oil, coal, natural gas, and diesel, as well as a small proportion of renewable sources. Table 4 presents the electrical energy mix patterns from 1990 to 2015, obtained from the Malaysia Energy Book Statistics (2016). Overall, the consumption of electrical energy in the country showed an increase from 2090 GWh to 145,000 GWh over the period from 1990 to 2015. Two factors crucial to the increasing electrical energy demand in the country are economic development and population growth (Shafie *et al.* 2012).

Although Malaysia has a plentiful supply of fossil fuels that can be used to generate electricity, Koh and Hoi (2003) anticipate that fossil fuel sources will be exhausted in the next 50 years. Therefore, there is an urgent need to consider renewable energy sources in the overall energy mix of the country. However, the proportion of renewable energy (which include hydro, solar, biomass, *etc.*) in the total energy mix of the country is relatively small compared to non-renewable energy, as shown in Fig. 1.

Table 4. Electrical Energy Generation Pattern in Malaysia

Year	Non-renewable Energy (GWh)				Renewable Energy (GWh)	
	Oil	Diesel	Gas	Coal	Hydropower	Other
1990	367	585	623	-	518	-
1992	9,720	862	11,400	3,840	4,290	-
1994	8,760	988	17,500	4,080	6,480	-
1996	9,510	1,580	29,600	4,180	5,180	189
1998	10,300	971	40,200	3,660	4,460	-
2000	2,380	552	50,300	4,040	6,990	-
2001	2,530	831	54,100	6,240	6,100	-
2002	4,470	746	54,000	9,560	5,420	-
2003	1,220	976	56,500	13,400	5,100	-
2004	1,130	729	61,400	22,600	5,570	-
2005	1,050	348	61,400	25,200	6,010	-
2006	1,260	643	64,800	26,600	6,320	50
2007	1,090	677	65,600	30,900	5,960	63
2008	1,050	601	67,800	31,000	7,810	66
2009	1,040	685	63,400	37,600	6,890	132
2010	933	726	61,300	49,400	6,360	170
2011	4,300	5,110	55,700	52,300	8,060	1,580
2012	2,280	4,340	61,000	55,600	9,250	1,600
2013	1,570	1,740	71,200	53,700	11,800	1,320
2014	376	756	74,500	53,700	13,500	995
2015	45	1,520	66,900	59,300	15,500	1,230

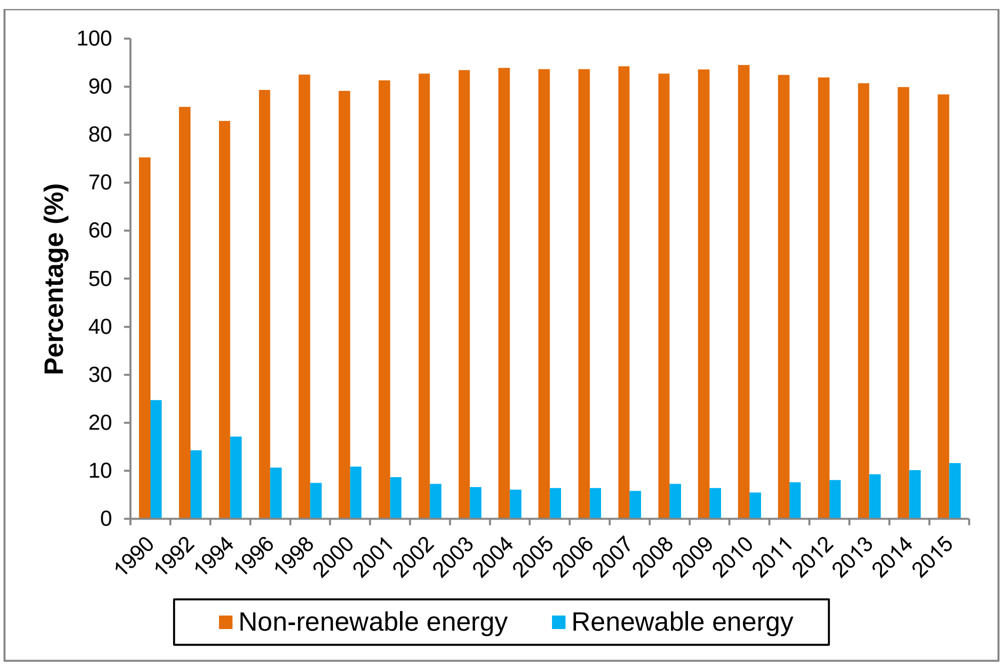

Fig. 1. Comparison of the utilization of non-renewable and renewable energy for electrical energy generation

The overwhelming dependence on fossil fuels for electrical energy generation in the country could be greatly reduced if the available renewable energy sources are seriously explored. As this study shows, incorporating logging residue as a renewable electrical energy source could reduce the energy required from fossil fuels. The electrical energy deficit, summarized in Table 5, revealed that logging residue could generate a small but substantial amount of electrical energy.

