Hindawi Publishing Corporation
Journal of Energy
Volume 2016, Article ID 5837154, 8 pages
http://dx.doi.org/10.1155/2016/5837154

Research Article

The Economics of Renewable Energy Sources into Electricity Generation in Tanzania

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Received 28 April 2016; Accepted 20 June 2016

Academic Editor: Soteris Kalogirou

The study analyzes the economics of renewable energy sources into electricity generation in Tanzania. Business as usual (BAU) scenario and renewable energy (RE) scenario which enforce a mandatory penetration of renewable energy sources shares into electricity generations were analyzed. The results show total investment cost for the BAU scenario is much lower as compared to RE scenario while operating and maintenance variable costs are higher in BAU scenario. Primary energy supply in BAU scenario is higher tied with less investment costs as compared to RE scenario. Furthermore, the share of renewable energy sources in BAU scenario is insignificant as compared to RE scenario due to mandatory penetration policy imposed. Analysis concludes that there are much higher investments costs in RE scenario accompanied with less operating and variable costs and lower primary energy supply. Sensitivity analysis carried out suggests that regardless of changes in investments cost of coal and CCGT power plants, the penetration of renewable energy technologies was still insignificant. Notwithstanding the weaknesses of renewable energy technologies in terms of the associated higher investments costs, an interesting result is that it is possible to meet future electricity demand based on domestic resources including renewables.

1. Introduction

Energy is an essential and dominant component in achieving the interrelated economic and sustainable development of any country. Global energy demand is increasing at an exponential rate as a result of the exponential growth of world population [1]. Increases in global energy demand combined with fossil fuel depletion and the concern over environmental degradation put renewable energy sources as future energy supply [2, 3]. The energy consumption status of Tanzania is dominated by biomass which accounts for approximately 90% of total primary energy supply [4, 5]. Renewable energy sources available are biomass, hydro, geothermal, biogas, wind, and solar [6–8]. Geothermal potential is approximated at 650 MW with resource assessment still under preliminary surface studies [7, 9, 10]. Biomass estimated energy potential was at 12 million TOE in 2010 mainly from agriculture wastes, plantation forests, and natural forests [11]. Hydropower potential of Tanzania is estimated at 4700 MW of which only 553 MW has been realized at macro level and 12.8 MW at micro level generations [9]. Tanzania experiences between 2800 and 3500 sunshine hours per annum with solar irradiation between average values of 4 and 7 kWh/m^2 per day across the country [7, 12, 13]. Proven wind potential of 200 MW has been identified so far in Singida with studies going on in other areas of the country [7].

The technologies mix in the Tanzanian electricity sector comprises mainly hydro and thermal power plants specifically gas-fired and heavy fuel oil (HFO) [5]. Dependence on higher shares of electricity generated from hydropower plants has previously affected the security of its supply due to changing weather patterns [14]. A high dependence on hydropower resulted into power cuts and rationing caused by severe drought conditions as experienced in the past decades [9, 14]. The challenges of security of supply due to changing weather patterns forced a shift to more thermal generation to compensate for the hydroelectricity shortage [7, 9]. The incorporation of thermal power plants into electricity generations helped to boot out challenges of security of supply with changed generation mix [15]. In contrast, a shift to more thermal power plants has considerably increased the level of greenhouse emissions and other pollutants from power sector [16]. With the exclusion of hydropower plants, the share of renewable energy sources in the portfolio of technologies generating electricity in the country is insignificant [5, 9]. The participation of renewable energy sources predominantly wind, solar PV, and thermal is uncertain and thus calls for a balanced and diversified range of electricity generation technologies with less level of greenhouse emissions and other pollutants. Renewable energy sources are less vulnerable to climate unpredictability and are generally clean energy [1, 17, 18].

