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Research article

Prediction of the Contribution of Renewable Energy Sources into Electricity Generation in Tanzania

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Abstract

This paper analyses through modelling the contribution of renewable energy into electricity generations in Tanzania. Two scenarios with regards to the Tanzanian power sector were developed representing renewable energy promotion scenario and the base case scenario. The base case scenario was developed as an overall scenario to predict the supply of energy resources for power generations, whereas the renewable energy promotion scenario was imposed with constraints requiring the gradual introduction of renewable energy technology into electricity generations. The analysis of the power sector for the two scenarios was based on installed capacity, power generation, CO_2 emissions and investment costs using Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE). The results from two scenarios show power generation will be optimally expanded from 11,291 GWh in 2015 to 54,981 GWh in 2035. The total installed capacity will be 2,383 MW in 2015 as compared to 13,177 MW in 2040. Total investment cost for the renewable energy promotion scenario is higher compared to the base case scenario. Renewable energy promotion scenario showed reduction in CO_2 emission contrary to the base case scenario. It is evident from results that without intervention in promoting renewable energy, its contribution in power generation will remain insignificant. The study concludes that it is possible to have renewable energy shares in the power generation mix with an associated rise in investment costs and reduction in CO_2 emissions.

Keywords: Electricity, Emissions, Energy Mix, MESSAGE, Renewable Energy

I. Introduction

Renewable energy is an important energy resource due to its availability and is generally clean, hence environmentally friendly (Dincer, 2000). The use of renewable energy sources in electricity generations is essential for socioeconomic development as it enables production of various products and services which are essential for human wellbeing ranging from domestic to industrial use with ensured security in supply. Tanzania total primary energy supply in 2011 is estimated at 20.75 MTOE while energy net imports stood at 1.64 MTOE (IEA, 2013). The total electricity generated in 2011 was estimated at 4,076 GWh with total system loss of 23% for interconnected grids. Tanzania's annual per capita electricity consumption stood at 81 kWh in 2011/2012 target being 200 kWh in 2015/2016 (MEM, 2012). In Tanzania 18.5% of total population have access to electricity (Msyani, 2013).

Total installed capacity for power generations as of 2012 was hydro 565MW, natural gas 501MW and oil products 375MW with a negligible contribution from renewable energy sources (MEM, 2013). Main sources of energy for electricity generations in Tanzania are coal, oil products, natural gas and hydro. Figure 1 illustrates electricity generation using different sources energy from 1990-2011. Power available for isolated grids through imports from Uganda and Zambia is 8MW and 5MW respectively (MEM, 2012; Vernstrom, 2010). Isolated grids comprise of installed capacity of 21.6MW both being from thermal sources (Mgonja, 2011). The sector has seen a rapid growth in power demands. It is projected the power demand will rise to 75% from the current status of 18.5% (MEM, 2012, 2013). Total country's distribution networks as of 2011 comprised of 400/240V lines having a total length of approximately 26,565km with a system total loss of 23.5% (MEM, 2012).

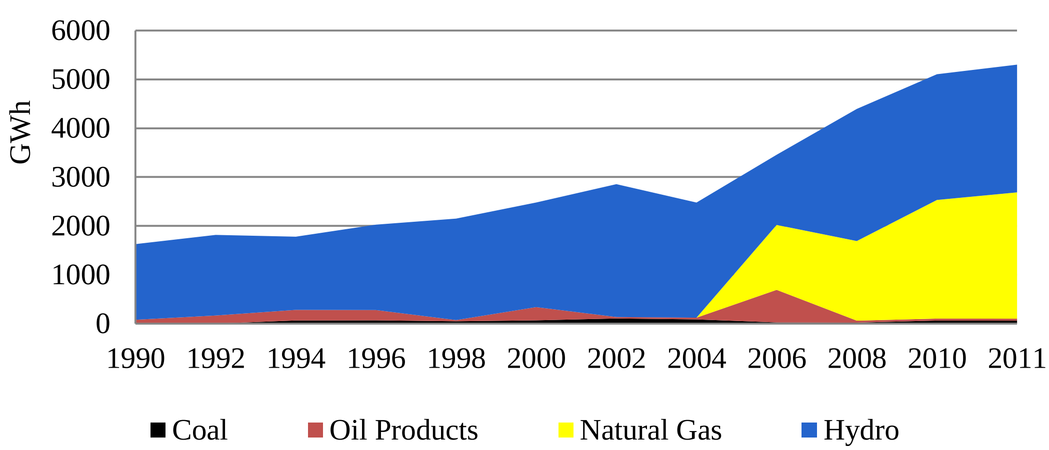

Figure 1: Power generation by fuel type (IEA, 2013).

