The Prospects of Rubberwood Biomass Energy Production in Malaysia

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Rubber has been shown to be one of the most important plantation crops in Malaysia, and rubber tree biomass has widespread applications in almost all sectors of the wood products manufacturing sector. Despite its abundance, the exploitation of rubberwood biomass for energy generation is limited when compared to other available biomass such as oil palm, rice husk, cocoa, sugarcane, coconut, and other wood residues. Furthermore, the use of biomass for energy generation is still in its early stages in Malaysia, a nation still highly dependent on fossil fuels for energy production. The constraints for large scale biomass energy production in Malaysia are the lack of financing for such projects, the need for large investments, and the limited research and development activities in the sector of efficient biomass energy production. The relatively low cost of energy in Malaysia, through the provision of subsidy, also restricts the potential utilization of biomass for energy production. In order to fully realize the potential of biomass energy in Malaysia, the environmental cost must be factored into the cost of energy production.

Keywords: Rubberwood; Biomass; Energy source; Energy generation

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INTRODUCTION

The cultivation of rubber in Malaysia began in 1879 in Kuala Kangsar, eventually resulting in a booming rubber industry. Since independence, the rubber industry has become one of the most important socio-economic sectors in the country, both in terms of foreign exchange earnings as well as rural economic development (Ratnasingam *et al.* 2012). In recent years however, Malaysia has been replaced as the largest producer of rubber in the world (Balsiger *et al.* 2000) to the third position after Indonesia and Thailand (Shigematsu *et al.* 2011). Despite that, the export earnings from the rubber industry reached more than 3 billion USD per annum over the last few years and provided employment to almost 75,000 people in the country (Ratnasingam and Scholz 2009). Hence, the country is still regarded as the leader in the rubber industry, both in terms of its cultivation as well as its utilization (Ratnasingam *et al.* 2012).

Sir Henry Wickham is renowned for introducing rubber to several countries in Asia, including Malaysia. The rubber tree (*Hevea brasiliensis*) originally grew in the wild in its native home in the Amazon Forest of Brazil, before it was cultivated as a plantation tree-crop (Ratnasingam *et al.* 2011) to meet the high demand for latex and natural rubber from the manufacturing sector. Although rubber is planted extensively in 20 countries for latex production (Teoh *et al.* 2011), Southeast Asia is the world leader for natural rubber production given that more than 70% of rubber in the world is cultivated in Indonesia, Thailand, and Malaysia (Shigematsu *et al.* 2011).

Apart from latex, the rubber tree also produces a large quantity of biomass. It is estimated that a standing tree can produce up to 2.1 m^3 of biomass, including the trunk, branches, twigs, and leaves (Ratnasingam and Scholz 2009). The woody biomass, previously discarded as waste, has found new application as the primary raw material for the booming wood industry in Malaysia, especially when the supply of logs from the natural forests started to dwindle from the mid-1980s (Menon 2000). Considering the need to reduce dependence on fossil fuels for energy and for environmental conservation, energy from biomass is becoming an increasingly important topic in Malaysia. Therefore, the purpose of this paper is to explore the viability of rubberwood biomass for energy production in comparison to other biomass available in Malaysia. The challenges and constraints to energy production from biomass will also be discussed.

RUBBERWOOD BIOMASS AND UTILIZATION

Rubber cultivation in Malaysia is undertaken by large estate owners and individual small holders. Large estate owners, which have largely been international companies such as Guthrie, Sime Darby, Golden Hope, KLK, and IOI, have been reducing their rubber cultivation over the years (Fig. 1). The main reason has been the low price of natural rubber, which has resulted in estate owners switching to the more profitable commodities, predominantly oil palm (Teoh *et al.* 2011). On the other hand, smallholdings managed by agencies such as the Rubber Industry Smallholder Development Authority (RISDA), Federal Land Development Authority (FELDA), and Federal Land Consolidation and Rehabilitation Authority (FELCRA), have been increasing their rubber cultivation acreage due to subsidies provided to the small holders (Ratnasingam *et al.* 2011).

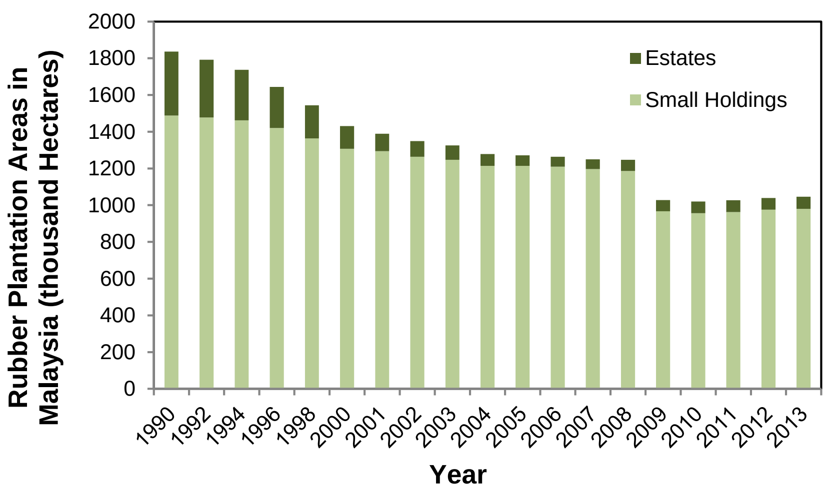

Fig. 1. Rubber plantation areas in Malaysia (thousand hectares)

Table 1 represents the production of rubberwood biomass in Malaysia, based on an annual replanting rate of 3% of cultivated area. This calculation was made based on several assumptions: (i) the replanting activity was carried out as per schedule, and (ii) all above-ground biomass up to 10 cm in diameter was extracted from the field. Given these data, it is clear that a large amount of rubberwood biomass becomes available on an annual basis in Malaysia.

Table 1. Production of Rubberwood Biomass

Year	Total Cultivation Area (thousand ha)		Replanting Area (ha) (3% x Total Cultivation Area)	Total Biomass Production (m^3) (180 m^3/ha x Replanting Area)
	Small holdings	Estates		
1990	1488.0	348.7	55 101	9 918 180
1992	1478.2	314.1	53 769	9 678 420
1994	1462.1	275.0	52 113	9 380 340
1996	1420.4	223.9	49 329	8 879 220
1998	1363.7	179.9	46 308	8 335 440
2000	1306.9	123.8	42 921	7 725 780
2001	1293.8	95.5	41 679	7 502 220
2002	1264.0	84.8	40 464	7 283 520
2003	1247.4	78.5	39 777	7 159 860
2004	1214.4	64.4	38 364	6 905 520
2005	1213.9	57.4	38 139	6 865 020
2006	1209.4	54.2	37 908	6 823 440
2007	1194.7	53.4	37 443	6 739 740
2008	1185.9	61.1	37 410	6 733 800
2009	967.1	61.1	30 846	5 552 280
2010	956.2	64.2	30 612	5 510 160
2011	962.8	64.2	30 810	5 545 800
2012	975.3	65.9	31 236	5 622 480
2013	979.9	77.4	31 719	5 709 420

Source: Data from the Rubber Research Institute of Malaysia (2014) and Department of Statistics (2014)

Note: The biomass of 180 m^3 per hectare includes trunk, branches, and twigs up to 10 cm in Diameter.
The left over biomass totals = 411,380.66 m^3 per annum (Hong and Sim 1994)

CURRENT UTILIZATION OF RUBBERWOOD

Rubberwood is regarded as the most important raw material for the wood industry in Malaysia, and its potential was recognized as early as the 1950s. However, the plentiful supply of wood materials from natural forests held back the acceptance of processing rubberwood for wood products. This was further hampered by the low durability of the wood. Efforts taken by the Forest Research Institute of Malaysia (FRIM) and the Malaysian Timber Industry Board (MTIB) in the mid-1970s promoted the use of rubberwood in wood products manufacturing sectors such as sawmilling, medium density fibreboard, particleboard, laminated veneer lumber, plywood, glulam, laminated finger-jointed boards, veneer, cement-bonded board, builders carpentry and joinery, flooring, door, pulp, and furniture (Hong and Sim 1994).

The success of rubberwood as a raw material for wood products manufacturing can be attributed to its pleasant appearance, light colour, abundant availability, good mechanical properties, low cost, and its renewable image (Ratnasingam *et al*. 2011). Further, Shigematsu *et al*. (2011) suggested that the high proportion of export of rubberwood products was due to logging control on natural forests, which limited the supply of natural forest wood, and that rubberwood is still the most widespread type of plantation material in Malaysia. Ratnasingam and Scholz (2009) pointed out that the commercial success of rubberwood as a raw material of international standing is due to the continuous effort of industrial players, namely Masco Corporation, Hong Teak Furniture Industry, and UMW Furniture Industries, who championed the use of rubberwood in knock-down furniture products exported to the United States since 1979. In fact, it is undeniable that the partnership between the public and private sectors has led to the successful utilization of rubberwood in Malaysia, and is possibly a feat to be followed by other countries (Ratnasingam *et al*. 2012). Table 2 shows the overall total export value (RM million) of rubberwood products which has been steadily growing over the years.

