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Nuclear Penetration for a Deregulated Electricity Market for Peninsula Malaysia: A Systemic Feasibility Analysis

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ABSTRACT

Objective – This paper aims to investigate the feasibility of employing nuclear power in peninsula Malaysia, within the context of a deregulated electricity market framework.
Methodology/Technique – System dynamics modelling and simulation has been adopted in this research. A qualitative causal loop diagram, which represent the relationships of key factors in the dynamics of nuclear power in peninsula Malaysia's electricity market, was first constructed. It is divided into three sections: (1) investment decisions, (2) power generation, and (3) maintaining business as usual. The causal loop diagram is converted into stock and flow diagram, where variables are quantified by input values and equation, before simulated for a set period of 38 years. Three scenarios were designed to facilitate the research: (A) business as usual, (B) nuclear power expansion, and (C) renewable energy expansion.
Findings – Simulations showed that scenario B can could potentially strengthen the region's energy security under specific conditions in addressing capacity redundancy and emissions reduction. Also, having a diverse market is paramount in contributing to responsiveness of market.
Novelty – A systemic and dynamic understanding on the implications of two energy scenarios on the country has been established.

Type of Paper: Empirical.
Keywords: Energy Security; Electricity Market; Deregulation; System Dynamics; Nuclear Power.

1. Introduction

1.1 Background of Malaysia's Energy Market

The Malaysian government has begun deregulating its electricity market since 1990 when it was opened up and allowed for competition; effectively transitioning it into a single buyer market (SBM) and introduced independent power producers (IPP) into the nation's electricity generation pool (Lee, Tan, & Lee, 2010). Although speculative, we can reasonably assume a fully deregulated electricity

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market in the foreseeable future. At the same time, future plans have also been made for a speculative inquiry to a potential nuclear penetration by the previous government but this was pushed to 2030 (Jaafar, Nazaruddin, & Lye, 2017). There is a widespread debate on the use of nuclear power worldwide and no less dialogue was engaged locally. This paper is hence aimed to evaluate the feasibility of using nuclear power in peninsula Malaysia within the framework of a deregulated electricity market and to contrast it with other potential choices. Consequently, the different predictions of a potential future market will be analysed and compared to determine if nuclear could be an option for the region's energy future.

1.2 Deregulation of the Electricity Market in Peninsula Malaysia

The electricity market is where electricity is bought, sold, or traded like a commodity, usually between electricity utility suppliers, resellers, and consumers. Deregulation of the electricity market is to remove the government's sole control on the market and allow for its natural forces to take place (Gencer, Larsen, & van Ackere, 2017). Peninsula Malaysia is currently in the first stage of deregulation, the Single Buyer Model (SBM). The SBM allows Independent Power Producers (IPP) to sell electricity to a single buyer (Lovei, 2000), namely Tenaga National Berhad (TNB), a government-linked utility company. IPPs work closely with TNB to fulfil the country's electricity needs. Being the first step in the deregulation process, the region's electricity market is still heavily regulated (Jalal & Bodger, 2009) and policies on the limitation for renewable energy (RE) producers and capping of licenses to limit RE capacity at 392 MW (Suruhanjaya Tenaga Energy Commission, 2017) are often relied upon.

1.3 Available Energy Sources in Peninsula Malaysia

The generation mix for peninsula Malaysia as of 2016 comprises of 94% fossil fuels (coal 53% and gas 41%), 4% hydroelectric, and 2% other RE sources including solar (Suruhanjaya Tenaga Energy Commission, 2017). It is evident that the country heavily relied on fossil fuel despite substantial efforts to increase RE's share since the 8th Malaysian Plan. In the 10th plan, the past government agreed to explore the possibilities of nuclear as an additional source of energy as it is a clean source of energy on top of it independent of external factors such as weather.