Power sector has been faced with recurrent challenges in power generations that have seriously affected national socio-economic development and environment. Major challenges facing the power sector are generations challenges, aging infrastructure, power demand growth outstripping supply, high transmission and distribution lossess, among many others (Kihwele et al., 2012). Generations challenges have been due to country's over reliance on hydro for electricity generations (Kihwele et al., 2012; MEM, 2013). Country's spatiotemporal distributions of rainfall suggest the decrease in an overall annual rainfall accompanied with intensified and prolonged dry and wet spells weather events making the predictability of seasonal weather patterns more challenging (Casmiri, 2009; Loisulie, 2010; Valimba, 2004). These effects can be traced back in 2006 where power demand was then 540 MW while six hydro power plants production reached a minimum record of 50 MW at some points (IEA, 2012; Loisulie, 2010).

An example of weather patterns predictability challenges were witnessed at Mtera dam which is the largest hydroelectric dam in Tanzania. The dam was built to ensure that there is sufficient water reserved upstream throughout the year to supply Kidatu hydropower plant. The dam has a catchment area of 68,000 square kilometers with a storage volume of 3,200 million cubic meters (Casmiri, 2009). Mtera dam has experienced high unpredictability in annual rainfall since 2008 as illustrated in Figure 2. The data in Figure 2 indicate an overall decrease in rainfall with the frequency of below average rainfall increasing (MEM, 2013).

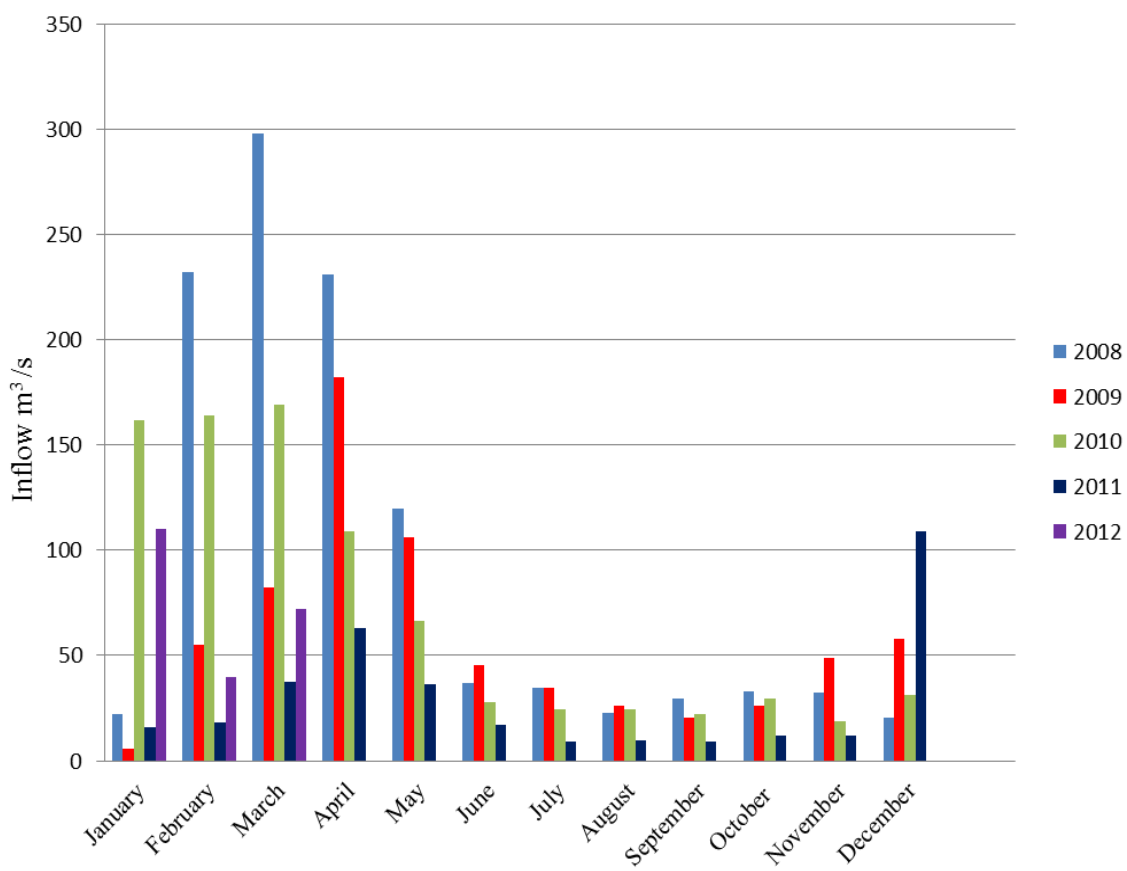

Figure 2: Mtera hydro reservoir inflows (MEM, 2013)