Table 2. The Export Value of Rubberwood Sub-sectors (RM million)

Year	Sawn timber	Furniture	Mouldings	MDF	Chipboard	Builders, Carpentry and Joinery	Wooden Frames	Total
2000	-	3,535.2	313.2	823.0	160.0	269.0	-	5,100.4
2001	87.3	3,022.9	224.3	873.3	134.0	243.4	-	4,585.2
2002	91.6	3,339.4	228.8	866.8	115.7	261.0	-	4,903.3
2003	60.3	3,735.8	208.1	978.6	102.2	281.3	-	5,366.3
2004	137.1	4,350.8	646.5	1,020.9	195.8	109.5	11.6	6,472.2
2005	386.2	4,665.3	698.1	1,106.7	266.7	116.1	12.7	7,251.8
2006	69.8	5,127.4	796.3	1,144.9	266.9	102.7	12.2	7,520.2
2007	55.2	5,331.9	915.3	1,180.9	364.9	101.8	13.2	7,963.2
2008	27.1	5,536.9	744.1	1,156.1	391.7	100.5	12.4	7,968.8
2009	34.3	5,536.9	686.4	1,033.4	250.1	98.8	10.5	7,112.1
2010	89.9	4,778.6	647.1	1,078.5	261.6	86.2	11.2	6,953.0
2011	74.2	5,234.7	698.3	1,044.6	234.5	89.0	11.5	7,386.8
2012	70.9	5,578.2	701.5	1,087.0	278.5	87.5	12.1	7,815.7
2013	67.9	5,429.3	678.4	1,019.1	256.9	90.5	10.9	7,553.0
Sources: Rubber Research Institute Malaysia (2014) and Malaysian Timber Industry Board (2014)								

Sawn Timber

India and Sri Lanka began processing rubberwood into sawn timber in the early 1950s, due to the scarcity of logs. The turning point was the fact that Malaysia was the first country to export rubberwood sawn timber in the late 1970s (Hong 1994). Hong and Sim (1994) pointed out that the export of this product from Peninsular Malaysia has been increasing over the years until June 1990, when the export levy was imposed on rubberwood sawn timber. This was followed by the imposition of an export quota on rubberwood sawn timber by the government of Malaysia in an effort to ensure sufficient supply of rubberwood sawn timber to the value added products industries (Hong 1995).

Panel Products

Mohd Shahwahid and Abdul Rahim (2009) stated that the use of rubberwood for medium density fibreboard manufacturing was a considerable success. As is shown in Table 2, the export value of medium density fibreboard (MDF) was the second largest after rubberwood furniture. Rubberwood biomass is also used in the production of other panel products such as blockboard, plywood, particleboard, and cement bonded particleboard.

Furniture Industry

Although the supply of rubberwood has been argued to be insufficient by furniture manufacturers in Malaysia, the export value of rubberwood furniture has shown significant progress over the years (Table 2). In fact, rubberwood furniture exports make up 80% of the total furniture exports from Malaysia (Ratnasingam *et al*. 2011).

Other Commercial Production

Although the export value of chipboard, mouldings, builders carpentry and joinery (BCJ), and wooden frames from rubberwood fluctuated from 2000 to 2013 (Table 2), these products are still considered as important contributors to the economy of the nation (Ratnasingam *et al*. 2011).

RUBBERWOOD AS A POTENTIAL ENERGY SOURCE

From the perspective of using rubberwood as fuel, it is apparent that rubberwood is a promising candidate as an alternative renewable energy source. In addition, the conversion technologies such as combustion, pyrolysis (Tan 1989; Shaaban *et al*. 2013) and gasification (Kaewluan and Pipatmanomai 2011; Adisurjosatyo *et al.* 2012) have been used to generate energy from rubberwood biomass. In fact, Lim *et al*. (2000) identified that the energy content of rubberwood can be as high as about 68.61 million gigajoules (GJ) per year or 40.04 GJ per hectare per year. Based on this estimation of energy content, Table 3 summarizes the potential energy production that could be realized from the rubberwood waste available for fuel.

Table 3. Estimation of Energy Generation from Rubberwood Waste as Fuel

Year	Total Plantation Area of Rubber (thousand ha)	Estimation Rubberwood Biomass Waste for Fuel (m^3)	Estimation of Energy Content of Rubberwood Waste for Fuel (47.59 GJ per m^3 x Waste for Fuel)
1990	1,836.7	2,777,090	132,161,713
1992	1,792.3	2,709,958	128,966,901
1994	1,737.1	2,626,495	124,994,897
1996	1,644.3	2,486,182	118,317,401
1998	1,543.6	2,333,923	111,071,396
2000	1,430.7	2,163,218	102,947,545
2001	1,389.3	2,100,622	99,968,601
2002	1348.8	1,611,641	76,697,995
2003	1325.9	1,544,206	73,488,764
2004	1278.8	1,476,619	70,272,298
2005	1271.3	1,448,194	68,919,552
2006	1263.6	1,447,135	68,869,155
2007	1248.1	1,476,014	70,243,506
2008	1247	1,491,134	70,963,067
2009	1028.2	1,554,699	73,988,125
2010	1020.4	1,542,815	73,422,566
2011	1027	1,552,884	73,901,750
2012	1041.2	1,574,279	74,919,938
2013	1045.8	1,598,592	76,076,993

Source: Rubber Research Institute Malaysia (2014) and Department of Statistics (2014)
Note: Potential Energy Content of 1 m^3 = 47.59 GJ (Lim *et al*. 2000)

As shown in Table 3, the energy supply from rubberwood waste reduced significantly owing to the reduction in rubber cultivation area, which consequently decreased the available amount of rubberwood biomass.

However, biomass in Malaysia contributes about 14% of the approximately 2.074 billion GJ of energy used every year according to Chuah *et al*. (2006). The relatively small amount of on-site waste in rubber processing activities means that it is a fairly low priority area for biomass-based renewable energy development. The major waste stream from replanting involves a variety of issues related to transporting to a central generation facility, which has a negative impact on the potential of this biomass for fuel.

Energy Use Pattern in Malaysia

The global demand for energy is fulfilled predominantly by fossil fuels, namely oil, coal, and natural gas, which are anticipated to be exhausted in the next 40 to 50 years (Koh and Hoi 2003). Certainly, this is also a matter of concern for Malaysia, as the rate of energy demand was projected to increase 5% to 7% annually for the next two decades (Hosseini and Abdul Wahid 2014). The industrial sector consumes 43% of the total energy demand, exceeding the 36% energy use accounted for by the transportation sector (Chandran *et al.* 2010; Koh and Lim 2010). The two main factors that contribute to the rapid depletion of fossil fuels are economic development and population growth (Goh *et al.* 2010; Shafie *et al.* 2012; Mekhilef *et al.* 2014). The population in Malaysia increased from 17.7 million in 1997 to 27.73 million in 2008 (Ong *et al.* 2011). Rosnazri *et al.* (2012) stated that the population in Malaysia may increase to as high as 33.4 million in 2020 and, possibly, to 37.4 million in 2030. This is expected to increase energy consumption significantly.

Generally, industrial and economic development in a country drives high consumption of energy, particularly electricity (Shafie *et al.* 2011). In the case of Malaysia, consumption has increased from 71 million GJ in 1990 to 310 million GJ in 2007, an increment of 337%. In fact, the period from 1990 to 2000 marked the period of rapid economic growth where double digit growth was recorded in the demand for electricity (Tick *et al*. 2011). In addition, the demand for electricity per capita was projected to be about 757 kwh/person by the year 2030 (Hosseini and Abdul Wahid 2014). Siti Indiati *et al*. (2010) explained that this high energy demand is inevitable and is expected to reach 130 million tonnes of oil equivalent (MTOE) in 2030. Although Malaysia possesses a relatively plentiful supply of fossil fuels, the country will deplete its energy sources as it is predicted to hold out only for the next 30 to 40 years. Table 4 shows the energy consumption pattern in Malaysia, as reported in the 5th Fuel Diversification Policy (FDP) of the country.

Fossil fuels remain the primary source of fossil fuels in Malaysia (Hoi 1999; Shafie *et al*. 2012; Mekhilef *et al*. 2014), and their continued use poses negative environmental consequences. Past and current economic growth in the country has been primarily fuelled by fossil fuels and little attention has been paid to other energy sources. The provision of energy subsidies, especially for gasoline, of up to RM 0.50 per litres continue to pose challenges to explore and develop new potential energy sources (Chuah *et al.* 2006).

Renewable energy, including biomass energy, must be seriously explored in Malaysia if this trend is to be changed. Figure 2 shows the current state of rubberwood biomass utilization in Malaysia. It is clear that the amount of rubberwood biomass available as a fuel source is quite limited. In fact, a large portion of rubberwood biomass has found application in the wood products manufacturing industry of Malaysia.

