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Unconventional fuel pathways for decarbonizing the electrical power generation in Malaysia by 2050

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Abstract

The importance of this research is to provide a long-term foresight for Malaysia to achieve a low carbon power sector by 2050 through the implementation of unconventional fuel diversification policies. The Integrated Market Allocation-Energy Flow Optimisation Model System (TIMES) was deployed to model the three tested scenarios, namely the business as usual (BAU) scenario, the nuclear (NUC2) scenario in which the 2.00 GW nuclear power is added to the reference energy system, and the renewable plus storage (RNW6S7) scenario that integrated 6 renewable technologies with 7 days of pump hydro storage capacity. An economic assessment on two baseload power plants is included to evaluate the investment viability. The results indicated that the BAU and NUC2 scenario are unsustainable as the dependency on fossil fuel for electrical power generation by 2050 is still high at 71.92% and 66.83% respectively. Contrariwise, the RNW6S7 scenario revealed a low carbon profile for power generation in Malaysia by 2050, whereby the emissions have declined to a minimum level of 11,490 kt which is equivalent to 92.45% of avoided CO_2 in contrast to the BAU levels. The low carbon state is attained due to 98.37% of the generation output is renewable electricity. Finally, the RNW6S7 scenario demonstrated that the CO_2 emissions in 2030 will drop by 46.22% relative to the 2005 levels which from the power sector perspective surpassed the Paris Agreement targets.

Keywords: Least cost optimization; Low carbon power sector; Malaysia; Nuclear energy; Renewable energy; The Integrated MARKAL-EFOM System (TIMES) model.

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1. Introduction

Malaysia ratified the Paris Agreement in 2016 which is a multilateral agreement to combat climate change, through this accord Malaysia had pledged to reduce 35% of its total greenhouse gases (GHG) relative to the 2005 levels by the year 2030 on a voluntary basis. Malaysia also agreed to expand the reduction target to 45% upon receipt of financial and technical aid. As electrical power generation accounts for 54.04% of the CO_2 emission in Malaysia [1], thus it is vital to explore unconventional pathways to reduce the carbon footprint of the power sector. Related studies to long term decarbonisation of the total energy system or specifically for the power sector has been conducted at regional, national and local level, as demonstrated by *C. Jägemann et al* (2013) for Europe [2], *F. Amorim et al* (2014) for Portugal [3], *K. Tigas et al* (2015) for Greece [4] and *C. Yang et al* (2015) for California [5]. The main goal of this research is to provide a long-term foresight for Malaysia to decarbonize its power sector by 2050 by simulating the implementation of nuclear or renewable fuel diversification policies in the referenced energy system (RES) as depicted in *R. Haiges et al* (2017) [6] with the ultimate aim to lower the carbon footprint to mitigate climate change.

2. Methodology

The Integrated Market Allocation - Energy Flow Optimisation Model System (TIMES) is a software developed by the International Energy Agency's (IEA) - Energy Technology Systems Analysis Program (ETSAP). TIMES is a linear programming, least-cost optimisation model suitable for long term assessment of the total energy system or also for a single subsector such as the power sector [7]. Exogenous electricity demand growth projection from 2015 until 2050 from the simple growth model based on the projected rates released by the Energy Commission of Malaysia [8] as per Table 1 was applied in the TIMES model. The simulated scenarios are defined in Table 2. The economic assessment approach by Short et al. [9] was applied for estimating net present value (NPV), levelised cost of electricity (LCOE) and payback period (PP) for the 2.00 GW baseload technologies explicitly the hydro and nuclear power plant. While TIMES generated the NPV for each scenario and the LCOE for scenarios was estimated based on a weighted average approach whereby a carbon tax of 3.5% was imposed on fossil fuel conversion technologies. This carbon tax rate assumed the same rates as implemented by Costa Rica as a benchmark for developing countries.

Table 1. Electricity demand growth rates

Year	Growth (%)
2016-2020	3.1
2021-2025	2.6
2026-2035	1.4
2036-2050	1.4[1]

Table 2. Scenario definition

Scenario	Description
BAU:	This scenario will incorporate the technology stock from the base year 2015, new capacity addition and retirement up to 2030 as planned by the government. This trend is then extrapolated until 2050;
NUC2:	This scenario simulates the addition of the 2.0 GW nuclear power reactor into the RES by 2030 if a nuclear policy is pursued;
RNW6S7:	This scenario will integrate six renewable technologies into the RES, along with pumped hydro storage technology that could fulfil seven days of electricity generation requirements.

