Journal of Optimization in Industrial Engineering
Vol.15, Issue 2, Summer & Autumn 2022, 323- 337
Doi:10.22094/joie.2022.1962173.1973

Research Article

Optimization Planning Model for Carbon Dioxide Emissions Reduction Via Renewable Energy Switch in a Coal Power Station

S. Siti Hafshar [a,*], A. Johari [b], H. Hashim [c], Saeed Isa Ahmed [d]

[a] *Instrumentation and Control Engineering Section, Malaysian Institute of Industrial Technology (MITEC), Universiti Kuala Lumpur, Johor Bahru, Johor, Malaysia*
[b] *Centre of Hydrogen Energy (CHE), Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia (UTM), Skudai, Johor, Malaysia,*
[c] *Process Systems Engineering Centre (PROSPECT), Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia (UTM), Skudai, Johor, Malaysia,*
[d] *Department of Chemical Engineering, Abubakar Tafawa Balewa University (ATBU), Bauchi, Nigeria*

Received 29 june 2022; Revised 28 August 2022; Accepted 31 August 2022

Abstract

Stable economy status has made many foreign investors invested in various industries sectors in Malaysia. Therefore, rapid development of industrial sector has caused the energy demand to increase tremendously year by year. To continue attract foreign investors, Malaysia has taken various efforts to maintain economic stability by developing a sustainable energy sector to ensure electricity demand is sufficient for industries with less cost, reliable supply, and also less impact to the environment. However, over dependence on fossil fuels as the main energy source could not guarantee the energy security and also could evoke issues of environmental problem mainly the increase in carbon dioxide (CO_2) emission in the atmosphere. In this study, a linear programming model and mixed integer linear programming optimization model under carbon constraints was developed to address issue of rising atmospheric concentrations of CO_2 from energy sector. The developed model was able to determine the optimum energy sources mix which is most economical and to satisfy the forecasted electricity demand at Tanjung Bin Power Station (TBPS) in Iskandar Malaysia region. The model includes energy source switching and analyzing different renewable energy technologies such as biomass system, biogas system, solar thermal and photovoltaic (PV) plant in power generation. The applicability of the model was tested on various CO_2 emission reduction targets which is at 6, 25, 40 and 50 % under several scenarios either without or with government subsidy. The results in this study indicated that the optimum energy source mix for TBPS is the mix of coal and solar energy (mainly solar thermal for without government subsidy and solar PV for with government subsidy). The results show that with government subsidy, the electricity tariff was acceptable for the consumers. The average electricity tariff at 6, 25, 40 and 50 % CO_2 emission reduction is RM 0.35, RM 0.44, RM 0.51 and RM 0.57 per kWh, respectively. Increase of CO_2 emission reduction show increase in electricity tariff compared to current tariff at RM 0.21 per kWh. Finally, by applying energy source switching, TBPS can significantly reduce CO_2 emission by avoiding 1.00 Mt of CO_2 emission at 6 % of CO_2 emission reduction, 4.14 Mt of CO_2 emission at 25 % of CO_2 emission reduction, 6.63 Mt of CO_2 emission at 40 % of CO_2 emission reduction, and 8.28 Mt of CO_2 emission at 50 % of CO_2 emission reduction by 2030. This is great contributions for TBPS in CO_2 reduction effort. The results gained in this study provide better understanding to the factors and impact of energy source switching to the capacity, CO_2 emission, and also cost of electricity. The model developed could help the TBPS to plan their future energy direction. The model develop also can serve as an example for other sectors, territories, states, and even countries.

***Keywords*:** Electricity Generation; Emissions; Renewable Energy; Solar Energy

1. Introduction

CO_2 emission is the main GHG on earth that is produced from human activities and responsible for global warming (Chouhan *et al.*, 2017). In 2018, the world human population contributes approximately 36.42 billion tonnes of CO_2 a year to the atmosphere. This value indicates a per capita share of CO_2 emissions to be around 4.72 tonnes annually (Ritchie and Roser, 2019). CO_2 emission increases in nations is due to increasing population, urbanization and rapid economic growth (Anwar *et al.*, 2020). This indirectly cause the reliance on the fossil fuel for electricity generation is growing. Fossil fuel is responsible for 65 % of world CO_2 emissions (IPCC, 2014). According to global ranking of CO_2 emitters, the top global CO_2 emitters is China at 1st ranked followed by the United States of America (USA) (Boden *et al.*, 2017; Investopedia, 2019; ICQI, 2021).

Traditionally, developed countries are known as the main emitters of CO_2. However, some developing countries have now surpassed developed country in emit of CO_2 due to rapid development activities (Boden *et al.*, 2017). In the world's view, CO_2 emissions is the main issue to the environmental problem as CO_2 emissions contributes to climate change and global warming significantly (Li and Zhao, 2017). CO_2 emission has caused increase in the earth surface temperature. The global mean temperature has risen by about 1.5 ºC and most of this warming is due to increases in CO_2 concentration in atmosphere (European Commission., 2019). This warming is expected to be accompanied by sea level rising, melting of glacier, and produce changes in precipitation patterns and storm severity (European Commission., 2019).

The largest source of CO_2 emissions in the world is generated from burning of fossil fuel for electricity

*Corresponding author Email address: sitihafshar@unikl.edu.my

production. PBL Netherlands Environmental Assessment Agency (2016) reported that global coal combustion was responsible for 46 % of CO_2 emissions from fossil fuel combustion, with 31 % of CO_2 emitted from coal fired power stations. It was expected that in 2030 the CO_2 emissions will increase rapidly due to coal is going to overtake gas and be the main energy source in electricity sector (IEA, 2016).

In the past decades, Malaysia had shifted from agriculture to industrialization caused the CO_2 emissions increased tremendously every year. The electricity demand has also increased approximately 3 % since 2008. Note that the increase of electricity demand is considered as linear relationship with CO_2 emission. This is because Malaysia is utilizing fossil fuel especially coal as the main energy source in electricity generation. In year 2017, coal share in electricity generation has reached 42.8 % of total energy source. The increase of coal utilization in power stations has contributed to the changes of CO_2 emissions pattern in Malaysia. Martunus *et al.* (2008) stated that CO_2 emissions from coal fired power stations in Malaysia had grown 4.1 % per year since 2003. It was estimated CO_2 emissions from coal consumption in coal fired power stations to be around 98 million tonnes by 2020. In other study, Zubir et al. (2017) indicated that coal type power stations in Malaysia has emitted 6,113,273 metric tonnes of CO_2 in year 2008. The CO_2 emissions continuously increased year by year until CO_2 emissions reaches 14,452,314 metric tonnes of CO_2 in year 2020.

In the future, it was expected that in each year, CO_2 emissions will continue to increase due to the increment of production capacity and new construction of coal fired power stations (Martunus *et al.*, 2008). With several new coal power stations coming into operation, coal consumption is expected to increase to more than 30 million tonnes per year (Energy Commission, 2017). In the medium term, coal is expected to maintain as the most used fossil fuels in the electricity generation.

The effects from CO_2 emission such as climate change and global warming that is happening now makes the country start to realize that immediate action is needed to escalate cuts in CO_2 emissions. Hence, the main objective of this study is to develop an optimization model to reduce CO_2 emission at minimum cost as well as maintaining the electricity supplied and energy reserves. This is achieved through development a linear programming (LP) model as mathematical tool for business as usual (BAU) scenario to analyzing low carbon scenario (LCS) and development a multi period, multi-type of energy source for electricity generation by using mixed integer linear programming (MILP), for LCS with low percentage of CO_2 emission reduction. This study also analyze different technologies used to reduce the CO_2 emission and to estimate the cost of electricity (COE) and calculate the COE if there are subsidies from the government for RE technologies.

2. Literature Review

In the context to reduce the CO_2 emissions from power stations, there are several environmentally sound technologies available. However, energy source switching (also known as fuel switching) is considered as one of the best technical solutions for the time being (Arasto *et al.*, 2014). Energy source switching is switching the energy source to less or zero carbon intensive industrial fuels in a cost effective manner. Adoption of energy source switching by electricity sector is one of the direct and effective measures in reduction of CO_2 emissions. It could give benefits to energy security and also environmental impact. In term of environmental impact, the benefit is in air pollution reduction by savings of 20 % CO_2/year by 2020 for electricity sector (DOE, 2007).

In electricity sector, energy source switching is necessary for successful reduction of CO_2 emissions. A study by Gelman *et al.* (2014) stated that energy source switching from coal to natural gas in the USA power sector be able to mitigate over 500 million metric tonnes of CO_2 from power sector. On the other hand, a study conducted at UAE by Torcat and Almansoori (2015) encountered that energy source switching to renewable energies (RE) could reduce at 0.43-0.59 MT/yr of CO_2 emissions from UAE power sector. The researchers also stated that switching to clean alternative energies particularly nuclear power is recommended when the CO_2 emissions in electricity sector is skyrocketing. It could be reduced approximately 16 MT/yr of CO_2 emissions. In another study by Winyuchakrit *et al.* (2011), after implementing of fuel shifting in power sector in Thailand, CO_2 emissions is reduced by 85,863 kt-CO_2 in 2030. In Malaysia, study by Muis *et al.* (2008) at power sector in Peninsular Malaysia concluded that switching to nuclear power is needed for maximum CO_2 reduction. It will reduce the CO_2 emissions by 50% from current CO_2 emission level. It is estimated as much of 13.59 MT/yr of CO_2 emissions could be avoided by adopting the nuclear power. In another study, Muis *et al.* (2010) stated that by switching to RE mix in power sector, the COE will be double from the current COE. Currently, the COE is USD 0.045/kWh (~ MYR 0.153/kWh). By mixing 5 % of RE in electricity supply generation, it makes the COE increase to United States Dollar (USD) 0.096/kWh (~ Malaysian Ringgit (MYR) 0.326/kWh) (Muis *et al.*, 2010). Energy source switching costs may vary considerably between projects due to national and regional differences (Sims *et al.*, 2003). Implementation of energy source switching could provide energy security benefit and co-benefit of climate change mitigation (Winyuchakrit *et al.*, 2011).