Whilst public opinion for RE has been always been positive, as it is the main contender to nuclear considering they are clean sources of energy with less perceived risks, public perception and concerns for nuclear power are its safety, especially after the Fukushima incident in 2011, becomes the largest barrier to a favourable nuclear power penetration (Patil, 2017). Despite that, recent studies have revealed that public acceptance of nuclear energy, worldwide and in Malaysia, has been increasing, albeit slowly (Misnon, Hu, Rahman, & Yasir, 2017). Biomass will be the RE focus of this research, as studies have shown that it is the most suitable and secure RE generation with a large potential of 2810 MW in the Peninsula compared to other RE technologies (Ong, Mahlia, & Masjuki, 2011; Ozturk et al., 2017).

2. Methodology

System dynamics (SD) modelling is a method incorporating systems thinking. It is used to model and evaluate the feasibility of nuclear power plants in comparison with renewable and fossil fuel plants. SD modelling is a method widely accepted to analyse complex systems and to gain understanding of the behaviour of the system in order to predict the possible future outcomes of that system, under different scenarios. Three scenarios are created to predict the outcome of using (1) nuclear power, (2) more renewable energy and no nuclear and (3) maintaining business as usual. Each scenario will yield trends which can be used to measure their feasibility.

2.1 Causal Loop Diagram

Figure 1 shows the causal loop diagram (CLD) of the electricity generation sector for the region's Electricity Market. The model is divided into three sections: (1) investment decisions, represented in red, (2) generation, represented in green and (3) demand represented in blue. The model inputs are Forecasted Demand, obtained from Suruhanjaya Tenaga's Energy Outlook 2017 (Suruhanjaya Tenaga Energy Commission, 2017). The main outputs of the model are the two key indicators, Reserve Margin and Total CO2 Emissions.