Table 5. Fossil Fuels Energy Supply Deficit from Logging Residues

Year	Potential Electrical Energy from Logging Residues (GWh)	Fossil Fuels Electricity Generation (GWh)	Energy Supply Deficit (GWh)
1990	0.97	1,580	-1,570
1992	1.05	25,800	-25,800
1994	0.86	31,300	-31,300
1996	0.72	44,900	-44,900
1998	0.52	55,200	-55,200
2000	0.56	57,300	-57,300
2001	0.46	63,700	-63,700
2002	0.50	68,800	-68,800
2003	0.52	72,100	-72,100
2004	0.53	85,900	-85,900
2005	0.54	88,000	-88,000
2006	0.53	93,300	-93,300
2007	0.53	98,200	-98,200
2008	0.49	101,000	-101,000
2009	0.44	103,000	-103,000
2010	0.43	112,000	-112,000
2011	0.39	117,000	-117,000
2012	0.38	123,000	-123,000
2013	0.34	128,000	-128,000
2014	0.35	130,000	-129,000
2015	0.33	128,000	-128,000

Although logging residues currently appear to play a very minor role in potential electrical energy generation, the exploitation of other biomasses will add further importance to the electrical energy generation from biomass. Shuit *et al.* (2009) highlighted that biomass accounts for only 14% of the total energy produced in the country. Table 6 shows the potential of biomass for electricity, provided by Petinrin and Shaaban (2015).

Table 6. The Potential of Electricity from Biomass in Malaysia

Biomass	Quantity (kton/year)	Potential Generation (GWh)	Potential Capacity (MW)
Rice mills	424	263	30
Wood industry	2,177	598	68
Palm oil mills	17,980	3,197	365
Bagasse	300	218	25
Palm oil mill effluent	31,500	1,587	177

Environmental Aspects

The production of bioenergy from logging residues could lead to a variety of co-benefits. Several studies have reported that the largest impact of using logging residues for bioenergy production is the observed improvement in environmental emissions (Gan and

Smith 2006; Sathre and Gustavsson 2011; Kukrety *et al.* 2015; Moon *et al.* 2015; Repo *et al.* 2015). Another important aspect is the reduction in fossil fuel dependency for overall energy production (Kukrety e*t al.* 2015; Moon *et al.* 2015; Rothe *et al.* 2015). Apart from lessening the overall environmental impact of electrical energy generation and promoting energy security, the utilization of logging residue for bioenergy production will create job opportunities (Kukrety *et al.* 2015).

It is well known that electrical energy in Malaysia primarily comes from the combustion of fossil fuels. Apart from the threat of fossil fuel depletion, another major concern is fossil fuel emissions that contribute to climate change and global warming. Ramasamy *et al.* (2015) reported that fossil fuels are comprised of carbon, sulfur, nitrogen, or their compounds. Therefore, the combustion of fossil fuels releases greenhouse gases (GHGs), particularly carbon dioxide, to the environment. In contrast, the discharge of methane and nitrogen oxide is slight in comparison to that of carbon dioxide, which is the main greenhouse gas. According to Tock *et al.* (2010), the concentration of carbon dioxide in Malaysia's environment is estimated to increase 0.5% annually.

The emission of GHGs due to the combustion of fossil fuels for electrical energy generation from 1990 to 2015 has been translated into a carbon footprint in the context of carbon dioxide equivalency (CO_2-eq) in Fig. 2. Each of the GHGs, including CO_2, CH_4, and N_2O, were converted into CO_2-eq by multiplying each of the components with the factors 1, 25, and 298, respectively (Ratnasingam *et al.* 2015b). Figure 2 exhibits the release of CO_2-eq associated with electricity generation from fossil fuels between 1990 and 2015.

