Title page

Techno-Economic and Environmental Analysis of Power Generation Expansion Plan of Ghana

Albert K. Awopone[a,b*], Ahmed F. Zobaa[a], Walter Banuenumah[b]

[a] College of Engineering, Design and Physical Sciences, Brunel University London,
Uxbridge UB8 3PH, UK

[b] College of Technology, University of Education, Winneba, P. O. Box 1277 Kumasi,
Ghana

Corresponding author: Tel.+447557090644
E-mail address: albert.awopone@brunel.ac.uk

Highlights

- LEAP demand projection for Ghana from 2010 to 2014.
- Develop scenarios using an adaptation of Schwartz’s scenario approach.
- Develop LEAP model for generation scenario.
- Each scenario represents possible generation expansion strategy.
- High renewable energy systems penetration results in net economic and environmental benefits.

1. Introduction

Ghana faces serious energy related challenges as the country struggles to meet generation requirement. The electricity supply system of the country is characterised by power outages which has serious implications on the quality of life as well as industrial development. Stable electrical energy is important with the recent development of the country's oil and gas industry which has the potential of attracting investors to the expected oil and gas driven economy in the near feature, since reliable and affordable electricity generation system is an indispensable commodity in the technological development of any country. Even though the country is unable to meet the current demand, the future demand is projected to be increasing at 10% per annum (Abledu, 2013). This does make the development of a realistic generation expansion plan very essential if the country is to achieve its medium to long term development goals. Inadequate appropriate expansion has resulted in the current situation where the generation capacities can only meet about 65% of the current demand (March 2014) (Energy Commission, 2015)

The conventional grid generation in Ghana is by Hydro, with the Akosombo Hydro dam providing almost all the grid power when it was commissioned in 1966 (Aryeetey, 2005). The Akosombo generating plant was originally constructed with a total installed capacity of 588 MW. The capacity was increased to 912 MW in 1972 with an addition of two generating units to the original four. (Aryeetey, 2005). The construction of the Akosombo hydro plant was tied to the Volta Aluminium Company (VALCO). The idea was to develop the huge bauxite reserves in the country to make use of the energy from the Akosombo dam (VALCO, 2016). The smelter was subsequently constructed consisting of five portliness capable of producing 200 000 MT of primary aluminium annually. The company today which is now 100% owned by the Government of Ghana operates about 20% its rated capacity as a result of insufficient supply of power (Energy Commission, 2015). An additional hydro dam, the Kpong dam, was constructed near Akuse, 24 km downstream of Akosombo dam. The Kpong hydroelectric plant was commissioned in 1982 with an installed capacity of 160 MW (Aryeetey, 2005). Thermal power generation was introduced to supplement the conventional Hydroelectricity after a drought in 1983 underscored the need to diversify the country's generation system. The introduction of Thermal power generation into the generation mix of the country occurred in 1997 with the construction of a combined cycle power plant with an installed capacity of 330 MW at Aboadze near Sekondi-Takoradi. The Takoradi Thermal Power Station (TAPCO), as it is officially called, was eventually expanded to 550 MW with the addition of 2x110 MW combustion turbine plants in 2000. This marked the beginning of a gradual shift to thermal generation in the country. The installed capacity as at March 2014 was 2851MW which is made up of 1580 MW (55.4%) from the three hydro dams, 1248 MW (43.77%) from Thermal plants and only 2.5 MW (0.09%) from photovoltaic plant (Energy Commission, 2015). All the plants are operated by Volta River Authority (VRA) except Bui, which is operated by Bui Power Authority (BPA). VRA and BPA are both government agencies. Sunon-Asogli, and CENIT are private entities which contribute about 11.61% of the installed capacity (Energy Commission, 2015).

There is a growing interest in power generation systems worldwide because of the growing demand of power and the environmental implications of these power systems. The adverse environmental and societal impacts and fluctuation in the prices of fossil fuels in the world market has necessitated the exploitation of sustainable power generation technologies. Ghana is endowed with a number of renewable energy resources which can be exploited to help meet the energy needs of the country. There an excellent solar radiation all year round, and in every part of the country, with an average radiation of 5.5kWh/m^2. Sites suitable for medium and small hydro power plants have also been identified in various part of the country with a potential of adding over 900 MW to the national grid if fully exploited. Sites near the coastal parts of the country have also been identified with excellent conditions for wind thermal generation (Gyamfi, et al., 2015).

The scenario approach was adopted to examine the possible pathways that future generation system in Ghana could evolve. Scenario approach is a key techniques applied by futurists in various disciplines to develop strategic plans and policies. Several definitions of scenario exist in literature, however the definition of the Intergovernmental Panel on Climate Change (IPCC) summarises the concept of scenario analysis as applied to the natural sciences (IPCC, 2013): *"A scenario is a coherent, internally consistent and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future can unfold".* It is deduced from this definition that scenarios are not predictions, and hence do not forecast, but rather present alternatives of possible outcomes. The term scenario as it is applied in strategic planning was pioneered by Herman Khan and was originally applied in military studies in the 1950s (William, 1988). The concept has since been applied in an increasing number of disciplines: Kahn and Wiener developed scenarios to explore the consequences of nuclear proliferation at the heart of the cold war (Kahn & Wiener, 1967) , while Brewer applied the concept to explore policies for Europe forestry sector (Brewer, 1986). The Intergovernmental Panel on Climate Change (IPCC) has applied this methodology by developing emission scenarios in its assessment reports (IPCC, 2016) . The application of scenarios for the energy studies are inspired by the work of Lovins who developed scenarios for Soft Energy Paths (SEP) (Swart, et al., 2004). Most recent energy scenarios with continental focus include Energy Technology Perspectives (IEA, 2014), International Energy Outlook (EIA, 2014), Greenpeace's Energy Revolution (Teske, et al., 2015) and World Energy Outlook (OECD/IEA, 2013) . At the national level, scenarios were employed for assessing alternative energy pathways in California (Ghanadan & Koomey, 2005), Venezuela (Bautista, 2012), Korea (Park, et al., 2013), Panama (McPherson & Karney, 2014) and most recently, for environmental assessment of energy production from landfill gas plants in Tehran (Nojedehi, et al., 2016).

