Journal of Engineering Science and Technology
Special Issue on ISSC'2016, April (2017) 114 - 125


# SUSTAINABLE AND OPTIMUM GENERATION MIX POSSIBILITIES FOR MALAYSIA POWER SECTOR

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**Abstract**

Malaysia's energy generation mix has long depended on a single fuel. This over-dependency harms long-term energy sustainability. This has led Malaysia to find other alternative resources to generate electricity. Options include coal, leading to dependency on imported coal and increases CO2 emissions; natural gas, though Malaysia is currently facing depletion of gas reserve and gas price fluctuations; nuclear, however the recent Fukushima incident and public acceptance are issues; or renewable energy (RE), which is interruptible and expensive. This paper proposes a study to determine the optimal long-term generation mix for Malaysia using Dynamic Programming. The price of natural gas, cost and availability of nuclear power, environmental policy and energy security are all considered in the model. The model was tested on the Malaysian power system. Result shows that an optimal generation mix for Malaysia in 2030 will be 40% coal, 38% gas, 11% renewable energy, 5% hydro, 5% nuclear and 1% oil. Increasing RE target capacity and introducing a carbon tax will affect the development of coal. On the other hand, increasing gas prices reduce the percentage of gas and increase the proportion of coal and nuclear.

Keywords: Generation mix, Dynamic Programming, energy policy.

## 1. Introduction

In 1977, about 85% of electricity generation in Malaysia used oil. The global oil crisis in the 1980s resulted in an increase in oil price. In addition to the discovery of natural gas, Malaysia's government was forced to introduce the Four-Fuel Policy (1981). The four fuel diversification policy focused on oil, gas, coal and hydro. This policy was implemented to reduce dependency on oil as a primary

**Nomenclatures**

| | |
|---|---|
| *CCt* | Total Carbon Emission |
| *FOMall,t* | Total Fixed Operation and Maintenance Cost |
| $IC_t$ | Total Investment Cost |
| $K_t$ | Retirement Year |
| $PC_{all,t}$ | Total Production Coast |
| $P_{RE\ Tot}$ | Total power generation from RE |
| $P_{Nuc\ Tot}$ | Total Power Generation from Nuclear |
| *TC* | Total Cost |
| $VOM_{\mathrm{all,t}}$ | Total Variable Operation and Maintenance Cost |
| $X_t$ | Generating Capacity |

fuel. Since then, the use of gas increased rapidly until it became the major resource of electricity (~75% of generation mix) in 2001. Later, depletion of natural gas reserves and limitation of gas supplies by PETRONAS in 2002 has made coal an attractive fuel strategy despite being environmentally hazardous. Hydro may be a cheap, environmentally friendly fuel, but complex technological requirements and high costs for building dam has made such plans unattractive. In 2001, in conjunction of fuel diversification and awareness in energy efficiency, the fuel policy was expanded with the introduction of renewable energy as the fifth generation fuel. The focus of 5th fuel policy was securing a safe, cost-effective, sustainable and secure energy supply for Malaysia's power sector [1].

In 2011, it was reported that approximately 57.65% of electricity was generated from gas, 33.3% from coal, 8.8% from hydro and 0.3% distillate [2]. Over-dependency on a certain fuel types is not a viable long-term option. This has led Malaysia to diversify its current generation mix with various fuel types for a more secure and sustainable electricity supply.

Genereration mix model has been developed in [3-5]. However, this paper proposes a Dynamic Programming (DP) approach for determining optimal long-term generation mix possibilities for Malaysia's power sector from 2013 to 2030. The model takes into account current fuel constraints, policy, and Malaysia's existing power development plan. A sensitivity analysis is performed to investigate the effect of economical and political constraints on Malaysia's future generation mix.

## 1.1 Fuel options for generation mix in Malaysia

Several fuel options may diversify the current generation mix. Fuel options and their limitations are described below:

### 1.1.1 Gas

In Malaysia, about 50% of gas producing fields are solely owned and operated by PETRONAS Carigali. As of January 2012, Malaysia ranked 12th worldwide for largest available gas reserves. Malaysia's gas reserves stood at 83.0 trillion standard cubic feet (tscf) [6]. The total generation capacity from gas in 2011 was 12,207 MW. This capacity has a contracted gas volume of 1,744 mmscfd. Depletion of gas reserves has forced PETRONAS to limit gas supply. With the current supply of gas limited to 1,150 mmscfd, gas-fired plants are limited in operation [2]. Furthermore, volatile global gas prices reduce investment in gas-fired power plants, as revenue is not promising. As a consequence, more coal and other fuels are required, affecting the future generation mix.