3. Tanjung Bin Power Station

This study was carried out at Tanjung Bin Power Station (TBPS) that located in Iskandar Malaysia (IM) region in Johor state. Tanjung Bin power station (TBPS) is known as the first private coal fired power plant in Malaysia. It is also considered as the biggest coal fired power plant in South East Asia. TBPS is owned by the Independent Power Producer (IPP) with 90 % of share by the Malakoff Corporation Berhad and another 10 % by the Employees Provided Fund (EPF) (TJSB, 2008). The generating capacity of TBPS is 2,100 MW. Tanjung Bin was constructed at a cost of MYR 7.1 billion (Tanjung Bin Power Station, 2014).

TBPS is built with coal as fuel sources because of coal is considered as an abundant reserve source compared to oil and gas. Its market price also stables with no subsidy by the government. During the construction of TBPS, the market price of coal MYR 160 –200 per tonne. Today, the current market price of coal has reach to MYR 300 – 400 per tonne (Tanjung Bin Power Station, 2014). In TBPS, the pulverized coal used was 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 carbon content causing the period of combustion is longer.

TBPS is constructed with three unit of boilers. During operation, in order to maintain maximum efficiency of every boiler, the maintenance for every boiler is carried out every 18 months. 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 assumed that 210 MW of electricity was produced by using the diesel during the startup process. The startup process that using diesel has cost TBPS approximately MYR 800,000 (Tanjung Bin Power Station, 2014). At TBPS, 280 tonnes of coal is used every hour to produce 2,100 MW of electricity per year (Tanjung Bin Power Station, 2014). Therefore, it is estimated that the total coal consumption by TBPS is 2.45 million metric tonnes per annum (mtpa). The used of coal by TBPS to fulfil the electricity demand, had contributed 14.9 million tonne per year of CO_2 emission.

4. Methodology

The complete methodology for CO_2 emission reduction at TBPS by energy source switching entails electricity supply estimation, CO_2 emission estimation, cost information, model formulation, data gathering, model execution in GAMS (as the optimizer) and GAMS output analysis. The steps in methodology is shown in Figure 1.

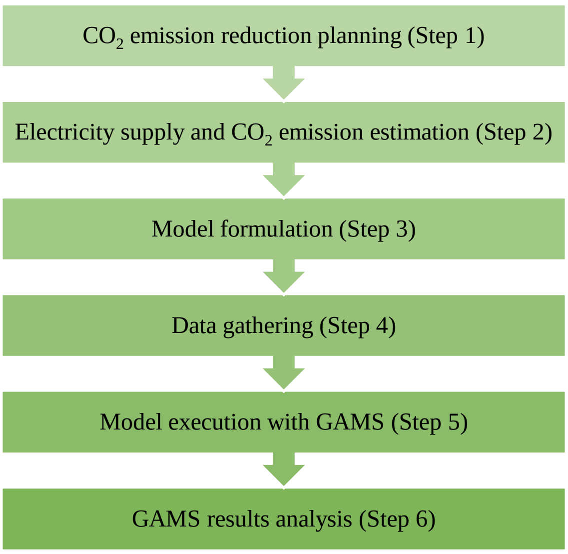

Fig. 1. General methodology for CO_2 emission reduction at TBPS

The general methodology comprised of six steps. All the steps were covered in the MILP tool development but not all is covered in LP tool.

Step 1 is the planning to reduce the CO_2 emission at minimum cost at TBPS through energy source switching. The planning involved estimation of CO_2 emission for 15 years from electricity demand estimation at TBPS. Several cases were set up under this planning to make IM region as low carbon region in the country. Two case studies were developed namely case 1 to developed LP model to test scenario I while case 2 to developed MILP model to considers more complex scenario which is scenario II to V. The model was developed for RE utilization form a simple case to more complex case, which were applied to TBPS at IM region as shown in the flow diagram in Figure 2.

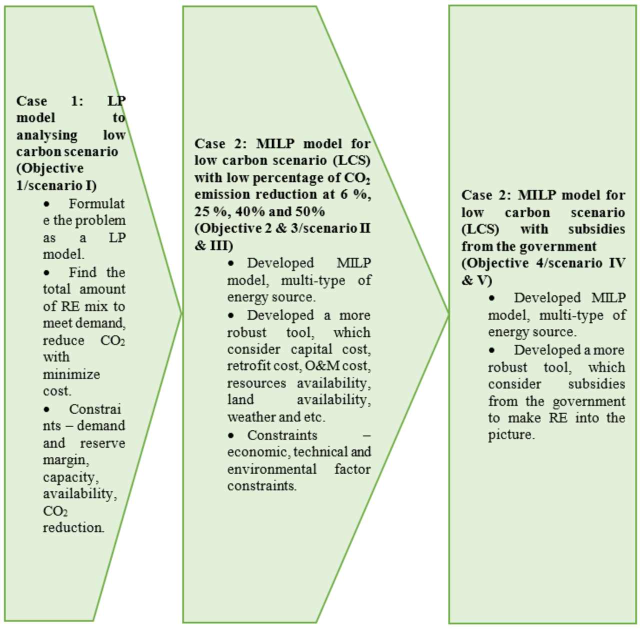

Fig. 2. Flow diagram of the research methodology

The second step in the methodology is the estimation of total electricity generation and CO_2 emission at TBPS. Table 1 presented the estimation values.

Table 1
Estimation of electricity generation and CO_2 emission at TBPS

Year	Total Electricity Generation (MW)	Total CO_2 Emission (Mt)
2015	1,890	14.90
2016	1,890	14.90
2017	1,890	14.90
2018	1,890	14.90
2019	1,890	14.90
2020	1,904	15.01
2021	1,918	15.13
2022	1,933	15.24
2023	1,947	15.35
2024	1,962	15.47
2025	1,977	15.58
2026	2,007	15.82
2027	2,038	16.06
2028	2,069	16.31
2029	2,100	16.56
2030	2,100	16.56
2031	2,100	16.56

The estimation is calculated based on the average growth rate of 0.75 % from year 2020 until 2024 and average growth rate of 1.53 % starting on 2025 onward, as approved by Planning and Implementation Committee of Electricity Supply and Tariff. At year 2029, the electricity generation at TBPS start to meet maximum capacity of electricity generation. The values of CO_2 emission generated is calculated based on CO_2 emission value of 7,884 tonnes per MW to make the values to reach at 15.58 million tonnes on 2025 and 16.56 million tons on 2030.

The model formulation involving presentation of the problems in diagrammatically – the Superstructure. Then, the superstructure was transferred into equations (models). The models comprised of objective function and constraints. The objective function defined the main goal of the planning while the constraints defined the conditions imposed on the planning. Figure 3 shows the general diagrammatic structure of the framework for LP model.

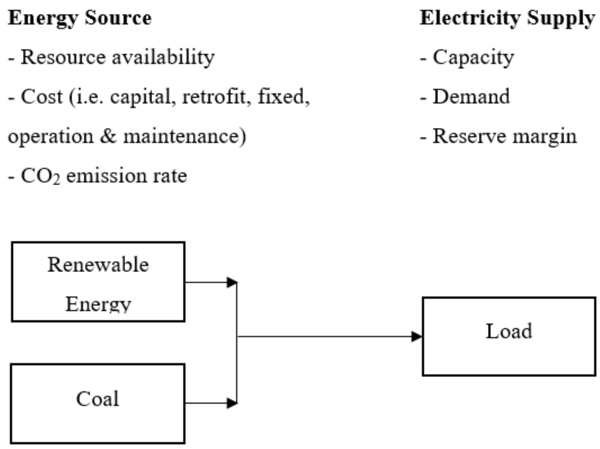

Fig. 3. General diagrammatic framework for LP model

This LP model aimed to minimize cost and to reduce CO_2 emission by introduce new energy source at TBPS. The decision variables are:

K = Total amount (MW) of coal fuel, and

N = Total amount (MW) of RE mix

Since the cost of electricity generation from coal fuel is 1,111,520 MYR per MW and from RE is 16,389,609 MYR per MW, therefore, the *Cost*, of producing *K* and *N* amount of electricity is formulated as follow:

$$Cost = 1111520K + 16389609N \quad (1)$$

The objective function, *Cost* is subjected to several constraints such as capacity, demand and reserve margin, availability and CO_2 reduction as discussed below.