The country's dependence on hydropower [15], the vulnerability of the hydropower generation to extreme weather conditions, the unpredictability of HFO and natural gas prices, and the global growth in demand for energy sources are all drivers encouraging the pursuit for alternative energy sources in electricity generation in Tanzania. Renewable energy sources are attractive to complement the country's primary energy sources mix of supply for electricity generation. Renewable energy technologies are commercially available and have shown promising cost reduction due to their increased global uses. Literatures shows that penetration of renewable energy sources into electricity generation decreases generation and transmission costs owing to learning effects and increasing fossil fuel costs [19]. Despites their promising benefits, the country's potential in terms of renewable energy sources is yet to be fully utilized for electricity generation primarily due to the limited policy interest and investment levels [18]. The contribution of renewable energy sources with the exclusion of hydropower was only 0.55% in 2013, which is a small proportion as related to nonrenewable sources [20].

The country's approach for assured sustainable energy future for electricity generation is on the use of renewable energy sources through the adoption of renewable energy technologies [9]. However, there is a need to increase renewable energy sources utilization as a means of diversifying energy mix for the country. But then again, electricity generation through the use of renewable energy sources requires sufficient information on their economics convenience. This study is therefore focused on the analysis of economic convenience in renewable energy sources penetration into electricity generation in Tanzania using MESSAGE model. Modelling results will open up knowledge for long-term electricity sector planning and provides additional information and facts for policy and decision makers.

2. Methodology

The methodology applied in this study is centered on the plausible scenarios optimization representing expansion of the electricity generation system with an objective of meeting projected demand. The optimization was done in the long-term basis with a planning horizon from 2010 to 2040 adopted for this study.

2.1. Modelling Tool. MESSAGE is the analytical tool that formulates and evaluates alternative energy supply strategies consonant with user-defined constraints on new investment limits, market penetration rates for new technologies, fuel availability and trade, and environmental emissions, among many others [21–23]. The choice of MESSAGE was based on its ability to offer the essential engineering methodology to optimize electricity demand in the long-term horizon [24]. MESSAGE is equipped with features which provides the opportunity to define constraints between all types of technology-related variables. MESSAGE allows the user to limit one technology in relation to some other technologies such as maximum share of a certain technology that can be handled in electricity network or define further constraints between production and installed capacity. Extreme flexibility of the model can be used to analyse energy and electricity markets and climate change issues [22, 23].

MESSAGE works on the principle of reference energy system which allows representation of the entire energy network including existing and future technologies [25–28]. MESSAGE modelling procedure is based on building the energy flows network to describe the whole energy system, starting from level of domestic energy passing through primary and secondary level and ending by the given demand at a final level. Final demand level is distributed according to the types of consumption, for example, electricity [21, 25, 28]. In MESSAGE specific technology performance is compared with its alternatives on a life cycle analysis basis. When energy consumption is to be met by various options, MESSAGE selects the optimal solution from the most appropriate option considering the calculated discounted cost of the delivered energy unit while taking account of the whole technology investment cost, operation and maintenance (O&M) costs, and fuel cost at a constant price of the base year. MESSAGE approach allows the realistic evaluation of the long-term role of an energy supply option under competitive conditions [21, 28, 29]. For the case of Tanzania, MESSAGE has been applied to model energy supply options for electricity generation [30] with the electricity demand based on the Model for Analysis of Energy Demand (MAED) [22, 23, 31].

2.2. Modelling Framework. Modelling the economics of renewable energy sources into electricity generation in Tanzania consists of the optimization of the energy supply system. The conceptual modelling framework as applied in this study follows an approach depicted in Figure 1. The framework includes formulation of plausible scenarios using MESSAGE model to optimize energy supply options considering energy resources and technologies constraints.

2.3. Electricity Demand Forecasts. The electricity demands in this study are based on the official projections as given in Power System Master Plan (PSMP) 2012 update [5]. The electricity demand as depicted in Figure 2 represents short-, medium-, and long-term forecasts of interconnected power

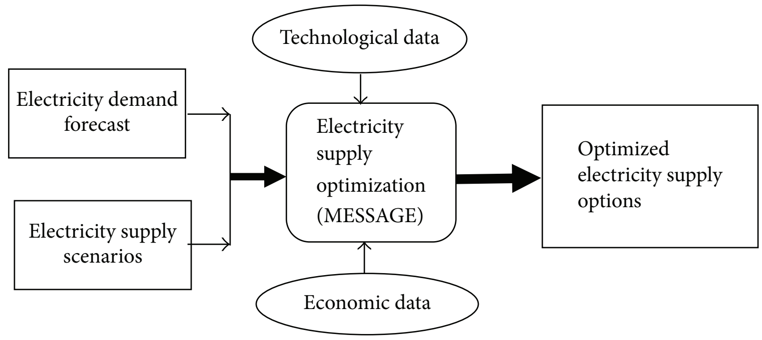

Figure 1: Conceptual modelling framework.