#### 1.1.2 Coal

Coal used to generate electricity in Malaysia is entirely imported. In 2011, 73% of coal was imported from Indonesia, 20% from Australia and another 8% from South Africa [2]. The issue became worse when the Indonesian government announced plans to limit coal exports in 2009 as domestic demand grew. A shortage of coal and an increase in price are the main issues of coal use in Malaysia. Moreover, coal has the highest carbon footprint among all fossil fuel resources. In an effort to enhance energy security, the Malaysian government is also exploring the potential for development of local coal sources, particularly in Sarawak, as well as securing long-term supplies from abroad.

#### 1.1.3 Hydro

Although Malaysia has an abundance of hydro potential, this generation technology has not been considered for expansion technology in this paper, because most of the hydropower potential is situated in Borneo and not the Peninsular [7]. The hydro potential for Peninsular Malaysia is limited due to flat terrain. Moreover, developing a new hydropower plant would require support from state governments, which is not easily obtained [2].

#### 1.1.4 **Renewable** energy (RE)

Renewable energy is a viable option for generation in Malaysia. However, the main issues hampering the expansion of RE are a high cost per kWh and low capacity. The Sustainable Energy Development Authority Malaysia (SEDA) is targeting 4,000MW of generation from RE by 2030 [8]. The cost and availability of RE as well as RE development policy will influence choices for RE and other technologies in Malaysia’s generation mix.

#### 1.1.5 Nuclear

Malaysia is considering building nuclear power plants to diversify its fuel mix. The Malaysia Nuclear Power Corporation (MNPC) is looking into the possibility of building a 2GW nuclear power plant, with the first 1GW expected to be ready by 2021 [9]. However, the recent Fukushima incident and the public acceptance are the major issues of implementation. Despite safety concerns, nuclear power plants have some advantages over conventional fossil fuel power plants in terms of providing a lower cost of electricity generation [10], producing a large amount of energy, and reducing CO2 emissions.

### 1.2 Committed expansion plants from competitive bidding exercise

EC is targeting 4,500 MW of new capacity by 2016 via competitive bidding [11]. This is intended to replace capacity from the 1st generation power purchase agreement (PPA) which will expire between 2015 and 2017, as well as preparing for future load growth [12]. The first track bidding process was completed on October 2012. TNB won the bid and is responsible for owning and operating a combined-cycle power plant with capacity of 1,071MW in Prai, Penang. The combined-cycle power plant will use two units of Siemens H-class gas turbines to achieve plant efficiency at around 60% compared to the efficiency of an F-class combined cycle plant in the system at around 55%. This power plant was expected to be commissioned by March 2016 [13]. The second track (restricted tender) bidding process associated with six first IPP agreements saw the retirement of three IPPs in 2015, which are YTL Power International Bhd (Paka and Pasir Gudang) with total capacity of 1,212MW, Powertek (Telok Gong) and Malakoff (Port Dickson) with both 440MW capacities. Meanwhile, Genting Sanyen Power Sdn Bhd and Segari Energy Ventures Sdn Bhd, with a capacity of 720MW and 1,303MW respectively, were given an extension to their agreement for another 10 years beginning in 2015. On the other hand, TNB's Pasir Gudang, with a 729MW capacity, will be extended for another five years beginning in 2017.

## 2. Generation Mix Modelling

### 2.1 Proposed model for generation mix

#### 2.1.1 Dp-based generation mix model

DP-based generation mix is designed to minimize the total cost of generation expansion. Some factors that contribute to the generation cost of the technologies are included in the generation mix model such as investment cost, construction time, plant lifetime, fixed and variable O&M costs, fuel cost, fuels escalation rate, and the carbon emission tax. The total cost of future generation expansion is given by the following equation:

$$TC = min \sum_{t=1}^{T} \left\{ \begin{matrix} PC_{all}(X_t)_t + IC(U_t)_t + \\ FOM_{all}(X_t)_t + VOM_{all}(X_t)_t + CC_t \end{matrix} \right\} \quad (1)$$

where *TC* is the total cost of generation mix over the simulation horizon, *PCall,t* is the total production cost of all the generating units in the system at year *t*, *ICt* is the total investment cost of the new investments, *Xt* is the cumulative capacity (MW), *Ut* is the capacity addition and *T* is the planning horizon. Multiplying the marginal cost by the energy produced gives the production cost of each unit. The energy produced each year is computed by performing economic dispatch for each segment of the load duration curve (LDC). On the other hand, *FOMall,t* is the total fixed O&M cost of all the generating units, *VOMall,t* is the total variable O&M cost of all the generating units and CCt is the total carbon emission cost of coal and gas power plant.