The capacity of the TBPS is 2,100 MW. Therefore, the maximum electricity generation must be equal or less than the plant capacity. Thus, the constraint is:

$$K + N \le 2100 \quad (2)$$

The annual and reserve margin capacity of TBPS is 0.72 and 0.25 respectively. Therefore, the total demand of electricity generation is 1,512 MW and the reserve capacity to maintain the electricity demand in case of peak demand is 378 MW. Thus, TBPS needs to produce at 1,890 MW in order to fulfill the demand and also to reserve margin requirement. Hence, the constraint is:

$$K + N \ge 1890 \quad (3)$$

The availability of RE sources is up to 500 MW according to the RE quota under 11th Malaysian Plan. Thus, the constraint is:

$$N \le 500 \quad (4)$$

The availability of coal as fuel at TBPS could fulfill all plant capacity. Thus, the constraint is:

$$K \le 2100 \quad (5)$$

The emission rate of coal fuel and RE sources is 0.9 tonne per MWh and 0.04 tonne per MWh. Therefore, each MW of electricity produced from coal fuel and RE is equal to 7,884 tonnes per MW and 350 tonnes per MW respectively. The total CO_2 emission (tonne per year) must be equal or less than the percentage required. The CO2red is percent of CO_2 reduction. The constraint is:

$$7884K + 350N \le (1 - CO2red) * (1890 * 7884) \quad (6)$$

The non-negativity constraint is:

$$K, N \ge 0 \quad (7)$$

The economic and environmental benefits through revenue from saving cost (*V*) in MYR was estimated using the equation as follows:

$$V = 209.00 \times CO2 \quad (8)$$

To enhance the understanding of CO_2 effect, the Energy Institute at Haas has stated that a tonne of CO_2 emission is equivalent to a 50 USD (United States Dollar) (Energy Post, 2019). Where 1 USD is equal to MYR 4.18 (Pound Sterling Live, 2019).

The development of the MILP model is to analyze low carbon scenario at TBPS which been divided into two stages. The first MILP model developed for low carbon scenario without subsidies from the government while the second MILP model considered subsidies from the government. The government subsidies are referring to the new Net Energy Metering (NEM) Mechanism that was launched in 2018. The general framework of MILP model is shown in Figure 4.

The MILP model considers five energy sources utilization for electricity supply generation at TBPS which are coal, biomass, biogas, solar PV and solar thermal. The superstructure development as shown in Figure 5.

Energy Source	**Electricity Supply**	**Others**
- Resource availability (i.e. types - Cost (i.e. capital, retrofit, fixed, operation & maintenance) - Energy source selection - CO_2 emission rate	- Capacity - Demand - Reserve margin	- Weather pattern - Land availability - Size of system (i.e. solar PV and – solar thermal) - NEM mechanism

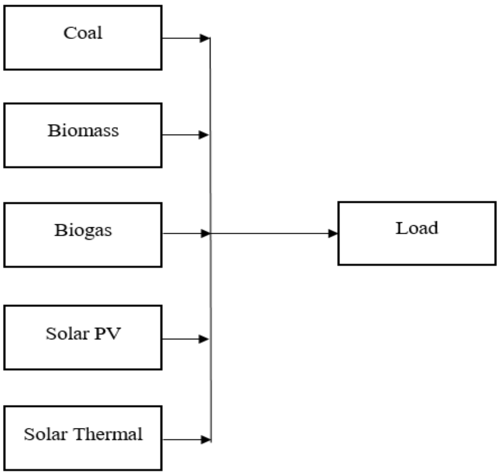

Fig.4. General diagrammatic framework for MILP model

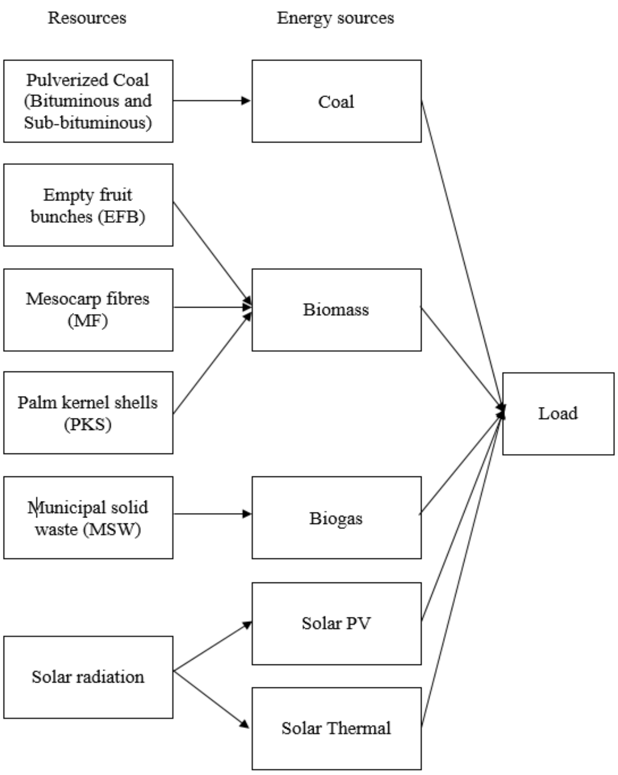

Fig. 5. Superstructure development

The objective function to minimizes the total cost (in MYR per year) by RE mix at TBPS is written as follow:

$$\begin{aligned}\text{Cost} = {} & \underbrace{F^{coal}}_{\text{Coal – fixed cost}} + \underbrace{M^{coal}\cdot E^{coal}}_{\text{Coal – maintenance cost}} + \underbrace{O^{coal}\cdot E^{coal}}_{\text{Coal – operating cost}} + \sum_b \underbrace{R^{biom}\cdot X_b^{biom}}_{\text{Biomass – retrofit cost}} + \\ & \sum_b \underbrace{E^{biom}\cdot X_b^{biom}}_{\text{Biomass – fixed cost}} + \sum_b \underbrace{M^{biom}\cdot E_b^{biom}}_{\text{Biomass – maintenance cost}} + \sum_b \underbrace{O^{biom}\cdot E_b^{biom}}_{\text{Biomass – operating cost}} + \\ & \underbrace{R^{biog}\cdot X^{biog}}_{\text{Biomass – retrofit cost}} + \underbrace{F^{biog}\cdot X^{biog}}_{\text{Biomass – fixed cost}} + \underbrace{M^{biog}\cdot E^{biog}}_{\text{Biomass – maintenance cost}} + \underbrace{O^{biog}\cdot E^{biog}}_{\text{Biomass – operating cost}} + \\ & \underbrace{C^{Tr}\cdot E^{Tr}}_{\text{Solar Thermal – capital cost}} + \underbrace{F^{Tr}\cdot X^{Tr}}_{\text{Solar Thermal – fixed cost}} + \underbrace{M^{Tr}\cdot E^{Tr}}_{\text{Solar Thermal – maintenance cost}} + \\ & \underbrace{C^{PV}\cdot E^{PV}}_{\text{Solar PV – capital cost}} + \underbrace{F^{PV}\cdot X^{PV}}_{\text{Solar PV – fixed cost}} + \underbrace{M^{PV}\cdot E^{PV}}_{\text{Solar PV – maintenance cost}} - \underbrace{E^{PV}\cdot NMS}_{\text{Solar PV – government subsidy}}\end{aligned} \quad (9)$$

The constraint sets to the objective function consist of economic, technical and environmental factor constraints as follows:

4.1. Economic factor constraints

The electricity generated, E^s from TBPS must be equal to or greater than the electricity demand and reserve margin requirement. The mathematical equation for electricity generation (MWh per year) is written as below, where D is total electricity demand and reserve margin at TBPS.

$$E^s \geq D \quad (10)$$

$$E^{coal} + \sum_b E_b^{biom} + E^{biog} + E^{Tr} + E^{PV} \geq D \quad (11)$$

4.2. Economic and technical factor constraints

The electricity generated from TBPS must be equal to or less than the capacity (T) of coal or RE technology that available. The mathematical equation of operational constraint is written as:

$$E^{coal} \leq T^{coal} \quad (12)$$

$$E_b^{biom} \leq T^{biom} \cdot X_b^{biom} \quad (13)$$

$$E^{biog} < T^{biog} \cdot X^{biog} \quad (14)$$

The electricity generated from solar technology considers the weather pattern and land availability (L). The mathematical equation of operational constraint for solar PV is written as:

$$E^{PV} < T^{PV} \cdot i \cdot f^{PV} \quad (15)$$

$$T^{PV} \cdot AFPV = A^{PV} \quad (16)$$

$$E^{PV} = \sum_d A \cdot r_d \cdot w_d \quad (17)$$

$$A^{PV} = LR \cdot X^{PV} + LG \cdot X^{PV} \quad (18)$$

The mathematical equation of operational constraint for solar thermal is written as:

$$E^{Tr} = T^{Tr} \cdot i \cdot f^{Tr} \quad (19)$$

$$T^{Tr} \cdot AFTR = A^{Tr}$$

(eq.