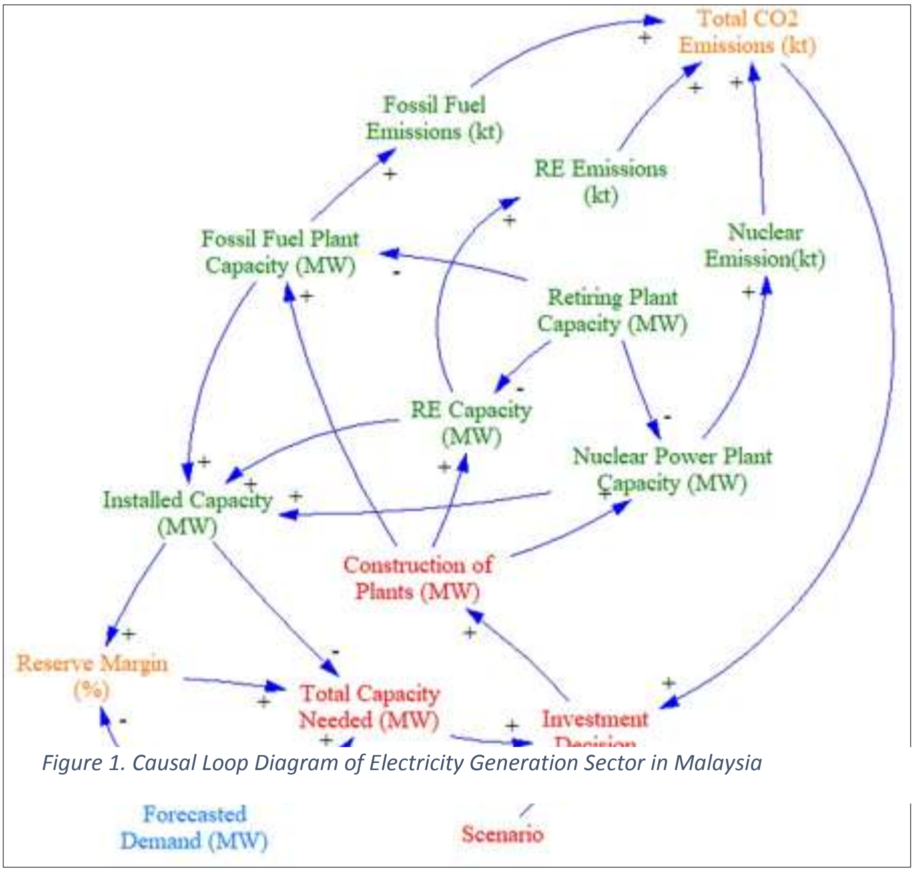

Figure 1. Causal Loop Diagram of Electricity Generation Sector in Malaysia

Figure 1. Schematic of two-stage SBR system

2.2 Stock and Flow Diagram

Figure 2 shows a detailed representation of the relationships modelled in the CLD drawn as a stock and flow diagram (SFD) with the corresponding colours from CLD, on top of having greyed shadow variables. The model predicts the future of the electricity market until 2035 but will start from year 1997 instead with all relationships and calculations evaluated yearly. The model measures energy security by considering two key indicators, reserve margin (%) and CO2 emission rate (kt). Generation capacities are represented on the right side of the model, which consists of nuclear, fossil fuel, and RE. Each structure shows the lifecycle of the plants, from initiating construction, functioning plants, and the retirement of the plants. Delays will manifest itself from initiating construction of a plant to actual production of capacity. The average rate of completion, retirement, and average lifespan vary for each plant type. Environmental emissions are captured as accumulation of emission produced from functioning plants, as shown at the top left part of Figure 2, as Total CO2 Emissions. Equation 1 (Eco-Ideal Consulting Sdn Bhd, 2014) and Equation 2 (Yah, Oumer, & Idris, 2017) demonstrated the calculation of greenhouse gas(GHG) emissions for that year.

$$GHG\ Emissions = Activity\ Level\ \times Emissions\ Factor \quad (1)$$
$$Activity\ Level = Capacity\ \times Working\ hours\ \times Capacity\ Factor \quad (2)$$

