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ANALYSIS OF CO_2 EMISSIONS REDUCTION IN POWER SECTOR FOR SUSTAINABLE ENVIRONMENT

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ABSTRACT

This study is conducted with aims to develop Mixed Integer Programming model in General Algebraic Modelling System for electricity supply generation plan at Tanjung Bin coal fired power station. Energy source switching with implementation of solar energy had been chosen as an initiative method for CO_2 emission reduction. The optimal results indicated that to achieve a 40% of CO_2 emission reduction, the model suggested that 669.8 MW of electricity supply generation should be produced from solar energy. This indicates that 2.4 million tons of CO_2 per year could be avoided. This scenario had increased the electricity cost (EC) by 86.4% to make the EC is MYR 1.34/kWh. These amounts hit the current EC value of MYR 0.18/kWh. The conclusion of this study shows that Malaysia has a strong need and great potential to implementation solar energy as an approach in reducing CO_2 emission.

Keywords: electricity supply; carbon dioxide; optimization; fuel switching; solar energy.

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1. INTRODUCTION

Malaysia is known as a consistent developing country. Consistent development of Malaysia economy is visible with the increases of gross domestic product (GDP) at a rate of 5-6% annually since 2002. GDP rate is used to show rapid growth of country development due to this rate is considered as primary indicator that can be used to gauge the health of a country's economy. The increase of GDP rate always has a strong correlation with energy consumption rate. Energy consumption is referred to the total amount of electricity supplies for daily usage. Based on recorded statistic, every 1% increase of GDP rate is equivalent to 1.2-1.5% of electricity consumption rate [1]. Electricity consumption in Malaysia is increasing rapidly due to Malaysia is known as developing country with new generation who live with modern life that uses sophisticated electrical appliances and latest electronic instrument. As a result, this may cause the electricity consumption rate to continuously increase. In view of this way of living, electricity consumption in our daily life is no longer charged by every minute but in every second. Today, the needs for electricity supply show the rapidity of Malaysia economy towards year 2020.

Referring to the annual report of Malaysian Energy Commission [2], the maximum average of electricity demand in Peninsular Malaysia has increased approximately 2.8% since 2010. This makes the electricity demand reach to 16,901 MW in 2014 [3]. Malaysia's electricity generation is based on the conventional (non-renewable) sources and non-conventional (renewable) sources. The conventional sources are always dependent on fossil fuel consisting of natural gas, coal and oil whereas the non-conventional source consists of hydro. Even though Malaysia has used mix energy sources in electricity supply generation to ensure sustainability in energy sector, approximately only 6.7% of electricity supply is produced from renewable source such as hydro whereas, another 93.3% of electricity supply is produced through the combustion of fossil fuels [4]. The usage of fossil fuels in electricity supply generation has contributed to the emissions of greenhouse gases (GHGs) such as carbon dioxide (CO_2) in the atmosphere. CO_2 is GHGs that is responsible for climate change that may cause an increase in the average surface temperature of the earth over time and also may produce changes in precipitation patterns, storm severity, and sea level. The concerning issue regarding GHGs emission had caused Malaysian Government to look into renewable source for electricity supply generation. Apart from that, the availability and the cost of fossil fuel also became a major factor that the governments change their view into renewable sources in electricity supply generation. The price of main fossil fuel for electricity supply generation such as gas and coal is uncertain and could be rising every year. The price for gas and coal based on TNB (TenagaNasionalBerhad) data is listed in Table 1.

Table 1. Current price for gas and coal [5]

Source	Quantity	Price (R)
Gas	≤ 1,000 mmscfd[1]	15.20 / mmBtu
	> 1,000 mmscf[2]	41.68 / mmBtu
Coal		276.50 / ton

[1]government-control price (The subsidy calculation is revised every 6 months by the Government)

[2]based on LNG price discount

The gas price starting from January 2015 is MYR 15.20/mmBtu after the increment was revised by the Malaysian Government in January 2014. In every 6 month, the price has increased by MYR 1.50/mmBtu for the first usage of 1,000 mmscfd. Then, entering to 2016 the gas price to the power sector is MYR 18.20/mmBtu. The increasing of gas price may cause in year 2024 the gas price can reach to LNG market price at MYR 41.68/mmBtu as shown in Fig. 1.