As a solution to hydropower generations challenges, the alternate option focused on thermal generations using locally available natural gas and imported oil products. Status shows the decline in hydropower dependence with recent share being at 35% in 2012 as compared to more than 50% prior to 2000 (MEM, 2013). Tanzania is now shifting from hydro generations to thermal generations as a measure to fill in the gap due to the frequent drought occurrences. This shifting has caused high cost of electricity due to the use of thermal emergency power producers (EPP's). Electricity has turned to be an expensive commodity primarily due to the dominance of thermal generation and secondly the obsolescence of hydropower plants as depicted in Table 1. More than half of hydropower plants in operations are of over twenty years of age. Average life span of hydropower plant is estimated at 50 years after which will require major overhaul (Yüksel, 2010). Thermal power generations have the consequences of high electricity tariffs as compared to hydro power generations. The average cost of electricity from hydro is 0.063 US$/kWh as compared to 0.33 US$/kWh for oil products thermal generations (Evans, Strezov, & Evans, 2009; MEM, 2012; Sims, Rogner, & Gregory, 2003).

TABLE 1: HYDRO POWER PLANT IN TANZANIA

Plant Name	Installation Year	Plant Capacity (MW)	Firm Energy (MW)
Mtera	1988	80	195
Kidatu	1975	204	601
Hale	1967	21	55
Kihansi	2000	180	492
Pangani Falls	1995	68	201
Nyumba ya Mungu	1968	8	20

Source: (MEM, 2012)

Power generation is an important area with strong potential to contribute towards the sustainable economic growth. The use of renewable energy sources is one of solutions in addressing the challenges related to the recurrent drought affecting hydropower generations and environment (Hossain, 2012). Renewable energy resource potential in Tanzania has not been fully exploited, predominantly due to the limited policy interest and investment levels as is the case for the rest of Africa (Karekezi & Kithyoma, 2003). This study focused on modelling the contribution of renewable energy sources into electricity generations using Model for Energy Supply Strategy Alternatives and their General Environmental Impacts abbreviated as MESSAGE. Modelling results from the study will be used as a tool for the policy and decision makers to arrive at a relevant solution interactively in the use of renewable energy resources to meet power demands of Tanzania. Through the output of this study, it is expected Tanzania will realize a sustainable economic development, a stable power supply based on a balanced energy resource mix and ensured energy security due to the use of local energy resources.

II. Methodology

In this study, a bottom-up integer programming based optimization model known as Model for Energy Supply Strategy Alternatives and their General Environmental Impacts (MESSAGE) was used. The model works on the principle of reference energy system which allows representation of the entire energy network including existing and future technologies (Pinthong & Wongsapai, 2009; Rečka, 2011; Selvakkumaran & Limmeechokchai, 2011; Van Beeck, 1999). MESSAGE has an objective of planning to meet demand while minimizing total energy system cost. Mathematical techniques used in MESSAGE are composed of linear and mixed-integer programming (Van Beeck, 1999).

MESSAGE has been chosen in simulating the scenarios in this study due to its features that provide a flexible framework for the wide-ranging modelling of diverse energy supply systems. MESSAGE is the sophisticated model that has the capability to optimize energy supply under user defined constraints such as energy policy constraints, rates of technology penetration in the market, fuel availability and environmental emission control (AlFarra & Abu-Hijleh, 2012; IAEA, 2008). Furthermore, MESSAGE considers current installations and expedient life span, the indigenous availability of energy resources, options for technology expansion and replacement of retired units (Hainoun, Seif-Eldin, & Almoustafa, 2006).

A. Modelling Scenarios

The modelling process applied two scenarios to analyze the contribution of renewable energy in power generations which are the base case scenario (BCS) and renewable energy scenario (RES). The renewable energy in this study is limited to wind, solar PV, solar thermal, geothermal and biomass and excludes hydropower since it is a matured technology in Tanzania and has been extensively in use for over forty years.

The BCS is an overall electricity generation scenario. The scenario intends to illustrate how the electricity generation mix would take into account the renewable energy technologies (RETs) into power generations. In the BCS renewable and non-renewable technologies compete equally for the share in electricity generations. The main feature of BCS is to consider the growth of energy systems to minimize total discounted energy costs based on the technology and resource cost as inputs to the model. This scenario focus on optimizing investments to get a least cost composition of energy sources and technologies to supply electricity in Tanzania.

The RES is developed to have a mandatory minimum share of renewable energy penetration into electricity generation. The scenario target is to introduce steadily the generation of electricity through the use of renewable energy technologies into the total country generations. In the RES scenario, it is required to have a 15% share of wind, solar PV, geothermal, biomass and solar thermal (added together) of the total electricity generation by 2040 starting from 5% in 2020 and progressively increase the share to 10% in 2025 and 15% in 2030 through 2040.