In Ghana, scenarios approach was applied to develop the strategic national energy plan from 2006 to 2020 (Energy Commission, 2006). This study examines three pathways: option1 is an expansion plan based on thermal and 10% Non-conventional Renewable Energy Technologies (NRET)[1] by 2020; option 2 based on thermal, Bui hydro and 10% NRET and option 3 is thermal, nuclear and 10% NRET. The current study presented in this paper made use of option 2 which represents the current official expansion plan as the base case scenario and explores the performance of generation system with higher levels of NRET. The aim of the analysis is to provide a framework that could lead to discussion for the development of renewable energy technologies in Ghana. Nonetheless, these scenarios can never be an exhaustion of all possible pathways. However, the findings in this paper will provide a useful platform for discussions with stakeholders and energy policy planners.

2. Methodology

2.1. Scenario Framework

Due to the diverse nature of the application of this technique, various methodologies have been developed to guide scenario development. The scenarios in this paper were developed to explore possible developments in the supply side of the generation system of Ghana using an adaptation of the Schwartz's scenario planning methodology (Schwartz, 1991). Schwartz's scenario methodology is one of the most comprehensive methods of scenario building and has been applied widely in literature for scenario planning. An adaptation of Schwartz's

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[1] NRET does not include large hydro generation

approach was used in developing scenarios to explore energy pathways in California (Ghanadan & Koomey, 2005). A framework developed to support environmental decision making was also based on this methodology (Mahmoud , et al., 2009). Schwartz's approach was also employed for analysing alternative generation pathways for the Panama's electricity sector Figure 1 shows the framework used in the development of the scenarios in this paper (McPherson & Karney, 2014).

Figure 1 Framework for Scenario development
(Schwartz, 1991)

Step 1: Identifying focal issue: the construction of scenarios begins with identification of the main topic or idea and building outward. The focal point of this paper was to explore the suitability of high integration of Renewable Energy Technologies (RET) in Ghana.

Step 2: identification of key variables: the second stage involves listing the key variables influencing the outcome of the decision as well as the social, economic, political, environmental and technological forces that influence the key factors. Examples of key variables that influence the generation sector of Ghana includes energy security and reliability, types of RET technologies, RET potential, cost of fuel, technical capacity, Cost of technologies as well as economic and population growth rates.

Step3: Evaluating key variables: the next stage involves ranking of key variables making use of two criteria: degree of importance and degree of uncertainty. The idea is to identify two or three of the most important and uncertain variables from the ranking. Figure 2 presents the ranking of the key variables influencing the generation system of Ghana.

Figure 2 Evaluating driving forces in generation system of Ghana (Ghanadan & Koomey, 2005)

Step 4: Developing scenarios logic: The scenario logic is then developed based on the ranking exercise. The key is to end up with few policy scenarios with clear policy direction to assist decision makers. The scenarios are developed to revolve around the key variables and enriched by adding details making use of the other key factors. This is done by making use of each key structure or trend of the ranking.

The most uncertainty and important driving forces highlighted in Figure 2 form the basis for the development of the four scenarios analysed in this paper:

The Base Case scenario which assumes the current generation capacity addition in Ghana and shows increased expansion in thermal power generation which operates largely on natural gas (NG) and crude oil will continue into the future. The capacity addition of NRET were based on the national strategic plan (Energy Commission, 2006) and the most recent modification of the country's renewable penetration target presented as part of the country's Intended Nationally Determined Contribution (GH-INDC) presented to the United Nations Framework Convention on Climate Change (UNFCCC) during COP21 in Paris in December 2015, as well as the committed systems that are either currently under construction, or have been granted permits by Energy Commission of Ghana (Energy Commission, 2015). Existing thermal plants will continue to operate on both natural gas and crude oil with the aim to switch fully into natural gas by 2030 to conform to the existing national strategy. New thermal generation plants will be fuelled by natural gas.

Coal scenario is similar to the base case except with the introduction of coal plants to take share of new natural gas thermal plants. This scenario assumes the introduction of coal plants to meet 10% of new thermal plants that are to be constructed from 2016 onwards.

Modest RET scenario focuses on the promotion of renewable energy technologies which have significant potential. Thus PV, Wind, small Hydro, wave, biomass and MSW are integrated in moderate amounts with the aim of increasing the renewable capacity[2] to about 20% by year 2030.

High RET Scenario explores the full potential of RET. Thus emphasis is placed at deploying renewable energy technologies based on confirmed domestic potential. This scenario assumes shifting of policy towards the development of low emission technologies with reduction in fossil fuel generation.

Step 5: Analyses of the scenarios: the final stage of the scenarios methodology used in this paper involves an analysis of the various scenarios in order to elaborate future generation development proposed by the various scenarios and their consequences. This involves the translation of the qualitative narration of the scenarios into quantity data and assessed using the Long-range Energy Alternative Planning (LEAP) energy planning tool. The Long-range Energy Alternatives Planning (LEAP) system developed by Stockholm Environmental Institute (SEI) is a widely used energy modelling tool for energy policy analysis and Greenhouse gases (GHG) emission mitigation studies, and is widely used especially in developing countries. Applications of LEAP for scenario analysis includes long term forecast

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[2] Renewable energy in this case does not include Large hydro generation

of Taiwan’s energy system (Huang, et al., 2011), analysis of alternative scenarios and their implications on the electricity sector of Lebanon (Dagher & Ruble , 2011), as well as that of Greece (Roinioti, et al., 2012) and for Cambodia and Laos (Luukkanen, et al., 2015). The model has also been applied for environmental and cost assessment of power scenarios in Nigeria (Gujba, et al., 2011). In Ghana LEAP was adopted for developing energy and emission scenarios as basis for the country INDC commitment (Republic of Ghana, 2015). A detail description of the LEAP methodology is available in Heaps (Heaps, 2012).

2.2 Development of Ghana LEAP demand Model

The Bottom-Up demand model approach in LEAP was adopted for modelling the future energy demand in this thesis. Bottom-Up or End Use approach provides a detailed engineering based modelling account for sectors as well as end users and energy consuming devices and is the most suitable method when assessing long term transitions (Heaps, 2012). The key factor in the development of future energy system is the projection of demand, which in turn depends on the demographic and macroeconomic indicators of the study area. A reliable energy system should be able to meet the demand requirement. The population of Ghana in 2010 was 24 658 845 million people which was projected to be increasing at a growth rate of 2.4% (Ghana Statistical Service, 2013). The electricity consumption pattern in Ghana varies significantly between urban and rural areas. In 2010, 83.8% of the urban households had access to electricity compared to only 39.5% of rural households. With the current average population growth rate of 55.8% in 2010, which is expected to increase to about 60% by 2040 (Ghana Statistical Service, 2013), the energy demand for domestic consumption is expected to increase significantly by 2040.

