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Energy Economical and Environmental Analysis of Industrial Boilers Using Fuel Switching

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Abstract: **The successful implementation of the industrialization plan in Malaysia in 1985 has led to change this country from an agricultural economy into industrial based economy. The industrial sector represents the highest consuming sector across all other sectors and accounts for about 48% of all total energy demand. This study is concerned with an energy saving, economic and environmental analysis of industrial boilers in Malaysian paper and pulp industries when applying the concept of fuel switching. It has been found that 11,946 ton of CO_2 and RM 1,872,532 could be saved annually, when switching between diesel fuel and biomass by a percentage of 50% for both instead of using 100% of diesel fuel. Also it has been found that 7,495,640 kg of CO_2 and RM 923,431 could be saved annually, when switching between diesel fuel and natural gas by a percentage of 50% for both instead of using 100% of diesel fuel. All these results represent high energy saving, environmental and economic benefits for a small developing country like Malaysia.**

Keyword: **Energy saving, economic benefits, environmental analysis, industrial boilers, fuel switching.**

I. INTRODUCTION

A. Energy demand trend in Malaysia

One of the recent studies has shown that Malaysian economy grew at 5% in 2005 [1]. Between 2000 and 2005, final energy consumption grew at a fast rate of 5.6% to reach 38.9 Mtoe. The final energy consumption is expected to reach 98.7 Mtoe in 2030, nearly three times the 2002 level as shown in Figure 1. The industrial sector will have the highest growth rate of 4.3%, followed by transport at 3.9%, residential at 3.1% and commercial at 2.7% [2]. The most striking feature among all Malaysian sectors' consumption is that the industrial sector accounted for some 48% of total energy use in 2007 which represents the highest percentage among all other sectors as shown in Figure 2[3].

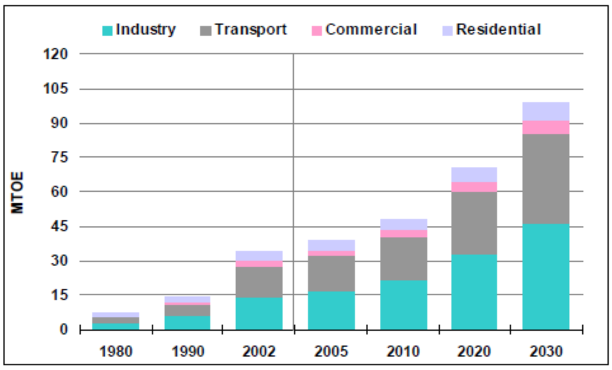

Figure 1 Statistics of energy uses in Malaysia from 1980-2030 [2]

In 2005, the statistics show that oil reserves are expected to last another 19 years while natural gas reserves are expected to last for about 33 years. As a result of the growing energy consumption (Figure 1) and domestic energy supply constraints, Malaysian government formulated the National Depletion Policy in 1980 which set the daily limit of oil and gas production levels. This policy has set the concept of sustainable development and diversification of energy sources as the main energy policy goals. The Five-Fuel Strategy has recognizes renewable energy resources (RE) as the economy's fifth fuel after oil, coal, natural gas and hydro in the long term. Nevertheless, substantial governmental intervention and support are necessary to implement this policy [2]. This papers aims to study energy saving, emissions reduction and cost benefits analysis when applying fuel switching approach in industrial boilers in Malaysian. The outcome of this study is expected to give the operators and policy makers many useful choices in many applications.

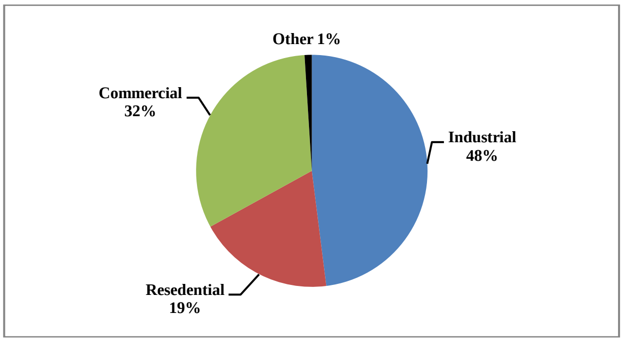

Figure 2 Statistics of energy uses in Malaysia in 2007 [3]

B. Fuel switching using biomass

Fuel switching can be defined as an emission control measure that involves the exchange of a less pure fuel to a cleaner one, also it can be defined as the use of alternative fuel or the substitution of one type of fuel for another, especially the use of a more environmentally friendly fuel as a source of energy in place of a less environmentally friendly one. This will help to reduce energy cost and emissions production.