B. Data

Data for the study consisted of electricity demand, technologies, technological constraints and efficiencies, technology's lifetime, investments, fixed costs and capacity boundary. These data are needed to optimize the energy investment through the least cost supply solution in the long-term. Additionally the annual load curve distributed hourly and monthly to capture the variations of demand for fuels within a year was generated.

The study applied eight different technologies using natural gas, biomass, geothermal, solar, wind, coal and imported oil products as fuels for the optimization of power generations under the two scenarios. Natural gas technologies that were used in the optimization were gas turbine (GT) and combined cycle gas turbine (CCGT) power plants. Technologies for solar were solar PV and solar thermal. Other technologies were coal, biomass, geothermal, hydro and wind power plants. Data for this study has been collected from Tanzania Electric Supply Company Limited (TANESCO), Ministry of Energy and Minerals (MEM) - Tanzania and International Energy Agency (IEA).

III. Results and Discussions

The optimal energy mix considering resources investment costs, installed capacity and technologies for the diversification of electricity supply in Tanzania is analyzed in the next sections.

A. Load Curves

The annual load curve distributed hourly and monthly was generated to capture energy consumption behavior. The hourly generation data collected for the years 2009 to 2012 were explored to reveal load demands characteristics in

Tanzania. Hourly load curves were generated by taking average and maximum of values in load demands for a particular hour throughout a year. The hourly load curve is illustrated in Figure 3. It is evident that there is a sharp decrease in demands from 21:00 to 4:00 where the lowest demand point is depicted. This is explained by the facts that most of load demands in households are switched off for the night time. The load demands start to peak slowly again at 5:00 and continues with the trend up to 10:00. At this time horizon most of load consumers at household level are awake for the day's activities and industry consumers often starts days' work at 8:00.

The load starts to level off from 10:00 to 18:00 though there are some drops in demands from 13:00 to 18:00. This is due to the fact that most industrial activities are scheduled for a lunch break at 13:00 and after that they wind up the day's activities. The hourly load curve that shows there is a very sharp rise in the load demands from 18:00 and reach peak level at 21:00. This is attributed mainly by a growing demand of load by a household consumer for lighting and other activities. Load peak hours of the day are observed between 18:00 and 21:00 and the lowest load demand being between 4:00 and 5:00.

The daily, hourly load pattern displays an equally constant load during the day followed by an evening peak with the exclusion of Sunday. Sunday hourly load pattern displays a morning and an evening peak and is typically at a lower demand level than the rest of the week day. An average hourly load curve was divided into five parts to capture the variations in load demands in the MESSAGE model.

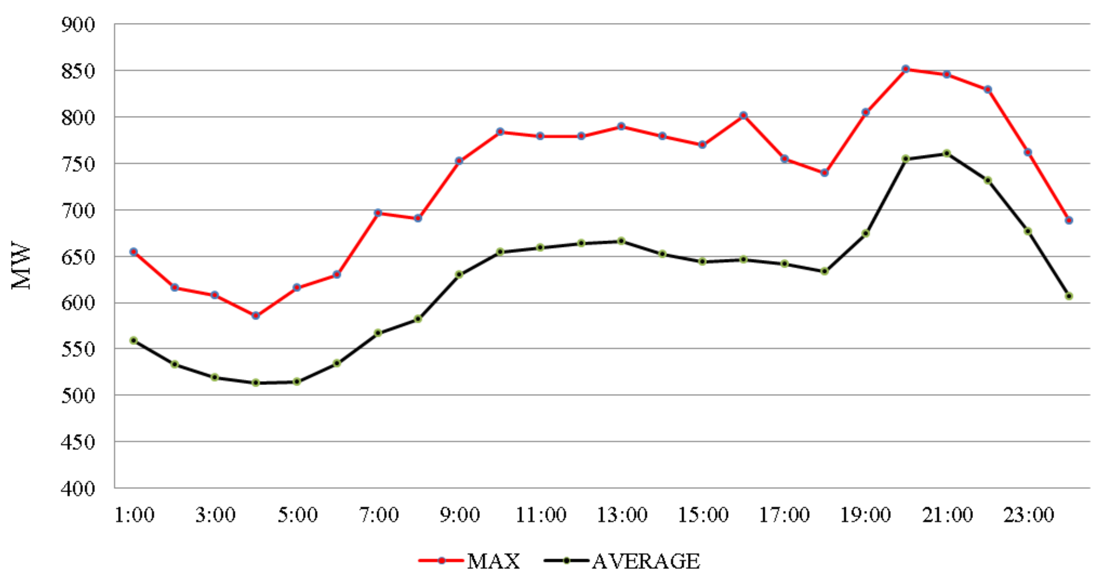

Figure 3: Hourly load curves

B. Scenario Analysis

Optimization results for electricity generation mix in BCS are as illustrated in Figure 4. Electricity generation mix in the BCS is dominated by hydro and coal. In BCS a total of 11,291 GWh will be generated in 2015 as compared to 54,981 GWh in 2035. Matching these results with official projections a total of 11,246 GWh and 47,724 GWh were projected as demands in the year 2015 and 2035 respectively (MEM, 2012, MEM, 2013).