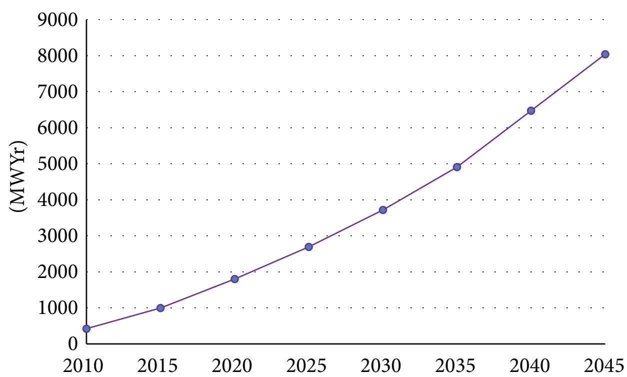

Figure 2: Electricity demand forecasts.

system and the isolated systems in the country. As opposed to MAED forecasts, the PSMP applies the trend methodology which is not consistent with the forecast of economic development [15].

2.4. Modelling Scenarios and Technologies. Two plausible modelling scenarios named as business as usual (BAU) and renewable energy (RE) were chosen in modelling the economics of renewable energy sources into electricity generations. BAU scenario is an overall electricity generation scenario (a reference case) which intends to illustrate how the electricity generation mix would take into account the renewable energy sources into power generations. BAU scenario follows official planned power system technologies capacities additions based on conventional energy sources such as natural gas, coal, HFO, and hydropower [5]. In BAU scenario, primary electricity conversion technologies which include hydro, coal, and natural gas power plants continue to dominate generation capacity without limitations in their expansion. Thermal power plants fired by natural gas continue their current domination with later entry of more coal fired power plants in the thermal portfolio for electricity generation. The BAU scenario also considers hydropower potential of 4700 MW to be unchanged over the study period due to the firm water sources availability as a result of rain and dry seasons being within the known and acceptable limits. The seasonality of hydropower in BAU scenario is accounted for by thermal generation primarily from natural gas and coal. Renewable and nonrenewable energy sources are allowed to compete equally for the share in electricity generation. The main feature of BAU 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.

As the objective of this study is to model the economics of renewable energy sources into electricity generation, an alternative RE scenario is developed to cater for that purpose. It is a known fact that electricity generated from coal, hydropower, and natural gas is characterized with low prices as compared to those from renewable energy sources. For example, cost of generating electricity using solar energy is quite higher than that of thermal generation such as combined cycle gas turbine (CCGT) [32]. Thermal generation technologies such as CCGT have the ability to infiltrate the market easily as opposed to renewable energy technologies [32, 33]. Without government support through internalization of external costs or providing incentives, penetration of renewable energy sources for electricity generation is difficult. However, the RE scenario is developed from BAU scenario to include a mandatory penetration of renewable energy sources into electricity generation. All technoeconomic inputs to the RE scenario are exactly the same as in BAU scenario. This makes RE scenario in effect as BAU scenario with additions of the mandatory penetration of renewable energy sources into electricity generation. The RE scenario introduces gradual increase of the renewable energy sources into electricity generation by imposing constraints in the model to allow their penetration. The imposed mandatory penetration of renewable energy sources requires a 15% share of wind, solar PV, geothermal, biomass, and solar thermal (added together) sources of the total electricity generation by 2040 starting from 5% in 2020 and progressively increasing to 10% in 2025 and 15% in 2030 through 2040.