[1] Assumed

3. Results and discussion

3.1. Electricity demand (PJ)

The electricity demand is expected to progressively increase from 475.92 PJ in 2015 to 892.30 PJ by 2050. The final demand projection by end-user sectors is presented in Fig. 1, this projection was extrapolated by the model on the basis that the base year sector-wise share was kept constant throughout the study period until 2050. Nevertheless, this sector wise proportions can be altered based on certain policy interventions without affecting the overall demand levels, for instance, if the Malaysian government were serious in pursuing emission-free vehicles and encouraged the usage of electric vehicles in both the transport and agriculture sectors, then the electricity demand levels in these categories will definitely increase. Apart from that with the implementation of energy efficiency policy such as switching to LED lighting systems and application of innovative energy saving electrical devices would lead to lower consumption of electricity in the industrial, commercial and residential sectors.

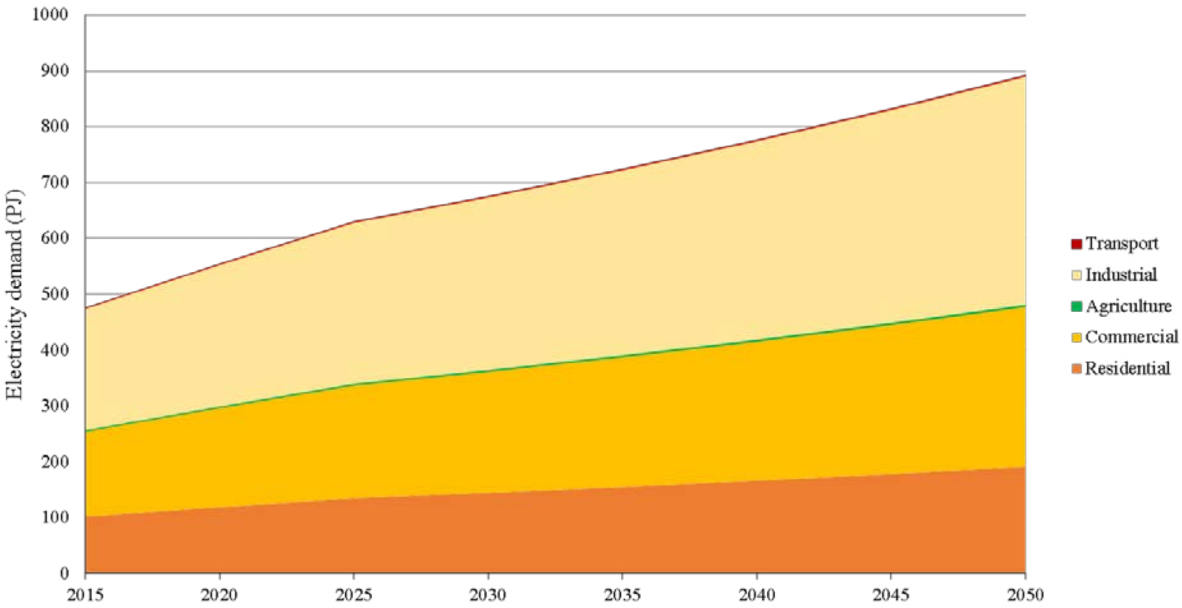

Fig. 1. Sectoral electricity demand

3.2. Capacity (GW)

As presented in Fig. 2 the power capacity levels in the BAU scenario increased by 57.50% from 25.06 GW in 2015 to 39.47 GW in 2050. It is eminent that the capacity expansion by 2050, is led by coal-fired power with 23.48 GW (59.49%) followed by 10.02 GW (25.39%) of hydropower, and 4.88 GW (12.36%) from gas-fired plants. Whereas renewable technology such as solar PV, geothermal, biomass and biogas only held a marginal capacity of 1.09 GW (2.76%). It is observed upon entry of the 2.00 GW nuclear power, the capacity levels of combined cycle power in the NUC2 scenario starts to decline from 2030 onwards, from 6.30 GW to 2.28 GW in 2050. However, the RNW6S7 scenario has the most dynamics whereby by 2050, only 0.60 GW is allocated for combined heat power, whereas 99.08% is powered by renewable technologies which comprise of 37.40 GW solar PV, 23.84 GW large hydro, 1.18 GW biomass, 1.10 GW biogas, 0.07 GW geothermal, 0.49 GW mini-hydro, and 0.69 GW of pumped hydro storage. This has impacted the capacity levels in 2050 to increase by 65.62 % compared to the BAU for the same period. This is instigated by the addition of the solar PV technology installed on rooftops which occupies a mere 0.15% of Malaysia's total land area. Due to the lower efficiency (15% to 17%) capability of PV technology to convert solar energy into electrical energy hence more panels need to be installed to achieve the expected generation levels.