In relation to the modelling results for BCS, natural gas will have the largest share at 44%, followed by coal and hydro at 31.8% and 24% respectively in 2015. The dominance of natural gas will continue through 2040 in which

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natural gas will command a share of 54.3%. The share of hydro will increase from around 24% in 2015 to 40% by 2030 and then decrease to 25% in 2040. The share of hydro and geothermal are limited due to potential constraint of 4700 MW and 650 MW respectively despite their low operating cost advantages (Dincer, 2000; Kihwele et al., 2012; Kusekwa, 2013). Power generations is expected to almost triple by 2025. Combined cycle gas turbine (CCGT) leads natural gas technologies for power productions commanding a share of 79%, 90% and 100% in the years 2015, 2020 and 2025 respectively. This is attributed to good availability, better efficiency and short construction times as compared to gas turbine (GT) technology which is suitable for peak times. CCGTs are the highly favored option where gas is available at reasonable prices due to the peak efficiency of 60% as compared to 40% for GT (Sharman, 2005; Sims et al., 2003).

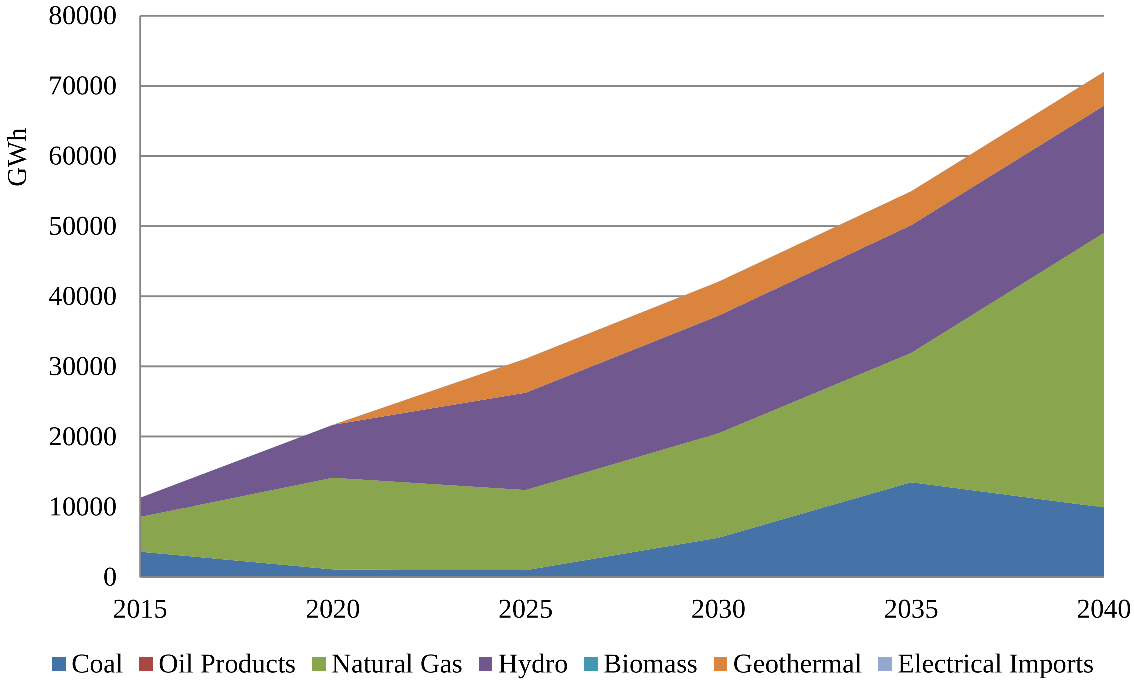

Figure 4: Electricity generation mix – BCS (This study)

Renewable energy technologies were not able to be competitive in the BCS as the optimization was based on meeting demand at a least cost composition of energy sources and technologies. This is due to cost profiles for renewable energy such as solar technologies being of high capital investment and low running costs, due to no fuel requirements (Evans et al., 2009). The only renewable energy technology which was able to penetrate into the energy mix in 2020 was geothermal. Geothermal is characterized by high availability capable to provide base load power for 24 hours a day and lower operating costs as compared to other renewable energy technologies (Evans et al., 2009; Karekezi & Kithyoma, 2003; Sims et al., 2003).