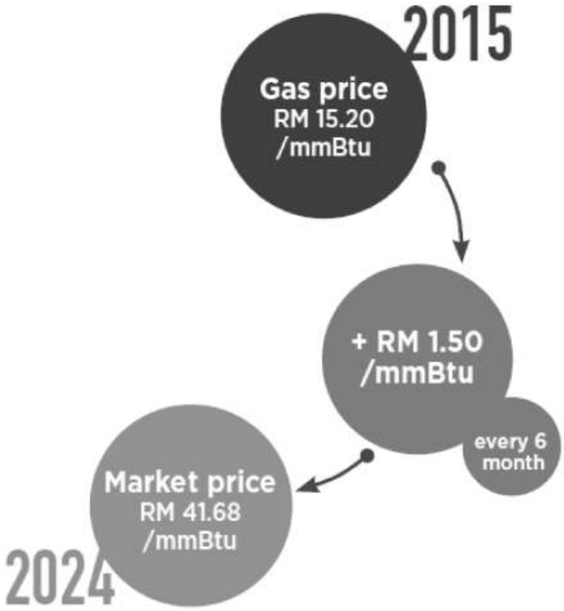

Fig.1. Gas price [6]

The continues increase of gas price may cause traditional trend of electricity generation that relied on gas is going to shift towards coal due to the cheaper price of coal compared to gas as well as concerns about depletion of gas resources. This can be seen clearly when the share of gas in electricity supply generation has decreased from 74% to 49%, whilst the share of coal increased from 11% to 38% [7]. The increase of coal share in electricity supply generation strengthen the expectation that coal will overtake gas and emerge as the dominant fuel in power sector by 2030. Shifting towards coal-fired generation in power sector will directly increase the CO_2 emissions. With this rising use of coal, the CO_2 emission is expected to rise more than 98 million tons by year 2020 [8].Therefore, if powers Sector Company refuse to take any steps to reduce the CO_2 emission and continue with existing power development plan by producing electricity supply from fossil fuel source, the CO_2 emission level will follow the current existing trend with continued increase. An action to reduce the CO_2 emission needs to be taken by the power sector due to this sector is the highest contributor towards CO_2 as shown in Fig.2.

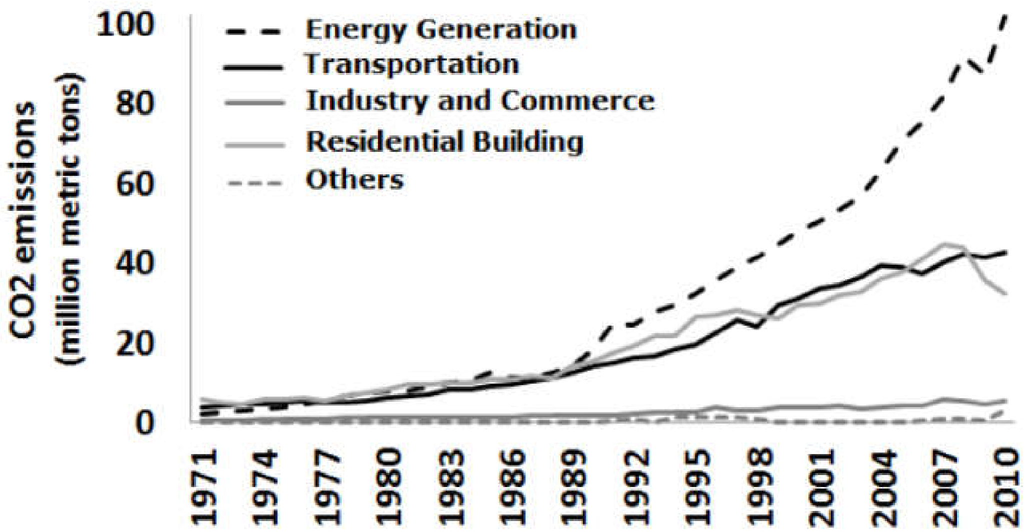

Fig.2. Trends in CO_2 emission by different sectors in Malaysia from 1971-2010 [9]

The initiatives in relation to electricity supply generation for reduction of CO_2 emission can be taken with consideration of these three initiatives namely energy efficiency, renewable energy and solid waste management. The energy efficiency is considered as short term roadmap for the reduction of emissions whilst renewable energy and solid waste management is considered as short to medium term roadmap in emissions reduction [9]. Thus, this study is conducted in order to apply the short to medium term roadmap in electricity Supply Company for the reduction of CO_2 emission. The initiative that has been used in this study is introducing the renewable energy (RE) specifically solar energy or the sun as source of fuel in electricity supply generation. Solar energy is being chosen as alternative source in electricity supply generation due to solar energy is functioning as source of energy that can save the natural resources or fossil fuel which is non-renewable and also can help to ensure energy security and sustainable environment. Solar energy can also be obtained for free, environmental friendly, and uninfluenced by the international politics or multinational conspiracy companies which dominate the world's energy sources.