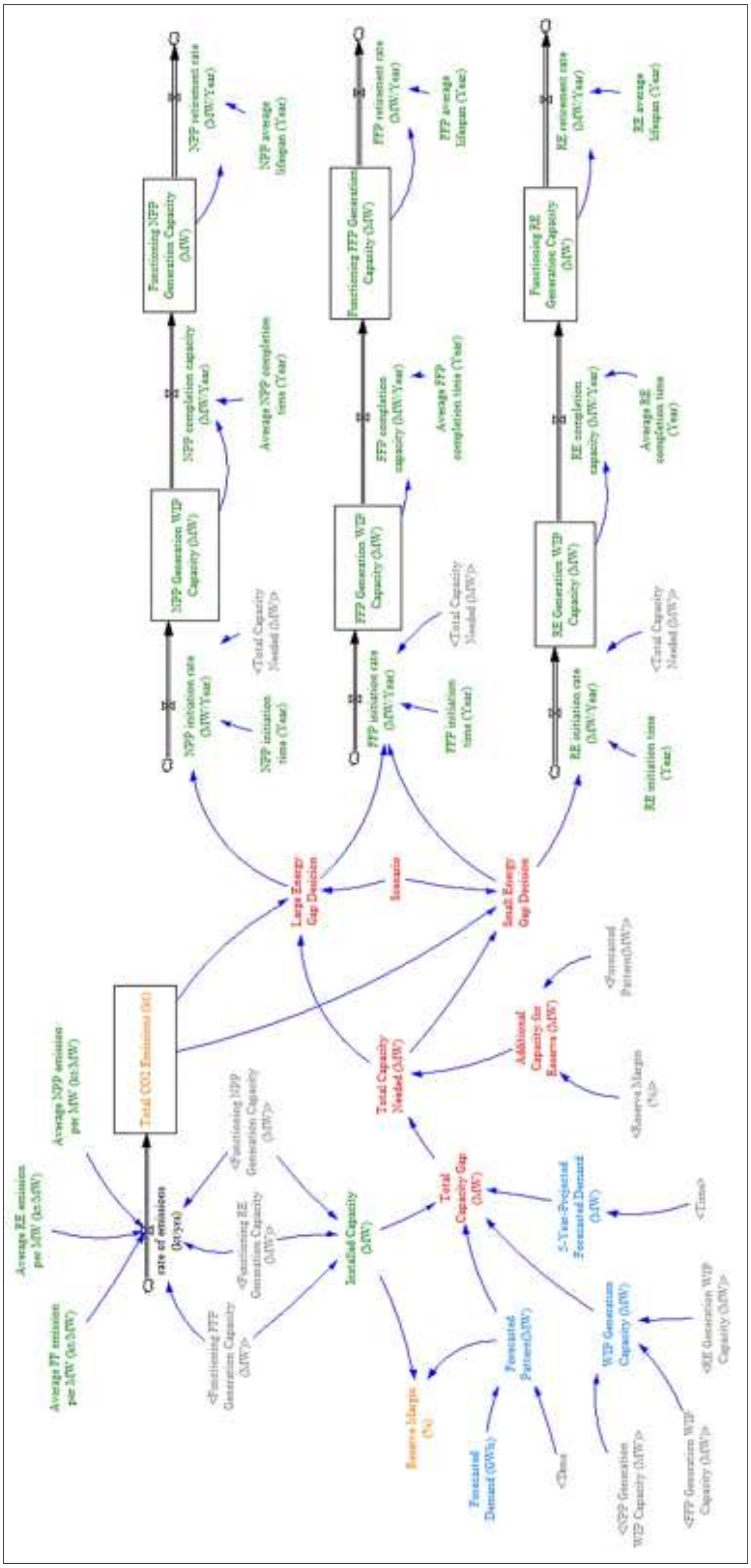

Figure 2. Stock and Flow Diagram of Electricity Generation Sector in Malaysia

Blue variables in Figure 2 shows the demand side of the modelled electricity market. This structure is used to calculate the Total Capacity Gap, given by equation (3):

$$Total\ Capacity\ Gap = (Forecast\ Demand + 5YP\ Forecasted\ Demand) - (Installed\ Capacity + WIP\ Capacity) \quad (3)$$

The values for the Forecasted Demand is the instantaneous current demand for electricity, as predicted by Suruhanjaya Tenaga's Electricity Supply Outlook 2017 (Suruhanjaya Tenaga Energy Commission, 2017). The values for the 5 Year Projected Forecasted Demand are those same values shifted 5 years ahead in time to provide for the capacity needed in the near future. Installed Capacity is the instantaneous total capacity whilst the work in progress (WIP) Generation Capacity provides the total capacity currently under construction.

The instantaneous Reserve Margin (EIA, 2012) is calculated by the equation:

$$Reserve\ Margin = \frac{Installed\ Capacity - Forecasted\ Demand}{Forecasted\ Demand} \times 100\% \quad (4)$$

The Total Capacity Needed compares the Total Capacity Gap and the Additional Capacity for Reserve for the larger capacity. The Additional Capacity for Reserve is the difference of installed capacity needed to reach the 25%, the optimum reserve margin, at the current margin. From Equation 4, the calculation for Additional Capacity for Reserve can be derived:

$$Additional\ Capacity = \frac{\Delta Reserve\ Margin \times Forecasted\ Demand}{100} \quad (5)$$

The red variables in Figure 2 shows the factors and relationships involved in the Investment Decision. This structure began with the decision where Total Capacity Needed will be built in the future. The model determines if it would be appropriate to build large plants (Large Energy Gap Decision) or several small plants (Small Energy Gap Decision). Depending on the Scenario and the Total CO2 Emissions, the model decides which plant to build. An additional feature built into the model considers when the current installed capacity is calculated to be capable of sustaining the current and future demand, the system holds back from making new plants until it is calculated to do so.

