Prospect of clean coal for sustainable energy mix in Malaysia

Siti Fatihah Salleh*, Abul Quasem Al-Amin and Tuan Ab Rashid Tuan Abdullah

Institute of Energy Policy and Research (IEPRe),
Universiti Tenaga Nasional,
Jalan Ikram-Uniten, Kajang, Selangor, Malaysia
Email: Siti.Fatihah@uniten.edu.my
Email: Al.Amin@uniten.edu.my
Email: TRashid@uniten.edu.my
*Corresponding author

Abstract: This study evaluates the current energy diversification policy in Malaysia and proposes clean coal as an alternative to address the environmental issues and economic sustainability concerns in the power generation sector. In order to clearly picture the competitiveness of the proposed alternative, this study explored two scenarios, namely, *Scenario a and Scenario b*. The former scenario acts as a baseline, where the conventional coal is consumed for power generation; while the latter scenario looks at the prospect of substituting the conventional coal with clean coal by 5%, 10% and 15%. Mixed with four other energy sources specified in the Five-Fuel Diversification Strategy for power generation, the total amount of GHG that would be generated is estimated for both scenarios. It was found that the substitution approach could reduce the greenhouse gas (GHG) emission significantly by 63%, from 823,498 kilotonne (kt) to 305,288 kt in year 2020. The findings highlight the potential of clean coal as a healthy alternative in reaching the Intended Nationally Determined Contribution (INDC)'s target on GHG emission reduction. The results would lessen the gap between the GHG mitigation potential and INDC target, and aid in the formulation of effective energy strategy for power generation in Malaysia.

Keywords: environmental impacts; fossil fuel; clean coal; energy; energy policy; Malaysia.

Reference to this paper should be made as follows: Salleh, S.F., Al-Amin, A.Q. and Abdullah, T.A.R.T. (2020) 'Prospect of clean coal for sustainable energy mix in Malaysia', *Int. J. Environment and Sustainable Development*, Vol. 19, No. 1, pp.59–71.

Biographical notes: Siti Fatihah Salleh earned her PhD in Bioprocess Engineering from Universiti Sains Malaysia and a BEng (Hons.) in Chemical Engineering from Universiti Teknologi PETRONAS. Her research interest includes clean energy, energy efficiency and sustainable building.

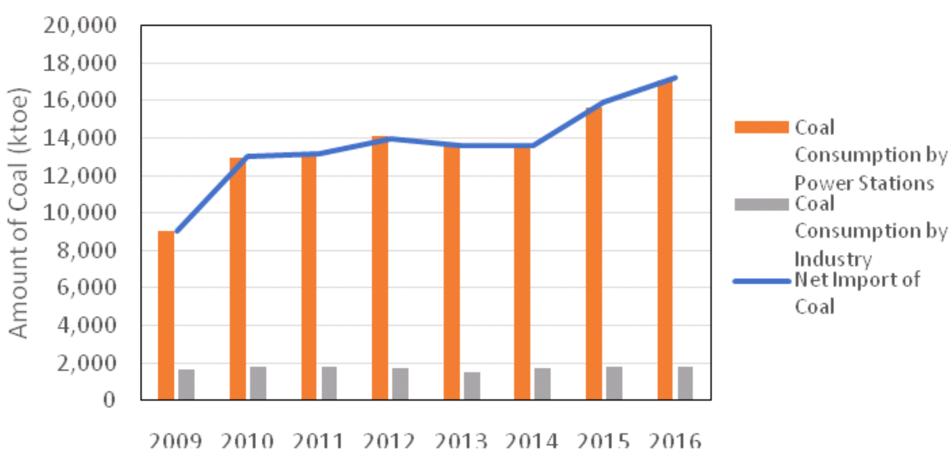
Abul Quasem Al-Amin is a Professor at the Institute of Energy Policy and Research (IEPRe), Universiti Tenaga Nasional (UNITEN), Malaysia. He also holds positions as a Visiting Professor at the Faculty of Environment, University of Waterloo; and the International Business School (IBS), Universiti Teknologi Malaysia. His areas of research include environmental modelling, sustainable development, and climate change. Previous projects have included climate change research with UNDESA as well as Asia Pacific Network & Institute for Global Environmental Strategies.

Tuan Ab Rashid Tuan Abdullah is a Professor at the Universiti Tenaga Nasional and an Electrical Engineer at Tenaga Nasional Berhad. He did his formal education in Malaysia, Canada, USA, Germany and UK and earned High School Diploma, BSc, MSc and PhD. He has 14 years working experience in utility companies and 12 years academic experience in UNITEN. He is also active in industry advisory on for power system asset management.