20)

$$E^{Tr} = \sum_d A \cdot r_d \cdot w_d \quad (21)$$

$$A^{Tr} = LG \,.\, X^{Tr} \quad (22)$$

The selection constraint for biomass resources must be equal to or less than one resource. Whereas for solar technology, the land available for solar technology adoption must be equal or less than the land available. The mathematical equation is written as:

$$\sum_b \quad X_b^{biom} \leq 1 \quad (23)$$

$$L \leq 1 \quad (24)$$

$$LG \cdot X^{PV} + LG \cdot X^{Tr} \leq LG \quad (25)$$

The mathematical equation for lower (J) and upper (U) boundaries for TBPS is written as:

$$E^{coal} + \sum_b \quad E_b^{biom} + E^{biog} + E^{PV} + E^{Tr} \geq (1 - J) \cdot D \quad (26)$$

$$E^{coal} + \sum_b \quad E_b^{biom} + E^{biog} + E^{PV} + E^{Tr} \geq (1 + U) \cdot D \quad (27)$$

4.3. Environmental factor constraints

The percentage of total CO_2 emission (tonne per year) at TBPS must be equal to or less than the reduction requirement. The mathematical equation for CO_2 emission reduction is written as:

$$H \leq (1\text{-}CO2_{red}) \cdot CO2 \quad (28)$$

The total emission of CO_2 (*H*) that generate based on total electricity generated as shown in mathematical eq.29.

$$H = E^{coal} \cdot G^{coal} + \sum_b \quad E_b^{biom} \cdot G_b^{biom} + E^{biog} \cdot G^{biog} + E^{PV} \cdot G^{PV} + E^{Tr} \cdot G^{Tr} \quad (29)$$

The parameters, scalars, variables, and abbreviation used for the objective function and constraints are listed in able 2.

Table 2
Lists of abbreviations

Sets	
b	Biomass resources
d	Type of weather
e	Fuel type
g	Type of greenhouse gases
Parameters	
r	Solar irradiation
w	Weather occurrence probability
Scalars	
C	Capital cost
E	Electricity generation
F	Fixed cost
M	Maintenance cost
O	Operating cost
D	Electricity demand
Coal	Coal
PV	Solar photovoltaics
Tr	Solar thermal
Biom	Biomass
Biog	Biogas
T	Capacity
NMS	Net metering scheme
i	Operating time
f	Efficiency
AFPV	Area factor for solar PV
AFTR	Area factor for solar thermal
LR	Land availability for solar installation on rooftop
LG	Land availability for solar installation on the ground
J	Lower boundaries electricity capacity
U	Upper boundaries electricity capacity
CO2red	Percent of CO_2 reduction
CO2	CO_2 emission
L	Land availability
G	Emission rate
P	Conversion factor for HHV
V	Ratio of carbon
NCV	Net calorific value
EF	Emission factor
Q	Quantity of fuel
Variables	
Cost	Annual total cost
X	Binary variable for selection
s	Total electricity supply
A	Area
H	Total CO_2 emission
K	Total amount (MW) of coal fuel
N	Total amount (MW) of RE mix
I	Emissions of GHG
P	Saving cost

The data such as electricity demand, reserve margin requirement, CO_2 emission, energy source, costs and so on, served as input to the optimizer.

The developed model was coded and solved by using GAMS (as an optimizer). GAMS was employed due to its simplicity of application, effectiveness and robustness as a result of its linkage with a number of solvers. The most important GAMS output are the objective values (minimized total cost), solVAR (results of variables such as total emission, total electricity supply, etc.), model statistics and so on. These outputs were analyzed statistically, economically as well as environmentally. The developed MILP model was programmed and implemented in the GAMS optimization package. The model was solved using the ILOG CPLEX 24.7.4 solver in order to solve complex problems. The programmed GAMS model was executed on Intel (R) Core (TM) i7-8550U CPU 1.99 GHz with 8.00 GB RAM computer. Once executed, GAMS was able to find the optimal solution.

5. Results

The optimal solution to the LP problem with minimizing objective function gives the RE mix needed at TBPS to reduce CO_2 emission as shown in Figure 6-9.

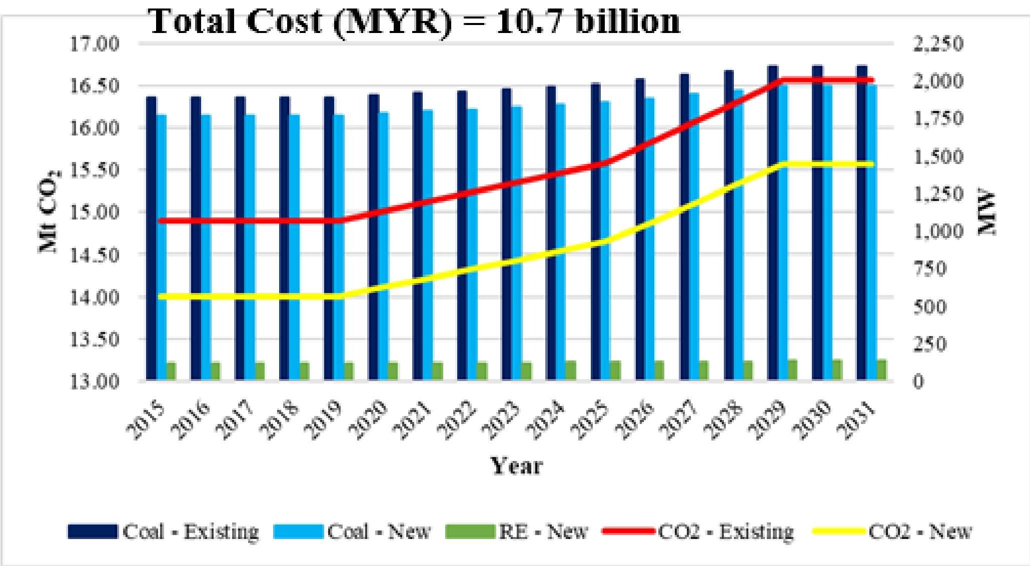

Fig. 6. RE mix at TBPS to reduce 6 % of CO_2 emission

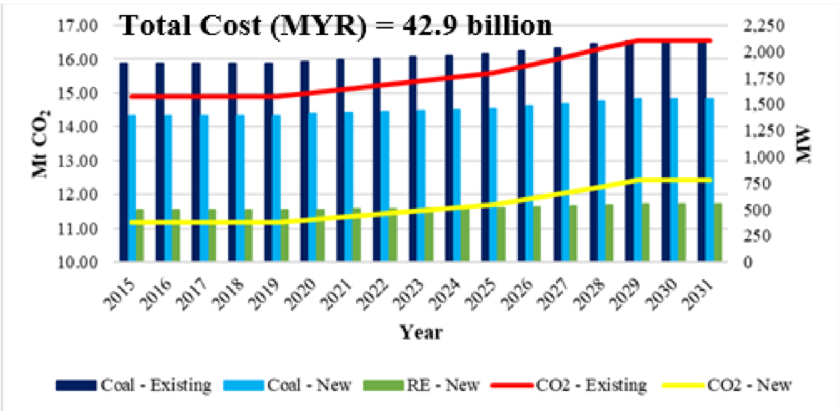

Fig. 7. RE mix at TBPS to reduce 25 % of CO_2 emission

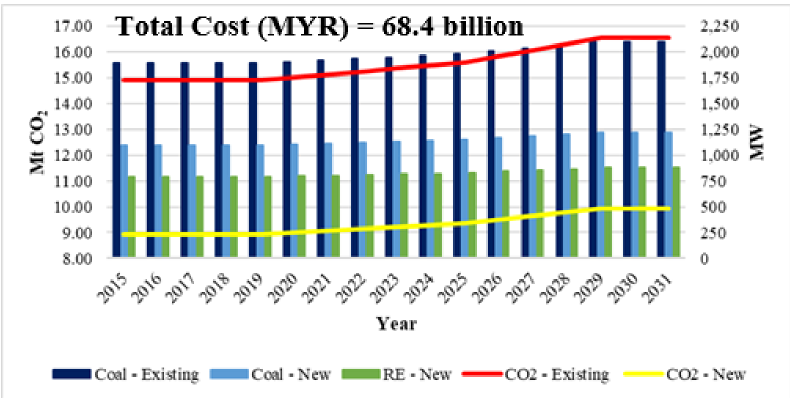

Fig. 8. RE mix at TBPS to reduce 40 % of CO_2 emission

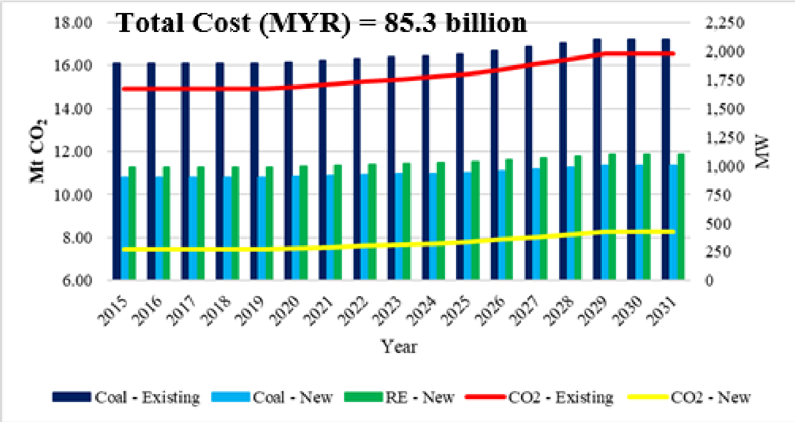

Fig. 9. RE mix at TBPS to reduce 50 % of CO_2 emission

Generating electricity from RE sources is an option to reduced CO_2 emissions. This is recognized as fuel switching phenomenon. By mixing RE, TBPS would be able to reduce CO_2 emission but still could meet the demand increase, maintain reserve margin at 25 % and minimize the total cost.