In this study, a power plant that used coal as source of fuel is done by energy source switching (fuel switching) with implementation of solar energy as method for CO_2 emission reduction. Coal fired power plant was selected as study area due to base on expectation from IEA 2016, as another 15 years, coal is going to overtake gas in electricity supply generation. In this study, an optimization model with the objective function to minimize the cost was formulated to let the optimizer makes the decision regarding the total percentage of renewable fuel that needs to be mixed with non-renewable fuel to meet with certain percentage of CO_2 reduction.

2. LITERATURE REVIEW

Entering to 21st century, the energy sector is forced to meet several goals including to conformance with the environmental, economic and social goals of sustainable development [10]. The existence of this multiple goals makes the existence of several system approaches to solving energy sector problems. Therefore, many valued researches such as modelling, optimization and simulation researches for energy sector was carried out as shown in Table 2.

Table 2. Potential researches in energy and power sector

References	Year	Study Domain/Emphasis
[11]	2016	This paper presents a Mixed Integer Linear Programming model for the long-term energy planning of national power supply systems in Greece. The model developed is least cost optimization model.
[12]	2016	A multi-objective optimization model at urban sector scale is proposed in this study to achieve sustainable development of energy, economic and environmental systems. The development model is applied to Beijing, China to obtain a reasonable solution of energy mix.
[13]	2015	A multi-period power optimization model for the UAE's electricity sector is developed in this study. The optimization problem was formulated as a multi-period MILP model in the GAMS modelling system with aims to minimize the cumulative costs and CO_2 emission.
[14]	2015	A multi-region model and single-region model is developed and compared to optimize the planning of China's power sector. The results indicate that there is a saving of cost when using multi-region model.

[15]	2014	The study is conducted to develop model for Thailand's power sector using Asia-Pacific Integrated Model (AIM/Enduse). The results demonstrate that the fossil fuel based technology would be replaced by clean technologies including CCS technology and renewable energies in order to makes Thailand as low-carbon society.
[16]	2014	A mixed integer linear programming (MILP) optimization model under carbon constraints is developed to determine the most economical low carbon power generation mix. The model includes fuel-switching, RE power generation and implementation of carbon capture and storage (CCS).
[17]	2013	This study is to build a multi-period superstructure optimization planning model of China's power sector. The levelized optimal pathway showed that in the presence of carbon tax, the CO_2 emissions of the power sector were reduced significantly by developing low-carbon technologies including nuclear power, renewables and CCS.
[18]	2013	This research is built a dynamic simulation model to explore the options for carbon mitigation in Turkish electric power industry. The analysis presented in this paper reveals that there are mitigation options below 50% of business as usual growth, with common policy options such as feed-in-tariffs, investment subsidies and carbon taxes.
[19]	2012	The analysis of this study is performed by development of optimization model based on linear programming. The results indicate that the increasing of CO_2 price makes fuel switching between coal and natural gas is become crucial for the abatement of CO_2 emissions.
[20]	2011	This research presents the possibility for Thailand to become

		a low-carbon society by development of current CO_2 emission inventory, and quantification of socio-economic activity level.
[21]	2010	A multi-period mixed-integer linear programming (MILP) model for the power sector is developed in this study. The model is to determine the optimal mix of energy supply sources and pollutant mitigation options that meet a specified electricity demand and CO_2 emission targets at minimum cost.
[22]	2010	This study presents a Mixed Integer Linear Programming (MILP) model that was developed for the optimal planning of electricity generation schemes for Peninsular Malaysia to meet a specified CO_2 emission target. CO_2 mitigating option includes Integrated Gasification Combined Cycle (IGCC), Natural Gas Combined Cycle (NGCC), nuclear and biomass from landfill gas and palm oil residues.
[23]	2010	The study presents an analysis of the options for the CO_2 emissions mitigation in the Brazilian power sector. This study is to verify the potential use of wastes for electrical energy generation and its competitiveness with other sources of RE.