In Malaysia it has been found that the gradual fuel substitution for electricity generation from harmful fossil fuels to less harmful fuels such as natural gas and renewable fuels such as hydro and biomass will contribute to CO_2 reduction for about 167,618,280 ton from 2001-2020 as shown in Figure 3 [4].

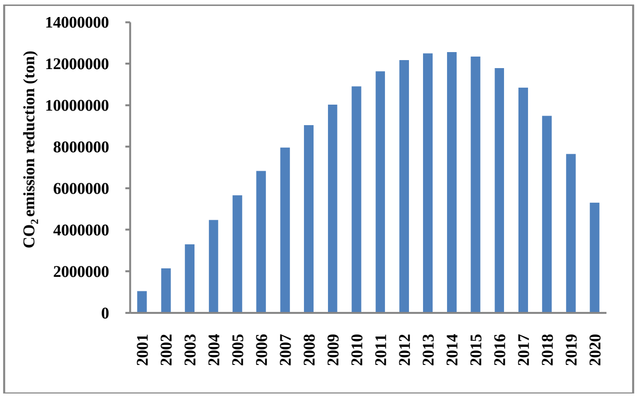

Figure 3 Potential CO_2 reduction due to the changes of energy sources for electricity generation in Malaysia [4]

For the switching to occur, several conditions have to be fulfilled. First, an economical incentive must be present for customer, which means alternative fuels must be offered in a good and competitive price in comparison to conventional types. Second, the physical and technical potential to implement fuel switching approach must exist such as dispatchability factor and technical modifications to the prime mover to suite the proposed type of alternative fuel [5, 6].

Biomass is the name given to the all earth's living matter and is the general term for material derived from growing plants or from animal manure. It is a rather simple term for all organic materials that originates from plants, trees, crops and algae. Biomass as the solar energy stored in chemical form in plant and animal materials is among the most precious and versatile resources on earth [7]. There are many benefits of using biomass including:

(i) Economic benefits: biomass could replace some of the money spent on oil.

(ii) Environmental benefits including:
  - Preservation of agricultural land that otherwise would be sold for residential development or industrial use.
  - Sustainable agricultural techniques for these crops can restore and ensure soil stability and health and minimize chemical residues and habitat destruction.
  - Methane is 20 times more powerful greenhouse than CO_2. Capturing methane from producers such as cows or rice fields and using it as fuel will significantly reduce this greenhouse gas.
  - Increased carbon sequestering from the crops grown for biomass.
  - Use of waste from agricultural and timber industries.
  - No net increase in atmospheric carbon dioxide.

In Malaysia, there is a good potential of using palm oil as a resource of biomass. Malaysia is regarded as the second largest producer of palm oil with 15.88 million tons; this represents 43% of the total world supply as shown in Figure 4. Currently palm oil represents 85.5% of total biomass production as shown in Figure 5 [8].

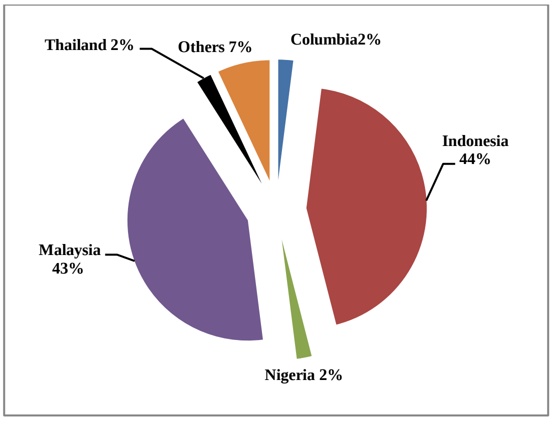

Figure 4 Top world producers of oil palm in 2006 [8]