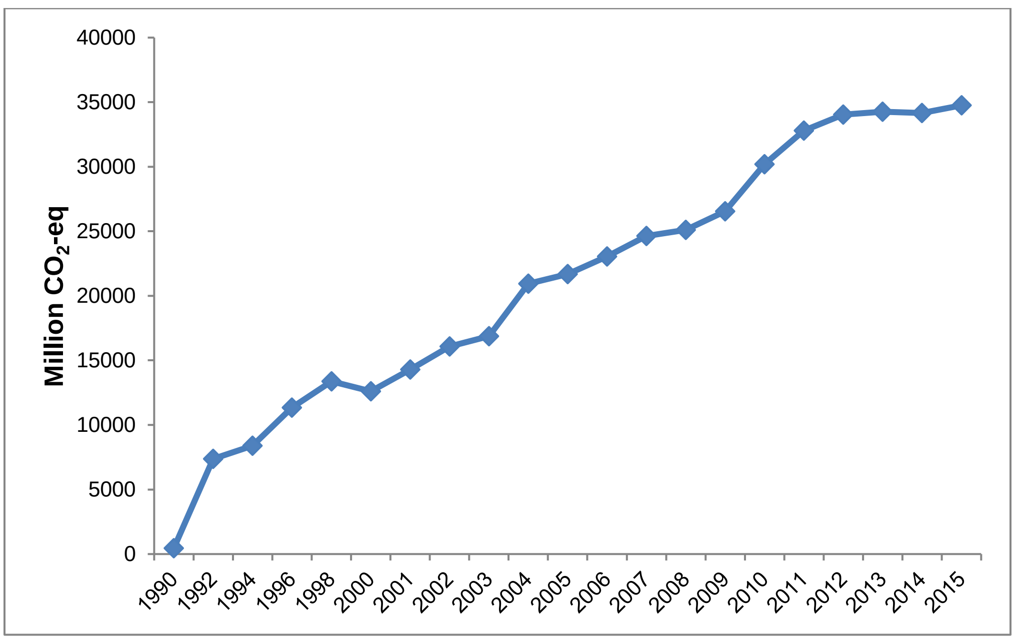

Fig. 2. The emission of CO_2-eq from fossil fuels combustion for electrical energy generation

Like fossil fuels, logging residues also store carbon. One kilogram of wood contains approximately 52.4% carbon (Wilson 2009). If logging residues were utilized for electrical energy generation, without any doubt, carbon dioxide would be discharged into the environment. The evaluation of CO_2 emission from logging residues was determined from the study by Wilson (2009), in which the molar mass ratio of carbon dioxide to carbon was

3.67 times the carbon content of the wood. Figure 3 depicts the amount of carbon stored in logging residues and their emission into the environment if the logging residues are combusted for electrical energy generation.

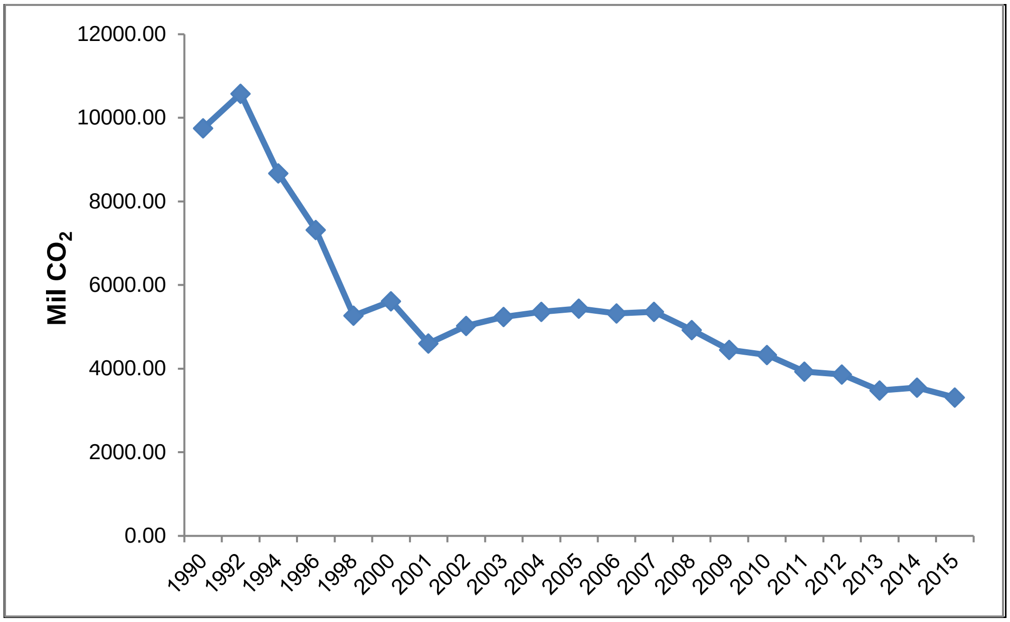

Fig. 3. The emission of CO_2 if logging residues are combusted for electrical energy generation