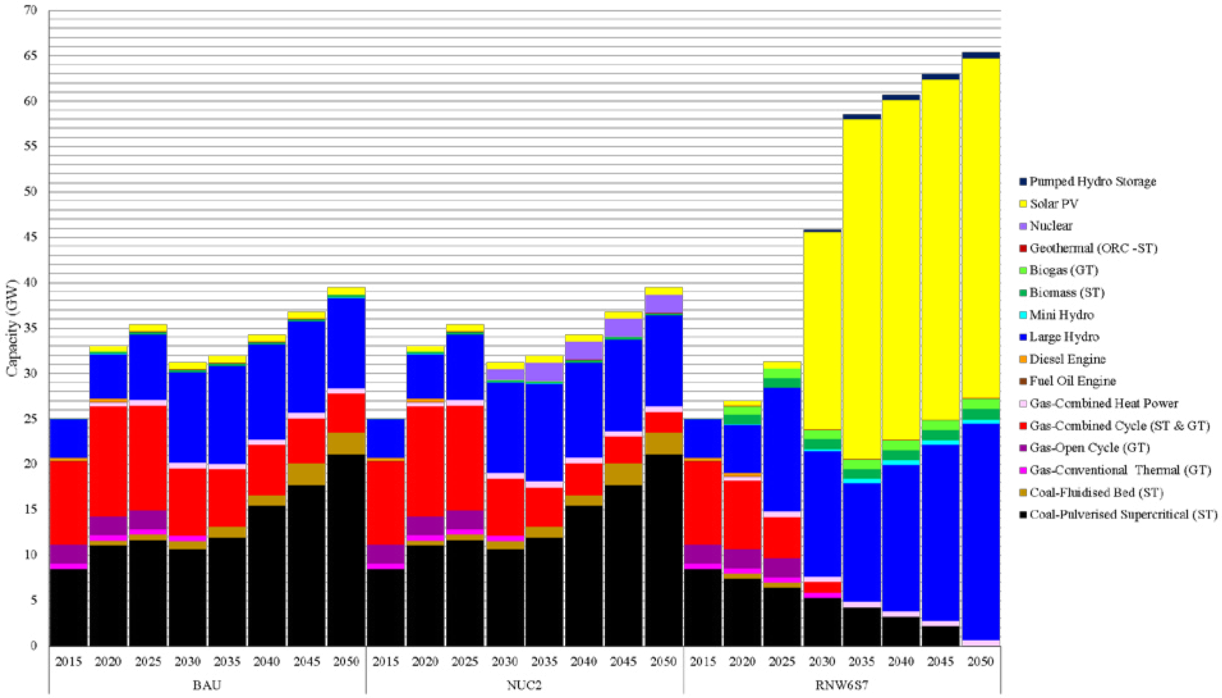

Fig. 2. Capacity levels by technology

3.3. Electricity production (PJ)

Comparison of the electricity generation profile is presented in Fig. 3 if we zoom into 2050 the electricity output for all three scenarios is 1115.37 PJ. In the BAU scenario, pulverized supercritical bituminous coal plants will be the dominant electricity producer with 53.64% share, followed by large hydro with 26.84% and combined cycle gas plants supplying 10.88%. While the fluidized bed supercritical lignite plants in Sarawak and combined heat power contributes a substantial 5.77% and 1.63% share respectively. Other renewable based technologies such as solar PV, mini-hydro, geothermal, biomass and biogas hold a collective minor share of only 1.25%. Whereas in the NUC2 scenario, similar share profile as per BAU are observed, however, a notable difference is that the electricity output from combined cycle plants has declined to 5.79% and nuclear power generates 5.09% of the electricity supply. Contrary to the BAU and NUC2 scenarios, the electricity output of the RNW6S7 scenario was supplied by 64.03% large hydro, 26.44% solar PV, 2.34% biomass, 2.18% biogas, 1.25% mini-hydro, and 0.19% by geothermal plants. Natural gas-fueled cogeneration plants still provides 1.63% of the total electricity output as heat is still required by the oil and gas