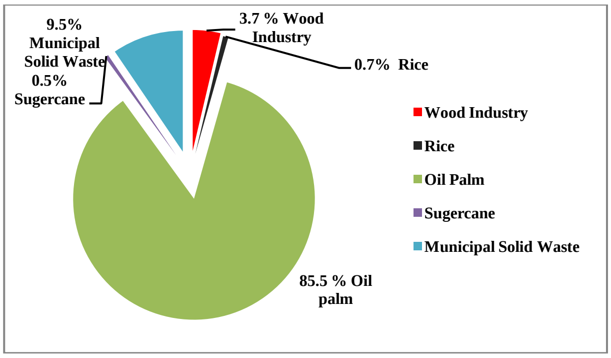

Figure 5 Biomass produced from different industry in Malaysia [8]

Sustainability of palm oil In Malaysia is judged by a body called Roundtable on Sustainable Palm Oil (RSPO). This body defines sustainable palm oil production as a legal, economically viable, environmentally appropriate and socially beneficial management and operations.

The environmental sustainability of oil palm biomass comes when burning it to generate energy. Based on current typical industry practices for palm oil production in Malaysia, using palm oil for bio-fuel applications renders an average net CO_2 reduction of approximately 60%. In other words, the CO_2 emissions incurred in the palm oil supply chain are roughly 40% of the CO_2 emissions avoided by replacing fossil fuels [9]. Recently some studies have shown that oil palm plantations are more effective carbon sink (an area of dry mass that is capable to absorb harmful greenhouse gases such as carbon dioxide) comparing to rainforest. Oil palm plantation assimilates up to 64.5 tons of carbon dioxide per hectare per year while virgin rainforest only can assimilate 42.2 tons per hectare per year [8].

Utilization of oil palm biomass could also ensure social sustainability by creating new employment opportunities in rural areas in the developing country like Malaysia. This is because labor requirement for biomass energy is relatively high, especially in the cultivation of energy crops [8].

II. METODOLOGY

A. Targeted manufacturing factories and audit data collection

The targeted industries in this paper are the paper and pulp. The necessary information to perform this study has been taken from PTM (Pusat Tenaga Malaysia) throughout a personal communication as shown in Table 1.

Table 1 Results of the industrial Malaysian energy audit [10]

Factory name	Location	Diesel consumption (Liter/year)
Tritex container	Selangor (Centre)	359,100
Cenpak holdings	Johor (South)	1,363,000
Orna paper	Melaka (centre)	102,000
Genting sanyen	Selangor (Centre)	1, 972,000
Malaysian newsprint	Pahang (North)	127,000
Kym industries	Selangor (Centre)	486,100
TOTAL		4,409,200

B. Cost saving of fuel switching

In this study two types of fuels have been suggested to switch with diesel in Malaysian paper and pulp industries. In Malaysia biomass and natural gas represent a very good choice to switch with diesel especially biomass as an abundant source. Table 2 shows fuel price, density and energy content of diesel, natural gas and biomass

Table 2 Prices, density and energy content of diesel, natural gas and biomass [11]

Fuel type	Unit fuel price	Density (kg/m^3)	Energy content (kJ/kg)
Diesel	1.002 RM/Liter	0.85	45,000
Natural gas	0.6012 RM/Liter	0.717	55,000
Biomass	15 RM/Ton	N/R	6,000