The mathematical description of yearly PC, FOM, VOM and CC of the individual generating units in the system are as follows:

$$PC_{i,t} = \sum_{s=1}^{S} MCb_{i,s} p_{i,s} d_s \quad (2)$$

$$FOM_{i,t} = F_{O\&M} P_i^{max} \quad (3)$$

$$VOM_{i,t} = \sum_{s=1}^{S} V_{O\&M} p_{i,s} d_s \quad (4)$$

$$CC_{i,t} = \sum_{s=1}^{S} CO_2 CT p_{i,s} d_s \tag{5}$$

where *S* is the number of segments in the LDC, *MCbi* is the marginal cost of generating unit i, *pi,s* is the power produced by generating unit *i* at segment *s* (obtain from economic dispatch) and *ds* is the duration in hours. *FO&M*, is the annual fixed O&M cost per MW capacity, *VO&M*, is the variable O&M cost per MWh of energy produced, $CO_2$ is the amount of carbon dioxide emission per MWh of energy produced by coal and gas technologies and *CT* is the carbon tax set by government for every tonne of carbon.

Optimization is subject to several of the following constraints:

$$X_t = X_{t-1} + A_t + U_t - K_t, \qquad \forall t \in \mathrm{T} \tag{6}$$

$$R^{min} \leq R(X_t), \forall t \in T \tag{7}$$

$$P_{REtot} = P_{REmax} \tag{8}$$

$$P_{NUCtot} \leq P_{NUCmax} \tag{9}$$

$$U_t \leq C_t, \ \forall t \in \mathrm{T} \tag{10}$$

where *Kt* is the capacity retirement in year *t*, *At* is the committed addition of units, *R* is the reserve margin resulting from the generation capacity *Xt*, and *Rmin* is the minimum reserve requirement each year. Equation (6) indicates that the cumulative capacity at year *t* is equal to the capacity at the previous year, plus the new committed addition of units and new capacity built from DP at year *t*, minus the capacity retirement. *At* and *Kt* are given data, and *Ut* is the unknown variable that need to be determined. Equation (7) constrains the installed capacity to be greater than the minimum reserve requirements allowed in the system. Equation (8) constrains the total cumulative installed capacity of RE at year *T* to meet the Government RE policy target. Equation (9) limits the total installed capacity of nuclear power at year *T* to be less than or equal to the maximum projected capacity. This is due to the constraint of locations for building nuclear plant in Malaysia. Equation (10) shows that capacity addition in each year is subjected to investment availability in year *t*.

### 2.1.2 Economic dispatch

Economic dispatch is a short term determination of the optimal output of a number of electricity generation facilities to meet the system load at the lowest possible cost, while serving power to the public in a robust and reliable manner. Economic dispatch is modeled in the DP-based generation mix model to calculate the power dispatch by the generating unit in the system and production cost of each unit. The economic dispatch is performed for each segment of the LDC of each year. The economic dispatch is modelled as an optimization problem, and the total yearly operating cost is minimized:

$$\min\left\{\sum_{s=1}^{S}\sum_{i=1}^{I}\left(MCb_i \ p_{i,s} \ d_s\right)\right\} \tag{11}$$

where $I$ is the number of generating units in the system.

The objective function is subject to several constraints:

$$\sum_{i=1}^{I} p_{i,s} = pd_s \quad (12)$$

$$\delta_{i,s} P_i^{min} \leq p_{i,s} \leq \delta_{i,s} P_i^{max} \quad (13)$$

where $\delta i,s$ is a binary variable $\epsilon$ {0,1}, that determines the status of generating unit $i$ at segment $s$, $pds$ is the system demand at segment $s$. The first constraint is enforced so that the selected generation meets the load demand of segment $s$; as in equation (12). Each of the generating units is also constrained by its minimum generation and the maximum capacity that can be supplied as in equation (13).