For the purpose of this study, the definition of renewable energy is limited to geothermal, biomass, solar thermal, solar PV, and wind sources and excludes hydro because it is a matured energy source that has been competitively used in Tanzania. Hydro is the renewable energy source which is commercially viable on a large scale level because of its least costly way of keeping large amount of energy in the form of electricity but constrained owing to societal and environmental barriers [33, 34]. Furthermore, hydro produces negligible amounts of greenhouse gases and can easily adjust the amount of electricity produced with regard to demands. The choice of the mandatory penetration of renewable energy sources shares was stirred by descriptive scenarios which depicts global shares for electricity generation ranging within 25%–70% by 2050 [32, 35].

Modelling employed technologies using natural gas, biomass, geothermal, solar, wind, coal, and imported oil products (HFO) as fuels for the optimization of power generations. Nonrenewable technologies that were employed included natural gas technologies, hydro, HFO, and coal power plants. Natural gas technologies were bounded on gas turbine (GT) and combined cycle gas turbine (CCGT) power plants. MESSAGE model data collection and entry for optimization purposes were preceded by a quantitative analysis, specifically projection of PSMP 2012 electricity demand beyond 2035 and future fuel and technology costs. Data for the study consisting of electricity demand [5], technologies, technological constraints and efficiencies, technology's lifetime, investments, fixed costs, and capacity boundary were derived from a number of similar studies.

3. Results and Discussions

BAU and RE scenarios, as previously defined in methodology section, have been optimized using the MESSAGE model to decide the optimal supply options for Tanzania electricity generation from 2010 to 2040. The optimal electricity generations mix for BAU and RE scenarios considering electricity generation mix, operating and variable costs, primary energy production, and investment costs is presented and discussed in the next section.

3.1. Least-Cost Electricity Generation Mix. It can be seen graphically from Figures 3 and 4 that there are four main energy supply sources for electricity generation throughout the study period distinguished by hydro, natural gas, geothermal energy, and coal. The plots present only the most relevant energy sources (those that can be easily seen in the plots, excluding nonrelevant sources). The distribution of energy supply mix for electricity generation in both scenarios has been characterized by a substantial increase in hydro, natural gas, and geothermal and coal shares mostly after the year 2020. In both scenarios a total of 11,291 GWh will be generated in 2015 as compared to 54,981 GWh in 2035. The results match official projections of which a total of 11,246 GWh and 47,724 GWh were projected as demands in the years 2015 and 2035, respectively [5, 9]. According to the results, BAU scenario is dominated by natural gas with a share of 4968.6 GWh of the total electricity generated in 2015, followed by coal and hydro at 3586 GWh and 2722.2 GWh, respectively. Optimization results suggest hydropower will continue having a weighty part in terms of the capacity and production as it is the least-cost technology with the greatest potential in the country. Furthermore, optimization results in BAU scenario suggest geothermal as the most promising renewable energy technology which is able to compete without a mandatory introduction policy of renewable energy. Geothermal technology achieves competitive costs for electricity generation in the BAU scenario where other renewable energy technologies did not. The competitiveness of geothermal technology is attributed to a combination of lesser investment costs and the assumed technology maximum operation time of 85% as compared to 25% and 35% for solar PV and wind technologies, respectively.

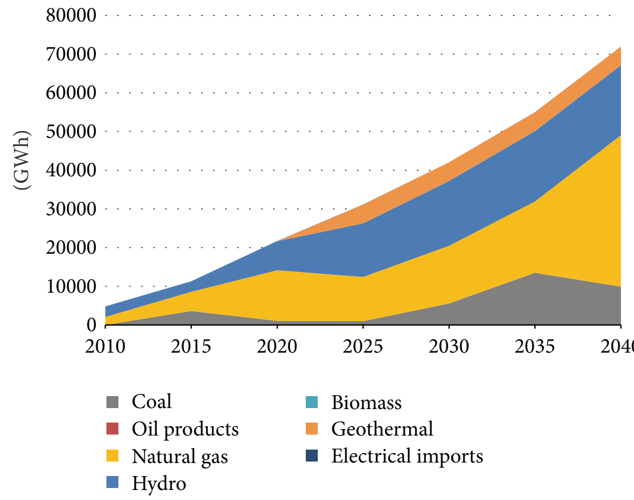

FIGURE 3: Electricity production by energy source, BAU scenario.