1 Introduction

Coal is an important source of energy in Malaysia's competitive energy marketplace. It is one of the cheapest fuels, by far cheaper than other conventional fossil fuels, such as natural gas and crude oil. Besides that, coal also provides a stable source of energy, as it is abundantly available worldwide and its price does not fluctuate abruptly, unlike oil. Figure 1 depicts the coal consumption and import trend lines for the past several years. Coal is largely consumed to generate electricity in power plants, accounting for around 90% of its total consumption. The balance is consumed by the industry, in which the consumption has not really changed and remained below 2,000 ktoe. On the other hand, coal consumption in power plants is progressively increasing, reaching 17,101 ktoe in 2016. Tagging along is the coal import, which covers over 90% of the demand [Energy Commission (Malaysia), 2017].

Figure 1 Coal utilisation in power industry (2009–2016) (see online version for colours)



Source: Energy Commission (Malaysia) (2017)

As Malaysia is progressing economically with a projected GDP per capita of USD 13,180 in year 2020 (International Monetary Fund, 2018), the demand for energy will undoubtedly continue to grow. Among the fossil fuels, coal consumption is projected to grow at the fastest annual rate of 9.7%, followed by natural gas at 2.9% and oil at 2.7%

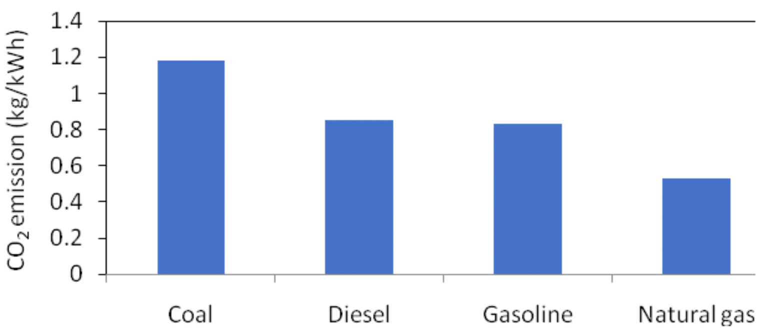
(TERI, 2010). The prospect of increasing the reliance on coal to power the Malaysian electricity subsector is unappealing due to two main arguments:

1 huge emission of CO_2

2 energy security as coal is largely imported.

Conventional fossil fuels are the primary sources of GHG emissions, such as CO_2, SO_2 and NO_x. Figure 2 demonstrates the amount of CO_2 emitted by some of the common fuels, including coal. Evidently, coal is the highest contributor of CO_2 compared to the other fuels, with 1.18 kg CO_2 per kWh of energy generated.

Figure 2 Approximate CO_2 emissions for common fuels (see online version for colours)



According to the report of World Bank (2013), Malaysian carbon emissions for the year 2009–2010 were 198×10^6 tonnes, placing Malaysia third in the list of countries with the highest carbon emissions in the Southeast Asian region (World Bank Databank, 2013). Malaysia emits 7.2 tonnes of CO_2 per capita, again, placing it third highest in the Southeast Asia (United Nations Statistics Division, no date). The greenhouse gas (GHG) inventory, as described in Malaysia's Third National Communication (NC3) and Second Biennial Update Report (BUR2) to the United Nations Framework Convention on Climate Change (UNFCCC), details the national anthropogenic emissions and removals for the year 2014. Emission estimates were carried out for four sectors, namely, the energy; industrial processes and product used (IPPU); agriculture forestry and other land use (AFOLU), and waste sectors. The net total GHG emission in Malaysia for 2014 was 50,479.06 Gg CO_2eq. The energy sector was the highest contributor for GHG emissions at 80%, followed by the waste sector at 9%, and other sectors at 6% and less.

The emission of CO_2 and other GHGs into the atmosphere due to human activities has been identified as the main cause of the global climate change, as recently reported by the IPCC (Solomon et al., 2007) and others (Lobell et al., 2007, 2008, 2011). Global warming and climate change are real threats to the modern society. Failure to adopt an efficient and effective alternative energy generation strategy would cause harmful environmental impacts that are irreversible. Serious efforts are needed to reduce GHG emission from the energy, industrial and agricultural sectors worldwide. In 2015, government leaders from 195 countries have gathered at the Paris climate conference (COP21) to adopt the first-ever universal agreement on global climate (United Nations, 2015). The agreement sets out a limit to global warming to below 2°C and pursuing efforts to limit it to 1.5°C. High reliance on conventional fossil fuels for power generation should be reduced and replaced with an effective substitute. Lower-emission technologies and renewable energy are promoted as a solution to mitigate the climate change (Ahmed et al., 2011, 2013; Hasanuzzaman et al., 2011, 2013; Saidur et al., 2011).