Table 4. Primary Energy Supplies in Malaysia (million Gigajoules)

Year	Crude Oil	Petroleum Products	Natural Gas	Coal and Coke	Hydropower	Total of non-renewable energy	Total of renewable energy	Grand total	Energy consumption per capita ('000)
1990	367.7	152.8	284.7	55.5	38.3	860.7	38.3	899.0	0.050
1992	426.0	213.5	476.4	68.6	41.7	1184.5	41.7	1226.2	0.064
1994	569.6	102.4	518.8	65.4	69.1	1256.2	69.1	1325.3	0.066
1996	764.3	46.0	651.7	70.2	52.0	1532.2	52.0	1584.2	0.075
1998	717.3	80.3	799.7	72.4	46.5	1669.7	46.5	1716.2	0.077
2000	907.4	-59.9	1,104.0	104.0	65.3	2055.5	65.3	2120.8	0.090
2001	987.6	-80.2	1,073.8	124.3	70.6	2105.5	70.6	2176.1	0.091
2002	948.1	-21.8	1,092.7	152.4	55.6	2171.4	55.6	2227.0	0.091
2003	1,061.1	-58.2	1,141.1	222.5	44.2	2366.5	44.2	2410.7	0.096
2004	1,060.7	-1.5	1,220.2	277.6	55.6	2557	55.6	2612.6	0.102
2005	1,019.0	-3.1	1,419.8	288.4	54.9	2724.1	54.9	2779.0	0.107
2006	1,042.8	-61.7	1,497.8	305.5	65.6	2784.4	65.6	2850.0	0.107
2007	1,112.4	-41.6	1,534.0	370.4	63.2	2975.2	63.2	3038.4	0.112
2008	1,121.0	-95.5	1,644.9	409.5	82.2	3079.9	82.2	3162.1	0.115
2009	1,104.7	4.0	1,501.0	444.7	68.1	3054.4	68.1	3122.5	0.111
2010	941.4	105.5	1,546.4	618.6	66.0	3211.9	66.0	3277.9	0.115
2011	1,033.2	93.1	1,496.3	618.4	77.4	3241	77.4	3318.4	0.114
2012	1,174.5	-45.9	1,618.1	664.9	89.9	3411.6	89.9	3501.5	0.119
Source: Malaysian Energy Information Hub (2014)									

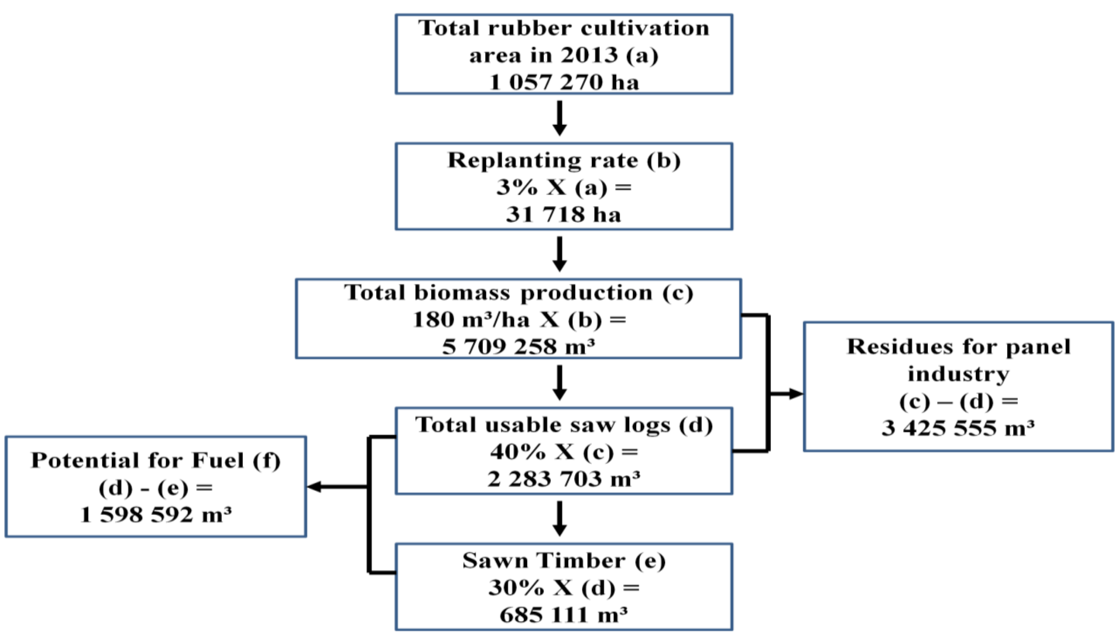

Fig. 2. Rubberwood biomass production and yield status in Malaysia in 2013
Source: Ratnasingam *et al.* (2012)

These calculations are based on several assumptions: (i) that replanting activity is carried out per schedule, (ii) all above ground biomass up to 10 cm in diameter is extracted from the field, and (iii) waste and residue from the secondary milling activities is used in the panel products sector. Therefore, there is apparently sufficient biomass to meet the demand of the various wood product sectors, provided that the biomass is fully recovered and utilized efficiently. From an agronomic perspective, with the average recorded growth rate for rubber cultivation areas in Malaysia of 15 m^3/ha/year, the country should be able to sustain the demand for rubberwood from the wood industry, provided that biomass recovery is maximized (Shigematsu *et al*. 2011; Ratnasingam *et al*. 2012).

Figure 3 shows the energy supply deficit scenario assuming the use of rubberwood biomass. The energy supply deficit indicates that rubberwood biomass could only contribute to a small amount of the total energy demand in Malaysia. Therefore, rubberwood biomass can only play a very minor role in energy production in the country.

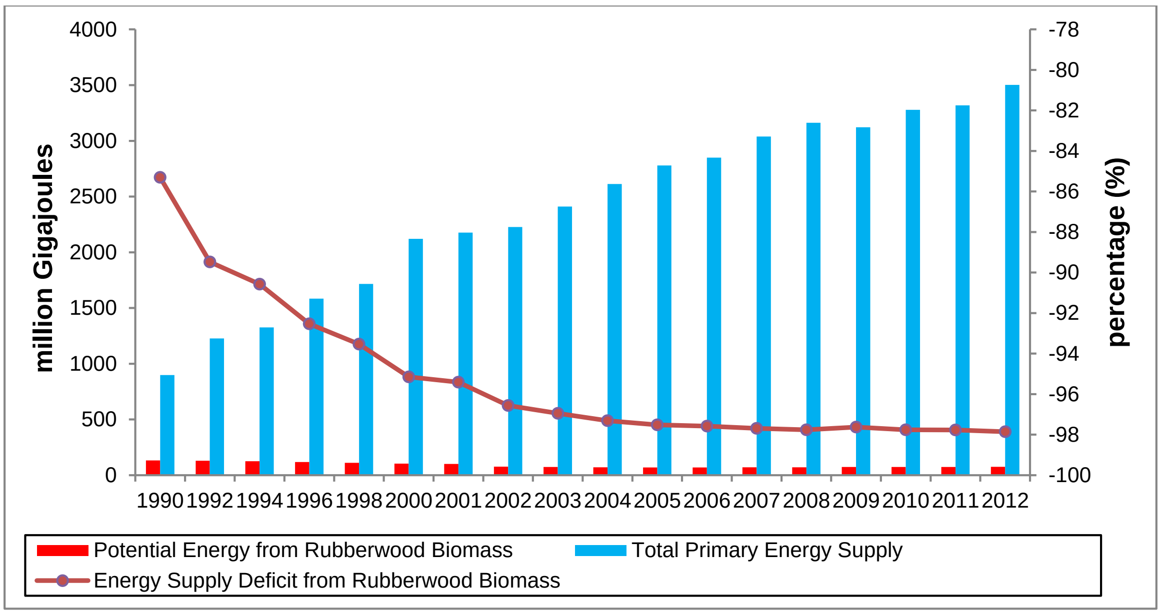

Fig. 3. Energy supply deficit from rubberwood biomass

OTHER AVAILABLE BIOMASS FOR ENERGY PRODUCTION IN MALAYSIA

Malaysia has several sources of renewable energy, namely solar, wind, biomass, and hydropower. Among all the renewable energy sources, biomass seems to have the highest potential to be exploited as a renewable energy source (Tock *et al*. 2010). Several types of biomass available in Malaysia are listed in Table 5.

Fatin Demirbas *et al*. (2007) stated that the energy from biomass contributed 10% to 15% of the total energy consumed in the world, which is estimated to be 45 exajoules (EJ). Table 6 provides the energy value of biomass resources in comparison to other renewable energy sources.

Table 5. Types and Quantities of Biomass Produced Annually in Malaysia

Types	Quantities (kg)	Source	Source (kg)	Moisture content (wt%)	Dry weight (kg)
Oil palm fronds	46,837	Oil palm fresh fruit bunch	81,920	60	18,735
EPFB	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.* (2011)					

Table 6. The Energy Value of Renewable Energy

Renewable Energy	Types	Energy Value (RM million per annum)
Biomass	Forest residues	11,984
	Oil palm biomass	6379
	Mill residues	836
	Municipal waste	190
	Rice husk	77
Non-biomass	Solar thermal	3023
	Hydro	506
	Solar PV	378
	Landfill gas	4
Source: Sumathi *et al.* (2008)		

Chuah *et al.* (2006) showed a significant potential for biomass energy production in Malaysia, but this has not been fully realized (Table 7). Shuit *et al.* (2009) highlighted that the use of biomass as a renewable energy is considered very low in Malaysia and it accounts for only 14% of the total energy produced in the country.