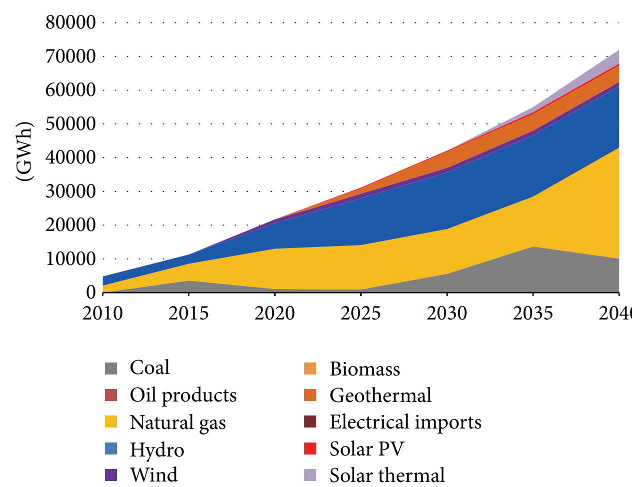

FIGURE 4: Electricity production by energy source, RE scenario.

Penetration of renewable energy sources into electricity generations in BAU is very small since optimization was based on meeting demand at a least-cost composition of energy sources and technologies. RE scenario represents an increase in the share of renewable energy from 1,124 GWh representing 5% in the year 2020 to 3,155 GWh (10%) in 2025, 6499 GWh (15%) in 2030, and 10,876 GWh in the year 2040. The increase follows a mandatory introduction of renewable energy into the scenario from 2020. Electricity generation in RE scenario is dominated by natural gas power plants which contributes 45.6% of the total electricity generated in the year 2040. RE scenario optimization results suggest wind as the most promising renewable energy technology. Wind technology achieves competitive costs in electricity generation earlier than other renewable energy technologies.

The competitiveness of wind technology is attributed to a combination of lesser investment costs and the assumed technology maximum operation time of 35% as compared to the adopted 25% for solar PV. Comparison between the scenarios suggests a decrease of nonrenewable sources from 49,023 GWh to 42,987 GWh with the difference being replaced by renewable energy sources. Optimization results in RE scenario suggest that a rising share of renewable energy technologies over the years will be able to replace a big portion of nonrenewable energy sources. Notwithstanding an important decrease of nonrenewable energy sources for electricity generation over the study period in RE scenario, the country's power system will however require these sources as least-cost solution.

Hydro and geothermal shares are limited in the electricity generation mix due to energy potential constraint of 4700 MW and 650 MW, respectively, even though they have low operating cost advantages [7, 36, 37]. Cost profiles for most of the renewable energy technologies are high in terms of capital investment though they have low running costs [38]. Geothermal energy was the only renewable energy source able to penetrate into electricity generations mix in 2020 due to the fact that it is characterized by high availability capable of providing base load power for 24 hours a day and lower operating costs as compared to other renewable energy technologies [18, 38, 39].

3.2. Economics of Scenarios. The total investments costs for BAU and RE scenarios are presented in Figure 5. It can be observed that there is a huge difference from an economic point of view in both BAU and RE scenarios. The total investment costs of RE scenario differ by a margin of 1818 million US$ as compared to BAU scenario. There is an observed marginal difference of investment costs in BAU and RE scenarios for the period from 2015 to 2020. This is because the constraints requiring the mandatory introduction of renewable energy were not yet imposed in that period leaving the model to choose the least-cost supply options. With mandatory inclusion of renewable energy imposed in the year 2020, the investment costs for RE scenario increased gradually and reached 2616.8 million US$ in 2035 as compared to 1624 million US$ for BAU in the same year. There were no investments in the year 2040 as was the last year of study.