According to the Institute of Energy Economics Japan (IEEJ), advanced technologies such as renewable energy, energy efficiency and carbon capture and storage (CCS) system will contribute significantly in reducing CO_2 emission in 2050 (IEEJ, 2018). Renewable energy is already in the national power generation mix since 2009. However, its progress is dismally slow and its present share is only 3.4% in terms of installed capacity [Energy Commission (Malaysia), 2018]. Therefore, it serves to complement rather than a replacement. As reported in Malaysia's Third National Communication (NC3) and Second Biennial Update Report (BUR2) to the UNFCCC, the National Renewable Energy and Action Plan has set a new target of renewable energy installation to reach 3,902 MW by 2030 [Ministry of Natural Resources and Environment (Malaysia), 2018]. However, the key policy and technology enabling strategies to accelerate the development of each type of renewable resources remain rather ambiguous. Meanwhile, as for energy efficiency, Malaysia has introduced the National Energy Efficiency Policy and Action Plan (NEEAP) in 2016 in order to promote optimal and efficient utilisation of electricity as a way of controlling the electricity demand growth. NEEAP's target is to achieve overall electricity savings of 52,233 GWh by 2025 over a 10-year period, which corresponds to 8% reduction in the electricity demand growth [Ministry of Natural Resources and Environment (Malaysia), 2018]. Successful energy efficiency implementation requires strong commitment from all sectors, not just from the energy sector. Both renewable energy and energy efficiency require massive investment cost and opportunity cost, yet obtaining sufficient funding has always been a major challenge in this country (Mekhilef et al., 2011; Sovacool and Drupady, 2011; Binti et al., 2017; Chien Bong et al., 2017).

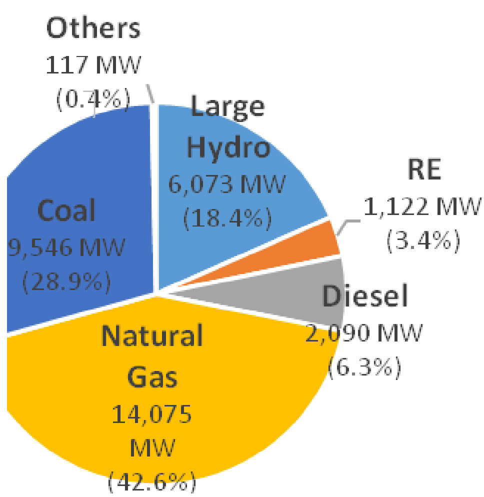
CCS stands for capture, compress, and store, where the CO_2 at storage site is prevented from release from a large point source, such as fossil fuel power generating facility. The captured CO_2 will be stored underground or utilised to assist in enhanced oil recovery. However, the cost of CO_2 recovery and storage is expensive; more so if it is applied at an existing plant that is far from the sequestration site. CCS is essentially a part of clean coal technology whose main role is to reduce carbon release at the powerhouse (Tang et al., 2015). Adopting clean coal technology system in a modern coal power plant is of high interest in many developed and developing countries (IPCC, 2005; Guan, 2017; Melikoglu, 2018; Oboirien et al., 2018; Zhang et al., 2018). This is especially when the demand for coal-based power generation is expected to increase annually until 2040 (Melikoglu, 2018). According to the International Energy Agency (IEA), the global energy consumption and coal demand will be strongly driven by emerging economies in Asia as the power demand in these countries soars (IEA, 2017, 2018). Southeast Asia has been reported to demonstrate the fastest growth rate of coal demand worldwide, with a projection 5% increment annually through 2023 (Okutsu and Suguira, 2018).

As the energy market continues to grow, it is hard to circumvent the future demand for coal. Despite the number of backlashes and public outcry on coal as a dirty fuel, the need for stable and affordable electricity source overshadows other greener alternatives. Acknowledging this reality is crucial, as it sheds light on current priorities and the way forward. Increasing use of coal for power generation in power-hungry developing countries will lead to widespread construction of new coal-fired power plants. Since this is nearly inevitable, promotion of clean and efficient use of coal through clean-coal technology in Southeast Asia region is of pressing importance in order to reduce GHG and CO_2 emissions. Driven by the curiosity to explore how the national power industry should move forward, the present study aims to unravel a sustainable alternative energy mix. In particular, the study attempts to elucidate the potential and advantage of substituting the conventional coal power generation with clean coal technology over time. A comparative analysis is conducted to show the possible environmental impacts of the current year 2020 vision, in addition to the potential improvements that would result from the clean coal energy technology utilisation. The detailed findings from this study would path the way to a healthier and more sustainable power generation system and hopefully will convince the policymakers in Malaysia to include clean coal in the national energy policy (NEP).