The Gross Domestic Product (GDP) average growth rate from 2005 to 2009 was about 6% rising to a peak of 14% in 2011 as a result of the production of crude oil in commercial quantities in Ghana, which began in late 2010 (Ghana Statistical Sevice, 2016). The GDP growth rate of 8% was adopted for base case load projection from 2010 to 2020, increasing to 12% from 2020 to 2040 when the power supply is expected to improve. The energy intensity data used for the model was developed from energy consumption survey conducted by the Energy Commission of Ghana in 2010 (Energy Commission, 2015).

The LEAP model was designed with 2010 as the base year, to analyse the possible developmental structure of the generation system of Ghana up to 2040. The choice the base year was due to availability of data: the national census conducted by the Ghana Statistical Service (Ghana Statistical Service, 2013) and a national energy survey by the Energy

Commission (Energy Commission, 2015) were conducted in 2010, providing reliable data for model. The selection of 2010 also provided opportunity to validate the results with real data for the past years (2010 to 2014).

The results of the energy demand projection from 2010 to 2040 using LEAP energy demand model is presented in Figure 3.

Figure 3 Electricity demand forecast

The results show that demand projection will increase into the future with an average demand growth rate of 9%, 8% and 8% within the periods of 2010 to 2020, 2020 to 2030 and 2030 to 2040 respectively. These growth rates follow the historical demand growth of the country, and are consistent with official load projections (GRIDCO, 2011). Figure 3 further shows that the total energy requirement of Ghana by 2020 will be 18.88GWh increasing to 62.5 GWh at the end of the study period. This means that the current installed capacity of 2.19 GW will have to be expanded to 5.0 GW and 16 GW in 2020 and 2040 respectively, if the country is to be able to meet its future electricity requirement. This therefore requires the exploration of all energy sources available in the country and long term energy development and expansion plan if the country is to benefit from its expanding economy due to its recent oil and gas production.

It is important to note that the actual demand may be higher than the projection in this study. This is because the projections are based on historical demand and GDP values which themselves may not reflect the actual demand. The insufficient generation and low electrification rate especially in rural areas lead to suppressed demand. Thus the historical trends alone may not fully capture the real demand which is best captured by back casting (Bazilian, et al., 2012). This is confirmed by the trend in historical demand data of Ghana (Energy Commission, 2015), which shows a negative demand growth during the energy crises in 2007. This clearly shows that the official demand projection is closely related to generating capacity. The focus of the paper is to explore possible pathways for sustainable power generation in Ghana and to undertake an environmental and economic analysis of the various scenarios. As a result, this demand will be used for all the scenarios.

The technology cost data was adopted from IEA (IEA, 2014), NREL (NREL, 2012) and GRIDCO (GRIDCO, 2011). The future year investment cost of the conventional energy systems in Ghana (large Hydropower and thermal power) were assumed to be constant throughout the study period while that of renewable systems were assumed to decrease according to projections presented in IEA (2014). Table 1 shows the investment, fixed operational and maintenance (O&M) and variable O&M values considered in the LEAP model for the various times intervals considered in the study. Fixed operation and Maintenance (O&M) is the part of the maintenance cost of a plant which does not depend on the operation of the plant. Components of fixed O&M includes property tax and insurance, planned and unplanned maintenance, administration, operation staff as well as re-investments within the scheduled lifetime of the plant. Variable O&M generally refers to consumption of auxiliary material such as fuel additives, lubricants and lubricants, and treatment and disposal of waste. Renewable energy systems such as wind and PV have very low variable O&M which was considered to be zero in this paper

Table 1 Cost data considered in LEAP

The operation and maintenance cost were calculated using the percentage rates from National Renewable Energy Laboratory (NREL) cost and performance data for power generation technologies rates (NREL, 2012).

The prices of fossil fuel resource are particularly very difficult to predict because of its high price fluctuations in the world market. However, the bench mark fuel price projections in IEA annual energy outlook 2015 (IEA, 2015) were considered as the most reliable assumptions and hence adopted for this paper. These prices are the average spot price in the United States and hence did not include local port as well as transportation charges. Even though Ghana started producing oil and gas in commercial quantities in 2010, the prices in the local market are determined by the international prices and are adjusted in line with fluctuations in the international market.

To model the feedstock fuel of the thermal plants considered in the Ghana LEAP model, the actual crude oil and natural gas prices made available for power generation in Ghana were used for the reference years, that is, from 2010 to 2015. For the future years, the price projections in (IEA, 2015) were adopted. Transportation and taxes were calculated using 20% and 90% for crude oil and natural gas respectively to reflect the current price trend. Table 2 shows the fuel prices used in the LEAP model.

Table 2 Fuel prices used in the model

Ghana has no known coal reserves. The model therefor assumed that all coal will be imported. The coal price projections were therefore based on the projections, while transportation, taxes and processing charges were assumed to be 60%.

2.3 Modelling the Generation System

The dependent installed capacity of Ghana in 2010 was 1865 MW consisting of two large hydro dams with capacity of 1040 MW with the remaining contribution from six thermal power plants. To model the generation system of Ghana in LEAP, the various generating plants were aggregated. This means that single hydro and thermal plants were modelled to represent the system.

The operational characteristics of the plants used in modelling the generation system from 2010 to 2014 are presented in Table 3.

Table 3 Operational characteristics of generation plans in Ghana

The data in Table 3 was developed from actual plant operational data obtained from energy outlook of Ghana from 2011 to 2015 (Energy Commission, 2015). All the plants were modelled as combined cycle plants because plans are far advanced to convert all the remaining simple cycle plants into combine cycle (Energy Commission, 2006).