Comparisons in terms of investments cost, operating and maintenance fixed costs (O&M), and operating and maintenance variable costs (O&M) are presented in Figure 6. It can be observed from data that the main difference among BAU and RE scenarios is in the variable O&M costs (which includes fuel costs) and investment cost. The RE scenario entails higher total fixed O&M costs which are 1187.35 million US$ but again lower variable O&M costs of 1318 million US$ as compared to BAU scenario. The collective effect of the total O&M costs for RE scenario is 2505.44 million US$ higher than those for the BAU scenario which stand at 2210 million US$. However, in terms of the total costs (which include investment and O&M costs), BAU scenario is characterized with lower total costs than those of RE scenario. RE scenario demonstrated less operating and maintenance variable costs for the years 2020 to 2040 as compared to BAU scenario

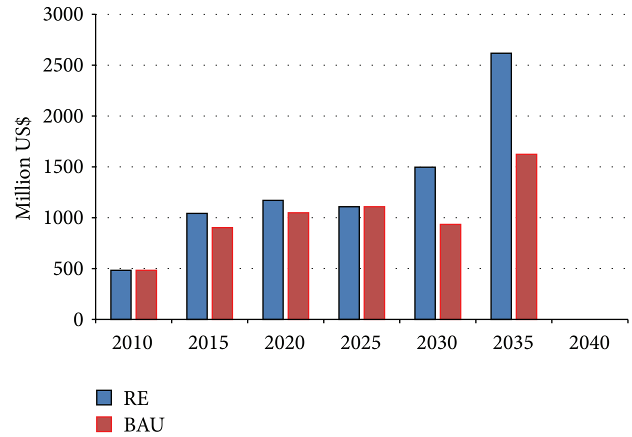

Figure 5: Investment costs comparison between BAU and RE scenarios.

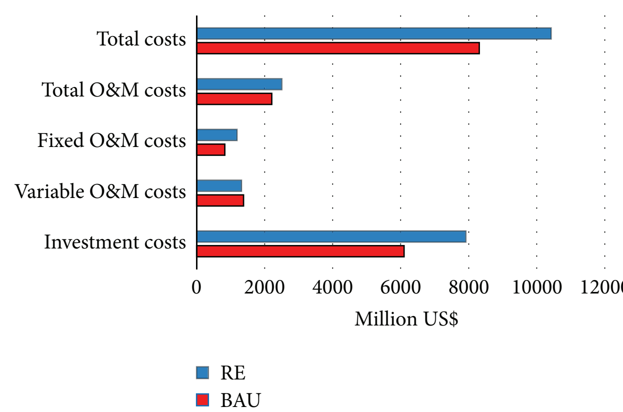

Figure 6: BAU and RE scenarios costs comparison.

except for the year 2015 where there was no penetration of renewable energy sources. Utilization of renewable technologies in electricity generation has a significant impact on operating and maintenance variable costs. This is due to less frequency of maintenance of parts particularly for wind and solar PV as compared to conventional technologies used in nonrenewable generations. Result depicts operating and maintenance variable costs for BAU are high as compared to RE scenario. However, the marginal differences in operating and maintenance variable costs are attributed to the fact that the renewable energy penetration accounts for a small proportion in share at only 5% in 2020 to 15% in 2040 of the total electricity generation. The differences in operating and maintenance variable costs would be higher if the share of renewable energy technologies is increased. As the technology in the production of renewable energy technologies improves, it is expected that these costs will be reduced [40, 41].

3.3. Primary Energy Production. The primary energy supply in BAU scenario is expected to increase from approximately 21,138.2 GWh in 2015 to approximately 109,799 GWh in 2040. If the proposed RE scenario is implemented in place of BAU from 2020 to 2040, the primary energy supply will be reduced to 96,742 GWh. On comparing primary energy supplies of the two scenarios, it is observed that 86,396 GWh of coal will be needed in RE scenario as compared to 87,380 GWh of BAU scenario for a period from 2015 to 2040. Similar observation is noted for the case of natural gas consumption in which only 209086 GWh will be required for RE scenario as compared to 240276 GWh for BAU scenario. Additionally, the reduced consumption of fossil fuel (coal and natural gas) translates into small variable O&M cost in RE scenario. The small proportions in the reduction of fossil fuel consumptions are attributed to marginal share of the renewable energy penetration which amounts to only 15%. The reduction in fossil fuel consumption would be much higher if the share of renewable energy technologies is increased in the generation of electricity. The reduction in primary energy supply in RE scenario as compared to BAU scenario translates into massive reduction in CO_2 emissions.