2 Energy outlook in Malaysia

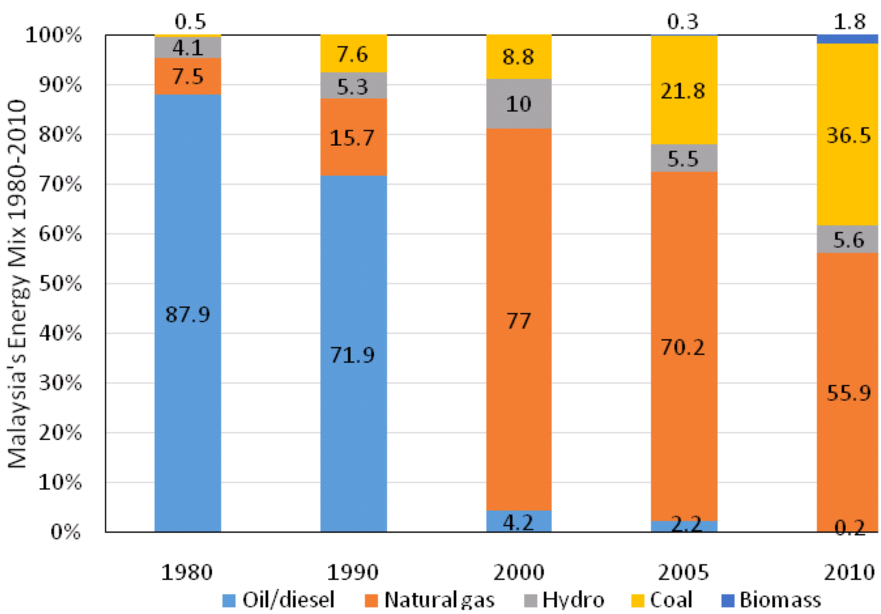
Along with its rising population and economic growth, the demand for energy is rising to new heights every year, reaching 33,023 MW of total installed power generation capacity in 2016 [Energy Commission (Malaysia), 2018]. Figure 3 shows Malaysia's power mix in terms of its installed capacity in 2016. Coal, for the first time, has overtaken gas as the dominant fuels in the power mix (46%), followed closely by natural gas (40%), then hydro (13%), oil (0.7%), and renewables (0.4%). Coal is becoming the most preferred source of fuels for power generation mainly due to the fact that it is among the cheapest sources of energy and it offers a constant supply. The dominance of coal power is undeniable in the foreseeable future, as more and more coal power plants are being built and planned. However, most of the coals consumed are imported and the coal combustion for power generation emits relatively high levels of carbon dioxide (CO_2), which is the primary cause of global warming.

Figure 3 Total installed capacity (MW) in 2016 by fuel type (see online version for colours)



According to a report by the UN Millennium Development Goal, the main contributors for the carbon emissions in Malaysia are the energy and transport sectors (United Nations Malaysia, 2016). The electricity supply industry on its own contributes 28% of Malaysia's total carbon emissions. In order to reduce Malaysia's high dependency on conventional fossil fuels in power generation, the Four-Fuel Diversification Strategy was introduced in 1981, in which petroleum oil, natural gas, hydro, and coal make up the fuel mix in decreasing composition order. Later in 1999, the diversification strategy was extended to Five-Fuel Diversification Strategy to include renewable energy. The changes in the composition of each energy sources from 1980 to 2010 can be found in Figure 4. The direct impact of this strategy is the drastic drop in the prevalence of petroleum fuels in the Malaysian energy mix from 87.9% in 1980 to 4.2% in 2000, and a further drop to 0.2% in 2010 (Zamzam et al., 2003; Oh et al., 2010).

Figure 4 Energy mix rate (%) in Malaysia (see online version for colours)



In contrast, coal utilisation is intensifying, from only 0.5% in 1980 to 36.5% in 2010, fostering environmental concerns reflected by recent studies by Jafar et al. (2008) and Oh et al. (2010). According to Jafar et al. (2008), if Malaysian coal-related annual efficiency continues to rise until 2020, the conversion efficiency would reach a maximum of 48%, which is still low compared to the international standards (70–80%). The Ministry of Energy, Communications and Multimedia Malaysia has also expressed similar concerns in recent years, as energy demand is increasing rapidly with economic development in Malaysia [Ministry of Energy Communications and Multimedia (Malaysia), 2009]. Since renewable energy is still in its infancy stage, its contribution in the energy mix is very small, reaching only 1.8% in 2010. As a result, coal is currently seen as the most promising source of energy and its share in the power generation is projected to increase substantially over time in order to meet the rising electricity demand. Malaysia would suffer negative impacts if its fossil fuels consumption continues to grow. A balance must be reached between environmental quality and sustainable economic development of the country.

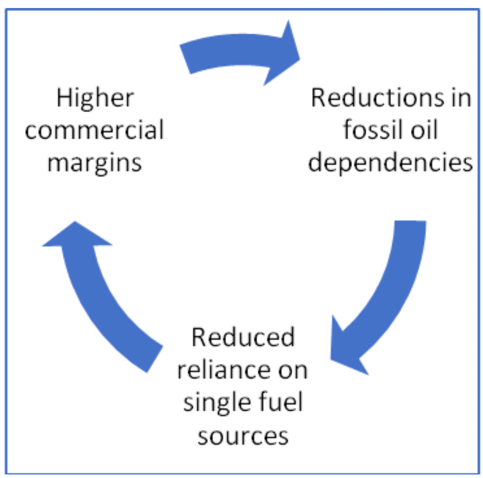
Jafar et al. (2008) have also explored the projected emissions and drawback of the proposed fuel mix option from electricity generation up to the year 2020 using the Malaysian 2020 fuel mix strategy. In addition, their study critically evaluated the Malaysian 2020 fuel mix strategy on the basis of the business-as-usual 2020 final demand. According to the study, the Malaysian 2020 fuel mix strategy by the Five-Fuel Diversification does not meet the environmental objectives set by NEP. The current policy initiatives were only effective in reducing Malaysia's dependence on conventional fossil fuels, but lacked in adequate environmental protections. This is because the focus of the proposed fuel mix consideration were mainly on three fundamental reasons, as illustrated in Figure 5; they are:

1 to reduce fossil oil dependencies

2 to reduce reliance on single fuel resources

3 to attain higher commercial margins.