Prices of electricity in Malaysia are dependent on factors such as cost of power generation, government subsidies, fuel costs and other costs generated during the period. However, the main factor that influence the price of electricity are fuel costs. In every six months, the price adjustments are carried using the Imbalance Cost Pass-Through (ICPT) mechanism by the Energy Commission (EC) (Bernama, 2019). Through this mechanism, electricity prices are determined by the average price of coal and gas fuels during the regulatory period due to coal and gas which are the main of energy source in electricity generation. The increase in coal fuel price is beyond of Malaysian Government control as it is based on global market prices (TNB, 2019).

The result that indicated the prices of electricity when the optimal energy sources mix is determined by the model. Figure 10 shows the new electricity prices at TBPS when existing energy source is mix with RE in order to reduce CO_2 emissions.

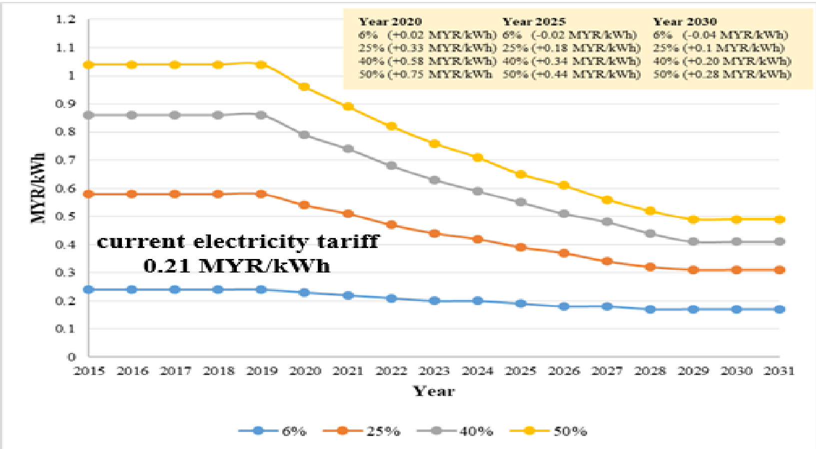

Fig. 10. New electricity prices at TBPS

The optimal solution to reduce CO_2 emission at TBPS by mixing RE with coal has led to an increase in the electricity tariff to be sold to consumers. This is because the operation cost in utilizing RE is cheap but the build-up cost might be high. It can be seen from Figure-10 that electricity tariffs are high at the beginning of the year when RE is mix in the generation of electricity and after that the tariff is start to decrease. This shows that in medium to long term, running a new renewable energy technology in generation electricity is cheaper than running existing coal plant.

The optimal solution for TBPS to reduce the amount of CO_2 gas can be achieved by mix RE with existing fuel which is coal. If this possible, it will give benefit to the environment by the total of CO_2 emissions that can be avoided in electricity generation and at the same time can meet the consumer demand fairly and efficiently. The amount of CO_2 emission avoided is denoted by the required price in treating CO_2 emission. Revenue from avoided cost was estimated by using eq.8. Using this equation, the CO_2 emission avoided is multiplying with MYR 209.00 (USD 50) to estimate the saving cost. The emission avoided and saving cost for the year 2020, 2025 and 2030 was figure in Figure 11-13.

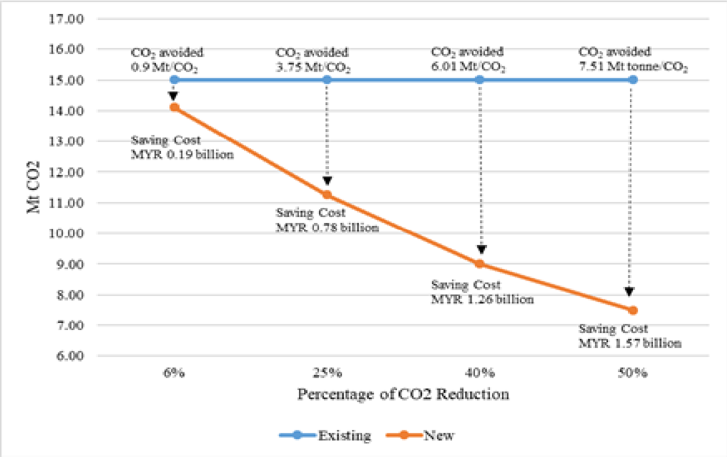

Fig. 11. CO_2 emission avoided and saving cost for year 2020

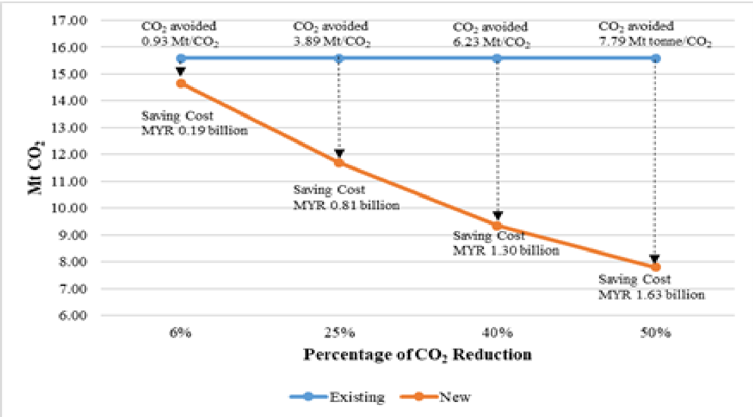

Fig. 12. CO_2 emission avoided and saving cost for year 2025

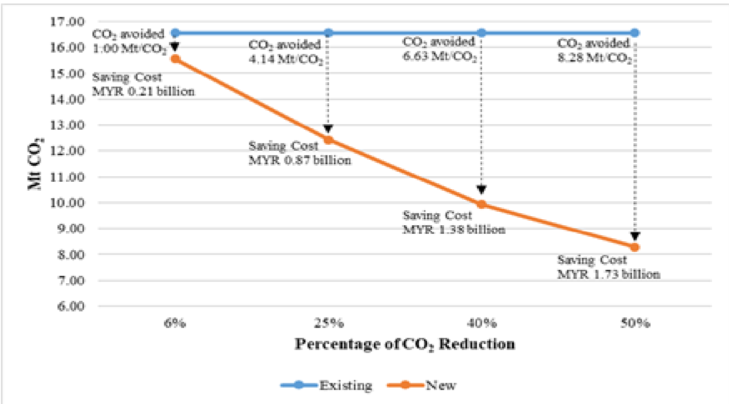

Fig. 13. CO_2 emission avoided and saving cost for year 2030

The LP model (Case 1) results discussed previously is developed to determine the optimal RE mix at TBPS for low carbon scenario. The model is applied to simple scenario which is scenario I and did not consider multi-type of energy source. Next, under scenario II-V (Case II) MILP model is developed. More factors are included in the model such as resource availability, land availability, weather pattern and solar irradiation intensity.

The optimal solution to the MILP problem with minimizing objective gives the RE mix needed at TBPS to reduce CO_2 emission as shown in Figure 14-17 for CO_2 emission reduction without government subsidy.

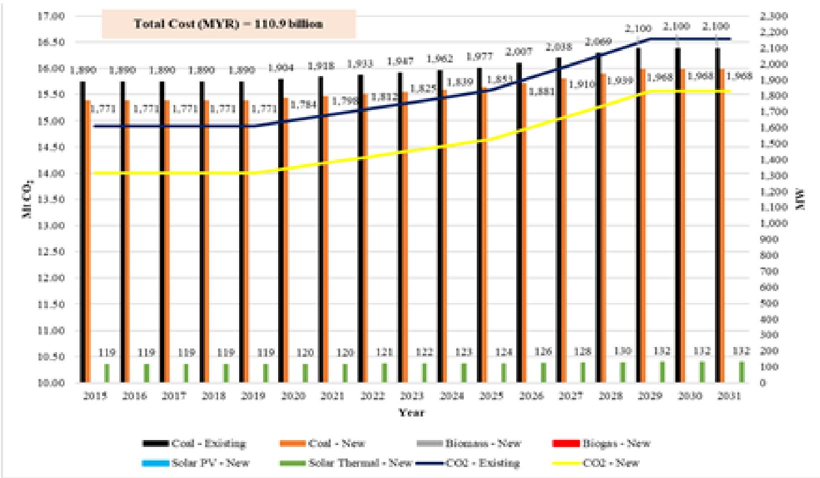

Fig. 14. Optimal RE mix at TBPS for scenario II - 6 % of CO_2 emission reduction without government subsidy