Most of the thermal plants in Ghana are designed to operate on LCO and natural gas. Natural gas is the preferred fuel when available because of its relative low cost and minimal environmental impact. However, because of insufficient supply, LCO continue to contribute almost half of the feed stock fuel (Energy Commission, 2015). The feedstock ratio of 55% NG and 45% LCO was assumed for 2010 to 2014. Beyond 2014, the ratio was interpolated to 80% and 20% for natural gas and LCO by 2020 respectively, and eventually to 100% natural gas by 2030. This is in line with the proposals to operate the thermal plants fully on natural gas described in the Strategic National Energy Plan (SNEP) of Ghana (Energy Commission, 2006).

Results and Discussion

3.1 Technical

The generation outlook of Ghana under various policy directions described in the scenarios is presented in Figure 4. It is observed from Figure 4 /that the installed capacity of Ghana will need to be expanded to at least 16 GW in order to meet demand and the specified reserved margin.

Figure 4 Installed capacities of scenarios

Higher installed capacities will be required for the RET scenarios. This is due to the relatively low capacity credit of renewables considered in higher capacities in RET scenarios and conforms to the finding of McPherson & Karney (2014) which suggest that higher capacities of RET need to be constructed to be able to meet the same demand as that of the thermal plants. The higher RET deployment will ensure higher diversity of the generation mix with a reduction of the thermal share of generation. This will result in 57% and 38% renewable share for high and modest RET scenarios respectively compared to only 18% for the base case.

3.2 Cost

The economic results of the scenarios expressed in 2010 US dollars, are presented in Table 4. O&M cost includes both fixed O&M and variable O&M. Environmental Externalities (Env. Ext.) costs were also captured to enable a quantification of the environmental effect of the scenario. The generation of power from fossil fuel leads to emission of Greenhouse gases (GHG) which has an adverse effect on society. The cost of these negative consequences therefore needs to be considered when appraising generation technologies. Currently, Ghana does not have a carbon tax mechanism in place; however, the study assumes an introduction of $10 /tonne carbon tax in 2020 rising up to $20 /tonne in 2030. The aim of this current study is not to achieve a level of carbon pricing that will overcome externalities associated with power production in Ghana but rather highlight the effect of the introduction of carbon tax on the various scenarios. Revenue from the sale of electricity was not capture in this analysis. This is because the same demand was applied to all the scenarios and the scenarios were modelled to meet this demand as well as the specified reserved margin. Thus the cost benefit summary in Table 4 expresses only the avoided transformation cost[3], fuel purchase and environmental externalities cost compared to the base case scenario. These results may therefore not indicate the exact cost values for the scenarios; however, they provide useful benchmark for comparing their economic performance.

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[3] Transformation cost = capital + O&M cost

Table 4 Cumulative discounted cost benefits 2010 to 2040 relative top base case scenario[4]

It is observed from Table 4 that the capital and O&M costs of the alternate scenarios are higher than the base case scenario. At the reference discount rate (10%), an extra $787 million and $2408 million in capital investment will be required to implement the modest RET scenario and the high RET scenarios respectively over the 30 year study plan considered. These results were not surprising considering the higher investment cost of technologies considered in the alternative scenarios. However, it was observed that the total Net Present Value (NPV) of the cost of the RET scenarios were lower than both the base case and coal scenarios. This is due to the significant savings in cost of fuel that occur in the two RET scenarios. These results show that the current generation system plan of Ghana (Base case scenario) is the obvious choice when consideration is given to only investment cost. However, the long term savings in fuel cost by the alternative scenarios over the study period of 2010 to 2040 increasingly makes the higher integration of RET into the generation plan a viable alternative. The trend in cumulated discounted cost/benefits of the scenarios over the study period is illustrated in Figure 5.

Figure 5 Cumulated discounted cost benefits of scenarios (Discounted Rate =10%)

The results in Figure 5 shows that economic benefits due to savings in fuel cost could be achieved within short term with modest introduction of renewables. However, high RET scenario will begin to yield economic benefits beyond 2033. This means that based on the assumptions and constrains used in developing the scenarios, RET can be deployed into the Ghana generation mix on their own merit when consideration is given to their long term benefits.

Table 4 further compares the NPV of the alternative scenarios under discount rates of 5% and 15%. An immediate observation of the trend in NPV seems to suggest that the choice of discount rate does not significantly affect the choice of the alternative scenario compared to the base case as a similar trend was observed. However an analysis in terms of the cumulative NPV compared to the base case clearly shows that the lower the discount rate, the higher the present value of the future cash flows. It is observe from Table 4 that lower discount rate favour the RET scenarios which are dominated with high capital intensive

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[4] Positive values represent extra cost while negative benefits, compared to base case scenario.

technologies. A key policy priority should therefore be geared towards the provision of guarantee long term finance to promote the high integration of RET.

The cost of fossil fuel was considered as the most important parameter that influences the cost of generation of the thermal plants, while that of RET is largely dependent on investment cost. These two parameters also have high variability in price: while the cost of RET especially wind and solar have seen a downward trend in capital cost; that of fossil fuel price is generally unstable. To this end, sensitivities on the capital cost of RET and cost of fossil fuel were undertaken to determine the effect of variation of these parameters on the economic performance of the scenarios.

Table 5 presents the NPV of the scenarios under the various fossil fuels and RET investment cost sensitivities. The top part of the table shows the cumulative NPV in 2010 billion US dollars, while the bottom part compares the NPV of the alternative scenarios to the base case.

Table 5 Economic performance with fuel and RET investment cost sensitivities[5]

It can be seen from Table 5 that the alternative scenarios are less expensive compared to the base case over the study period. This is mainly due to the higher fuel savings in the alternative scenario with increase in fuel cost. This trend is similar to the trend in Table 4 and seems to suggest that variation in fuel and RET investment cost does not significantly affect the comparative performance of the scenarios. However, a closer look at the percentage change of NPV compared to the base case shows a better understanding of the variation. Modest RET scenario's will be 3.69% to 4.77% less expensive, while that of high RET will be 9.59% to 13.23%, compared to the base case. It was however surprising to note that RET scenarios resulted in higher benefits with higher fuel prices. This was evidenced with the highest savings for the alternative scenarios occurring with HF + LR sensitivity. It can thus be suggested that the inclusion of modest to high RET into the generation mix of Ghana will not only help to diversify the generation system but will also lead to economic benefits of between 0.5% to 13.23% depending on the development of fuel and RET investment cost. This finding has important implications for developing of RET by showing that based on the current economic trends, technologies and energy resources in Ghana, higher penetration of RET is competitive on its own merit to conventional expansion when considered over a 30 year period.