Figure 5 Reasons for introducing fuel diversification strategies in Malaysia (see online version for colours)



Therefore, dialogue on clean energy, green technology and alternative energy sources as green energy options has been intensified among Malaysian regulatory agencies in recent times, as Malaysian policymakers begin to recognise that climate change is a real matter of future concern that must be resolved. The scientific evidence on the issue has been augmented recently through the publication of popular reports by the Intergovernmental Panel on Climate Change (IPCC) (Solomon et al., 2007). Though the consequences, timescales and impacts of climate change are still the subject of ongoing exploration, international policymakers agree on the importance of greener energy options for a sustainable future, and Malaysia is no exception. Malaysia's commitment in reducing GHG emissions is established upon the declaration of the Intended Nationally Determined Contribution (INDC) target to reduce GHG emissions intensity of GDP by 45% by 2030 relative to the emissions intensity of GDP in 2005 (INDC, 2015). This consists of 35% on an unconditional basis and a further 10% is condition upon receipt of climate finance, technology transfer and capacity building support from developed countries. It is a huge target and essential to work by successful implementation of a greener pathway and low carbon development on energy and transport sectors in particular. To be successful in meeting the set target by 2030 in Malaysia, additional focus must be placed on action related to green technology development and technology transfer from advanced countries without further delay.

Sustainable energy alternatives are necessary if Malaysia is to alter its energy situation, as reflected by the current Fuel Diversification Strategy, which focuses only on future coal energy reserves and demands. It is of vital concern for Malaysia to find a healthy balance between national environmental objectives and sustainable economic growth. It has been argued that the effects of GHG emissions can be mitigated by making smart and green policy initiatives through cooperative action. As a start, Malaysia is seeking power generation through clean coal option to carry lower emission intensity profiles, compared to the conventional fossil fuels. Pulverised fuel firing (PFF) combustion technology, electrostatic precipitators (ESP) and flue gas desulphurisation (FGD) technologies are among the clean coal technologies available that have been adopted by the energy utility sector in Malaysia [Energy Commission (Malaysia), 2014]. However, none of the contemporary studies and initiatives have compared this promising clean coal alternative to a conventional fuel scenario through rigorous comparative analysis. Therefore, the present study provides essential vision into the future environmental impacts through our proposed alternative energy options. The findings should be given serious consideration for policy formulation and future desirable energy mix strategy in Malaysia.

3 Methodology

3.1 Estimation of resource intensity

This study used Leontief's input-output (I-O) framework (Rahman and Lee, 2006; Miller and Blair, 2009), where Leontief's system of equations is expressed as:

$$x = Ax + f, \tag{1}$$

which states the correlation between the gross output (x), the sum of all intermediate demands (Ax), and the final demand (f). Leontief's system is a matrix that specifies the final demand vector by f, the output vector by x and the input coefficients by A. The solution of Leontief's system is expressed as:

$$x = (I - A)^{-1} f \tag{2}$$

where $(I - A)^{-1}$ is known as the 'Leontief inverse', and I is an identity matrix [Economic Planning Unit (Malaysia), 2006]. It is possible to extend the input-output system to the environment by integrating a matrix $\boldsymbol{e}$, which includes each sector's direct and indirect resources such as conventional fossil fuels for one unit of national production and power. In Leontief's system, the resource intensity can be obtained as follows:

$$\varepsilon = \boldsymbol{e}(I - A)^{-1} \tag{3}$$

where $\boldsymbol{e}$ is the environmental matrix that generates the energy co-efficient in the economy.

3.2 Estimation of GHG emission

The national energy-related emissions per million tonnes of fuel equivalent (mtoe) were estimated using this formula;

$$\begin{pmatrix} Emissions\ per \\ mtoe\ of\ fuel \end{pmatrix} = \begin{pmatrix} Fuel's\ emission \\ factor \end{pmatrix} \times \begin{pmatrix} Fraction\ of \\ pollution\ oxidised \end{pmatrix} \times \begin{pmatrix} Molecular\ weight \\ ratio\ of\ emission \end{pmatrix} \quad (4)$$

Finally, the GHG emissions (i.e., $CO_2 + SO_2 + NO_x$) were estimated following the five-fuel diversification strategy with reference to the national energy demand, $(\hat{\hat{f}})$ (f) as follows:

$$\begin{bmatrix} c' \\ s' \\ n' \end{bmatrix} = \begin{bmatrix} c_1 & c_2 \\ s_1 & s_2 \\ n_1 & n_2 \end{bmatrix} \begin{bmatrix} (a_1' + b_1') \\ (a_2' + b_2') \end{bmatrix} \mathbf{L}\, \hat{\hat{f}} \equiv \begin{bmatrix} d' \\ f' \\ g' \end{bmatrix} \mathbf{L}\, \hat{\hat{f}} \quad (5)$$

where c', s', n' are the row vectors of total emissions of CO_2, SO_2, and NO_x at the sector-specific level, respectively, and $a_1'.....b_2'$ are energy intensity ***e*** vectors. In Leontief's system, $(a_1' + b_1')$ indicates the coefficients of conventional fossil fuel utilisation, $(a_2' + b_2')$ indicates the coefficients of coal utilisation, and $c_1.....n_2$ are the conversion factors.