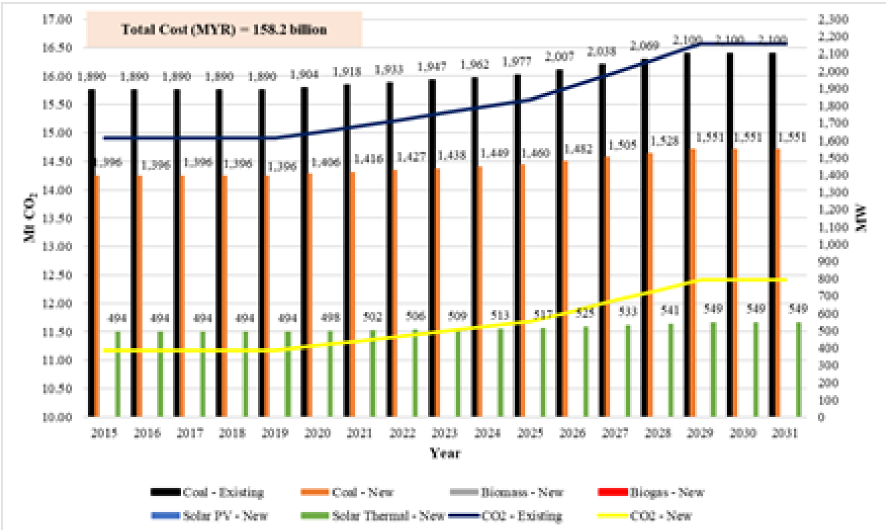

Fig. 15. Optimal RE mix at TBPS for scenario II - 25 % of CO_2 emission reduction without government subsidy

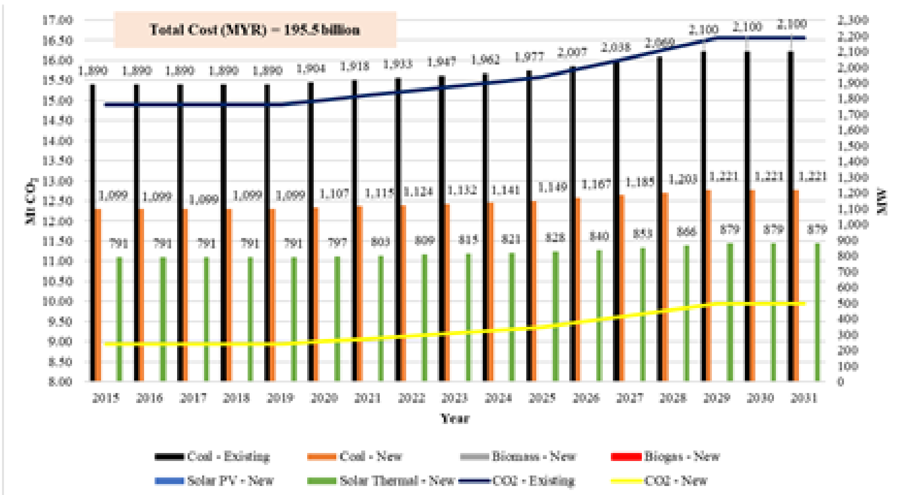

Fig. 16. Optimal RE mix at TBPS for scenario III - 40 % of CO_2 emission reduction without government subsidy

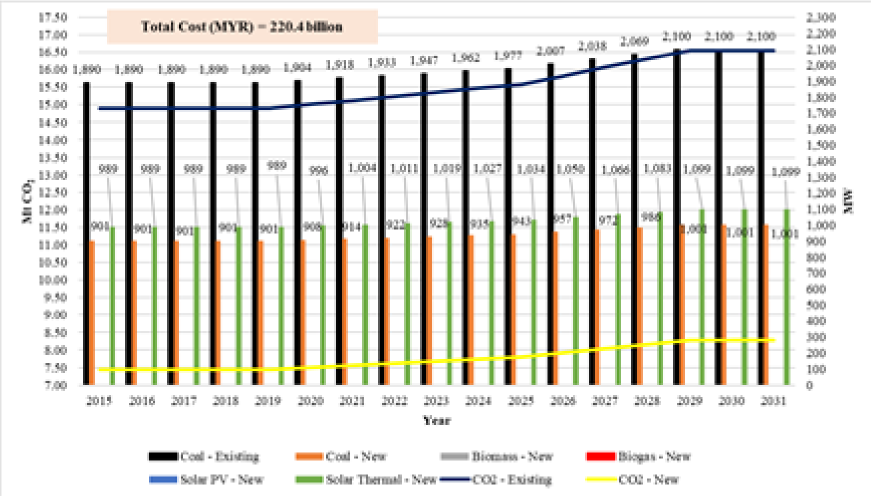

Fig. 17. Optimal RE mix at TBPS for scenario III - 40 % of CO_2 emission reduction without government subsidy

As the CO_2 emission reduction increases, the energy source mix capacity also increased in order to dropped the CO_2 emission values as target. The result analysis shows that energy source switching is significantly could reduce the CO_2 emission at TBPS. However, prior to implementation of energy source switching, a new technology is required. Other than that, implementation of energy source switching may cause the electricity tariff impose to the consumers will increase due to the total cost has increased. However, availability of government subsidy makes RE mix in electricity generation is viable and new electricity tariff is acceptable by the consumers. Figure 18-21 for CO_2 emission reduction with government subsidy. Figure 22 show the comparison of electricity price without and with government subsidy.

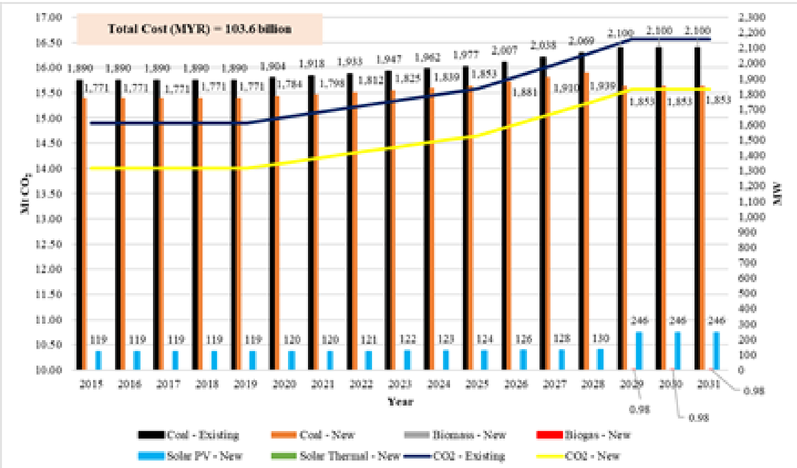

Figure.18. Optimal RE mix at TBPS for scenario IV - 6 % of CO_2 emission reduction with government subsidy

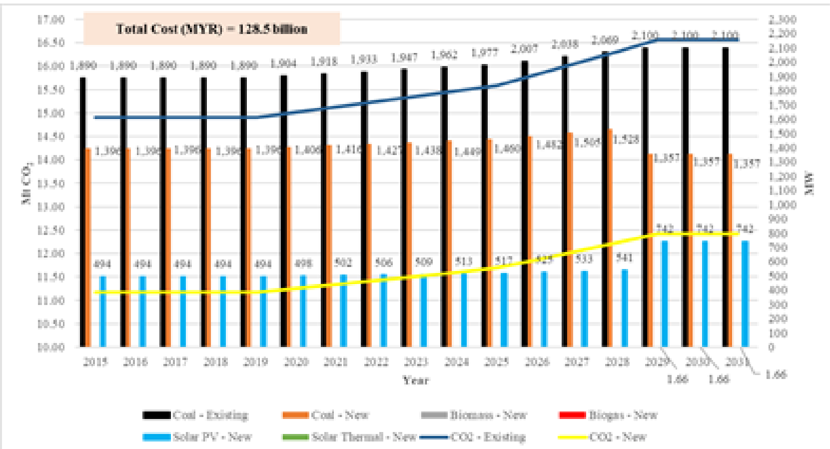

Fig. 19. Optimal RE mix at TBPS for scenario IV - 25 % of CO_2 emission reduction with government subsidy

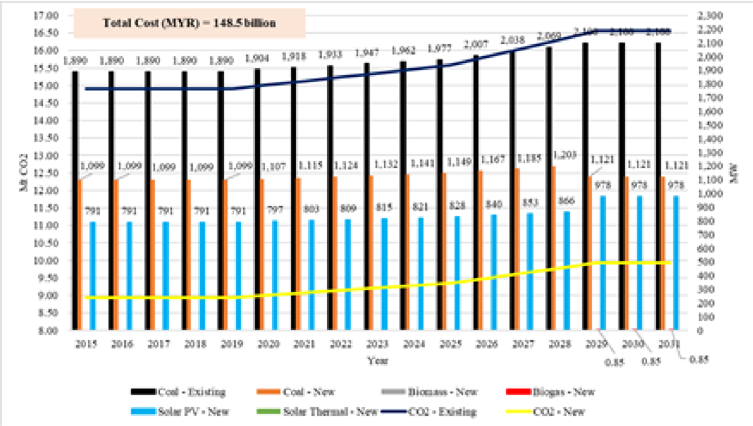

Fig. 20. Optimal RE mix at TBPS for scenario V - 40 % of CO_2 emission reduction with government subsidy