However, the CO_2 emissions from the combustion of logging residues are very small compared to that of fossil fuel combustion. Logging residues are categorized as biomass that are comprised of biogenic carbon. Biogenic carbon, also known as biomass-derived carbon, is in fact carbon neutral. The released CO_2 from burning or decomposition is reabsorbed by trees in the forests. Meanwhile, the emission of carbon dioxide from fossil fuel is known as an anthropogenic emission. With anthropogenic emissions GHGs, particularly carbon dioxide, remain in the environment.

Hence, the co-utilization of logging residues with fossil fuels for electricity production could result in a reduction of CO_2 emissions from fossil fuels. The release of CO_2 from the combustion of logging residues will remain in the environment for a certain amount of time, but with tree growth, these gases will be reabsorbed from the atmosphere. In addition, biogenic carbon will also be discharged to the environment through the decay and decomposition processes of plant materials (Wilson 2009; Sathre and Gustavsson 2011; Mi and Han 2014).

Although CO_2 emission from logging residue is regarded as zero, Jäppinen *et al.* (2014) opinioned that other GHGs may also be emitted when biomass is combusted for electrical generation. Therefore, in this paper, the release of CO_2-eq from logging residues was enumerated and compared with the release of CO_2-eq from fossil fuels and is shown in Table 7.

Table 7. The Reduction of CO_2-eq with the Assumption that Biomass is used for Electrical Energy Generation

Year	CO_2-eq Emission from Logging Residues (mil kg)	CO_2-eq Emission from Rubberwood and Oil Palm (mil kg)	Total CO_2-eq Emission (Logging Residues, Rubberwood and Oil Palm) (mil kg)	CO_2-eq Emission from Fossil Fuels (mil kg)	CO_2-eq Reduction from Fossil Fuels (mil kg)
1990	9,750	39,600	49,300	460	-48,900
1992	10,600	40,500	51,100	7,400	-43,800
1994	8,670	45,100	53,700	8,400	-45,400
1996	7,320	48,800	56,100	11,400	-44,800
1998	5,270	45,500	50,800	13,400	-37,400
2000	5,610	55,000	60,600	12,600	-48,000
2001	4,600	57,500	62,100	14,300	-47,800
2002	5,000	57,100	62,100	16,100	-46,000
2003	5,200	61,200	66,400	16,900	-49,500
2004	5,400	62,800	68,100	20,900	-47,200
2005	5,440	65,800	71,300	21,700	-49,600
2006	5,320	68,800	74,100	23,000	-51,000
2007	5,360	68,100	73,400	24,600	-48,800
2008	4,930	73,300	78,200	25,100	-53,100
2009	4,500	70,000	74,400	26,500	-47,900
2010	4,330	67,600	71,900	30,200	-41,700
2011	3,930	74,300	78,300	32,800	-45,500
2012	3,860	73,000	76,800	34,000	-42,800
2013	3,480	75,500	79,000	34,300	-44,800
2014	3,550	75,900	79,400	34,200	-45,200
2015	3,310	76,200	79,500	34,800	-44,700

Note: Source of data for rubberwood was adapted from Ratnasingam *et al.* (2015a); source of data for oil palm was adapted from Shafie *et al.* (2012) and Department of Statistics Malaysia (DOSM); density for rubberwood: 640 kg/m^3

Although the contribution of logging residues as a potential bioenergy for electrical generation is comparably small, when all available biomass in the country is utilized for electrical energy production, the amount of bioenergy generated can be substantial, with a positive impact on the CO2-eq emitted (Table 7). The success of this option greatly depends on the economic incentive of such ventures (Lim *et al.* 2016).

Economic Aspects

The Kyoto Protocol has sanctioned offsets as a way for governments and private companies to earn carbon credits that can be traded within a marketplace. The protocol established the Clean Development Mechanism (CDM), which validates and measures projects to ensure they produce authentic benefits and are genuinely "additional" activities that would not otherwise have been undertaken (Noridah *et al.* 2014). Organizations that are unable to meet their emissions quota can offset their emissions by buying CDM-approved Certified Emissions Reductions.