2.3 Investment Decision

Investment Decisions represent the decisions affecting IPP and the government's choice in building different types of power plant. To represent a deregulated market, the model will freely and independently choose the next power plant to build for the following years. These choices are governed by a number of factors in an actual situation but the model will take into consideration three main decisions in selecting either fossil fuel, renewable or nuclear, i.e. (1) the 'Total Capacity Needed', (2) which 'Scenario' was chosen, and (3) 'Emission Rate'. The model first determines the size of the capacity needed, whether it will be a large or small capacity by looking at the 'Total Capacity Needed'. Next, it considers the 'Scenario' the model that it is forecasting. Finally, should the scenarios require, the 'Emissions' determines if a clean energy source is needed.

Table 1 shows the how each plant is categorised for the aspects Plant Size and Emissions.

Table 1. Comparison for plant types

Plant Type	Plant Size	Emissions production

FFP	Large & Small	✓
RE	Small	✓
NPP	Large	✗

2.4 Validation of Model Variables

To validate the designed model, Table 2 lists the variables and past works found to support the importance of factors used in the model. The SFD's installed capacity, reserve margin, and emissions rate were validated to ensure it meets peninsula Malaysia's energy demand without any inconsistency and unsuitable outcomes. The factors were validated using the region's past demand record from 1997 to 2015 (Suruhanjaya Tenaga, 2017).

Table 2. Validation of Model Variables

Factors	Past Works
Installed Capacity (MW)	(Ahmad, Mat, Muhammad-sukki, & Bakar, 2016), (Petitet, Finon, & Janssen, 2017)
Forecasted Generation Demand (GWh)	(Ahmad et al., 2016; Momodu, Oyebisi, & Obilade, 2012; Petitet et al., 2017)
Total capacity needed (MW)	(Ahmad et al., 2016; Momodu et al., 2012)
Reserve Margin (%)	(Momodu et al., 2012)
Retiring Plants	(Momodu et al., 2012)
Construction of Plants	(Momodu et al., 2012)
CO_2 Emissions	(Ahmad et al., 2016)
Investment Decision	(Davies & Simonovic, 2011)

Figure 3(a) and Figure 3(b) shows Installed Capacity and the reserve margin respectively, as produced by the model using historical demand data. Installed capacity closely follows the demand trend whilst staying above it. For reserve margin, despite having fluctuations, all values stay above 0%, which ensures that there is at least some reserve to allow for disruption of electricity supply and unpredictability of a demand surge. The trend shows this fluctuation because of the delay in availability of the capacity caused by the construction time of the power plants.

Figure 3. Figure 3(a) Forecasted Demand and Modelled Installed Capacity, (b) Modelled Reserve Margin

Figure 4 shows the emissions rate produced from the modelled capacity per year. The trend modelled is lower than historical emissions recorded by UNFCCC, because the emissions recorded by UNFCCC included secondary emissions in the energy sector, such as transportation of fuel and construction of plants (Ministry of Natural Resources and Environment Malaysia, 2015).

2.5 Scenarios

Table 3 shows the summary of scenarios used in this simulation. The first scenario, business as usual (BAU), predicts the outcome when there is no change in the current state of the energy generation. Government and public demand will be at an unfavourable position for nuclear, fossil fuel will remain the main contender to power producers, and RE growth is negligible. In scenario B, the government and power producers are designed to be more open to using nuclear power. Nuclear