Agricultural Residues

The main agricultural crops in Malaysia consist of oil palm, rubber, cocoa, rice, and coconut. Among these crops, oil palm and rubber plantations are the major plantations in terms of acreage. The Malaysian government is focused on using biomass from oil palm processing activities, which includes empty fruit bunches (EFB), fibre, and shells to produce energy. In fact, a considerable amount of literature is available to show that oil palm biomass dominates the biomass energy industry (Chuah *et al*. 2006; Shamsuddin 2010; Sulaiman *et al.* 2011; Shafie *et al*. 2012; Seyed Ehsan and Mazlan 2014). Salsabila *et al.* (2011) highlighted that biomass from oil palm waste accounts for about 85.5% of the total biomass available in Malaysia (Fig. 4). This trend is inevitable, as Malaysia is among the largest palm oil producers in the world (Ong *et al*. 2011).

Table 7. Category of Biomass Production and Estimation of the Biomass Energy Productivity in Malaysia

Crops / Activities	Biomass Production (million kg/year)		Moisture content (%)	Biomass Production in dry weight (million kg/year)	Average Calorific Value (MJ/kg)	Potential Biomass Energy Production (PJ)	Current Amount of Biomass Energy Produced (PJ)
Oil Palms	Empty fruit bunches (EFB)	38550	60	15420	6.028	92.95	-
	Fruit fibres	1320	40	792	11.34	8.98	0.14
	Palm shell	4410	20	3528	18.84	66.47	0.08
Paddy Plants	Rice husks	375.5	13-14	326.7	14.93	4.88	-
Coconut Trees	Coconut husk	171	11.5	151.3	19.6	2.97	0.0139
Sugarcane	Bagasse	203.7	50	101.9	14.4	1.47	0.0025
Logging	Logging residues	2649	12	2331.1	18.41	42.92	-
Wood industry	Wood residues	3652	12	3213.8	18.41	59.17	0.0219

Sources: Chuah *et al.* (2006); Shamsuddin (2010); Mekhilef *et al*. (2011); Shafie *et al.* (2012)
Note: 1 tonnes = 1000 kg
MJ = megajoule
PJ = petajoule
Potential biomass energy production = Biomass production in dry weight x average calorific value
1 MJ = 1 x 10^{-9} PJ

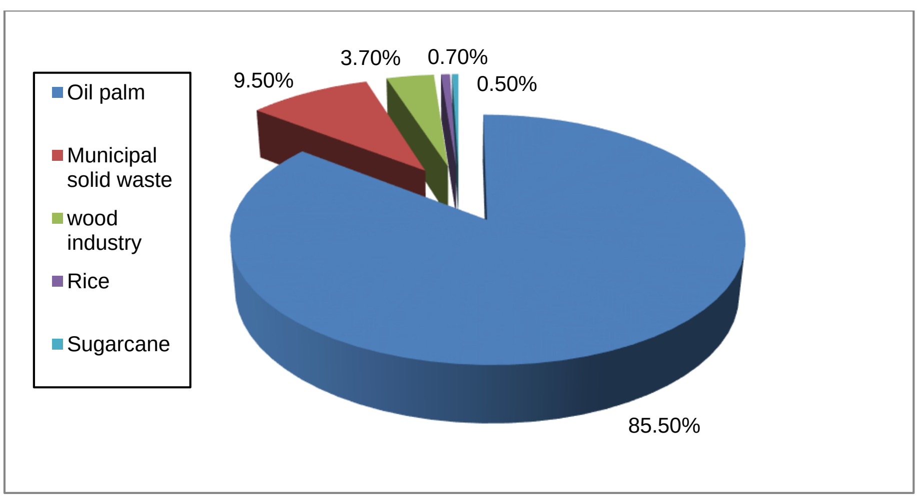

Fig. 4. The types of biomass in Malaysia

As the leading producer and exporter of palm oil in the world, Malaysia has 362 operational oil mills (Mohamed and Lee 2006) as of 2013. These mills process 71.3 million tonnes of fresh oil palm fruit bunches per year, which produces 19 million tonnes of biomass per year in the form of empty fruit bunches, shells, and fibre (Ong *et al.* 2012).

On the contrary, biomass from rubber has not been recognized as a significant energy source. This is mainly due to the fact that the total rubber cultivation area in Malaysia has been declining over the years, while oil palm cultivation has been increasing due to its higher profitability (Fig. 5).

In a recent study by Ratnasingam and Jones (2011), it is shown that rubberwood cultivation and processing is viable and profitable under the following conditions: (i) the minimum volume of biomass (up to 10 cm) recovered should be above 180 m^3 per hectare; (ii) the minimum volume of sawn logs produced should be 45 m^3 per hectare; (iii) the average cost of saw-logs per m^3 should be 60 USD; (iv) the minimum volume of sawn timber produced should be 15 m^3 per hectare; (v) the approximate processing cost, excluding preservative treatment and kiln drying costs, should be approximately 60 USD per m^3; (vi) the average preservative treatment and kiln drying costs should be 75 USD per m^3; and (vii) the minimum sawn timber price should be approximately 380 USD per m^3 or more. It was found that in most instances these conditions were not met and the rubber growers suffered from reducing profits.

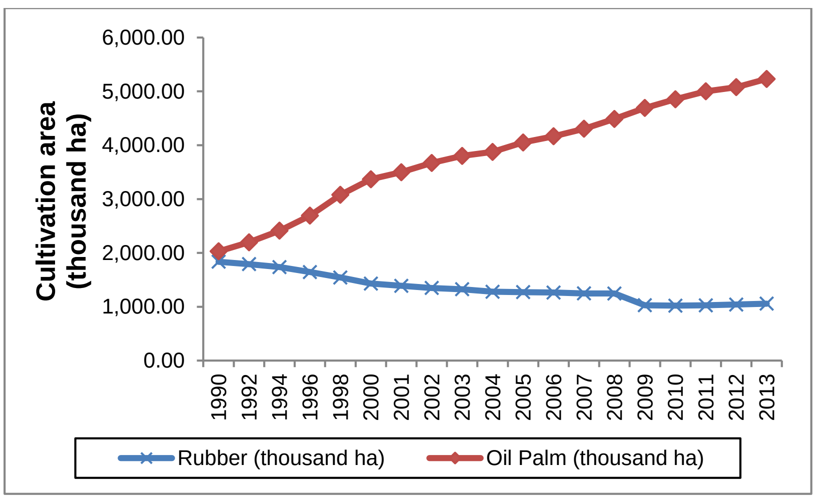

Fig. 5. Total cultivation area of rubber and oil palm (Sources: Rubber Research Institute Malaysia 2014; Malaysian Palm Oil Board 2014)

According to Yusof *et al.* (2008), rice husk from rice mills has become the third most important biomass resource, after oil palm and wood waste, for energy production. Besides rice husk, biomass from paddy straws is also an important source (Shafie *et al.* 2012). Other biomasses from sugarcane, coconut, and cocoa cultivation are of minor importance because of their lesser available quantities per annum (Mekhilef *et al.* 2011; Shafie *et al.* 2012).

Wood Residues

Wood residues are divided into two main categories: logging residues and wood-based industries residues. Wood-based industries residues are comprised of sawmilling, plywood, veneer, and secondary processing residues (Mekhilef *et al.* 2011). It is estimated that the amount of wood residues from the logging, primary, plywood, and secondary industries are 5.1, 2.92, 0.91, and 0.90 million m^3 per annum, respectively (Noridah *et al.* 2014). However, energy production from wood residue is rather inefficient due to the large mixture of wood waste from many different species that have different calorific characteristics. As a result, energy production from wood residues is often confined to large mills with boilers that use this waste for energy and heating steam production. Since direct combustion of biomass is not recommended due to its low efficiency and high pollutants emission, flameless combustion of biomass appears to be the best method for boilers (Abuelnuor *et al.* 2014).

When compared to other biomasses, the potential energy generation from rubberwood biomass appears to be mixed. However, Table 8 shows that oil palm empty fruit bunches has a higher potential energy production compared to rubberwood. This explains why energy production from oil palm empty fruit bunches is very common in many plantations throughout the country, especially in close proximity to oil palm mills. Although the potential energy generation for rubberwood is estimated to be 60.75 PJ, the larger oil palm cultivation area in the country makes oil palm biomass abundantly available, which in turn encourages its use for energy generation.

Table 8. Comparison of Potential Energy Generation between Rubberwood and other Biomasses

Comparison of Energy Potential	Ratio
Rubberwood : empty fruit bunches	1 : 1.53
Rubberwood : fruit fibres	1 : 0.15
Rubberwood : palm shell	1 : 1.09
Rubberwood : rice husks	1 : 0.08
Rubberwood : coconut husk	1 : 0.01
Rubberwood : bagasse	1 : 0.02
Rubberwood : logging residues	1 : 0.71
Rubberwood : wood residues	1 : 0.97

COMMERCIAL SUCCESSES FOR BIOMASS ENERGY PRODUCTION IN MALAYSIA

Malaysia is a country with an abundance of renewable biomass such as EFB fibre, saw dust, straw, rice husk, and wood chips, which suggests that Malaysia has a high potential to produce pellets for energy. From a commercial perspective, production of pellets from rubberwood has been more successful compared to pellets from empty oil palm fruit bunches. This is because oil palm EFB has high condensates and its heat generating capacity is comparatively low. The calorific values of rubberwood and oil palm biomass pellets are shown in Table 9.