By comparing the electricity generation costs using fossil fuels and biomass, it is apparent that the cost of producing 1 kWh of electricity from biomass is comparatively higher. This cost figure includes the collection, comminution, and transport of the logging residues to existing power generation sites to be burnt by direct combustion. In fact, Lim *et al.* (2016) suggested that the small price differential in power generation between fossil fuel and biomass explains the lackluster interests among local industrials and power generation companies to explore this option seriously. However, with the necessary government subsidy the use of biomass in the form of logging residues as a possible bioenergy option may soon become a reality. Further, the carbon credit earned from the voluntary market through the use of such biomass is quite substantial and will further reinforce the country's commitment towards mitigating climate change through green energy production (Table 8). In lieu of this potential scenario, due diligence is recommended to help in the assessment and identification of "good quality" offsets to ensure offsetting provides the desired additional national environmental benefits, and to avoid reputational risk associated with poor quality offsets derived from the use of logging residues for energy production (Ratnasingam *et al.* 2015a).

Table 8. Economic Aspects of Fossil Fuels and Biomass

Year	Cost of Electricity Production from Fossil Fuel (RM million)	Cost of Electricity Production from Biomass (RM million)	Carbon Credit Earned from Biomass Utilization in the Voluntary Market (RM million)
1990	700	1,410	620
1992	9,630	1,450	640
1994	12,100	1,610	670
1996	16,100	1,740	700
1998	19,100	1,620	630
2000	20,600	1,960	760
2001	22,300	2,050	770
2002	23,700	2,040	780
2003	24,700	2,180	830
2004	29,300	2,240	850
2005	30,100	2,350	890
2006	31,900	2,450	920
2007	33,400	2,430	920
2008	34,700	2,620	980
2009	35,100	2,500	930
2010	38,100	2,410	900
2011	40,700	2,650	980
2012	42,900	2,600	960
2013	45,200	2,700	990
2014	46,000	2,710	990
2015	46,300	2,720	990

Note: Cost of producing 1 kWh of electricity from fossil fuel is RM 0.32; cost of producing 1 kWh of electricity from biomass is RM 0.36; 1 metric tonne of carbon credit is RM 24; source: National Energy Council of Malaysia

Despite the economic viability of energy production from logging residues, it is pertinent to state the fact that logging activities have been deemed as the "financial chauffer" of the respective state governments in the country, as the forest and forestry activities are under the jurisdiction of the state government (Lim *et al.* 2016). Inevitably, a common incentive scheme that is applicable throughout the country may not be possible, which in turn may hinder the effective collection, comminution and transport of this residues from the various logging sites to the nearest power generation point. Nevertheless, in states such as Pahang, Kelantan, Sarawak, Perak, and Johor with substantial logging activities, localized production of energy from logging residues could well be realized earlier, provided the proper incentive and system be put in place.

Although the National Biomass Strategy 2020 (NIA 2013) of the country clearly underlines the importance of biomass as an important source of energy, its implementation has been relatively slow due to present insignificant cost differentials compared to energy production from fossil fuels. In the case of logging residues, the collection and transportation from the forests to the energy generation sites must be coordinated to ensure that its commercial viability becomes a reality. The provision of subsidies and incentives are necessary tools to ensure that the potential energy generation from logging residues as well as other types of biomass is fully exploited for energy production.

CONCLUSIONS

1. Studies on methods to reduce the utilization of fossil fuels to sustain energy security and reduce the emission of CO_2 to the environment have been extensively conducted. In this study, the potential electrical energy that could have been generated from logging residues in Malaysia by direct combustion was determined for the period from 1990 to 2015.
2. Although the quantity of logging residues from harvesting activities has decreased due to reduced logging activities, the potential of bioenergy generation from this biomass is worth considering against the present primary energy sources.
3. The co-utilization of logging residues together with the biomass from the rubber and oil palm plantations, presents a very compelling case to minimize the dependency on fossil fuels for electrical energy generation in Malaysia. Further, the additional income that could be earned from the carbon credits and the resultant employment opportunities will serve well for the bioenergy sector in the country.
4. The choice, in terms of cost savings and carbon emission reduction benefits, is very site specific and the least-cost option in terms of RM0 per tonne C avoided will differ from case to case.

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