The simulation results for installed capacities of various technologies to produce electricity through 2040 in the BCS are illustrated in Figure 5. Total installed capacity for the years 2015, 2035 and 2040 are 2,383 MW, 9,083 MW and 13,177 MW respectively. Relating these optimization results with official projections, a total of installed capacity for 2015 and 2035 was projected at 2,088 MW and 7,645 MW respectively (MEM, 2012, 2013). The contribution of fossil fuels sources in BCS for 2035 in the installed capacity will be 1808 MW equivalent to 76% of the total installed capacity whereas hydro will contribute 24%. In the year 2040 natural gas will contribute 55% which is the largest share among fossil fuels in the total installed capacity followed by 11% and 29% from coal and hydro respectively with the rest from geothermal. There is little contribution of renewable energy in the base case scenario rather the contribution of fossil fuel technologies which constitutes more than half of the total installed capacity.

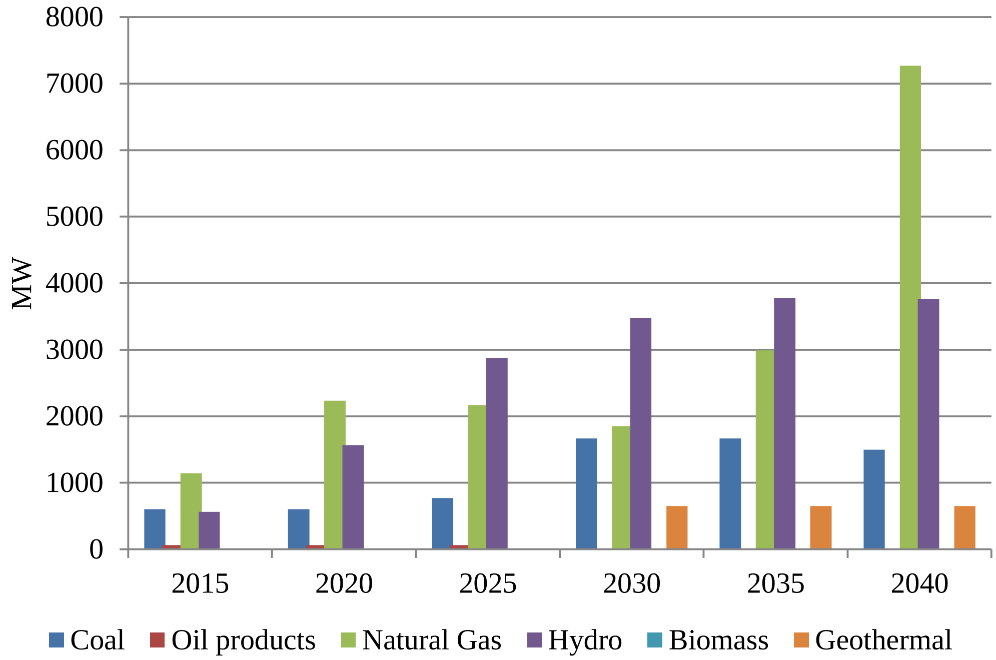

Figure 5: Total Installed capacity – BCS

Optimization results for electricity generation mix in RES are as illustrated in Figure 6. Electricity generation mix for the RES show an increase in the share of renewable energy from 5% in the year 2020 to 10% in 2025 and 15% in 2030 through 2040. Overall electricity generation in renewable energy promotion scenario show natural gas power plants to contribute 45.6% of the total electricity generated in the year 2040 followed by 25% from hydro power plants and 14% from coal. The amount of electricity from fossil fuel sources will decrease from 49,023 GWh in BCS to 42,987 GWh in RES the difference being taken by renewable energy sources. In the year 2040 the total contribution from renewable energy sources will amount to 10,876 GWh as compared to 4840 GWh in the BCS.

Total installed capacity in RES is illustrated in Table 2 for the period from 2015 to 2040. A total of 1,216MW in renewable energy sources will be installed in 2035 of which wind, solar thermal and solar PV geothermal will contribute 500MW, 516MW and 200MW respectively. The contribution of coal and natural gas for the year 2035 will be 1800 MW and 3618 MW respectively in the total installed capacity. Hydro power plants make 3775MW and 3759MW into the total installed capacity in the years 2035 and 2040 respectively. Installed capacity for solar PV will increase gradually from 44MW in 2030 up to 200MW in 2035 and then retreat to 156 MW in 2040. This is due to availability of geothermal which is cheaper than solar PV. Solar thermal will increase gradually from 516MW in 2035 to 1400MW in 2040.