- N/R ≡ Not Required

When using diesel as the main source of energy (100%) in Malaysian paper and pulp's boilers the equations that used to calculate annual diesel energy consumption and fuel price are as follow:

$$ADC_{kg} = ADC_L \times \rho_D \tag{1}$$

$$ADC_{kJ} = ADC_{kg} \times DEC \tag{2}$$

$$ADC_{kWh} = \frac{ADC_{kJ}}{3600} \tag{3}$$

$$ADP_{RM} = ADC_L \times UFP_D \tag{4}$$

When switching between diesel, natural gas and biomass in these boilers, annual energy consumption and fuel prices of diesel, biomass and natural gas will be as follow:

$$ADCS_{kWh} = ADC_{kWh} \times \%D_{FS} \tag{5}$$

$$ANGECS_{kWh} = ADC_{kWh} \times \%NG_{FS} \tag{6}$$

$$ABECS_{kWh} = ADC_{kWh} \times \%B_{FS} \tag{7}$$

$$ADCS_L = \frac{ADCS_{kWh} \times 3600}{\rho_D \times DEC} \tag{8}$$

$$ADPS_{RM} = ADCS_L \times UFP_D \tag{9}$$

$$ANGCS_L = \frac{ANGECS_{kWh} \times 3600}{\rho_{NG} \times NGEC} \tag{10}$$

$$ANGPS_{RM} = ANGCS_L \times UFP_{NG} \tag{11}$$

$$ABCS_{kg} = \frac{ABECS_{kWh} \times 3600}{BEC} \tag{12}$$

$$ABPS_{RM} = ABCS_{kg} \times UFP_B \tag{13}$$

Thus, total bill saving when applying fuel switching equals to the result of subtracting annual diesel fuel price without switching from the summation of annual diesel, natural gas and biomass fuel price when switching. Total annual bill saving can be represented as follow:

$$TABS_{RM} = ADP_{RM} - (ADPS_{RM} + ANGPS_{RM} + ABPS_{RM}) \quad (14)$$

C. Emissions reduction of fuel switching

The environmental impact of the fuel switching methods is a potential reduction of greenhouse gasses or other elements which give negative impact to the environment. The common potential reductions include carbon dioxide CO_2, sulfur dioxide SO_2 and nitrogen oxide NO_x. This study is concerned with all these emissions when using natural gas and CO_2 when using biomass. The emission factors of all these gases have already been shown in the Table 3. The emissions production is a function of annual energy consumption and the emission factor of the particular fuel. Emissions production when burning diesel can be calculated as follow:

$$ADEP_{CO_2} = ADC_{kWH} \times EF_{CO_2} \quad (15)$$
$$ADEP_{NO_x} = ADC_{kWH} \times EF_{NO_x} \quad (16)$$
$$ADEP_{SO_2} = ADC_{kWH} \times EF_{SO_2} \quad (17)$$

Table 3 Emission factors of fossil fuels for electricity generation [12]

Fuels	Emission factor (kg/kWh)			
	CO_2	SO_2	NO_x	CO
Coal	1.18	0.0139	0.0052	0.0002
Petroleum	0.85	0.0164	0.0025	0.0002
Gas	0.53	0.0005	0.0009	0.0005
Hydro	0.00	0.0000	0.0000	0.0000
Others	0.00	0.0000	0.0000	0.0000

When switching between diesel and natural gas in these boilers, annual emissions productions of CO_2, SO_2 and NO_x depends on the percentage by which each fuel has been used and emission factor of each fuel. This can be expressed as follow:

$$ADEPS_{CO_2} = ADCS_{kWh} \times EF_{CO_2} \quad (18)$$
$$ADEPS_{SO_2} = ADCS_{kWh} \times EF_{SO_2} \quad (19)$$
$$ADEPS_{NO_x} = ADCS_{kWh} \times EF_{NO_x} \quad (20)$$
$$ANGEPS_{CO_2} = ANGECS_{kWh} \times EF_{CO_2} \quad (21)$$
$$ANGEPS_{SO_2} = ANGECS_{kWh} \times EF_{SO_2} \quad (22)$$
$$ANGEPS_{NO_x} = ANGECS_{kWh} \times EF_{NO_x} \quad (23)$$