industry. In terms of storage, the pump hydro storage holds a 1.94% share out of the total generation profile which is sufficient to store 7 days of electricity supply. This is similar to the pumped hydro storage model practised in the United States which maintains nearly 2% of the total generation levels [10]. The results in the RNW6S7 scenario indicated that 98.37% of the generated electricity is renewable electricity.

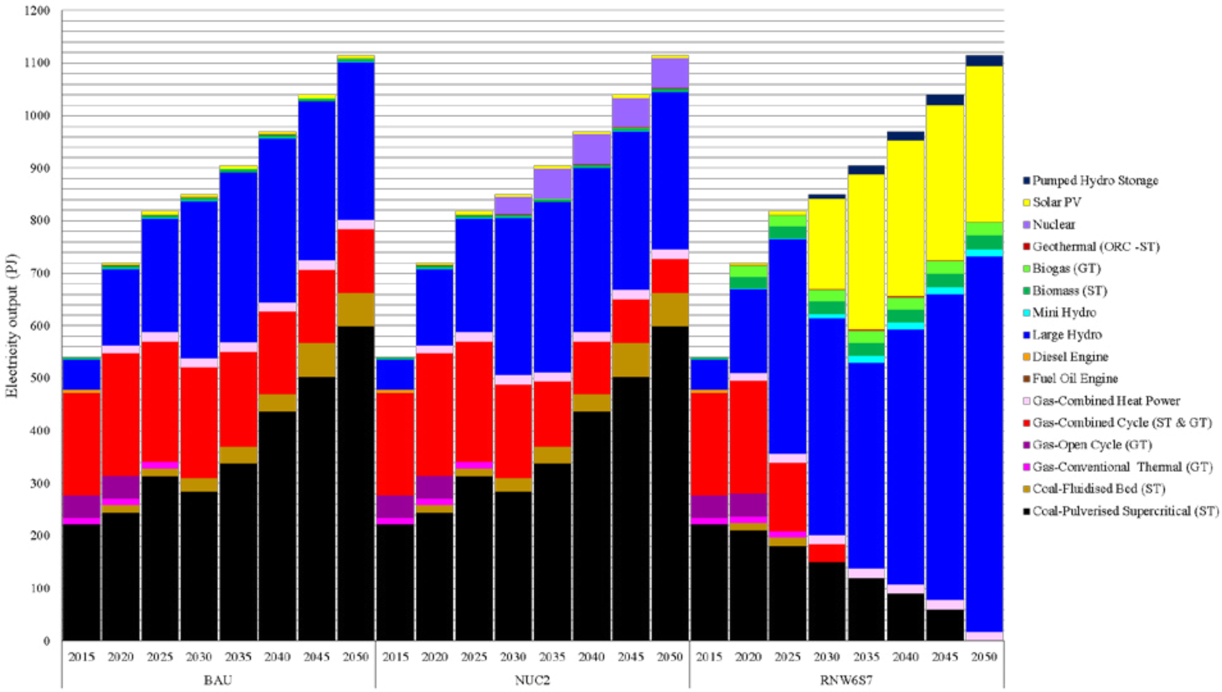

Fig. 3. Electricity production by technology

3.4. CO_2 emission (kt)

The 35% to 45% emission reduction targets by 2030 pledged by Malaysia in the Paris Agreement can be achieved if the RNW6S7 scenario is initiated, it has been demonstrated in Fig. 4 that the emission levels have dropped in 2030 by 46.22% relative to the 2005 levels. Conversely, no signs of emission reduction were detected in the BAU scenario by 2030, while a slight drop of 0.26% was detected in the NUC2 scenario. Eventually by 2050, the BAU and NUC2 scenarios anticipated an increase in CO_2 emission by 69.31% and 63.40% corresponding to the base year levels. However, the RNW6S7 scenario managed to produce a low carbon profile, whereby the emission curve will eventually plateau at 11,490 kt which is equivalent to 92.45% of avoided CO_2 in contrast to the BAU levels owing to the combustion of biomass, biogas, and natural gas.