From these previous researches, it shows clearly that the econometric model and optimization modelling for CO_2 emissions reduction in energy planning have been widely used in various fields.

3. METHODOLOGY

In this study, the analysis of CO_2 emission reduction is scoped on power sector. The power plant type is coal fired power plant. An optimization model with the objective function to minimize the cost [21] was formulated with several factors that affect the CO_2 emissions level in the power sector are considered as shown in Fig. 3.

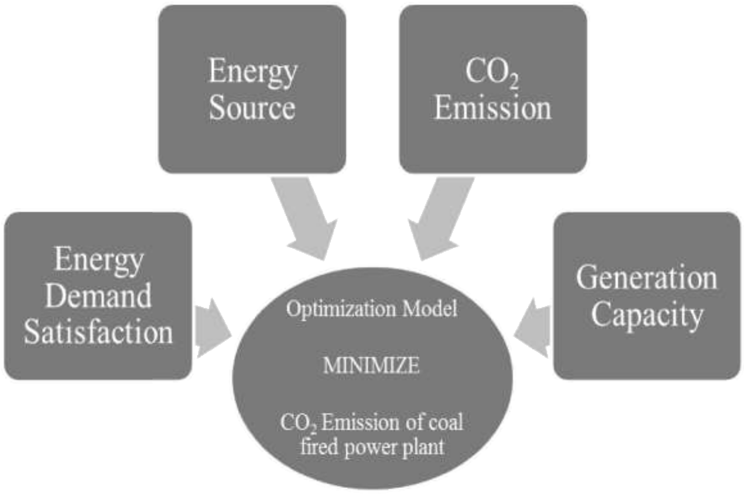

Fig.3. Schematic representation of CO_2 emission reduction for coal fired power plant

3.1. Objective Function

The objective function formulated is to find compromise decisions under economic and environmental objectives. The combination of both objectives gives the objective function as written in Eqn. (1).

$$MinCost = \sum_{F} \sum_{j} Elec_{Fj} FosOpr_{Fj} + \sum_{F} \sum_{j} CapCost_{Fj} X_{Fj} + \sum_{F} \sum_{j} CO2emis_{Fj} Elec_{Fj} \quad (1)$$

The objective function in Eqn. (1) is subject to the following factors.

3.2. Energy Demand Satisfaction

The total of electricity generation from all energy sources (fossil and RE) must be equal or greater than the demand as shown in Eqn. (2).

$$totMW = \sum_{F} \sum_{j} Elec_{Fj} \div Optime \geq Demand\ (MW) \quad (2)$$

3.3. Energy Source

The plant process is operating with at least one energy source or it is shut down as Eqn. (3).

$$swi\ (F) = \sum_{F} X_{Fj} \leq 1 \qquad \forall \in F \quad (3)$$

3.4. CO_2 Emissions

The percentage of total CO_2 emission reduction must be equal or less than the reduction requirement as shown by Eqn. (4).

$$totCO2 = \sum_{F} \sum_{j} CO2emis_{Fj} Elec_{Fj} \leq (1 - CO2red) * CO2 \quad (4)$$

3.5. Generation Capacity

The generation capacity of the plant must greater than the minimum capacity and cannot exceed than the maximum capacity as in Eqn. (5) and (6).

$$MinCap = Elec_{Fj} \geq (L * F\max) * X_{Fj} \quad \forall \in F \tag{5}$$

$$MaxCap = Elec_{Fj} \leq (1 + R) * Efossil(F) * X_{Fj} \quad \forall \in F \tag{6}$$

Indices

F = Fossil boiler

j = Energy source

Scalars

MaxE = Electricity Generated at Peak Time

Optime = Annual Operating Time

CO_2 = CO_2 Emission

CO_2red = Percent of CO_2 Reduction

R = Allowable electricity increment

L = Lower Bound

Parameters

Fmax = Maximum Fossil Electricity Generation

Efossil (F) = Electricity from Fossil Boiler Power Plant

FosOpr = Operational cost

Capcost = Capital cost

CO_2emis = Carbon dioxide emission from fossil

Variables

MinCost = Total cost

Positive Variables

Elec (F, j) =Adjusted Electricity Generation

v (F) =Percentage Reduction

Binary Variables

X (F, j) = Type of Energy Source Used

4. CASE STUDY FOR TANJUNG BIN POWER STATION (TBPS)

Tanjung Bin Power Station (TBPS) is the first private coal fired power plant in Malaysia. It also considered as the biggest coal fired power plant in South East Asia. The TBPS is owned by the Independent Power Produce (IPP) with 90% share by the Malakoff Corporation Berhad and another 10% by the Employees Provided Fund (EPF) [24]. The generating capacity of TBPS is 2,100 MW. TBPS was constructed at a cost of MYR 7.1 billion [25].