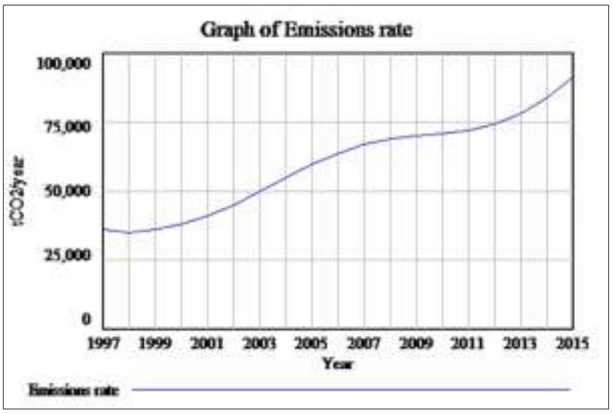

Figure 4. Emissions Rate

power is to be freely governed by the forces of the market but fossil fuel and RE are still available options for power producers to build. ‘Emissions rate’ will be capped at 2000 ktCO2/year to represent the driving factor for clean energy. When emissions exceed this value, the market is configured to favour nuclear and renewable energies. To compare the most debated alternative energy source to nuclear, scenario C, expansion of RE, predicts the outcome for a case of higher demand of RE but no demand for nuclear. Having no demand for nuclear was chosen in this scenario as it demonstrates the case in point for having RE as sufficient for peninsula Malaysia’s energy demand. Fossil fuel plant production remains a choice for investors as well. The emission rate cap will also be enforced in this scenario to support clean energy production.

Table 3. Summary of Scenarios

Scenario	**Expansion in Market**	**Available Plants**	**Emissions Policy**
A	BAU	FFP	×
B	NPP	FFP, RE & NPP	✓
C	RE	FFP & RE	✓

3. Results and Discussion

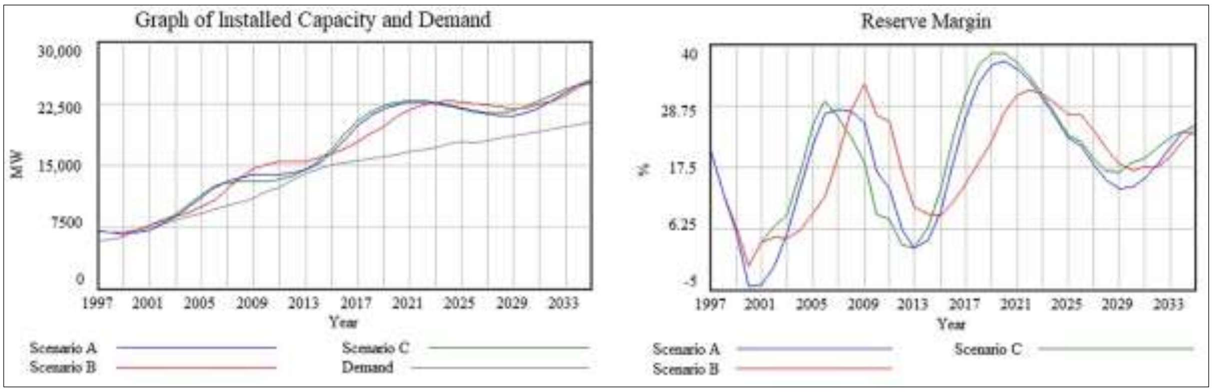

Figure 5. (a) Predicted Installed Capacity and Demand, (b) Predicted Reserve Margin

Figure 5 and Figure 6 shows a comparison of each scenario for the key indicators, reserve margin and emission rate, as well as installed capacity and cumulative emissions, predicted by the SFD for the period from 1997 to 2035. The demand forecast data used was obtained from Suruhanjaya Tenaga's forecasted required generation (Suruhanjaya Tenaga Energy Commission, 2017). The modelled installed capacity in Figure 5(a) shows an increasing trend for all three scenarios with similar patterns. All scenarios were able to meet the electricity demand forecasted. The trends show that scenario C reaches its peak first followed closely by scenario A, and finally scenario B. This is also shown in greater detail in Figure 5(b) depicting reserve margin. This is due to the different construction time for the different plant type and the availability of those plants in each scenario, i.e. RE has the shortest construction time and is available in scenario B and C. Therefore in scenario C, we can see that the decisions to construct more RE shifts the trends towards the left. The trends for each scenario shows an increasing average reserve margin as time goes on.