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[5] key: LF = Low fuel cost; HF = high fuel cost; HR = high RET investment cost; LR = low RET investment cost

3.3 Environment

The Forth Assessment Report (AR4) 100 year GWP factors were adopted for this study. This is in line with IPCC's 2013 conference of parties(COP 19) guidelines which recommends that as of 2015, national communications should use the AR4 factors to ensure uniformity in reporting (UNFCCC, 2014). The cumulative one hundred year direct GWP at point of emissions of the scenarios compared to base case scenario is shown in Figure 6. The environmental effect of the introduction of coal on the environment is evidenced by the higher emission of the coal scenario compared to the cleaner NG generation in the base case. The only difference between the coal and base case scenarios is the endogenous addition of coal plants to take up a maximum of 20% of new natural gas plants share. The introduction of coal plants has resulted in a cumulative emission of about 30 million metric tonne CO_2eq compared to base case (Figure 6).

Figure 6 Cumulative GHG emissions compared to base case scenario

There is currently no enforcement of CO_2 emissions limitation on power generation plants in Ghana. This is because of the comparatively lower emission levels in the country because of the relatively low emission factors. This has informed the continuous expansion of thermal plants as represented in the base case scenario. Coal which has presently topped the list of possible candidate plants, will lead to higher emission levels in the country. The contribution of coal generation plants to global GHG emissions is further highlighted in the International Energy Agency (IEA) world energy report (IEA, 2011). According to the IEA, even though coal share of world generation in 2009 was 41%, it accounted for 73% of the world 11.8 Giga tonne of CO_2 emissions for that year (IEA, 2011). Aside the major GHG, coal ash which is solid waste produced after combustion, contains a number of toxins including arsenic, cadmium, selenium. The adoption of the coal scenario will therefore be at the expense to the environment. It is important for the country to consider the introduction of emission standards with the liberalisation of the energy sector to encourage independent power producers to not only invest in renewable energy but to continue to explore more efficient thermal generation such as combine cycle gas plants

Figure 6 further confirms the general idea of the contribution of renewable energy technologies in the reduction of CO_2 emissions. The results shows that if the country could afford to follow the generation expansion plan proposed in the high RET scenario, about 90 million metric tonne CO_2eq will be avoided over the study period, a reduction of about 40%

to the base case plan. It is however essential to further analyse the environmental effect of high introduction of biomass generation which was considered in higher capacities in the RET scenarios. This is because biomass generation lead to higher emission of photochemical oxidation (POCP) and Eutrophication (EP) (Gujba, et al., 2011) as well a source of particulate matter (PM1, PM2,5, PM10) and heavy metals (Paiano & Lagioia, 2016). Over exploitation of forest a reserve leading to deforestation is also possible with biomass generation. These negative implications were not considered in this study. There will therefore be the need to further assess this renewable energy source if the scenarios proposed in this study are to be adopted for implementation. However, Paiano & Lagioia (2016) suggested that innovation in bioenergy convertions could control these emmissions, while the cultivation of dedicated energy crops for power generation may help to solve the problem of deforestation (Zafeiriou, et al., 2016).

The environmental results in LEAP can also be expressed in terms of cost of avoided CO_2 emission. Cost of CO_2 avoided is the cost of reducing CO_2 emission to the atmosphere expressed as $/tonne of CO_2 not emitted with respect to the base case scenario. The decision criterion is to identify the least cost alternative in reducing a tonne of CO_2. The results of the cost of CO_2 avoided under different discount rates are shown in Table 6.

Table 6 Cost of avoided CO_2 emissions (US $/tonne of CO_2eq)

It is interesting to note that even though the GHG savings is higher in the high RET scenario, the modest RET scenario results in net higher benefits at 5% and 10% discount rates. It should be noted that cost of avoided CO_2 is not applicable to the coal scenario since it resulted in higher emission compared to the base case. These results show that Ghana could secure funding through Clean Development Mechanism (CDM) under the Kyoto protocol if the country makes maximum use of its abundant renewable energy potential. CDM allows developing countries to sell carbon credits to developing countries with mandatory greenhouse emission reduction targets.

4. Conclusions and Policy Implications

This study explored a number of policy options that can be adopted to meet the increasing electricity requirements of Ghana based on the available energy resources and technologies. The generation system of the country will need to be expanded more than five times from 2014 to 2040 if the country is to meet the future energy requirement. The country therefore faces a number of policy choices in balancing environmental implications and social cost, as well as diversification of the system.

The results show that an adaption of the coal scenario which is one of the official generation options, will lead to cumulative incremental cost benefits compared to the base case scenario as a result of fuel cost savings over the study period. However, this will be at the expense of environmental implications, as the coal scenario will lead to overall higher 100 year global warming potential. RET scenarios offer favourable options if the appropriate choice is based on environmental and net incremental cost. The significant increase in capital cost is the main hindrance for implementing the RET scenarios. However, the results show that significant savings in fuel cost over the study period will be sufficient to offset the capital investment resulting in net benefits. A long term perspective is thus critical and suggest that RET deployment can be cost effective on their own merit compared to conventional fossil fuel generation when considered over long term horizon.

Diversification of the generation mix with renewable energy technologies will reduce the overall fossil fuel generation which is characterised by unreliable feedstock fuel supply as well as price shocks. The results show significant greenhouse emissions savings is achieved in the RET scenarios resulting in net benefits in cost of avoided emissions compared to the base case. These findings suggest that if the country could afford to develop its generation system with high deployment of RET, additional benefits in the form of carbon trading under the Kyoto could be achieved. This will have significant implication for further development of renewables with availability of funds which is the main obstacle for the implementation of these technologies.

The results reveal that overall benefits are achieved with higher integration of RET. Even though high integration of RET require higher capital investment, significant savings in fuel cost over the study period lead to overall benefits with higher integration of RET. Sensitivities on the development of fuel prices and investment cost of RET revealed that, the integration of modest to high RET into the generation mix will lead to economic benefits of 0.5% to 13.23% depending on the costs development over the 30 year study period. The high RET offers the highest economic and environmental benefits. Policy direction should therefore explore mechanisms which will lead towards higher development of RET technologies.