The macro-forecasted growth rate formula and Leontief's system were then used to calculate the total emissions for 2020. The growth rate between 2005 and 2012 was used to estimate the 2020 final demand, Y_t, for Malaysia using data based on the Malaysian Development Plan. This research utilises the real base year of 2005 and updated to 2010 to estimate the Y_t for 2020 as follows:

$$Y_t = Y_{2005}\left(1 + {}^{r}{}_{Y}\right)^t \quad (6)$$

where t =1,2,3,…, is the timeline, and ${}^{r}{}_{Y}$ is growth rate of the energy demand of the Malaysian economy. The same macro-forecasted growth rate formula was used to estimate the energy demand in 2020 as follows:

$$Y_e = Y_{2005}\left(1 + r_e\right)^t \quad (7)$$

This study considered the proposed 2020 Five-Fuel Diversification Strategy, business-as-usual states, and 2012 fuel mix intensities for all comparative analyses.

4 Results and discussion

4.1 GHG emission simulation results

This study utilised the Leontief's system with an extension of the environmental matrix to predict the energy-related emission by the Malaysian economic system in two scenarios, namely, *Scenario a* and *Scenario b*. *Scenario a* simulates the GHG gas emission results if Malaysia's current energy utilisation levels are sustained, while *Scenario b* simulates the GHG emissions resulting from substitution of clean coal alternatives for conventional fuel sources for energy generation in Malaysia.

Table 1 shows the result of the simulations made on both scenarios. According to the findings in Scenario *a*, the amount of GHG emissions in 2020 would be 353,523 kt using 2005 energy intensity. The amount would then increase gradually to 405,118 kt, as the reference for energy intensity changes from year 2005 to 2012, and later to business-as-usual (BAU). The increase in GHG emission is due to the higher conventional energy demand by the national economy.

Table 1 Scenario impacts of GHGs emissions (i.e., $CO_2 + SO_2 + NO_x$) using the conventional fuel-mix and clean coal substitution for 2020

2020 GHG gas emissions scenarios				
Simulation results	*2005 emission intensity (kt)*	*2012 fuel mix intensity (kt)*	*Business-as- usual fuel mix intensity (kt)*	*Proposed fuel mix (2020) intensity (kt)*
Scenario a	353,523	374,551	405,118	823,498
Alternative renewable energy substitution				
Clean coal utilisation	-	5%	10%	15%
Scenario b	-	339,964	329,834	305,288

Meanwhile, when the proposed fuel mix and energy intensity prescribed by the Five-Fuel Diversification Strategy was used as reference, the GHG emissions was estimated to reach 823,498 kt in 2020, twice more than the amounts simulated previously using 2005, 2012 and BAU fuel mix intensity. The major cause of high GHG emissions in 2020 in the Five-Fuel Diversification Strategy scenario is the high conventional coal mix in the power generation portfolio. Though the Five-Fuel Diversification Strategy secures Malaysia's fuel supply for power generation into the next century, it lacks adequate consideration of environmental attention and ecological responsibility. Eventually, Malaysia would face a major environmental challenge should the future fuel mix continue to follow the same policy.

On the other hand, Scenario *b* serves to provide the estimation on GHG emissions when conventional coal was substituted by clean coal by 5%, 10% and 15%. The results show that the total GHG emissions from the proposed fuel mix in 2020 would be reduced to 339,964 kt, 329,834 ktand 305,288 kt, equivalent to59%, 60% and 63%, respectively, of GHG emissions reduction. These findings highlight the importance of adopting sustainable fuel alternatives. The study also proves that Malaysia could reduce GHG emissions substantially by a factor of 2.7 when clean coal technology is used concurrently with the Five-Fuel Diversification Strategy fuel mix power generation. For that reason, clean coal could be regarded as one of the most promising and effective sources of alternative energy for a sustainable power generation. It holds the promise of decreasing environmental degradation while satisfying Malaysia's goal for fuel diversification.