Table 9. Calorific Value (CV) of Rubberwood and Oil Palm Biomass Fuels

Fuel Sample	CV ($MJkg^{-1}$)	References
Palm Kernel Shell	18.0	Mahlia *et al.* (2001)
Palm Fibre	15.4	Mahlia *et al.* (2001)
Rubberwood Waste	18.41	Werther and Saenger (2000)

Pellet production from oil palm EFB fibres is limited and confined to local market use only. On the other hand, the densified rubberwood pellets made from chips and sawdust offer better and more uniform heating properties per unit volume. It burns cleaner and produces fewer particulate emissions compared to coal. Furthermore, rubberwood pellets are more economical to transport due to their increased bulk density. This application of the rubberwood biomass reduces the amount of waste sent to landfills, which increases overall profitability through an integrated and more efficient use of the waste. Wood pellets are increasingly becoming an important energy source due to the increasing price of fossil fuels in the world market. Furthermore, wood pellets are an ideal energy alternative for biomass power plants and they produce comparatively lower fume discharge during burning.

Rubberwood and oil palm biomass have unique chemical compositions. Table 10 and Table 11 show the properties of these biomasses by proximate and ultimate analyses. Rubberwood tends to have lower ash and nitrogen content compared to oil palm biomass. Table 12 shows the comparative inorganic residues left on the field by rubberwood and palm fibre biomass. One notable point is the higher sulfur trioxide (SO_3) content in palm fibre which indicates the possibility of higher SO_3 emissions that could lead to health and environmental problems.

Table 10. Proximate Analyses of Rubberwood and Oil Palm Biomass Fuels (wt% of dry fuel)

Fuel Sample	Ash	Volatile Matter	Fixed Carbon	References
Palm Kernel Shell	3.2	69.5	21.7	Mahlia *et al.* (2001)
Palm Fibre	8.4	69.7	18.9	Mahlia *et al.* (2001)
Rubberwood Waste	0.4	81.7	9.8	Werther and Saenger (2000)

Table 11. Ultimate Analyses of Rubberwood and Oil Palm Biomass Fuels (wt% of dry fuel with ash)

Fuel Sample	C	H	N	S	Cl	O	References
Palm Kernel Shell	45.6	6.2	37.5	-	-	37.5	Mahlia *et al.* (2001)
Palm Fibre	51.5	6.6	1.5	0.3	-	40.1	Mahlia *et al.* (2001)
Rubberwood Waste	50.7	5.9	0.2	0.04	-	43.1	Werther and Saenger (2000)

Table 12. Inorganic Residues from Rubberwood and Oil Palm Biomass Fuels

Fuel Sample	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	P_2O_5
Palm Fibre	63.2	4.5	0.2	3.9	-	3.8	0.8	9.0	2.8	2.8
Rubberwood Waste	12.8	4.1	5.2	5.2	45.2	0.9	0.6	0.5	-	2.1
Sources: Werther and Saenger (2000) and Mahlia *et al.* (2001)										

Due to the high demand for rubberwood from the wood products manufacturing industry, the amount of rubberwood biomass available for energy production is significantly lower compared to the oil palm biomass available. Furthermore, the production of one cubic meter of wood products from rubberwood has an average value of 890 USD compared to one cubic meter of rubberwood pellets, which has a value of only 63 USD. As a result, interest in wood pellet production is very much at an infancy stage in Malaysia. On the other hand, the production of energy from oil palm biomass is comparatively more visible as cogeneration of energy and heating steam is widely practiced in most oil palm mills in the country (Yusuf *et al.* 1993; Ma and Yusof 2005).

BENEFITS OF BIOMASS AS AN ENERGY SOURCE

Biomass is an advantageous renewable resource that can be used as a fuel to produce electricity and other forms of energy. Biomass feedstock is any organic matter available on a renewable basis for conversion to energy. Agricultural crops and residues, industrial wood and logging residues, farm animal wastes, and the organic portion of municipal waste are all types of biomass feedstock. Biomass fuels, also known as biofuels, either in solid, liquid, or gas form, are derived from biomass feedstock. Biofuel technologies can efficiently transform the energy in biomass into transportation, heating, and electricity generating fuels (Sorda *et al.* 2010; Adenle *et al.* 2013).

Biomass is a proven option for electricity generation (Muis *et al.* 2010; Shafie *et al*. 2012). Biomass used in today's power plants includes wood residues, agricultural residues, food processing residues such as nut shells and methane gas from landfills (Zamzam Jaafar *et al*. 2003). In the future, farms cultivating energy crops such as trees and grasses could significantly expand the supply of biomass feedstock. For instance, the pulp and paper industry, the wood manufacturing industry, electric utilities, and independent power producers could own these power plants for the benefit of society amidst the increasing global cost of energy.

Socioeconomic Implications

The use of biomass as an alternative energy source could bolster the economy of Malaysia by providing job opportunities in rural areas as well as making use of wood waste and agricultural residues. Use of biomass can reduce the dependence on out-of-state and foreign energy sources, as is currently the case in many developing countries. The cultivation of biomass energy crops could be a profitable venture for farmers, which will complement their source of income. Crops for biomass energy production may be grown on currently underutilized agricultural land, which will create jobs for rural communities. Expanded biomass power deployment can create high-skilled and high-value job opportunities for utility, power equipment, and agricultural equipment industries (Domac *et al*. 2005; Faaij and Domac 2006; Verdonk *et al*. 2007; Lim and Lee 2010).

Environmental Implications

Generally, global climate change is attributed to the excessive burning of fossil fuels for energy (von Hippel *et al.* 1993; Hoel and Kverndokk 1996; Shafie *et al.* 2012). Since the industrial revolution in the late 18th century, the use of fossil fuels has catalysed the economic development of many nations (Reddy 2002). It is undeniable that the burning of fossil fuels contributes to the release of carbon dioxide, the main greenhouse gas, into the atmosphere. Tock *et al*. (2010) reported that the concentration of carbon dioxide in the atmosphere has increased by 30% with an increase of about 0.5% every year. According to Hosseini *et al.* (2013), the rate of CO_2 generation has been rising fast over the last 50 years. It is estimated that 30 billion tonnes of CO_2 is emitted annually to the environment as a result of human activities. Figure 6 shows the total carbon dioxide emissions from fossil fuels in Malaysia, which have been increasing yearly since 1998 (Lim and Lee 2010). Besides that, other greenhouse gases such as methane, nitrogen oxide, and sulfur oxide are also released into the air, but their cumulative effects are vague. As a result of these greenhouse gas emissions, the average temperature has increased by 0.5 °C to 1.5 °C in Peninsular Malaysia, while the temperature rise in East Malaysia is approximately 1 °C (Shafie *et al*. 2012).

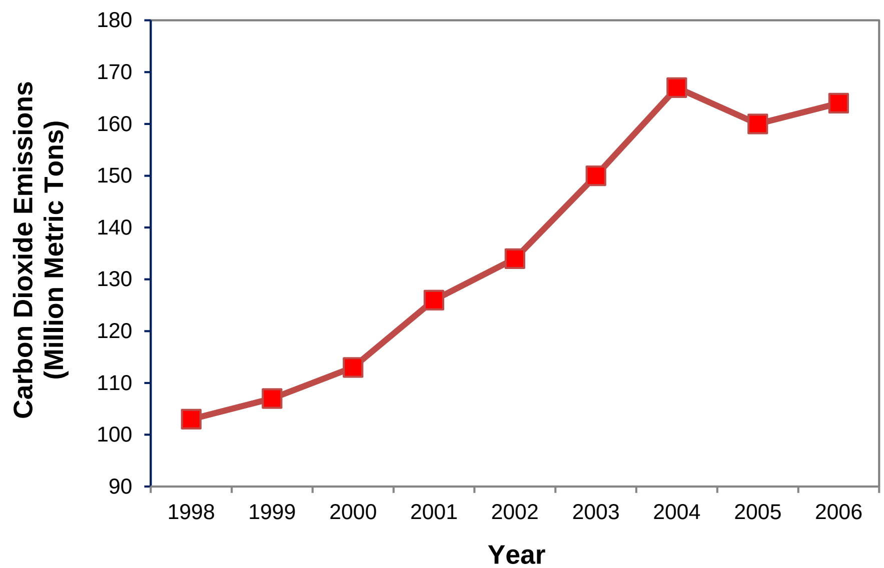

Fig. 6. Malaysia total carbon dioxide emission from consumption of fossil fuels. (Source: Lim and Lee 2010)

The value for CO_2 emissions in metric tons per capita in Malaysia was 7.67 as of 2010. As shown in Fig. 7, over the past 41 years this indicator has reached a maximum value of 7.81 in 2008 and a minimum value of 1.34 in 1970. Carbon dioxide is produced during the consumption of solid, liquid, and gas fuels and gas flaring (CDIAC 2014).