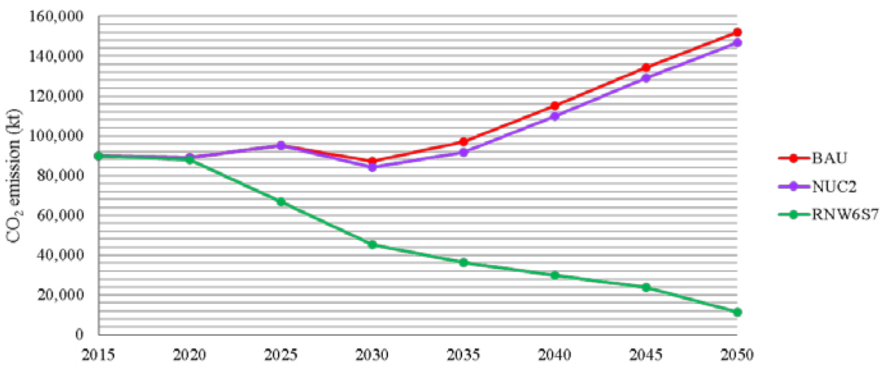

Fig. 4. CO_2 emission levels

3.5. Economic analysis on the scenarios

Comparison of the system cost (billion USD) or the NPV for all scenarios at 3% discount rate is presented in Fig. 5, the model assigned the lowest NPV to the BAU scenario which is valued at USD 88.95 billion. An increment of 3.41% was observed in the NUC2 scenario bringing up the NPV to USD 91.98 billion, this is due to the savings on fuel price due to the decline of natural gas consumption. While the highest NPV is observed in the RNW6S7 scenario with a 36.81% rise which is equivalent to USD 121.69 billion. The higher NPV reflects that the RNW6S7 scenario has higher revenues compared to cash outflow which is a direct consequence of fuel savings from cost-free renewable resources.

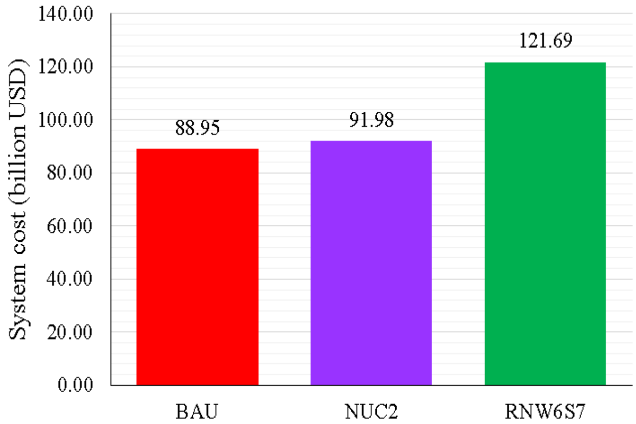

Fig. 5. System cost for all scenarios

The LCOE for all scenarios before accounting for the 3.5% carbon tax is reflected in Fig. 6, the ranking sorted in ascending order is accorded to BAU (USD 0.019 per kWh), followed by NUC2 (USD 0.020 per kWh) and RNW6S7 scenario with USD 0.027 per kWh. The increase in generation costs for each kWh is due to the higher technology cost introduced in the NUC2 and RNW6S7 scenarios.