4.2 Policy implications

These research findings imply that clean coal technology is highly instrumental in alleviating CO_2 emission in Malaysia's energy sector. The current NEP approaches should be reviewed to ensure widespread dissemination of clean coal technology in Malaysia. Some of the policy recommendations include the:

- Establishment and implementation of new laws and mandatory regulations that favour clean coal utilisation. A legal liability of pollution related to coal use should be imposed. Carbon tax, for example, could be introduced to curb acquisition of new coal power plants and force the power industry to adopt enabling technology such as clean coal as part of their CO_2 mitigation plan.
- Establishment of a new policy framework that outlines the role of clean coal technology in coal-fired power generation, as well as the method to estimating the associated carbon emission reduction. Government incentive shall be given based on the amount of carbon emission reduction achieved. The high initial capital cost to adopt high-efficiency, low-emissions (HELE) technologies such as the supercritical (SC), ultrasupercritical (USC), and advanced ultrasupercritical (AUSC) boilers could be minimised through provision of attractive private financing and loan schemes.
- Implementation of awareness program through active government engagement with power industry stakeholders, including the public community. Existing knowledge gap should be identified and lessened through strategic professional hiring and institutional training from more advanced countries to accelerate technology transfer. This, in turn, will reduce risks and uncertainties, thus facilitating the decision-making with respect to the deployment of clean coal technology.
- Establishment of a long-term international cooperation framework among developing countries in Southeast Asia. This is to stimulate strategic inter-government collaborations in clean coal technology financing by leveraging resources and fostering market push innovations.

4.3 Model limitation and future work

There are some limitations in this study. Firstly, this study did not consider the cost of technology for clean coal option and system. Secondly, although many variables were analysed to meet the objective on clean coal option, the exclusion of some other variables such as durability, efficiency and cost-effectiveness might limit the result analysis. Thus, future studies should consider electricity vision 2030 with investment options and pricing strategies. Multiple relevant analyses could then be carried out, providing more accurate estimations on the affordability and acceptability of clean coal energy prospect for power generation in Malaysia.

5 Conclusions

This study used a modelling technique to explore the GHG emissions resulting from Malaysia's Fuel Diversification Strategy. The study found that the Five-Fuel Diversification Strategy will cause high GHG emissions in 2020 due to its high conventional coal mix in the power generation portfolio. However, when the conventional coal is substituted with clean coal, the GHG emissions in the year 2020 could be significantly lessened. The discussed findings would help national policymakers to formulate an effective and greener energy strategy in Malaysia and other developing Southeast Asian countries.

Acknowledgements

The authors wish to thank the Universiti Tenaga Nasional, especially the Institute of Energy Policy and Research (IEPRe), for providing the support to carry out this study.

References

Ahmed, F. et al. (2013) 'Alternative energy resources in Bangladesh and future prospect', *Renew. Sust. Energ. Rev.*, Vol. 25, No. 1, pp.698–707.

Ahmed, S. et al. (2011) 'Climate volatility and poverty vulnerability in Tanzania', *Glob. Environ. Change-Human Policy Dimens.*, Vol. 21, No. 1, pp.46–55.

Binti, Z. et al. (2017) 'Determinants and outcome of a clean development mechanism in Malaysia', *Journal of Cleaner Production*, Vol. 142, pp.1979–1986, Elsevier Ltd., doi: 10.1016/j.jclepro.2016.11.086.

Chien Bong, C.P. et al. (2017) 'Review on the renewable energy and solid waste management policies towards biogas development in Malaysia', *Renewable and Sustainable Energy Reviews*, June, Vol. 70, pp.988–998, Elsevier Ltd., doi: 10.1016/j.rser.2016.12.004.

Economic Planning Unit (Malaysia) (2006) *Ninth Malaysia Plan 2006–2010*.

Energy Commission (Malaysia) (2014) *Energy Malaysia: Towards a World-Class Energy Sector*, p.2, Malaysia.

Energy Commission (Malaysia) (2017) *National Energy Balance 2015*, p.106, Putrajaya, Malaysia.

Energy Commission (Malaysia) (2018) *National Energy Balance 2016*, p.114, Putrajaya, Malaysia.

Energy Commission of Malaysia (2017) *Review on Electricity Tariff in Peninsular Malaysia under the Incentive-based Regulation Mechanism (FY2014-FY2017)* [online] https://www.st.gov.my/ms/contents/presentations/tariff/1_ST_Proses semakan dan keputu (accessed 1 April 2018).

Guan, G. (2017) 'Clean coal technologies in Japan: a review', *Chinese Journal of Chemical Engineering*, Vol. 25, No. 6, pp.689–697, Elsevier B.V., doi: 10.1016/j.cjche.2016.12.008.

Hasanuzzaman, M. et al. (2011) 'Energy savings and emissions reductions for rewinding and replacement of industrial motor', *Energy*, Vol. 36, pp.233–240.

Hasanuzzaman, M. et al. (2013) 'Energy savings in the combustion based process heating in industrial sector', *Renew. Sust. Energ. Rev.*, Vol. 16, No. 7, pp.4527–4536.

INDC (2015) *Intended Nationally Determined Contribution Malaysia to United Nations Framework Convention on Climate Change (UNFCC): Final Revision*, UN.

International Energy Agency (IEA) (2017) *World Energy Outlook*, Paris.

International Energy Agency (IEA) (2018) *World Energy Outlook*, Paris.