The main weakness of this study is the key assumptions used in the model. It was not possible to explicitly determine the development of fossil fuel prices into the future considering historical price fluctuations. Also investment cost of energy technologies are site specific, thus using average values may not fully represent the cost at a particular location. The cost results in this study should therefore be interpreted with caution and should therefore not be considered as the exact cost values for the scenarios. Nonetheless the results provided a useful benchmark for analysing the possible generation pathways.

Further studies need to be carried out to assess the impact of high penetration of renewable generation technologies on the stability of the grid as well has grid expansion studies to accommodate the potential generation expansion.

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Table(s)

Table 1 Cost data considered in LEAP

Technology	Investment Cost ($/kWh)		Fixed O&M ($/kW-Yr)		Variable O&M ($/MWh)	
	2010	**2040**	**2010**	**2040**	**2010**	**2040**
Large Hydro	1600	1600	7	7	2.72	2.72
Small Hydro	3300	3300	15	15	6	6
Thermal (NG)	1200	1200	6.31	6.31	3.67	3.67
PV	3200	2010	50	37	0	0
Onshore Wind	1620	1620	49	49	0	0
Tidal wave	4000	3420	147	112		
Biomass	3300	3300	83	83	13	13
MSW	7320	6000	278	223	28	23
Coal	2300	2300	23	23	3.71	3.71

Table 2 Fuel prices used in the model

Fuel	2010	2011	2012	2013	2014	2015	2020	2025	2030	2035	2040
Crude oil ($/bbl)	92	128	130	125	114	60	103	129	163	207	263
NG ($/MMBtu)		6.56	8.19	8.38	8.49	8.80	10.5	12.8	14.5	18.4	24.2
Coal ($/MMBtu)	-	-	-	-	-	3.17	3.42	4	4.67	5.46	6.34

Table 3 Operational characteristics of generation plans in Ghana

	Dependable installed capacity(MW)					
Plants	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Hydro	1040	1040	1040	1420	1420	1420
Thermal	765	765	875	1130	1130	1376
PV				2	2	2
	Average availability (%)					
Hydro	76.78	83	88.6	66.2	67.4	47
Thermal	46.77	46.77	47.45	46.8	46.8	46.7
PV				20	20	20

Table 4 Cumulative discounted cost benefits 2010 to 2040 relative top base case scenario[1]

Cost (Million US$)	5% Discount Rate			10% Discount Rate			15% Discount Rate		
	Coal	**Modest RET**	**High RET**	**Coal**	**Modest RET**	**High RET**	**Coal**	**Modest RET**	**High RET**
Transformation	467.46	2120.37	6249.27	180.62	786.89	2407.60	81.63	309.98	1053.59
Fuel	-1815.21	-3757.94	-8238.53	-685.67	-1290.07	-2856.71	-299.37	-497.37	-1115.76
Env. Ext.	120.72	-213.40	-465.84	39.96	-71.97	-157.84	14.76	26.91	59.35
NPV	**-1227.03**	**-1850.98**	**-2455.09**	**-465.09**	**-598.15**	**-606.96**	**-202.98**	**-214.30**	**-121.52**

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[1] Positive values represent extra cost while negative benefits, compared to base case scenario.

Table 5 Economic performance with fuel and RET investment cost sensitivities[2]

	NPV (Billion 2010 US$)			
	Base	**Coal**	**M. RET**	**H. RET**
LF + LR	15.43	15.24	14.86	13.95
HF + LR	19.50	19.06	18.57	16.92
LF + HR	15.94	15.76	15.86	15.82
HF + HR	20.00	19.56	19.56	18.77
	Percentage change			
LF + LR	0	-1.23	-3.69	-9.59
HF + LR	0	-2.26	-4.77	-13.23
LF + HR	0	-1.13	-0.50	-0.75
HF + HR	0	-2.2	-2.2	-6.12

Table 6 Cost of avoided CO_2 emissions (US $/tonne of CO_2eq)

	Discount rate (%)		
	5	10	15
Modest	-46.15	-14.91	-5.34
High	-28.06	-6.94	-1.39

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[2] key: LF = Low fuel cost; HF = high fuel cost; HR = high RET investment cost; LR = low RET investment cost

Figure(s)

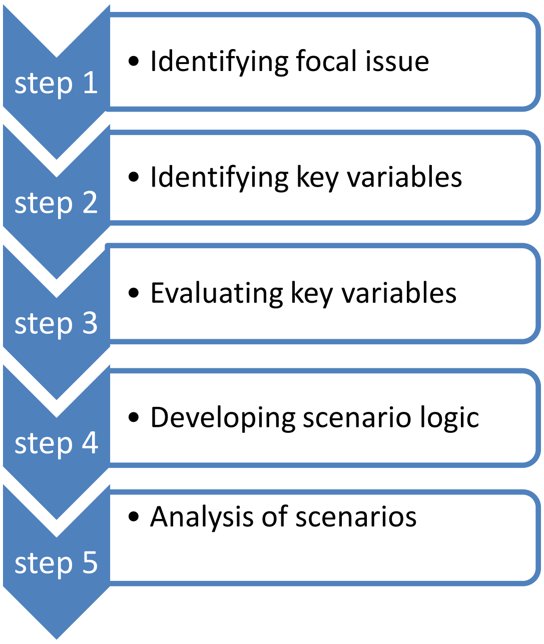

Figure 1 Framework for Scenario development (Schwartz, 1991)