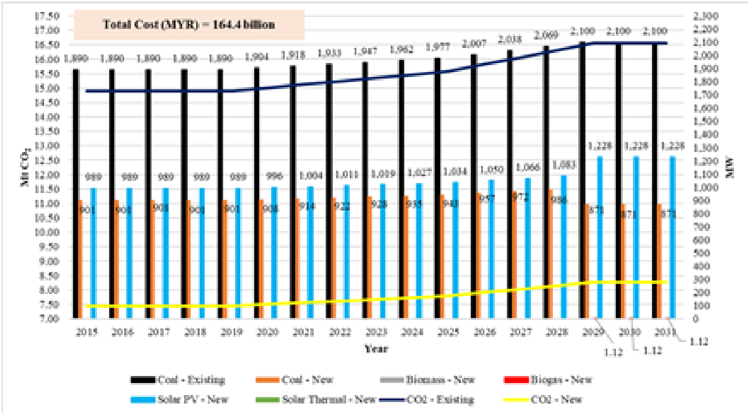

Fig. 21. Optimal RE mix at TBPS for scenario V - 50 % of CO_2 emission reduction with government subsidy

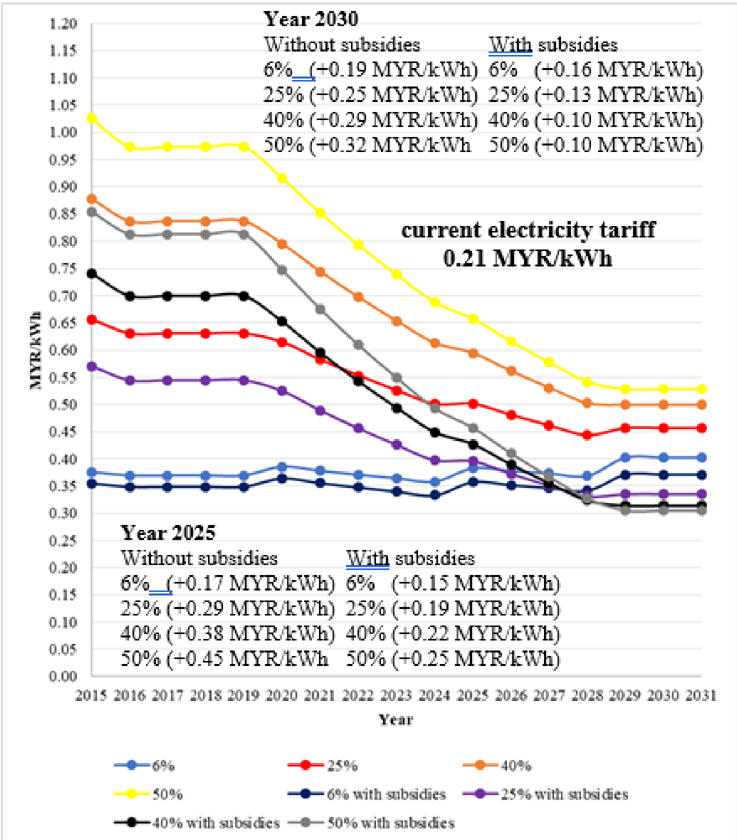

Fig. 22. Comparison of new electricity prices at TBPS

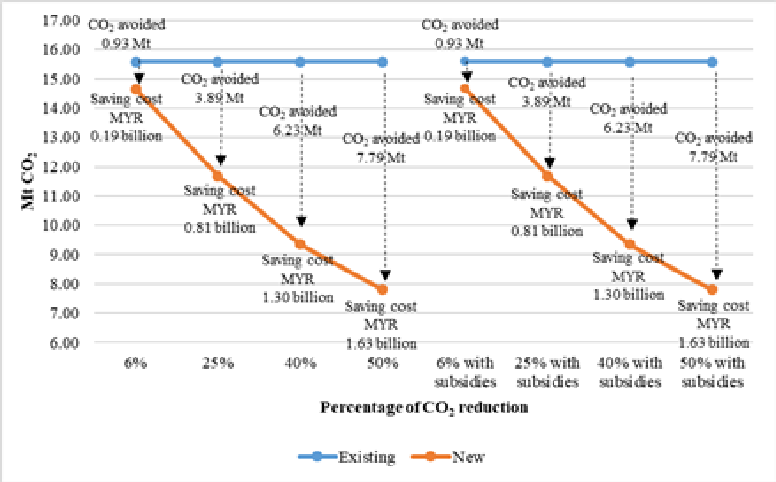

Fig. 23. CO_2 emission avoided and saving cost for year 2025

Increase in percentage of CO_2 emission reduction has increased the total amount of CO_2 emission avoided. This indirectly could reduce the cost needs to treat CO_2 emission, where figure as saving cost in Figure 23-24.

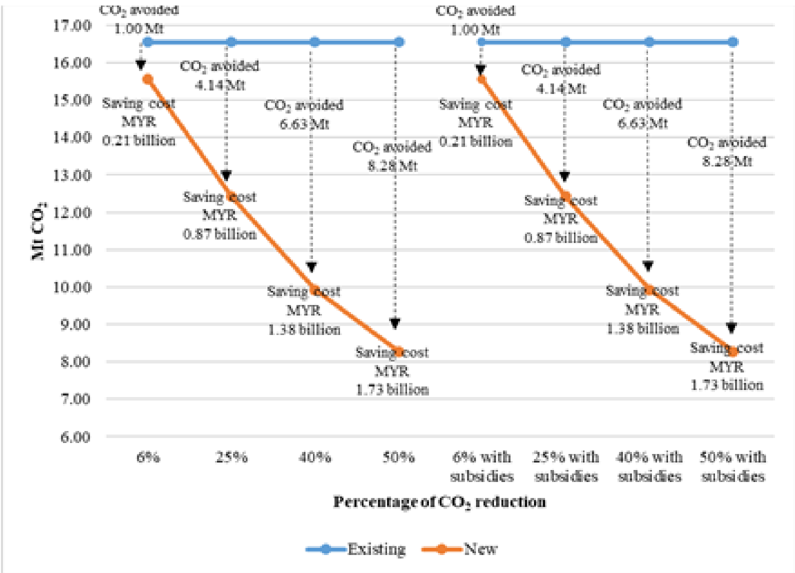

Fig. 24. CO_2 emission avoided and saving cost for year 2030

6. Summary and Conclusion

A mathematical modelling and optimization framework for Tanjung Bin Power Station (TBPS) in Iskandar Malaysia (IM) region is presented in these study. A linear programming (LP) and mixed integer linear programming (MILP) model was developed and evaluated in this study. The model was developed in order to determine the optimal energy source mix of electricity generation and greenhouse gases (GHG) emissions reduction that meet a specific electricity demand and reserve margin requirement, and also CO_2 emission targets at minimum total cost. To accomplish this, an objective function was formulated that seeks to minimize the total cost of electricity generation over a period of about 15 years. The formulation subjected to several parameters such as forecasted electricity demand, reserve margin requirement, an increase in operation and maintenance cost, and so on. In these study, different technologies such as biomass system, biogas system, solar thermal plant, and solar PV plant are analyzed to be used in reduce the CO_2 emission. The cost of electricity (COE) was estimated in order to determine whether the new electricity tariff is acceptable by the consumers. Based on this framework, a case study was conducted using real life industrial data gather from the power station is useful and representative of energy sector in Malaysia.

The model was applied to two case studies specific to TBPS electricity sector. A base case is to analyzing low carbon scenario (LCS) to find the total amount of renewable energy (RE) mix to meet demand and reserve margin and reduce CO_2 emission with minimize total cost. Second case is to analyzing LCS with different technologies in which TBPS must comply with CO_2 emission reduction at 6 %, 25 %, 40 % and 50 %. The relatives impact of the two cases were analyzed based on economic (i.e. the total cost and electricity tariff) and environmental (i.e. the CO_2 avoided and saving cost) affects. The sensitivity analysis results show that energy source mix in electricity generation is substantially effected for changes of CO_2 avoidance.

A LP model (first objective - Case 1) that was developed is applied to Scenario I which is simple scenario to evaluate the optimal RE mix to reduce CO_2 emissions. Under this scenario, the new electricity tariff was estimated and the environmental benefits in terms of saving cost in treating CO_2 emission is evaluated. The results analysis indicated that energy source switching phenomenon is significantly could reduce CO_2 emission. As the CO_2 emission reduction target is increase, the electricity generation from RE sources also increase. Since this model involves a simple scenario, there are many cost is consider fixed, has resulted the total cost is inaccurate. However, through this LP model, it is known that energy source switching to RE could reduce CO_2 emissions. Thus, another model which is MILP model (Case 2) to achieved second to fourth objectives is developed in order to evaluate more complex scenario which reflected Scenario II-V. In this model, factor such as degression rate to capital cost and retrofit cost, an increase in cost of operation and maintenance are consider. Under Scenario III and IV, the government subsidies are taken into consideration in order to make electricity tariff is acceptable to the users.

Under Scenario II, model results have estimated the optimal energy source mix to reduce CO_2 emission at 6 %, 25 %, 40 % and 50%. At 6 % reduction, the total cost is MYR 110.9 billion whilst at 25 % reduction, the total cost increase to MYR 158.2 billion. As increase in percentage of CO_2 reduction, the total cost also increase due to the capacity of energy source mix is increase. The maximum RE capacity needed at 6 % of CO_2 emission reduction is 132 MW whilst at 25 % of CO_2 emission reduction is 549 MW. Therefore, to achieved at 25 % and above of CO_2 emission reduction, the government needs to increase the quota (i.e. current quota is 500 MW only) for RE in generation of electricity. Afterward, under Scenario III model results have estimated the optimal energy source mix to reduce at more stringent CO_2 emission at 40 % and 50 %. The total cost at 40 % of CO_2 emission reduction is MYR 195.5 billion whilst at 50 % of CO_2 emission reduction is MYR 220.4 billion. The maximum RE capacity needed at 40 % of CO_2 emission reduction is 879 MW whilst at 50 % of CO_2 emission reduction at 1,099 MW. This indicated that, to achieve higher percentage of CO_2 emission reduction, almost half of the TBPS capacity needs to operate by using RE sources. According to the model results, the REs selected in scenario II and III are solar thermal.