Around the year 2000, the trend for scenario A was observed to drop to almost -5%, where installed capacity was not able to meet the demand. In comparison, scenarios B and C still remained positive. This could be attributed to smaller RE plants available in these scenarios having a relatively lower construction time and therefore are able to provide the needed capacity to the market earlier. Although all three scenarios show a decrease in amplitudes as time progresses, becoming more stable, scenario B's reserve margin fluctuation can be seen to stabilise earlier.

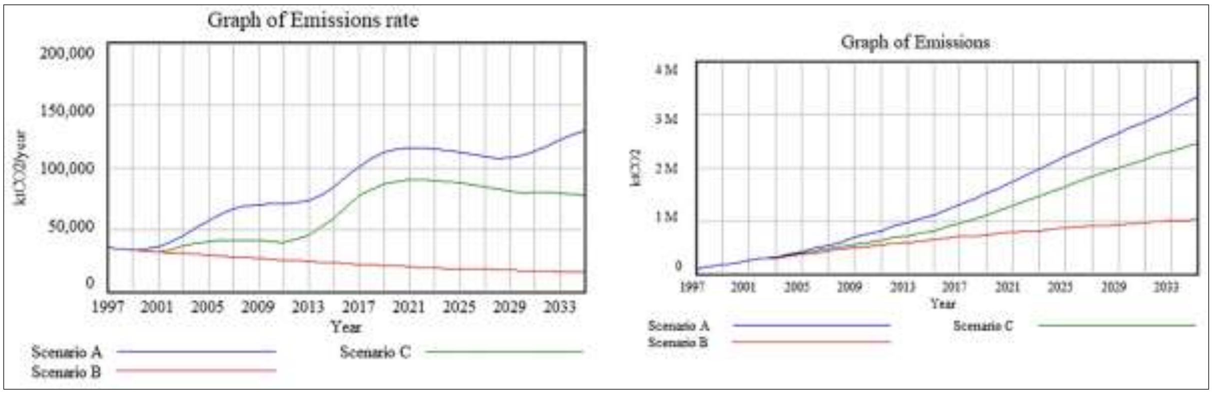

Figure 6. (a) Emission Rate per Year, (b) Predicted Cumulative Emissions

Figure 6 (a) shows the emission rate for all years. The emissions rate per year for scenario A and C show an increasing trend as the installed capacity increases over the years. They follow a similar pattern to their respective capacity produced but scenario C has a lower average slope. This is due to scenario C having a higher demand for RE technology which has a lower emission factor. On the other hand, scenario B shows a decreasing trend in emission rate per year as the market is open to NPP, which has a negligible emission. The emissions rate approaches zero as the older FFP retire and are replaced with nuclear plants when the emission rate is considered too high. Figure 6(b) also shows the cumulative emissions produced for each scenario. This is to demonstrate the long term effects of limiting the options for power plant type. Scenario A has the largest accumulation of emissions from the three scenarios, with over 3 million kilo ton of CO2 by 2035. This is followed by scenario C with 2.5 million kilo ton of CO2 and lastly scenario B with the least accumulated emission at around 1 million kilo ton of CO2 by 2035. Based on the results of the key indicators, scenario B, the deregulated market opened to choose a variety of plant types, is the most robust scenario in the context of the nation's energy security. This is due to different construction time, lifespan, and emissions factor. This scenario can easily respond to large or small capacity gaps with the ability to choose different plant types based on capacity size as well as swiftly responding to emissions policies given the choice of RE or NPP.

4. Conclusion

In conclusion, nuclear power can be beneficial to the country's electricity market in providing energy security from a systemic perspective. It is known to have the potential to replace large fossil fuel power plants whilst significantly reducing CO2 emissions. Having a diverse energy portfolio also allows for a swifter response by the electricity market to secure a safe margin of reserve. Whilst it is shown that including nuclear contributes to the diversification, its usage will have to be considered very carefully with a robust and safe management of its radioactive waste placed at the forefront of any appetite for nuclear in Malaysia. There can be no compromise for national security and this has to be a priority.

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