Annual emissions reduction of CO_2, SO_2, CO and NO_x equals to the result of subtracting annual emissions production from the annual diesel and natural gas emissions production when switching depending on the percentage of each fuel used. This can be equal to

$$AER_{CO_2} = ADEP_{CO_2} - \left(ADEPS_{CO_2} + ANGEPS_{CO_2}\right) \quad (24)$$
$$AER_{SO_2} = ADEP_{SO_2} - \left(ADEPS_{SO_2} + ANGEPS_{SO_2}\right) \quad (25)$$
$$AER_{NO_x} = ADEP_{NO_x} - \left(ADEPS_{NO_x} + ANGEPS_{NO_x}\right) \quad (26)$$

When switching between diesel and biomass in these boilers, annual emissions productions of carbon dioxide depends on the percentage by which each fuel has been used and emission factor of biomass. It has been found that the CO_2 emissions produced when burning biomass are roughly 40% of the CO_2 emissions produced by fossil fuels [8]. Annual biomass emissions production of $CO_2$when switching can be expressed as follow:

$$ABEPS_{CO_2} = (ADEP_{CO_2} - ADEPS_{CO_2}) \times 0.4 \quad (27)$$

Thus, Annual emissions reduction of CO_2 equals to the result of subtracting annual diesel emissions production before switching from annual diesel and biomass emissions production when switching depending on the percentage of each fuel used. This can be equal to:

$$AER_{CO_2} = ADEP_{CO_2} - \left(ADEPS_{CO_2} + ABEPS_{CO_2}\right) \quad (28)$$

III. RESULT AND DISCUSSION

A. Cost saving of natural gas and diesel switching

Based on the input data in Tables 1 and 2, and equations (1-14), the results of total annual cost saving when switching between natural gas and diesel in different percentage are illustrated in Figures 6.

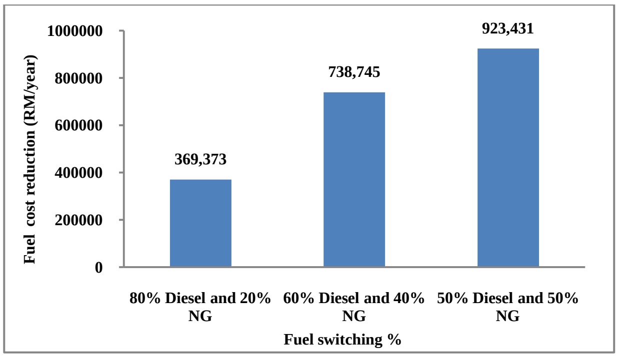

Figure 6 Total fuel cost reduction (RM/year) at different natural gas and diesel switching

The results in Figure 6 show that the total annual bill saving when switching in different percentage between natural gas and diesel in the Malaysian industrial boilers are about RM 369,373 in case of 80% diesel and 20% natural gas consumption, RM 738,745 in case of 60% diesel and 40% natural gas consumption and RM 923,431 in case of 50% diesel and 50% natural gas consumption respectively. It can be observed that total annual bill saving increases with the increased percentage of natural gas consumption. These results represent a huge amount of annual bill saving that can be achieved when increasing the percentage of natural gas consumption in Malaysian industrial boilers.

B. Emissions reduction when switching between natural gas and diesel

Based on the input data in Table 3 and equations (15-28), the results of annual emissions reduction of CO_2, NO_x and SO_2 when switching between natural gas and diesel are tabulated in Table 4.

Table 4 Total emissions reduction (kg) when switching between natural gas and diesel

Fuel switching percentage	80% diesel and 20% NG	60% diesel and 40% NG	50% diesel and 50% NG
CO_2 reduction	2,998,256	5,996,512	7,495,640
SO_2 reduction	148,976	297,952	372,440
NO_x reduction	14,991	29,983	7,478

The results in Table 4 show that the total emission reduction of CO_2, NO_x and SO_2 when switching in different percentage between natural gas and diesel are about 2,998,256 kg, 14,991 kg and 148,976 kg respectively in case of 80% diesel and 20% natural gas consumption. In case of 60% diesel and 40% natural gas consumption, the total annual emission reduction of CO_2, NO_x and SO_2 are about 5,996,512 kg, 29,983 and 297,952 respectively. Finally in case of 50% diesel and 50% natural gas consumption, the total annual emission reduction of CO_2, NO_x and SO_2 are about 7,495,640 kg, 37,478 kg and 372,440 kg respectively. It can be observed that total emissions reduction increase with the increased percentage of natural gas consumption. These results represent a huge amount of total emissions reduction that can be achieved when increasing the percentage of natural gas consumption in Malaysian industrial boilers.