## 2.2 Test data

The proposed model has been implemented in MATLAB. The analysis has been carried out on Malaysia's power system. The system consists of forty generating units with a total installed generation capacity of 22,722MW. The existing technologies in the system are listed in Table 1. Table 2 shows two expansion plants that have been scheduled to be built in the future based on the EC plan from the results of competitive bidding exercise and nuclear development program by MNPC. The first power plant is a CCGT with 1,071MW capacity in Prai, Penang in 2016 and second is a 1,000MW nuclear power plant in 2021. Two IPPs (Genting Sanyen Power, Segari Energy Ventures) will be granted a 10-years PPA extension and will be retired on 2025. Meanwhile, TNB's Pasir Gudang plant will extend its services for another five years and will be retired on 2022. These plants are also shown in Table 3. The plants have been determined to emerge in the DP generation mix model during the simulation. Four IPPs plants (YTL Power (Paka and Pasir Gudang), Malakoff Berhad (Port Dickson) and Powertek Berhad (Telok Gong)) will be shuttered in 2015 upon expiry of their PPAs, as shown in Table 3.

We considered three generation technologies, namely nuclear, coal and gas, to be selected as DP each year for future generation expansion. The technical and cost characteristics of the expansion plants are shown in Table 4 as presented in [14]. Similar costs data and carbon intensity of different technologies have been used for the existing system. The cost functions of the generating units are assumed to be linear. Fig. 1 graphically shows the position of the technologies in the system on the supply curve according to their marginal cost.

It is also assumed that the load of each segment of the LDC increases by 3.0% every year [2]. Fig. 2. shows a six-segment of discretized LDC for Malaysia in 2013, based on the hourly load data in year 2011. The minimum system reserve margin in the DP-based generation mix model is set at 20% as targeted by [15]. The RE has been assumed to consistently increase 220.6MW each year to achieve a target cumulative capacity of 4000MW in 2030.

**Table 1. Existing generation technologies for Malaysia Power System.**

| Power Plant | Name | Type | Cap | Power Plant | Name | Type | Cap |
|---|---|---|---|---|---|---|---|
| S.A.S. Bersia | 01 | hyd | 72 | Nur Gen. | 21 | gas | 220 |
| Chenderoh | 02 | hyd | 40.5 | Paka | 22 | gas | 808 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| S. A.S. Kenering | 03 | hyd | 120 | Pasir Gudang | 23 | gas | 404 |
| Sungai Piah U | 04 | hyd | 14.6 | Petronas Gas | 24 | gas | 324 |
| Sungai Piah L | 05 | hyd | 54 | Port Dickson | 25 | gas | 440 |
| Temenggor | 06 | hyd | 348 | Prai | 26 | gas | 350 |
| S. Ismail Petra | 07 | hyd | 600 | Putrajaya | 27 | gas | 625 |
| Sultan Mahmud | 08 | hyd | 400 | S. Iskandar | 28 | gas | 729 |
| Sultan Yusof Jor | 09 | hyd | 100 | Sultan Ismail | 29 | gas | 1136 |
| Sultan idris Woh | 10 | hyd | 150 | T.Kling | 30 | gas | 330 |
| Odak | 11 | hyd | 4.2 | Telok Gong1 | 31 | gas | 440 |
| Habu | 12 | hyd | 5.5 | Telok Gong2 | 32 | gas | 720 |
| Kampong Raja | 13 | hyd | 0.8 | Tek. Tenaga P | 33 | gas | 650 |
| Kampong Terla | 14 | hyd | 0.5 | T. Jaafar | 34 | gas | 1500 |
| Robinson Falls | 15 | hyd | 0.9 | Jimah | 35 | coa | 1400 |
| Sg Kenerong | 16 | hyd | 20 | Manjung | 36 | coa | 2295 |
| C.Bridge | 17 | gas | 832 | S. S. Abd. AS | 37 | coa | 2420 |
| G. Sanyen K.L | 18 | gas | 720 | Tanjung Bin | 38 | coa | 2100 |
| Lumut GB3 | 19 | gas | 651 | Gelugor | 39 | oil | 398 |
| Lumut | 20 | gas | 1303 | RE | 40 | RE | 29 |