TBPS is built with coal as fuel sources because of coal is considered as abundant reserve source compared to oil and gas. Its market price also stable with no subsidy by the government. During the construction of TBPS, the market price of coal is MYR 160-200 / tonne. Today, the current market price of coal has reach to MYR 300-400 / tonne [25]. In TBPS, the pulverized coal used is bought from Australia, Indonesia and South Africa. The type of coal used is bituminous and sub-bituminous. The usage of bituminous coal is higher than the sub-bituminous coal due to the higher content of carbon causing the period of combustion is longer.

TBPS is constructed with 3 unit of boiler. In order to maintain maximum efficiency of every boiler, the maintenance for every boiler is carried out at every 18 month. After the maintenance, to start up the combustion, light fuel oil (diesel) is used until reach 70% of combustion and then continues with coal. It can be assume that 210 MW of electricity is produce by using the diesel during the start-up process. The start-up process that using diesel has cost TBPS approximately MYR 800,000 [25].

At TBPS, 280 tonne of coal is used in every hour to produce 2,100 MW of electricity supply [25]. Through this amount, can be estimate that the total coal consumption by TBPS is 2.45 million metric tonnes per annum (mtpa). The used of coal by TBPS to fulfill the electricity supply demand, had caused the total CO_2 emission generated is reach 11.5 million tonne/year.

In this study, the optimization model are formulated to provide short to medium term roadmap for TBPS to implement solar energy in the electricity supply generation with the CO_2 emission reduction was set at ranging from 1-40%. The costing, carbon emission and solar energy data was listed in Table 3.

Table 3. Costing, carbon emission and solar energy data for power sector

Power Plant	TBPS	Large SolarPV
Capital Cost(MYR/MW)	3300000	19020000[4] [26]
Operational Cost[3] (MYR/ MW)	104 [4]	0.25 [4]
CO_2 Emission Rate (Tonne/ MWh)	0.63 [27]	0
Installed Capacity (MW)	2100 [24]	-
Boiler (No. of unit)	3 [24]	-
Nett Capacity	3 x 700MW [12]	-
RE Availability	-	-

[3]The operational cost was included operational, maintenance and price of energy source;

[4]The cost of solar PV is calculated 4 times higher than actual cost. This is due to the intermittency of solar energy with an average sunlight of up to 6 h/day makes 1 MW capacity of photovoltaic is insufficient to meet the actual demand of 1 MW of electricity [26].

In order to simplify the model several assumptions were set as listed below:

- The electricity supply generation in TBPS is generated from coal only.
- The nominal amount of electricity generated is fixed.
- The operational cost of energy source is constant.
- Solar energy is considered as carbon neutral.
- The annual capacity of the TBPS is 0.72 [24].

To calculate the electricity cost (EC), the formula shown in Eqn. (7) was used:

$$ElectricityCost = \frac{TotalCost}{ElectricitySupplyGenerated(kWh)} \quad (7)$$

5. RESULTS AND DISCUSSION

The finding of this study shows that energy source switching with implementation of solar energy is a good initiative towards CO_2 emission reduction at TBPS. According to Fig. 4 and Table 4, energy source switching is required for all percentage of CO_2 emission reduction.