C. Cost saving of biomass and diesel switching

Based on the input data in Table 1 and 2 and equations (1-14), the results of total annual bill saving when switching between biomass and diesel are illustrated in Figures 7.

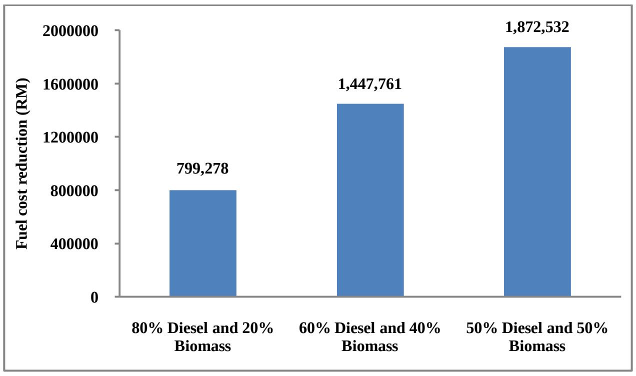

Figure 7 Total fuel cost reduction (RM/year) when switching between biomass and diesel

The results in Figure 7 show that the total annual bill saving when switching in different percentage between biomass and diesel in the Malaysian industrial boilers are about RM 799,278 in case of 80% diesel and 20% biomass consumption, RM 1,447,761 In case of 60% diesel and 40% biomass consumption and RM 1,872,532 in case of 50% diesel and 50% biomass consumption respectively. It can be observed that total annual bill saving increases with the increased percentage of biomass consumption. These results represent a huge amount of annual bill saving that can be achieved when increasing the percentage of biomass consumption in Malaysian industrial boilers.

D. Emissions reduction of biomass and diesel switching

Based on the input data in equations (15-28), the results of total annual emission reduction of CO_2 when switching between biomass and diesel are illustrated in Figures 8.

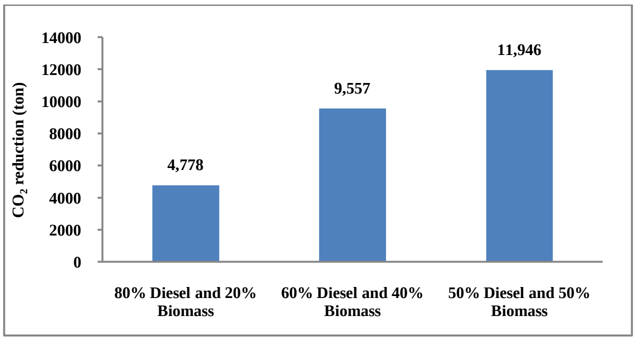

Figure 8 Total CO_2 reduction (ton) when switching between biomass and diesel

The results in Figure 8 show that the total emission reduction of CO_2 when switching in different percentage between biomass and diesel are about 4,778 ton in case of 80% diesel and 20% biomass consumption, 9,557 ton in case of 60% diesel and 40% biomass and 11,946 ton in case of 50% diesel and 50% biomass consumption. It can be observed that total emissions reduction increase with the increased percentage of biomass consumption. These results represent a huge amount of total emissions reduction that can be achieved when increasing the percentage of biomass consumption in Malaysian industrial boilers.

From the results that have been obtained in section A and B respectively, it has been found that total annual cost saving is higher when switching between diesel and biomass than diesel and natural gas. For instance, RM 1,872,532 can be saved annually in case of 50% diesel and 50% biomass fuel switching, however in case of 50% diesel and 50% natural gas RM 923,431 could be saved annually.

Carbon dioxide reduction is an another evidence of the advantage of using biomass over natural gas with 11,946 ton of CO_2 reduction in case of 50% diesel and 50% biomass fuel switching and 7,496 ton reduction in case of 50% diesel and 50% natural gas fuel switching.