International Monetary Fund (2018) *GDP Per Capita, Current Prices* [online] http://www.imf.org/external/datamapper/NGDPDPC@WEO/THA/IDN/PHL/VNM/MYS/SEQ/BRN/SGP (accessed 3 May 2018).

IPCC (2005) 'Carbon dioxide capture: summary for policymakers', *Angewandte Chemie (International ed. in English)*, Vol. 49, No. 35, pp.6058–82, doi: 10.1002/anie.201000431.

Jafar, A., Al-Amin, A. and Siwar, C. (2008) 'Environmental impact of alternative fuel mix in electricity generation in Malaysia', *Renew. Energy*, Vol. 33, No. 10, pp.2229–2235.

Lobell, D. et al. (2008) 'Prioritizing climate change adaptation needs for food security in 2030', *Science*, Vol. 319, pp.607–610.

Lobell, D., Bonfils, C. and Duffy, P. (2007) 'Climate change uncertainty for daily minimum and maximum temperatures: a model inter-comparison', *Geophys. Res. Lett.*, Vol. 34, pp.05711–05715.

Lobell, D., Schlenker, W. and Costa-Roberts, J. (2011) 'Climate trends and global crop production since 1980', *Science*, Vol. 333, pp.616–620.

Mekhilef, S. et al. (2011) 'Biomass energy in Malaysia: current state and prospects', *Renewable and Sustainable Energy Reviews*, Vol. 15, No. 7, pp.3360–3370, doi: 10.1016/j.rser.2011.04.016.

Melikoglu, M. (2018) 'Clean coal technologies: a global to local review for Turkey', *Energy Strategy Reviews*, October, Vol. 22, pp.313–319, Elsevier, doi: 10.1016/j.esr.2018.10.011.

Miller, R. and Blair, P. (2009) *Input-Output Analysis: Foundations and Extensions*, 2nd ed., Cambridge University Press, New York.

Ministry of Energy Communications and Multimedia (Malaysia) (2009) *National Energy Balance of Malaysia*, Putrajaya, Malaysia.

Ministry of Natural Resources and Environment (Malaysia) (2018) *Malaysia Second Biennial Update (BUR) to United Nations Framework Convention on Climate Change (UNFCC)*, Final Draft Version, Malaysia.

Oboirien, B.O. et al. (2018) 'Analysis of clean coal technology in Nigeria for energy generation', *Energy Strategy Reviews*, Vol. 20, pp. 64–70, Elsevier Ltd, doi: 10.1016/j.esr.2018.01.002.

Oh, T., Pang, S. and Chua, S. (2010) 'Energy policy and alternative energy in Malaysia: Issues and challenges for sustainable growth', *Renew Sust. Energ. Rev.*, Vol. 14, pp.1241–1252.

Okutsu, A. and Suguira, E. (2018) 'Southeast Asian coal demand to grow at fastest rate in world', *Nikkei Asian Review* [online] https://asia.nikkei.com/Business/Markets/Commodities/Southeast-Asian-coal-demand-to-grow-at-fastest-rate-in-world (accessed 10 February 2019).

Rahman, M. and Lee, K. (2006) 'Energy for sustainable development in Malaysia: energy policy and alternative energy', *Energy Policy*, Vol. 34, pp.2388–2397.

Saidur, R. et al. (2011) 'Chillers energy consumption, energy savings and emission analysis in an institutional buildings', *Energy*, Vol. 36, No. 8, pp.5233–5238.

Solomon, S.D. et al. (2007) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Sovacool, B.K. and Drupady, I.M. (2011) 'Examining the small renewable energy power (SREP) program in Malaysia', *Energy Policy*, Vol. 39, No. 11, pp.7244–7256, Elsevier, doi: 10.1016/j.enpol.2011.08.045.

Tang, X. et al. (2015) 'Clean coal use in China: challenges and policy implications', *Energy Policy*, Vol. 87, pp.517–523, Elsevier, doi: 10.1016/j.enpol.2015.09.041.

TERI (2010) *Reviewing Select Climate Relevant Technologies and Pertinent Issues for Countries*, India.

The Institute of Energy Economics Japan (IEEJ) (2018) *IEEJ Outlook 2019: Energy Transition and a Thorny Path for 3E Challenges*.

United Nations (2015) *Paris Agreement*, United Nations Framework Convention on Climate Change, UN.

United Nations Statistics Division (no date) *Millennium Development Goals Indicators*, New York, USA.

World Bank Databank (2013) *The World Bank*, USA.

Zamzam, J., Kheng, W. and Kamaruddin, N. (2003) 'Greener energy solutions for a sustainable future: issues and challenges for Malaysia', *Energy Policy*, Vol. 31, No. 11, pp.1061–1072.

Zhang, L. et al. (2018) 'Modeling and implication of coal physical input-output table in China – based on clean coal concept', *Resources, Conservation and Recycling*, Vol. 129, pp.355–365, Elsevier B.V., doi: 10.1016/j.resconrec.2016.10.005.