**Table 2. Scheduled future expansion and extension plant by EC and MNPC.**

| Power Plant | Name | Type | Cap | Year Commission/ Extension | Year Retire |
|---|---|---|---|---|---|
| Prai (TNB) | PGEV_02 | gas | 1071 | 2016 | - |
| Nuclear | PGEV_01 | nuc | 1000 | 2021 | - |
| Genting Sanyen K.L. | Unit_18 | gas | 720 | 2015 | 2025 |
| Lumut (Segari) | Unit_20 | gas | 1303 | 2015 | 2025 |
| Sultan Iskandar (TNB) | Unit_28 | gas | 729 | 2017 | 2022 |

**Table 3. Future retirement plant from IPPs.**

| Power Plant | Name | Type | $P_{max}$ | Year retirement |
|---|---|---|---|---|
| Paka (YTL) | Unit_22 | gas | 808 | 2015 |
| Pasir Gudang (YTL) | Unit_23 | gas | 404 | 2015 |
| Port Dickson (Malakoff) | Unit_25 | gas | 440 | 2015 |
| Telok Gong (Powertek) | Unit_31 | gas | 440 | 2015 |

**Table 4. Technical and cost characteristics of the expansion plant.**

| Parameters Name | Unit | Nuclear | Coal | Gas |
|---|---|---|---|---|
| | | PGE1_03 | PGE1_02 | PGE1_01 |
| **Technical parameters** | | | | |
| Net capacity | MW | | 1000 | |
| Heat rate | MBTU/MWh | 19.78 | 7.35 | 7.04 |
| Construction time | years | 9 | 4 | 5 |
| Plant life time | years | 40 | 30 | 25 |
| Carbon intensity | tC/MBTU | 0 | 0.0258 | 0.0145 |
| **Cost parameters** | | | | |
| Fixed O&M | $/kW/yr | 57.14 | 20.63 | 14.29 |
| Variable O&M | $/MWh | 0.365 | 3.063 | 0.476 |
| Fuel cost | $/MBTU | 0.55 | 2.46 | 4.23 |
| Fuel escalation rate | % | 0.5 | 0.5 | 1.5 |
| Nuclear waste fee | $/MWh | 0.91 | 0 | 0 |

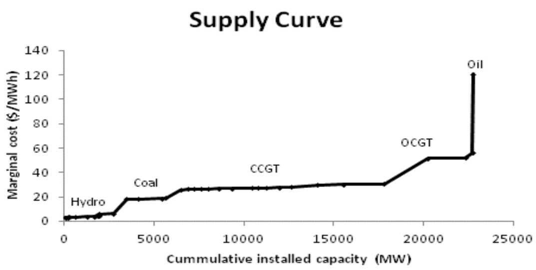



**Fig. 1. The position of the technologies in the system on the supply curve according to their marginal cost.**

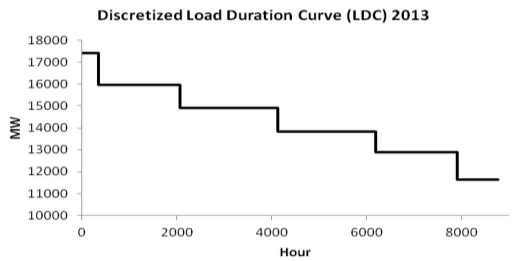



**Fig. 2. Six-segment of discretized LDC for Malaysia in 2013.**

## 3. Results and Discussion

### 3.1 Base case

A base case study is first carried out using the proposed model to forecast Malaysia's generation mix for the next 17 years from 2013 to 2030. This base case is a benchmark for the other analyses in this paper. In this base case, carbon tax is not considered. Fig. 3. shows the results of optimal long-term generation mix in the base case. Gas power plants are more competitive in the earlier years; however, they are replaced by the coal and nuclear plants towards the end of the planning horizon as gas becomes more expensive than coal and uranium. The proportion of RE increases to meet the RE target in 2030.