Also this study confirms the results in the literature which stated that when utilities switch to other renewable energy sources, such as biomass, substantial emissions reduction could be achieved

IV CONCLUSION AND RECOMMENDATIONS

The principle of fuel switching has been applied in this study, it has been found that total annual cost saving is higher when switching between diesel and biomass than diesel and natural gas. For instance, RM 1,872,532 can be saved annually in case of 50% diesel and 50% biomass fuel switching, however in case of 50% diesel and 50% natural gas RM 923,431 could be saved annually. Carbon dioxide reduction is another evidence of the advantage of using biomass over natural gas with 11,946 ton of CO_2 reduction in case of 50% diesel and 50% biomass fuel switching and 7,496 ton reduction in case of 50% diesel and 50% natural gas fuel switching. This study satisfies the results in the literature which stated that when utilities switch to other renewable energy sources, such as biomass, substantial emissions reduction could be achieved

NOMENCLATURE

$ABCS_{Kg}$	Annual biomass consumption when switching (kg/year)
$ABECS_{kWh}$	Annual biomass energy consumption when switching (kWh/year)
$ABEPS_{CO_2}$	Annual biomass emissions production of $CO_2$when switching (kg/year)
$ABPS_{RM}$	Annual biomass price when switching (RM/year)
ADC_{kg}	Annual diesel consumption (kg/year)
ADC_L	Annual diesel consumption (Liter/year)
$ADCS_L$	Annual diesel consumption when switching (kg/year)
$ADCS_{kWH}$	Annual diesel energy consumption when switching (kWh/year)
ADC_{kJ}	Annual diesel energy consumption (kJ/year)
ADC_{kWH}	Annual diesel energy consumption (kWh/year)
ADP_{RM}	Annual diesel price (RM/year)
$ADPS_{RM}$	Annual diesel price when switching (RM/year)
$ABPS_{RM}$	Annual biomass price when switching (RM/year)
$ADCS_{kWH}$	Annual diesel energy consumption when switching (kWh/year)
AER_{CO_2}	Annual emissions reduction of CO_2 (kg/year)
$ANGECS_{kWh}$	Annual natural gas energy consumption when switching (kWh/year)
$ANGPS_{RM}$	Annual natural gas price when switching (RM/year)
$ADEP_{CO_2}$	Annual diesel emissions production of CO_2 when switching (kg/year)
$ADEP_{NOx}$	Annual diesel emissions production of NO_x (kg/year)
$ADEP_{SO_2}$	Annual diesel emissions production of SO_2 (kg/year)
$ADEPS_{CO_2}$	Annual diesel emissions production of CO_2 when switching (kg/year)
$ADEPS_{CO}$	Annual diesel emissions production of CO when switching (kg/year)
$ADEPS_{NO_x}$	Annual diesel emissions production of NO_x when switching (kg/year
$ADEPS_{SO_2}$	Annual diesel emissions production of SO_2 when switching (kg/year)
$ANGEPS_{NO_x}$	Annual natural gas emission production of NO_x when switching (kg/year)
$ANGEPS_{CO_2}$	Annual natural gas emission production of CO_2 when switching (kg/year)
$ANGEPS_{SO_2}$	Annual natural gas emission production of SO_2 when switching (kg/year)
DEC	Diesel fuel energy content (kJ/kg)
EF_{CO_2}	Emission factor of CO_2 (kg/kWh)
EF_{CO}	Emission factor of CO (kg/kWh)
EF_{SO_2}	Emission factor of SO_2 (kg/kWh)
EF_{NO_x}	Emission factor of NOx (kg/kWh)
$TABS_{RM}$	Total annual bill saving RM/year
UFP_f	Unit fuel price (RM/Liter or RM/kg)
$\%B_{FS}$	Percentage of biomass fuel switching
$\%D_{FS}$	Percentage of diesel fuel switching
$\%NG_{FS}$	Percentage of natural gas switching
ρ_f	Density of a particular fuel (kg/m^3)
0.4	Percentage of CO_2 emission avoided by palm oil when replacing fossil fuel
3600	Conversion factor from kWh to kJ

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