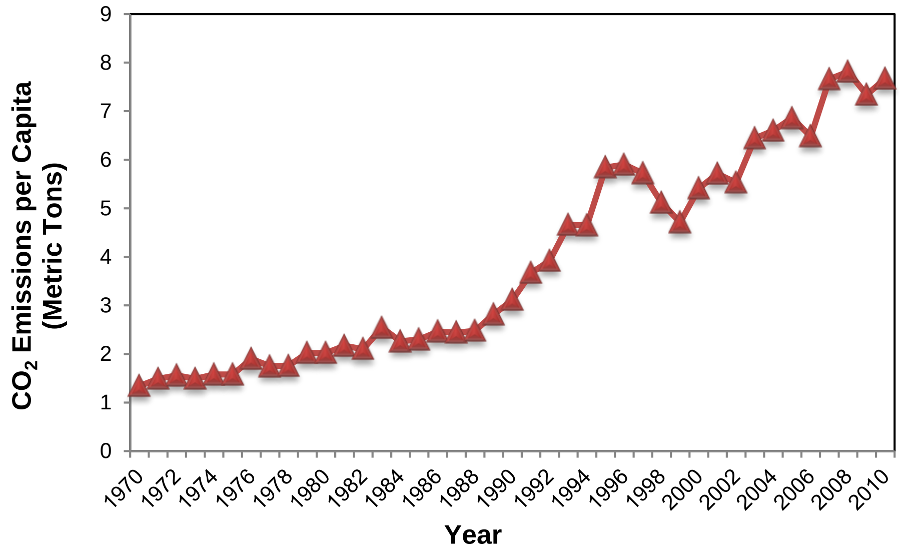

Fig. 7. CO_2 emissions per capita (metric tons) in Malaysia

Carbon dioxide emissions from liquid fuel consumption in Malaysia were reported to be 32.60% of the total fuel consumed in 2010. The highest value over the past 41 years was 94.32% in 1970, while its lowest value was 29.64% in 2006 (Fig. 8). The CO_2 emission from liquid fuel consumption shown in Fig. 8 refers mainly to emissions from the use of petroleum-derived fuels.

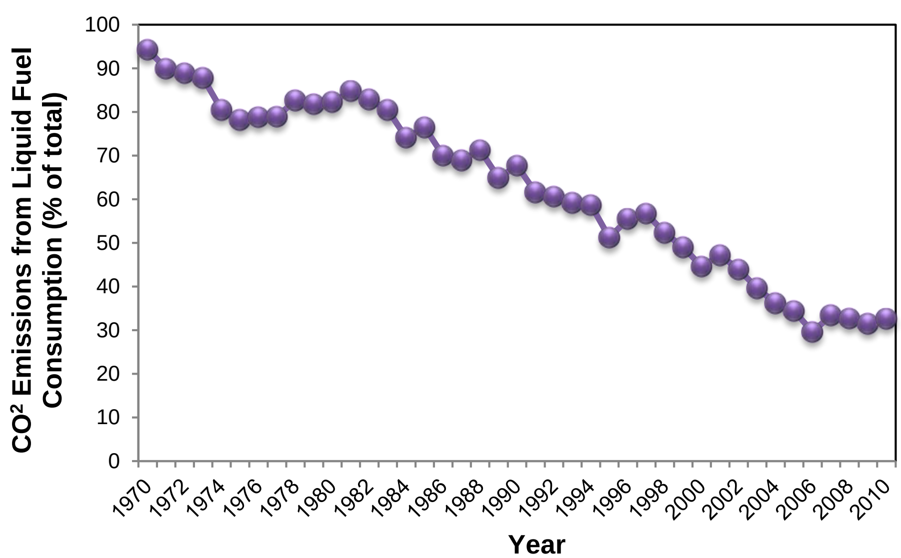

Fig. 8. CO_2 Emissions from liquid fuel consumption (% of total)

Carbon dioxide emissions from solid fuel consumption in Malaysia were reported to be 28.40% of the total of fuel consumed in 2010 (Fig. 9). Its highest value over the past 41 years was 28.40% in 2010, while its lowest value was 0.20% in 1972. The CO_2 emission from solid fuel consumption shown in Fig. 9 refers mainly to emissions from the use of coal as an energy source (CDIAC 2014).

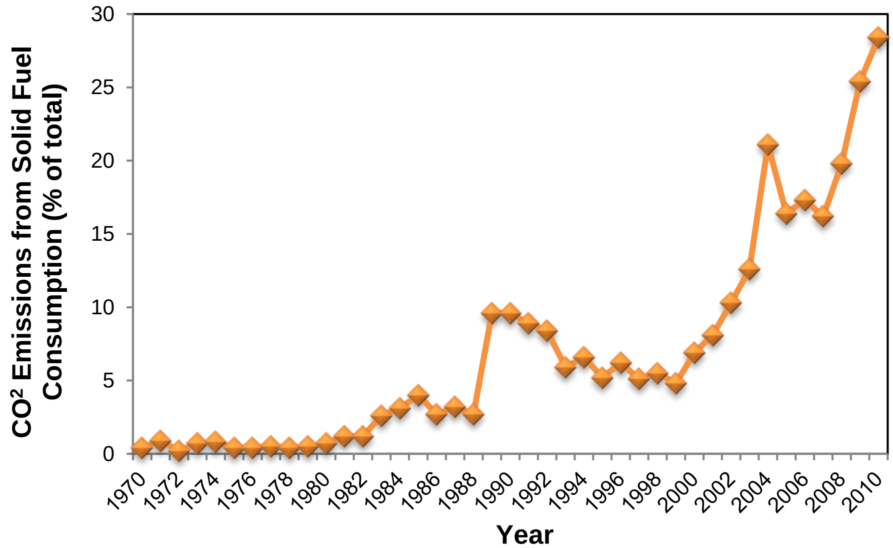

Fig. 9. CO_2 emissions from solid fuel consumption (% of total)

Considering these facts, biomass energy may be considered a promising alternative energy source in Malaysia. Furthermore, biomass energy has several unique advantages. Biomass fuels produce virtually no sulphur emissions and help to mitigate acid rain (Arndt *et al*. 1997; Velásquez-Arredondo *et al*. 2010). These biomasses help to recycle atmospheric carbon, minimizing global warming impacts since zero net carbon dioxide is emitted during biomass combustion. For instance, the amount of carbon dioxide emitted is equal to the amount absorbed from the atmosphere during the biomass growth phase (Van De Broek *et al*. 1996; Velásquez-Arredondo *et al*. 2010). The recycling of biomass waste reduces the need to create new landfills and extends the life of existing landfills. Biomass combustion produces less ash content than coal and can reduce ash disposal costs and landfill space requirements. The biomass ash can also be used as a soil amendment in farm land.

Perennial energy crops such as grasses and trees have distinctly lower environmental impacts than conventional agricultural crops. Energy crops require less fertilization and herbicides, and provide greater vegetative cover throughout the year, providing protection against soil erosion and watershed quality deterioration, as well as improved wildlife cover.

CONSTRAINTS TO RUBBERWOOD BIOMASS ENERGY PRODUCTION IN MALAYSIA

High Demand from Wood Industry

It is anticipated that there will be slight improvement in the outlook for the supply of rubberwood for energy production over the next several years. This is primarily due to the high demand of rubberwood from the wood-based manufacturing sector (Hong 1994; Ratnasingam and Jones 2011). In reality, the demand for rubberwood has been increasing by almost 5% per annum and accounts for almost 86% of the total wood material consumed by the value-added wood products manufacturing sector in Malaysia (Ratnasingam *et al*. 2012). In order to cope with the insufficient supply, about 220,000 m^3 of sawn rubberwood was imported into Malaysia in 2013. The existing scenario in the high utilization of rubberwood biomass by the wood products sector in Malaysia leaves very little room for large scale energy production from this biomass.

On the other hand, the large quantities of other types of biomass such as oil palm, paddy husk, cocoa, coconut, and sugarcane bagasse appears to have much better viability for energy production. Apart from being used as mulch, fertilizers, and soil amelioration agents, this biomass has untapped potential for energy production on a large commercial scale (Faaij *et al.* 1998; Ignaciuk and Dellink 2006). Nevertheless, the problems associated with the logistics, variable qualities, stock, and transportation distance must be tackled first if this objective is to be realized.

Limited Research and Development (R&D)

The attention given by the related research and development (R&D) agencies towards the exploitation of biomass for energy production is undeniable. However, as reported by Shamsudin (2010), the extensive R&D activities on the topic of biomass energy are focused on oil palm biomass due to its abundant availability. On the other hand, R&D activities by the rubber industry related agencies, such as the Rubber Industry Smallholding Development Agency of Malaysia (RISDA) and the Malaysian Rubber Board (RRM), are very much concentrated on natural rubber or latex and the yield of rubber plantations (Shigematsu *et al*. 2011). Although Malaysia has a national blue-print for biomass energy production, its implementation is rather weak due to the lack of interest among industry players. The fact that biomass energy production requires a large capital outlay means that small and medium enterprises (SMEs) that dominate the wood-based sector are not capable of venturing into this business. As a result, much of the biomass energy is produced by large mill operators in order to fulfil their own energy demands. Although the excess energy produced by the large mills can be fed into the national power grid, the quota system in place for the in-feed tariffs (IFT) for such energy producers has prevented many potential small and medium sized energy producers from venturing into biomass energy production (Mohd Shaharin *et al.* 2014).