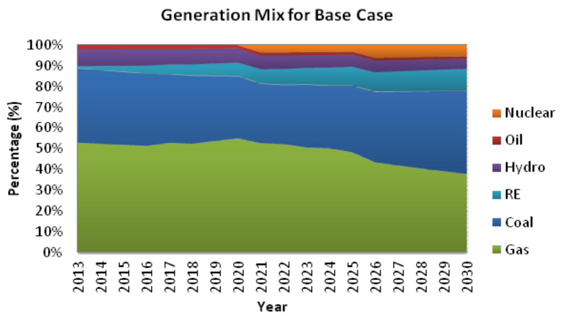



**Fig. 3. The combination results of optimal long-term generation mix in the base case per year till 2030.**

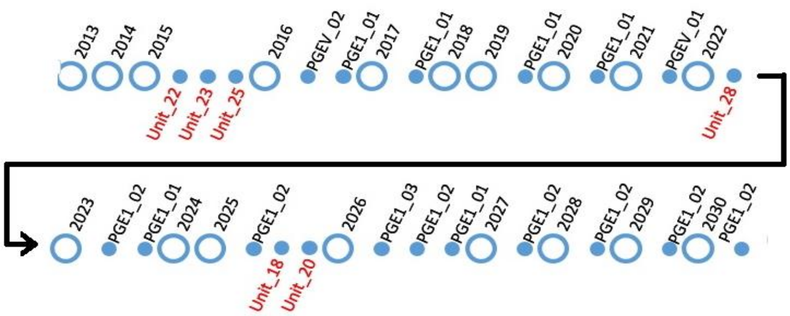



**Fig. 4. Plants expansion and retirement from the DP-based generation mix in the base case.**

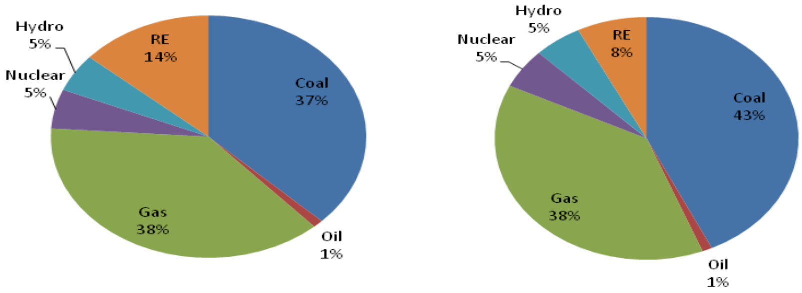
Figure 4. shows the result of selected plants and retirement plants from DP-based generation mix model each year from 2013 to 2030. The upper block contains the expansion plants selected by the DP and the power plants that have been scheduled for expansion and extension by EC, while the lower block represents the retirement units during the simulation. It can be seen that the committed expansion plants, CCGT in Prai (PGEV_2) and the nuclear plant (PGEV_01) emerge in 2016 and 2021, respectively. Four IPPs plants, namely Paka Power Station (Unit_22), Pasir Gudang (Unit_23), Port Dickson (Unit_25) and Telok Gong (Unit_31), will retire in 2015. The extended IPPs plants at Sultan Iskandar (Unit_28) will retire in 2022 and at Genting Sanyen (Unit_18) and Lumut (Unit_20) in 2025.

Other expansion plants in Fig 4. are selected by the DP to meet demand growth and to replace the retirement units. Another nuclear power plant besides the one scheduled by the MNPC is selected by the DP in year 2025 to replace some units that retire in that year. A more balance generation mix in 2030 is found with 40% generation is from coal, 38% from gas, 11% from RE, 5% from hydro, 5% from nuclear and 1% from oil.

### 3.2 Sensitivity to the development of RE

Sensitivity analysis towards the development of RE in Malaysia is carried out to study the effect of the RE target capacity set by the Government on the generation mix. The analysis is performed by varying the target capacity to a lower and a higher value from the base case.

Figure 5, shows the result of sensitivity analysis when the RE capacity target is set 30% higher than the base case of 5,200MW. In this case, it is assumed that the RE capacity increases 287MW each year until cumulative installed capacity reaches 5,200MW in 2030. Results show that increasing the target capacity of RE reduces the dependency on coal from 40% in the base case to 37% in 2030. When the RE capacity target is lowered by 30%, the percentage of coal in the optimal generation mix increases to 43% in 2030 (Fig. 5). These show that coal is the most relevant technology to change the capacity of RE in the system.




(a) Varying RE target to 5,200 MW (b) Varying RE target to 2800 MW

**Fig. 5. The result of sensitivity analysis when the RE capacity target changes.**

## 3.3 Sensitivity to a CO2 Tax

Since carbon emission trading is relatively new in Malaysia, one of the possible initiatives that Malaysia's government could implement is introducing a carbon tax scheme. In this study, the impact of $CO_2$ tax scheme on Malaysia's generation mix is analyzed. The analysis is performed by varying the $CO_2$ tax from no tax to 40$/tC.