Under Scenario IV, model results have estimated the optimal energy source mix to reduce CO_2 emissions reduction at 6 % and 25 % by include subsidies from the government which is the Net Energy Metering (NEM) scheme. Under Scenario V, subsidies from the government also considered for CO_2 emissions reduction at 40 % and 50 %. The result analysis shows that with government subsidies, the total cost for RE mix in electricity generation is lower than total cost without subsidies. At 6 % of CO_2 emission reduction, the total cost is MYR 103.6 billion which is 6.6 % lower than the total cost without subsidies whilst at 25 % the total cost is MYR 128.5 billion which is 18.8 % lower than the total cost without subsidies, at 40 % the total cost is MYR 148.5 billion which is 24.0 % lower than the total cost without subsidies, and at 50 % the total cost is MYR 164.4 billion which is 25.4 % lower than the total cost without subsidies, respectively. According to the model results, the REs selected in scenario IV and V is different from Scenario II and III. The REs selected is solar photovoltaic (PV). This is because under the NEM mechanism, subsidies for RE are given to solar PV.

The optimal solution by mixing RE with coal may cause an increase in the total cost. This directly affect the electricity tariff to be impose to the consumers. According to the results analysis, the electricity tariff for CO_2 emission reduction with government subsidies is cheaper than CO_2 emission reduction without government subsidies. At 6 % of CO_2 emission reduction, the electricity tariff is increase at range of MYR 0.17-0.19 /kWh if without subsidies whilst if with subsidies the tariff increase at MYR 0.12-0.16 /kWh from the current tariff. Same with if more stringent CO_2 emission reduction is imposed, such as at 50 %, the electricity tariff increase range is cheaper if with subsidies compare to without subsidies. The tariff increase range is at MYR 0.10-0.64 /kWh if with subsidies and at MYR 0.32-0.82 /kWh if without subsidies from the current tariff. This clearly shows that government subsidies help the energy industry to increase energy security while maintaining sustainable environment. Diversified energy source in electricity supply generation could increase security of energy and switch to sustainable energy sources, such as solar, can help to reduce CO_2 emission.

In this study, the benefit to the environment are estimated from the total saving of CO_2 emissions avoided. The result analysis indicate that the total saving cost is increase with the increase of CO_2 emission reduction.

A MILP model for low carbon scenario has been successfully developed. The model developed is useful to determine the optimal energy source mix for electricity generation at TBPS. The model was analyzed in five scenarios. The results analysis show that energy source mix at TBPS substantially affect the CO_2 emission. Even though, this model is developed for TBPS in IM region, it can also be applied to other power industry in planning the electricity generation system with some modification to the data. Finally, by applying energy source switching to REs, CO_2 emissions of TBPS power sector can be significantly reduced, making great contributions for IM region CO_2 reduction effort.

References

Anwar, A., Younis, M. and Ullah, I. (2020). Impact of urbanization and economic growth on CO_2 emission: a case of Far East Asian Countries. *International Journal of Environmental Research and Public Health* 17: 1-8.

Arasto, A., Tsupari, E., Karki, J., Sormunen, R., Korpinen, T. and Hujanen, S. (2014). Feasibility of significant CO_2 emission reductions in thermal power plants –

comparison of biomass and CCS. *Energy Procedia* 63: 6745 – 6755.

Bernama. (2019). No electricity tariff surcharge for domestic consumers in January-June 2020. Available from: https://www.theedgemarkets.com/article/no-electricity-tariff-surcharge-domestic-consumers-januaryjune-2020. [4 December 2019].

Boden, T.A., Marland, G., and Andres, R.J. (2017). National CO_2 emissions from fossil-fuel burning, cement manufacture, and gas flaring: 1751-2014. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, doi 10.3334/CDIAC/00001_V2017.

Chouhan, B. S., Rao, K. V. S. and Saxena, B. K. (2017). Reduction in carbon dioxide emissions due to wind power generation in India. *International Conference on Smart Technologies for Smart Nation (SmartTechCon)*. August 17 – 19, 2017. Bangalore, India.

DOE, Department of Environment. (2007). Impak. Issue 4. Available from: <http://www.doe.gov.my>. [1 September 2013].

Energy Commission. (2017a). Peninsular Malaysia Electricity Supply Outlook 2017. Published by Energy Commission, Putrajaya, Malaysia. Available from: <https://www.st.gov.my/en/contents/publications/outlook/Peninsular%20Malaysia%20Electricity%20Supply%20Outlook%202017.pdf>. [29 March 2018).

European Commission. (2019). Fossil CO_2 and GHG emissions of all world countries. Available from: < https://edgar.jrc.ec.europa.eu/booklet2019/Fossil_CO2andGHG_emissions_of_all_world_countries_booklet_2019report.pdf >. [15 November 2020].

Gelman, R., Logan, J. and Max, D. (2014). Carbon mitigation from fuel-switching in the U.S. power sector: state, regional and national potentials. *Electricity Journal* 27(7):63-72.

ICQI. (2021). Developing countries list. Available from: < https://icqi.org/developing-countries-list/>. [11 January 2021].

IEA. (2016). Reducing emissions from fossil-fired generation; Indonesia, Malaysia and Viet Nam. Paris, France. Available from: <https://www.iea.org/publications/insights/insightpublications/ReducingEmissionsfromFossilFiredGeneration.pdf>. [29 November 2017].

Investopedia. (2019). Top 25 developed and developing countries. Available from:< https://www.investopedia.com/updates/top-developing-countries/>. [17 September 2020].

IPCC (2014). Climate change 2014: mitigation of climate change. Exit Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Li, Z. and Zhao, J. (2017). Environmental effects of carbon taxes: a review and case study. *World Journal of Social Science* 4 (2): 7-11.

Martunus, Othman, M. R., Zakaria, R. and Fernando, W. J. N. (2008). CO_2 emission and carbon capture for coal fired power plants in Malaysia and Indonesia. *International Conference on Environment (ICENV 2008).*

Muis, Z. A., Hashim, H., Manan, Z. A. and Taha, F. M. (2008). Optimal electricity generation mix with carbon dioxide constraint. *Conference on IGCES*. December 23 – 24, 2008. Universiti Teknologi Malaysia, Johor, Malaysia.

Muis, Z. A., Hashim, H., Manan, Z. A., Taha, F. M. and Douglas, P. L. (2010). Optimal planning of renewable energy-integrated electricity generation schemes with CO_2 reduction target. *Renewable Energy* 35:2562-2570.

PBL Netherlands Environmental Assessment Agency. (2016). Trends in global CO_2 emissions: 2016 report. Available from: <https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=4&cad=rja&uact=8&ved=2ahUKEwi3obGottXcAhVLWysKHfY1C6AQFjADegQIABAC&url=http%3A%2F%2Fedgar.jrc.ec.europa.eu%2Fnews_docs%2Fjrc-2016-trends-in-global-co2-emissions-2016-report-103425.pdf&usg=AOvVaw1EekZzG-MCaDLxE4Q7GPwr>. [10 May 2017].

Ritchie, H. and Roser, M. (2019). CO_2 emissions. Available from: < https://ourworldindata.org/co2-emissions>. [1 October 2020].

Tanjung Bin Power Station. (2014). Study visit. 22 October 2014.

TJSB, Teknik Janakuasa Sdn. Bhd. (2008). Tanjung Bin power plant. Available from: <http://www.tjsb.com>. [1 May 2011].

TNB (Tenaga Nasional Berhad). (2019). TARIF & ICPT. Available from:< https://www.tnb.com.my/faq/bm-tarif/>. [1 September 2019].

Torcat, A. B. and Almansoori, A. (2015). Multi-period optimization model for the UAE power sector. Energy Procedia 75: 2791 – 2797.

Winyuchakrit, P., Limmeechokchai, B., Matsuoka, Y., Gomi, K., Kainuma, M., Fujino, J. and Suda, M. (2011). Thailand's low-carbon scenario 2030: analyses of demand side CO_2 mitigation options. *Energy for Sustainable Development* 15:460–466.

Zubir, A. A. M., Rusli, N. S., Abbas, F. M., Alkarkhi and Yusup, Y. (2017). Emission inventory for power plants and passenger cars in Peninsular Malaysia for the years 2008-2014. *International Conference on Environmental Research and Technology (ICERT 2017).*

This article can be cited: Hafshar, S. S., Johari, A., Hashim, H., & Ahmed, S. (2022). Optimization Planning Model for Carbon Dioxide Emissions Reduction Via Renewable Energy Switch in a Coal Power Station. *Journal of Optimization in Industrial Engineering*, *15*(2), 323-337. Doi: 10.22094/joie.2022.1962173.1973