Financial Constraints

Lack of financial resources is one of the main barriers for the development of biomass-based power generation projects in Malaysia. Most of the projects are small, relatively new, and require high capital investments. This is further worsened by the fact that financial institutions are reluctant to finance bioenergy projects as it is deemed to be an infant industry with a high risk factor (Shamsuddin 2010). Sumiani and Roozbeh (2012) listed the high capital costs, lack of experience, low investor confidence, limited access to capital and consumer credit, and the absence of appropriate financing modes as the main financial constraints for biomass energy development in Malaysia.

CONCLUSIONS

1. The abundant rubberwood biomass in Malaysia is used extensively in the wood products sector. As a result, energy production from this biomass is limited when compared to the possibility of energy production from other lesser used biomass such as oil palm, rice husk, cocoa, sugarcane, and coconut as well as wood residues from

forest and wood-based industries. However, the present use of these biomasses for energy production is limited due to logistical and cost factors.

2. Biomass energy production in Malaysia is very much at an infant stage, compared to energy produced from fossil fuels. The large capital outlay required for the establishment of biomass power plants limits the opportunity for small and medium sized enterprises from generating biomass energy. Further, the lack of end financing for such projects together with the limited research and development on efficient production of biomass energy are the other constraints facing the bioenergy sector in the country. The fact that energy is subsidized to keep its cost low in Malaysia is another hidden factor that limits the demand for biomass energy. Until the environmental implications are factored into the cost of energy production, the full potential of energy production from biomass may not be realized in Malaysia.

REFERENCES CITED

Adenle, A. A., Haslam, G. E., and Lee, L. (2013). Global assessment of research and development for algae biofuel production and its potential role for sustainable development in developing countries, *Energy Policy* 61, 182-195. DOI: 10.1016/j.enpol.2013.05.088

Adisurjosatyo, Vidian, F., and Nugroho, Y. S. (2012). Performance gasification per batch rubber wood in conventional updraft gasifier, *Journal of Engineering and Applied Sciences* 7(8-12), 494-500. DOI: 10.3923/jeasci.2012.494.500

Arndt, R. L., Carmichael, G. R., Streets, D. G. and Bhatti, N. (1997). Sulfur dioxides emissions and sectoral contributions to sulfur deposition in Asia, *Atmospheric Environment* 31(10), 1553-1572. DOI: 10.1016/S1352-2310(96)00236-1

Balsiger, J., Bahdan, J., and Whiteman, A. (2000). *The Utilization, Processing and Demand for Rubberwood as a Source of Wood Supply*. APFC-Working Paper No. APFSOS/WP/50. FAO, Bangkok. http://www.fao.org/docrep/003/Y0153E/Y0153E00.HTM.

CDIAC. (2014). *Environmental Sciences Division, Oak Ridge National Laboratory*, Carbon Dioxide Information Analysis Center, http://cdiac.ornl.gov/.

Chandran, V. G. R., Sharma, S., and Madhavan, K. (2010). Electricity consumption-growth nexus: The case of Malaysia, *Energy Policy* 38(1), 606-612. DOI: 10.1016/j.enpol.2009.10.013

Chuah, T. G., Wan Azlina, A. G. K., Robiah, Y., and Omar, R. (2006). Biomass as the renewable energy sources in Malaysia: An overview, *International Journal of Green Energy* 3(3), 323-346. DOI: 10.1080/01971520600704779

Department of Statistics. (2014). *Rubber Plantation Area*, http://statistics.gov.my/portal/download_Economics/files/DATA_SERIES/2013/pdf/09Getah.pdf.

Domac, J., Richards, K., and Risovic, S. (2005). Socio-economic drivers in implementing bioenergy projects, *Biomass and Bioenergy* 28(2), 97-106. DOI: 10.1016/j.biombioe.2004.08.002

Faaij, A. P. C., and Domac, J. (2006). Emerging international bio-energy markets and opportunities for socio-economic development, *Energy for Sustainable Development* 10(1), 7-19. DOI: 10.1016/S0973-0826(08)60503-7

Faaij, A., Steetskamp, I., Wijk, A. V., and Turkenburg, W. (1998). Exploration of the land potential for the production of biomass for energy in the Netherlands, *Biomass and Bioenergy* 14(5-6), 439-456. DOI: 10.1016/S0961-9534(98)00002-6

Goh, C. S., Tan, K. T., Lee, K. T., and Bhatia, S. (2010). Bio-ethanol from lignocelluloses: status, perspectives and challenges in Malaysia, *Bioresource Technology* 13, 4834-4841. DOI: 10.1016/j.biortech.2009.08.080

Hoel, M. and Kverndokk, S. (1996). Depletion of fossil fuels and the impacts of global warming, *Resource and Energy Economic* 18(2), 115-136. DOI: 10.1016/0928-7655(96)00005-X

Hoi, W. K. (1999). Biomass energy utilisation in Malaysia - Prospects and problems, *Renewable energy* 16(1-4), 1122-1127. DOI: 10.1016/S0960-1481(98)00439-X

Hong, L. T., and Sim, H. C. (1994). *Rubberwood Processing and Utilisation*, Forest Research Institute Malaysia, Kuala Lumpur.

Hong, L. T. (1994). Introduction, in: *Rubberwood Processing and Utilisation*, L. T. Hong and H. C. Sim (eds.), Forest Research Institute Malaysia, Kuala Lumpur.

Hong, L. T. (1995). Rubberwood: Powering Malaysias furniture and panel industry, *Asian Timber* 17, 16-22.

Hosseini, S. E., and Abdul Wahid, M. (2014). The role of renewable and sustainable energy in the energy mix of Malaysia: a review, *International Journal of Energy Research* 38, 1769-1792. DOI: 10.1002/er.3190.

Hosseini, S. E., Abdul Wahid, M., and Aghili, N. (2013). The scenario of greenhouse gases reduction in Malaysia, *Renewable and Sustainable Energy Reviews* 28, 400-409. DOI: 10.1016/j.rser.2013.08.045

Ignaciuk, A. M., and Dellink, R. B. (2006). Biomass and multi-product crops for agricultural and energy production - An AGE analysis, *Energy Economics* 28(3), 308-325. DOI: 10.1016/j.eneco.2006.01.006

Kaewluan, S., and Pipatmanomai, S. (2011). Potential of synthesis gas production from rubber wood chip gasification in a bubbling fluidised bed gasifier, *Energy Conversion and Management* 52, 75-84. DOI: 10.1016/j.enconman.2010.06.044

Koh, M. P. and Hoi, W. K. (2003). Sustainable biomass production for energy in Malaysia, *Biomass and Bioenergy* 25(5), 517-529. DOI: 10.1016/S0961-9534(03)00088-6

Koh, S. I. and Lim, Y. S. (2010). Meeting energy demand in developing economy without damaging the environment - A case study in Sabah, Malaysia, from technical, environment and economic perspectives, *Energy Policy* 38(8), 4719-4728. DOI: 10.1016/j.enpol.2010.04.044

Lim, K. O., Zainal Alimuddin, Z. A., Ghulam, A. Q., and Mohd Zulkifly, A. (2000). Energy potential and utilisation of plantation crops in Malaysia, *ASEAN Journal on Science and Technology for Development* 17(2), 1-15.

Lim, S. and Lee, K. T. (2010). Recent trends, opportunities and challenges of biodiesel in Malaysia: An overview, *Renewable and Sustainable Energy Reviews* 14(3), 938-954. DOI: 10.1016/j.rser.2009.10.027

Ma, A.N. and Yusof, B. (2005). Biomass energy from the palm oil industry in Malaysia, *Buletin Ingenieur* 27, 18-25.