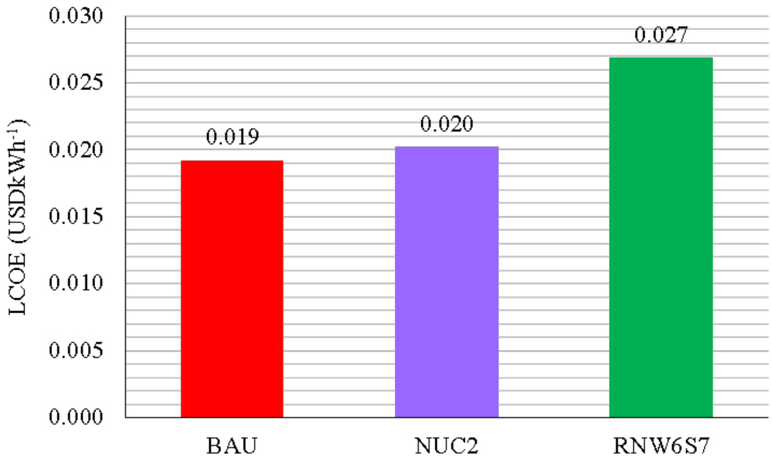

Fig. 6. LCOE for all scenarios before carbon tax

Fig. 7 indicates the LCOE for all scenarios after considering the 3.5% carbon tax, the RNW6S7 scenario obtained the lowest LCOE (USD 0.030 per kWh), a significant increase is observed in the NUC2 and BAU scenarios with corresponding LCOE at USD 0.154 per kWh and USD 0.163 per kWh. The increase in generation cost for each kWh in all scenarios is due to the carbon tax imposed on fossil fuel conversion technologies, even in the RNW6S7 scenario there is a slight increase due to carbon tax imposed on natural gas-fired combined heat power cogeneration plants.

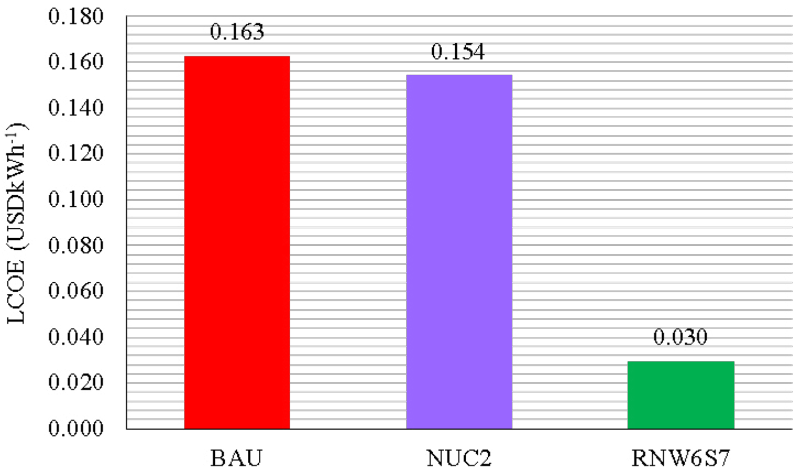

Fig. 7. LCOE for all scenarios after carbon tax

3.6. Economic analysis on baseload technologies

The economic valuation for the two types of baseload power plants with 60 years lifetime as depicted in Table 4 implies that the hydropower project is economically more feasible compared to nuclear power since the NPV for hydropower is higher at USD 40.77 billion compared to USD 38.06 billion. Moreover, the discounted PP at 3% discount rate for the hydropower project can be retrieved within 3.4 years, while nuclear power requires 8 years to gain back the principal investment cost. Despite pioneer status being granted to both hydro and nuclear power utility companies in which corporate tax has been exempted for the first 10 years from the commencement date, the LCOE from hydropower is still lower at USD 0.02 per kWh compared to nuclear power which cost USD 0.03 per kWh. This higher LCOE for nuclear power is due to the additional cost incurred on the consistent imports of uranium fuel.

Table 3. Economic valuation on 2.0 GW baseload power plants

Indicators	Unit	Hydro	Nuclear
NPV	Billion USD	40.77	38.06
PP	years	3.4	8.0
LCOE	USD per kWh	0.02	0.03

4. Conclusion

The power sector would be able to meet the obligations of the Paris Agreement by 2030 if the RNW6S7 scenario is pursued by the Malaysian Government and utility companies. Besides that, the power sector would be prominently decarbonised by 2050 with 92.45% of mitigated CO_2. This research provided a sustainable pathway towards a low carbon power sector by 2050 through linking the grid with 6 types of renewable technologies combined with the pumped hydro storage system that could sustain electricity supply equivalent to 7 days.

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