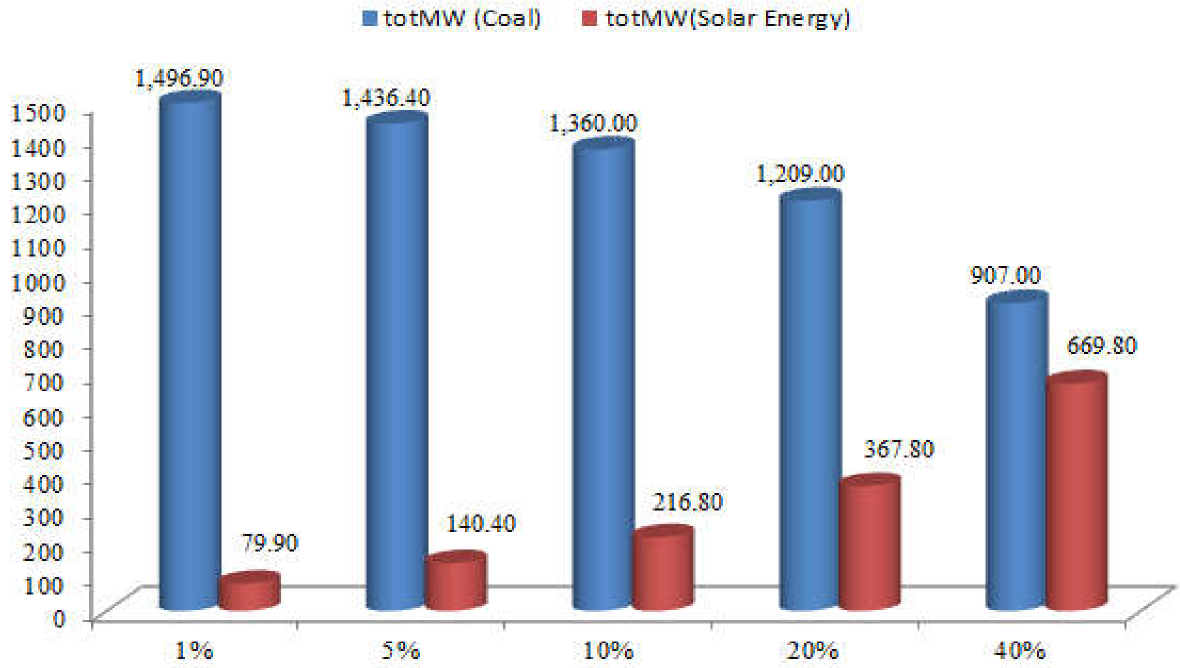

Fig.4. CO_2 emission reduction for TBPS

Table 4. CO_2 emission target

	CO_2 Emission Target				
	1%	**5%**	**10%**	**20%**	**40%**
totMW (Coal)	1,496.90	1,436.40	1,360.00	1,209.00	907.00
totMW(Solar Energy)	79.90	140.40	216.80	367.80	669.80
MYR/kWh	0.19	0.38	0.57	0.77	1.34

In order to achieve the minimum percentage of CO_2 emission reduction at 1%, 79.9MW of electricity supply generation need to be produced from solar energy whilst to achieve the maximum percentage of CO_2 emission reduction at 40%, 669.8MW of electricity supply generation need to be produced from solar energy. The maximum percentage of CO_2 emission reduction does not exceed the net capacity of a boiler at TBPS. Therefore, one boiler only needs to be switched to use solar energy. The EC is increase parallel with the percentage of CO_2 emission reduction. This is due to the cost of renewable energy is still higher than the cost of fossil fuel. To achieve 1% of CO_2 emission reduction, the EC increases as much as 4.2% to makes the EC is MYR 0.19/kWh whilst for 40% of CO_2 emission reduction, the EC increases 86.4% to makes the EC is MYR 1.34/kWh. These amounts hit the current EC value of MYR 0.18/kWh [28].

The effect of energy source switching by implementation of solar energy is towards the CO_2 emission reduction could be avoided by the TBPS as shown in Table 5.

Table 5. CO_2 avoided by TBPS

Reduction Target	CO_2 Emission Avoided(Mt/year)
1%	0.06
5%	0.30
10%	0.60
20%	1.20
40%	2.40

6. CONCLUSION

Optimization is a good approach for electricity supply generation plan. An optimization model with the objective function to minimize the cost was formulated in GAMS. The optimal results indicated that energy source switching from coal to solar energy could reduce the CO_2 emission. Focus is given on solar energy due to solar energy is environmental friendly and able to achieve the sustainable environment.

In this study, to achieve a 40% of CO_2 emission reduction, the model suggested that 669.8MW of electricity supply generation at TBPS should be produced from solar energy. This indicates that 2.4 million tons of CO_2 per year could be avoided. This scenario had increased the EC by 86.4% which make the EC is MYR 1.34/kWh. Currently, fossil fuel still becomes the main choice in electricity supply generation due to the production cost that is still low in comparison to RE. However, resource scarcity of fossil fuel in the future will make RE as an alternative source in electricity supply generation with priority is given to solar energy. This is because Malaysia's position that lies directly on the equatorial zone makes Malaysia receives sunshine along the year.

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