Mahlia, T. M. I., Abdulmuin, M. Z., Alamsyah, T. M. I., and Mukhlishien, D. (2001). An alternative energy source from palm wastes industry for Malaysia and Indonesia, *Energy Conversion and Management* 42(18), 2109-2118. DOI: 10.1016/S0196-8904(00)00166-7

Malaysia Energy Information Hub. (2014). *Malaysia Energy Statistics Handbook 2014*, http://meih.st.gov.my/documents/10620/adcd3a01-1643-4c72-bbd7-9bb649b206ee.
Malaysian Palm Oil Board. (2014). *Malaysian Oil Palm Statistics 2013*, http://www.mpob.gov.my/faqs/804-malaysian-oil-palm-statistics.
Mekhilef, S., Barimani, M., Safari, A., and Salam, Z. (2014). Malaysias renewable energy policies and programs with green aspects, *Renewable and Sustainable Energy Reviews* 40, 497-504. DOI: 10.1016/j.rser.2014.07.095
Mekhilef, S., Saidur, R., Safari, A., and Mustaffa, W. E. S. B. (2011). Biomass energy in Malaysia: Current state and prospects, *Renewable and Sustainable Energy Reviews* 15(7), 3360-3370. DOI: 10.1016/j.rser.2011.04.016
Menon, P. (2000). Status of Malaysia's timber industry, *Asian Timber* 20(6), 12-15.
Mohamed, A. R., and Lee, K. T. (2006). Energy for sustainable development in Malaysia: Energy policy and alternative energy, *Energy Policy* 34, 2388-2397. DOI: 10.1016/j.enpol.2005.04.003
Mohd Shaharin, U., Jennigs, P., and Urmee, T. (2014). Generating renewable energy from oil palm biomass in Malaysia: The feed-in tariff policy framework, *Biomass and Bioenergy* 62, 37-46. DOI: 10.1016/j.biombioe.2014.01.020
Mohd Shahwahid, H. O. and Abdul Rahim, A. S. (2009). A preliminary study of strategic competitiveness of MDF industry in Peninsular Malaysia by using SWOT analysis, *International Journal of Business and Management* 4(8), 205-214. DOI: 10.5539/ijbm.v4n8p205
Muis, Z. A., Hashim, H., Manan, Z. A., and Taha, F. M. (2010). Optimization of biomass usage for electricity generation with carbon dioxide reduction in Malaysia, *Journal of Applied Sciences* 10(21), 2613-2617. DOI: 10.3923/jas.2010.2613.2617
Noridah, B. O., Helmy, T. O., Rose Amira, K., and Mohammad Amir, F. M. (2014). Biomass in Malaysia: Forestry based residues, *International Journal of Biomass and Renewables* 3(1), 7-14.
Ong, H. C., Mahlia, T. M. I., and Masjuki, H. H. (2011). A review on energy scenario and sustainable energy in Malaysia, *Renewable and Sustainable Energy Reviews* 15(1), 639-647. DOI: 10.1016/j.rser.2010.09.043
Ong, H. C., Mahlia, T. M. I., Masjuki, H. H., and Honnery, D. (2012). Life cycle cost and sensitivity analysis of palm biodiesel production, *Fuel* 98, 131-139. DOI: 10.1016/j.fuel.2012.03.031
Ratnasingam, J., and Scholz, F. (2009). *Rubberwood an Industrial Perspective*, World Resource Institute, Washington.
Ratnasingam, J., Ioras, F., and Wenming, L. (2011). Sustainability of the rubberwood sector in Malaysia, *Not Bot Horti Agrobo* 39(2), 305-311.
Ratnasingam J., and Jones, M. L. (2011). *Recovery Problems in Rubberwood Plantations*, IFRG Report No. 14, Kuala Lumpur.
Ratnasingam, J., Ramasamy, G., Ioras, F., Kaner, J., and Wenming, L. (2012). Production potential of rubberwood in Malaysia: Its economic challenges, *Not Bot Horti Agrobo* 40(2), 317-322.
Reddy, A. K. N. (2002). A generic southern perspective on renewable energy, *Energy for Sustainable Development* 6(3), 74-83. DOI: 10.1016/S0973-0826(08)60327-0
Rosnazri, A., Ismail, D., and Soib, T. (2012). A review on existing and future energy sources for electrical power generation Malaysia, *Renewable and Sustainable Energy Reviews* 16(6), 4047-4055. DOI: 10.1016/j.rser.2012.03.003

Rubber Research Institute Malaysia. (2014). *RRIM Natural Rubber Statistic 2014*, http://www.lgm.gov.my/nrstat/nrstats.pdf.

Salsabila, A., Mohd Zainal Abidin, A. K., and Suhaidi, S. (2011). Current perspective of the renewable energy development in Malaysia, *Renewable and Sustainable Energy Reviews* 15(2), 897-904. DOI: 10.1016/j.rser.2010.11.009

Seyed Ehsan, H. and Mazlan, A. W. (2014). Utilization of palm solid residue as a source of renewable and sustainable energy in Malaysia, *Renewable and Sustainable Energy Reviews* 40, 621-632. DOI: 10.1016/j.rser.2014.07.214

Shaaban, A., Se, S.-M., Mitan, N. M. M., and Dimin, M. F. (2013). Characterization of biochar derived from rubber wood sawdust through slow pyrolysis on surface porosities and functional groups, *Procedia Engineering* 68, 365-371. DOI: 10.1016/j.proeng.2013.12.193

Shafie, S. M., Mahlia, T. M. I., Masjuki, H. H., and Ahmad-Yazid, A. (2012). A review on electricity generation based on biomass residue in Malaysia, *Renewable and Sustainable Energy Reviews* 16(8), 5879-5889. DOI: 10.1016/j.rser.2012.06.031

Shafie, S. M., Mahlia, T. M. I., Masjuki, H. H., and Andriyana, A. (2011). Current energy usage and sustainable energy in Malaysia: A review, *Renewable and Sustainable Energy Reviews* 15(9), 4370-4377. DOI: 10.1016/j.rser.2011.07.113

Shamsuddin, A. H. (2010). Status of renewable energy applications in the Malaysian energy mix, *Journal of Energy and Power Engineering* 4(12), 24-30.

Shigematsu, A., Mizoue, N., Kajisa, T., and Yoshida, S. (2011). Importance of rubberwood in wood export of Malaysia and Thailand, *New Forests* 41(2), 179-189. DOI: 10.1007/s11056-010-9219-7

Shuit, S. H., Tan, K. T., Lee, K. T., and Kamaruddin, A. H. (2009). Oil palm biomass as a sustainable energy source: A Malaysian case study, *Energy* 34(9), 1225-1235. DOI:10.1016/j.energy.2009.05.008

Siti Indiati, M., Leong, Y. P., and Amir Hisham, H. (2010). Issues and challenges of renewable energy development: A Malaysian experience, *PEA-AIT International Conference on Energy and Sustainable Development: Issues and Strategies*, Chiang Mai, Thailand.

Sorda, G., Banse, M., and Kemfert, C. (2010). An overview of biofuel policies across the world, *Energy Policy* 38(11), 6977-6988. DOI: 10.1016/j.enpol.2010.06.066

Sulaiman, O. O., Saharuddin, A. H., and Wan Nik, W. B. (2011). Potential of waste based biomass cogeneration for Malaysia energy sector, *Arabian Journal of Business and Management Review* 1(4), 77-101.

Sumathi, S., Chai, S. P., and Mohamed, A. R. (2008). Utilization of oil palm as a source of renewable energy in Malaysia, *Renewable and Sustainable Energy Reviews* 12(9), 2404-2421. DOI: 10.1016/j.rser.2007.06.006

Sumiani, Y., and Roozbeh, K. (2012). Barriers and challenges for developing RE policy in Malaysia, *International Conference on Future Environment and Energy* 28, 6-10.

Tan, A. G. (1989). Pyrolysis of rubberwood – a laboratory study, *Journal of Tropical Forest Science* 1(3), 244-254.

Teoh, Y. P., Don, M. M., and Ujang, S. (2011). Assessment of the properties, utilization and preservation of rubberwood *(Hevea Brasiliensis)*: A case study in Malaysia, *Journal of Wood Science* 57(4), 255-266. DOI: 10.1007/s10086-011-1173-2

Tick, H. O., Shen, Y. P., and Shing, C. C. (2011). Energy policy and alternative energy in Malaysia: Issues and challenges for sustainable growth, *Renewable and Sustainable Energy Reviews* 14(4), 1241-1252. DOI: 10.1016/j.rser.2009.12.003

Tock, J. Y., Lai, C. L., Lee, K. T., Tan, K. T., and Bhatia, S. (2010). Banana biomass as potential renewable energy resource: A Malaysian case study, *Renewable and Sustainable Energy Reviews* 14(2), 798-805. DOI: 10.1016/j.rser.2009.10.010

Van De Broek, R., Faaij, A., and Wijk, A. V. (1996). Biomass combustion for power generation, *Biomass and Bioenergy* 11(4), 271-281. DOI:10.1016/0961-9534(96)00033-5

Velásquez-Arredondo, H. I., Ruiz-Colorado, A. A., and Oliveira junior, S. De. (2010). Ethanol production process from banana fruit and its lignocellulosic residues: Energy analysis, *Energy* 35(7), 3081-3087. DOI: 10.1016/j.energy.2010.03.052

Verdonk, M., Dieperink, C., and Faaij, A. P. C. (2007). Governance of the emerging bio-energy markets, *Energy Policy* 35(7), 3909-3924. DOI: 10.1016/j.enpol.2006.12.028

Werther, J., and Saenger, M. (2000). Combustion of agricultural residues, *Progress in Energy and Combustion Science* 26(1), 1-27. DOI: 10.1016/S0360-1285(99)00005-2

Yusof, I., Farid, N. A., Zainal, Z. A., and Azman, M. (2008). Characterization of rice husk for cyclone gasifier, *Journal of Applied Science* 8, 622-628.

Yusuf, B., Sivasothy, K., Maycock, J. H., and Ma, A. N. (1993). *Biomass Co-generation and alternative Energy have a Commercially Feasible Role to Play.* Palm Oil Industry Experience MPOB, Cogeneration Conference. Kuala Lumpur.

Zamzam Jaafar, M., Wong, H. K., and Horhayati, K. (2003). Green energy solutions for a sustainable future: Issues and challenges for Malaysia, *Energy Policy* 31(11), 1061-1072. DOI: 10.1016/S0301-4215(02)00216-1

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