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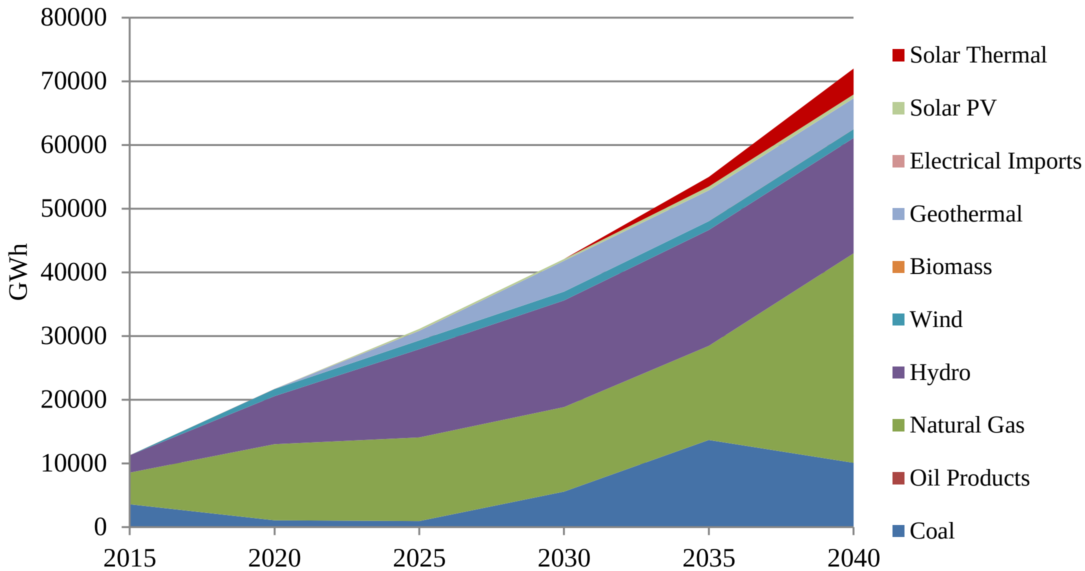

Figure 6: Electricity generation mix – RES

TABLE 2: TOTAL INSTALLED CAPACITY - RES

	2015	2020	2025	2030	2035	2040
Coal	412	412	712	1800	1800	1500
Oil Products	63	63	63	0	0	0
Natural Gas	541	1394	2228	2313	3618	6278
Hydro	565	1564	2875	3475	3775	3759
Wind	0	0	0	500	500	0
Biomass	10	10	0	0	0	0
Geothermal	0	0	200	650	650	650
Electrical Imports	0	200	200	200	0	0
Solar PV	0	0	0	44	200	156
Solar Thermal	0	0	0	0	516	1400
Total	**1590**	**3642**	**6277**	**8983**	**11059**	**13743**

C. Comparison of BCS and RES

Comparison of investment costs between BCS and RES is illustrated in Figure 7. Compared with RES, higher investment costs for renewable energy technologies drive the use of hydro, coal, oil products, geothermal and natural gas technologies in electricity generations under the BCS. The general trend of RES shows the replacement of coal and oil products based generation with renewable energy technologies. This is achieved after imposing constraints that require the introduction of renewable energy shares. The consequence of the replacement is associated with the rise in investment costs. There is an increase of approximately 10% in investment cost under RES as compared to BCS. It is more expensive to implement renewable energy electricity generations as compared to conventional fossil fuel. Furthermore, simulation results reveal that without imposing constraints, it is difficult to have a reasonable share in renewable energy technologies for electricity generations.