Figure 6. shows the results of generation mix in year 2030 for different cases of $CO_2$ taxes. Results show that increasing the $CO_2$ tax reduces the development of coal power plant in the generation mix. This is because the $CO_2$ tax increases the cost of generating electricity from coal. On the other hand, a gas plant, which has a lower carbon content compared to coal, increases its proportion in the generation mix at a small and increment rate. This is to replace coal power plants that are affected by the scheme. This tax scheme encourages the development of nuclear in the system. Nuclear plant contributes to 13% of generation mix in 2030 when the $CO_2$ tax is set to 30$/tC. There is no change in the generation mix when the $CO_2$ price is set higher than 30$/tC.

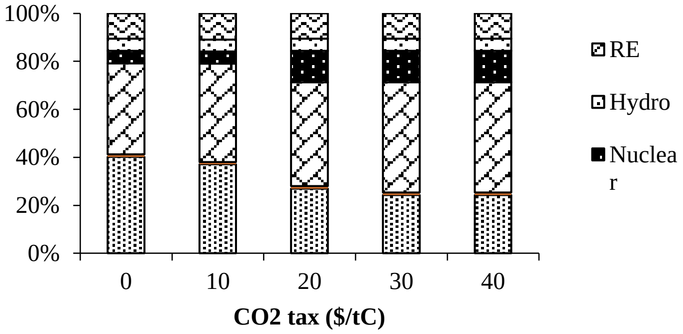



**Fig. 6. Various $CO_2$ taxes.**

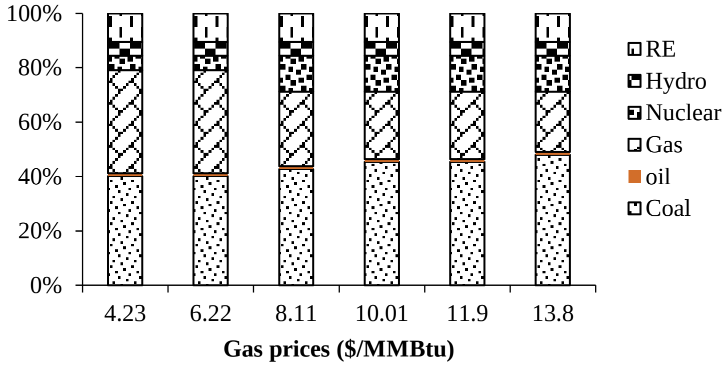



**Fig. 7. Various gas prices.**

## 3.4 Sensitivity to gas price

In this analysis, the effect of increasing the gas price on the generation mix is explored. The analysis is performed by varying the gas price from the subsidy price, for example 13.70 RM/MMBtu to the market price at 45.50 RM/MMBtu. The gas prices in RM/MMBtu are converted to $/MMBtu for different cases, such as 4.23 $/MMBtu (subsidy price), 6.22 $/MMBtu, 8.11 $/MMBtu, 10.01 $/MMBtu, 11.9 $/MMBtu and 13.8 $/MMBtu (market price). In this analysis, $CO_2$ tax is not considered.

Figure 7. shows the results of generation mix in 2030 when the gas price is varied. Increasing the gas price from the current subsidy price to the market price reduces the dependency on gas from 38% (with subsidy) to 22% (market price). This scenario gives opportunity for the coal to be selected and increases its proportion in the generation mix from 40% (with subsidy) to 48% (market price). Clearly, also encourages the development of nuclear from 5% (with subsidy) to 13% (market price).

## 4. Conclusions

This paper presents a least cost DP-based model to determine a long-term generation mix for Malaysia's industry supply from year 2013 to 2030. Four of five fold-key points highlighted by TNB will shape Malaysia's generation mix, including price of natural gas, cost and availability of nuclear power, environment policy and energy security are considered in the model. Results show that the optimal generation mix for Malaysia in 2030 in the base case is 40% coal, 38% gas, 11% RE, 5% hydro, 5% nuclear and 1% oil. Results of sensitivity analysis show that introducing carbon tax reduces the contribution of coal plant in the generation mix. However, increasing the gas price reduces the percentage of gas power plant and increases the proportion of coal. Clearly, both incentives encourage the development of nuclear power plant in the future Malaysia's generation mix. On the other hand, increasing renewable energy target reduces dependency on the fossil fuels.

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