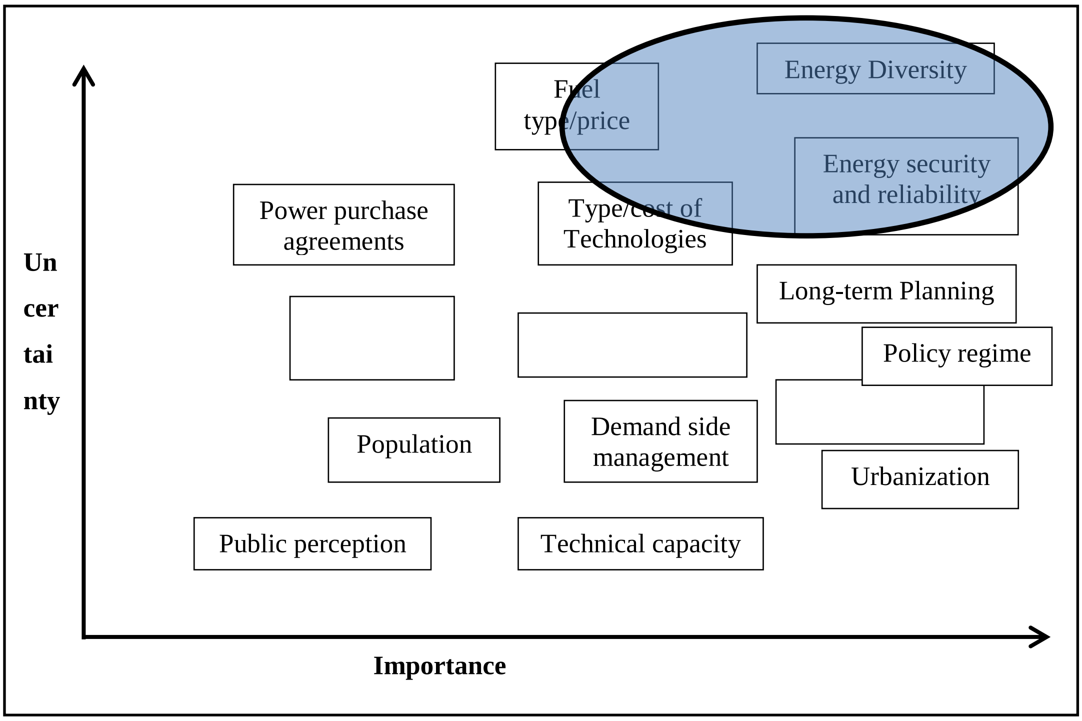

Figure 2 Evaluating driving forces in generation system of Ghana (Ghanadan & Koomey, 2005)