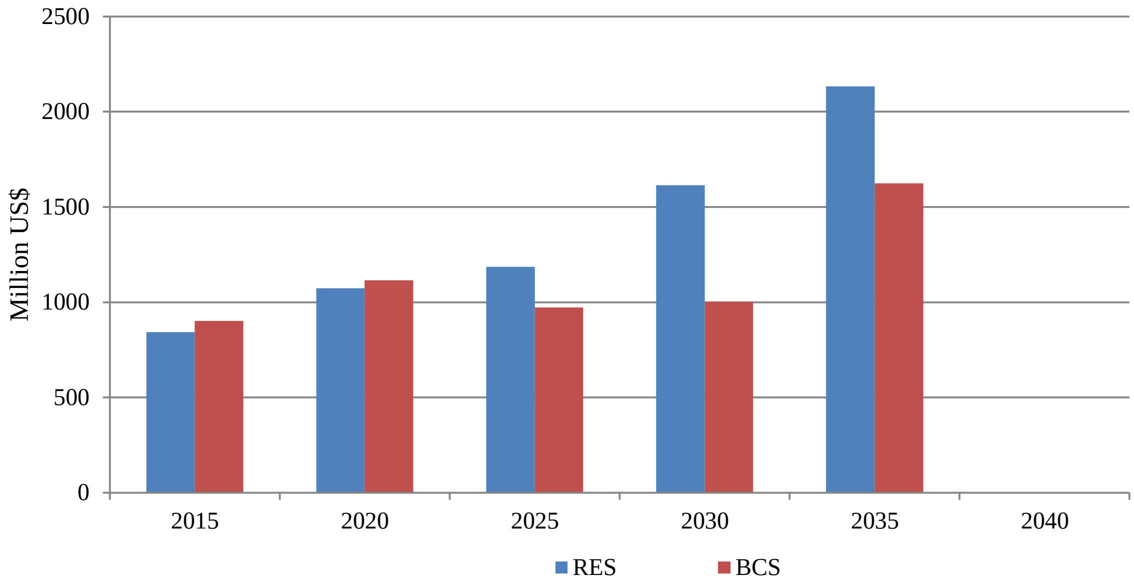

Figure 7: Investments cost comparison

Comparison of scenarios in terms of environmental impacts has shown BCS to produce more CO_2 as compared to RES. The level of emissions under BCS and RES are illustrated in Figure 8. The level of CO_2 in 2015 is the same for both scenarios, but decreases in RES as imposed constraints are effected. As the share of renewable energy increases, the amount of CO_2 decreases too. The CO_2 emissions saving in RES amounts to 2,565 kilo tonnes of CO_2 in 2040 as compared to BCS. The saving in CO_2 will help curbs greenhouse emissions which are on increase globally causing climate change (Ziuku & Meyer, 2012).

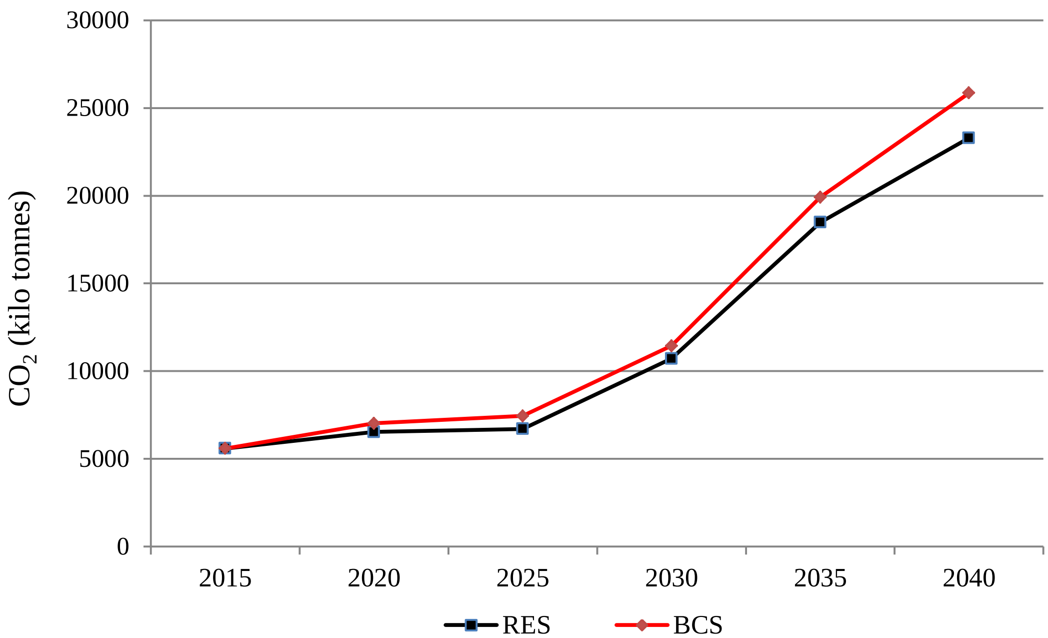

Figure 8: CO_2 Emissions levels comparison

IV. Conclusion

Optimization in renewable energy scenario showed that it is possible to have a share of the renewable energy mix in electricity generation with an associated rise in investment costs. Inclusion of renewable energy sources in power mix will increase 10% of investment cost as compared to BCS in the 2015 - 2040. Renewable energy for generations of electricity is more expensive to implement than fossil fuels. Apart from cost implications, renewable energy sources in energy mix will replace a considerable amount of coal, natural gas and oil products hence less polluted environment. Renewable energy sources can play a leading role in moving Tanzania on a more secure, reliable and sustainable energy track. The potential of renewable energy sources in Tanzania is enormous, but their contribution in Tanzania power generation hubs on the government support to make them cost-competitive. This has been demonstrated by the analysis of the two scenarios which indicate that without policy interventions renewable energy will not be able to penetrate power generation mix.

The government should implement a renewable energy feed-in tariff (REFiTs) which is in draft stage to encourage investment in renewable energy generation. REFiTs have the potential to successfully increase overall electricity generations while reducing the greenhouse gas emission and other economic development problems related to energy use.

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