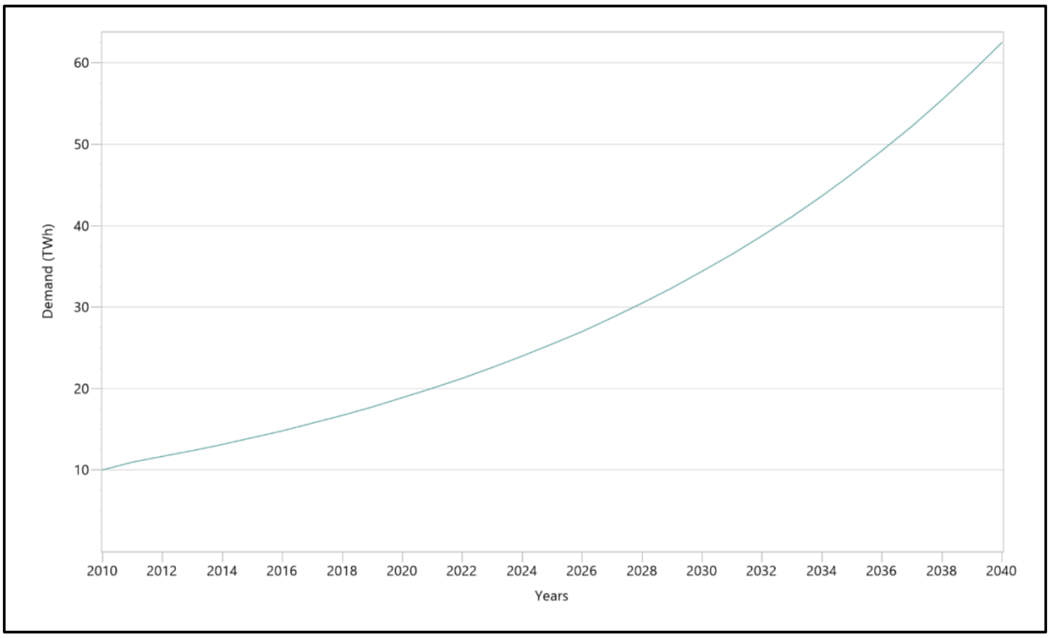

Figure 3 Electricity demand forecast

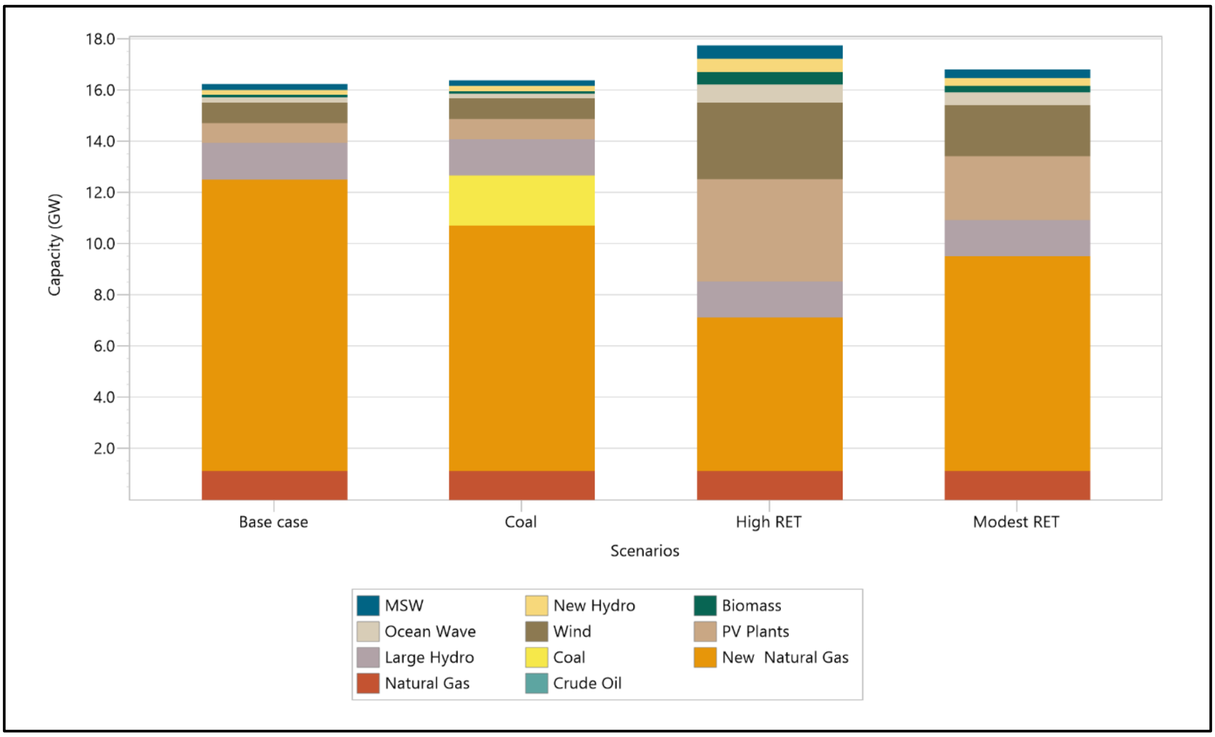

Figure 4 Installed capacities of scenarios

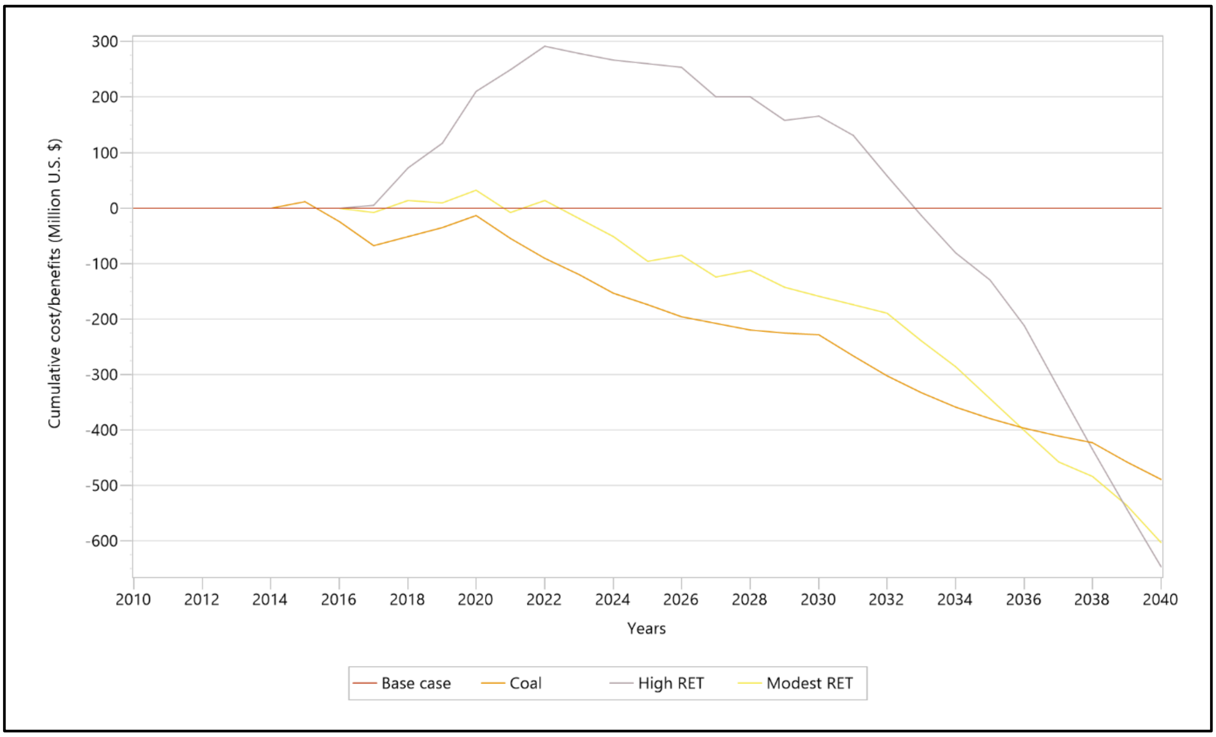

Figure 5 Cumulated discounted cost benefits of scenarios (Discounted Rate =10%)

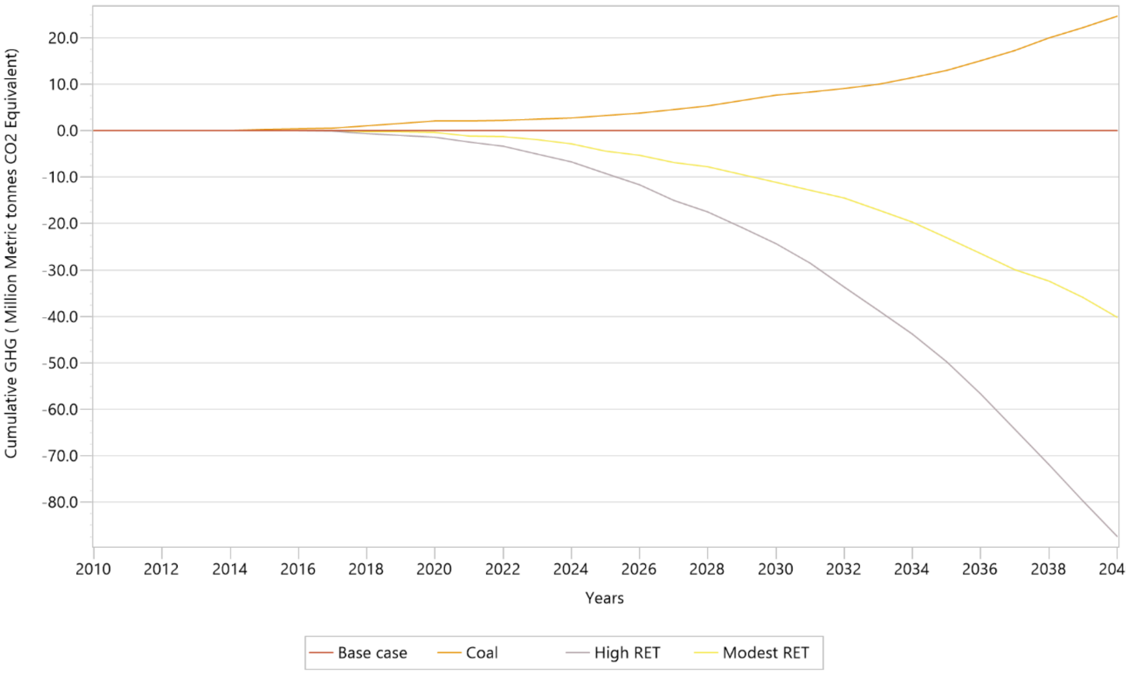

Figure 6 Cumulative GHG emissions compared to base case scenario