3.4. Sensitivity Analysis. In the sensitivity analysis carried out in this section, the technical parameters for all technologies in the model were not altered as they are the results of literature review and experience facts. Therefore, throughout the sensitivity analysis workout, the study assumed the uncertainty is anticipated to be a result of economic variables. In view of that, the sensitivity analysis adopted for this study consisted of the variations in renewable energy shares and the variations in investments and fuel costs.

3.4.1. Economic Effects of Variations in Renewable Energy Shares. Along with the BAU and RE scenarios, additional scenario abbreviated as RE1 was developed and modelled in order to evaluate the economic consequences with respect to the renewable energy share changes. RE1 scenario technoeconomic inputs are exactly as those of RE except for the mandatory shares of renewable energy sources penetration into electricity generation. RE1 scenario requires a 25% share of wind, solar PV, geothermal, biomass, and solar thermal (summed together) energy of the total electricity generation by 2040 starting from 10% in 2020 and progressively increasing the share to 15% in 2025 and 20% in 2030 and thereafter to 25% in 2035 through 2040. The effect of mandatory penetration of renewable sources to the model depicts the displacement of generation from fossil fuel sources, particularly natural gas and coal energy sources. As the mandatory contribution of renewable energy sources reaches the capacity set in the RE and RE1 scenarios and it is not increased, other least-cost sources occupy the generation system. Still thermal and hydropower generations support the system but the generation from these technologies decreases as renewable energy technologies specifically solar PV, solar thermal, wind, and geothermal energy enter the system as visible from 2020 throughout 2040.

Results show renewable energy shares increases in RE1 scenario upsurge the total investments cost to 10426 million US$ in comparison to 7918 million US$ and 6099.9 million US$ for RE and BAU scenarios, respectively. The general conclusion with regard to an increased share of renewable energy is that the more the shares of renewable energy sources are included in the electricity generation the more the impact of increased investments costs observed is. However, the increased shares of renewable energy entail reduced O&M costs and the reduced CO_2 emissions as compared to that of BAU scenario. With increased renewable shares, there is substantial opportunity for Tanzania to meet its future electricity demand sustainably and thus economic growth through renewable energy sources. Since electricity supply in the country is dominated by fossil fuels and hydropower, political will and policies tailor-made to the promotion of other renewable energy sources are necessary to accomplish their penetration. RE and RE1 are sustainability scenarios as they are being provided for with sources that are likely to continuously be at disposal opposite to fossil fuels sources which are depletable and endure heavy environmental costs in terms of CO_2 emissions into the atmosphere.

3.4.2. Economic Effects of Variations in Investments and Fuel Costs. The investments cost of coal and natural gas power plant specifically CCGT was changed to observe the change in the installed capacity of the whole system and its impacts on the penetration of renewable energy technologies without mandatory penetration policy. The choice of these technologies was based on the fact that they have dominated the entire least-cost generation system as observed in the results. What is more, these technologies have been the priority for development of the existing generation capacity in PSMP as hydropower plants capacity is limited at 4700 MW [8, 9]. Sensitivity analysis on the investment cost was carried out by step increase of coal power plant investment cost from study adopted value of 1900 US$/kW to 2400 US$/kW. Similarly, the investment cost of coal power plant was decreased to 1700 US$/kW. During sensitivity analysis, the value of discount rate was 10% while the investments costs of other technologies including natural gas were kept constant as in BAU scenario.

The observed changes on the installed capacity shares of coal power plant as compared to that of CCGT power plant from the year 2020 are depicted in Figures 7 and 8. Coal power plants shares increase as their investment cost decreases while at the same time there is an observed marginal decrease in the shares of CCGT power plants. Similarly, as the investment cost of coal power plant increases there is a similar decrease of the technology shares as compared to that of CCGT power plant. In general, the sensitivity analysis on investment costs of coal and CCGT power plants suggests the rise of CCGT power plant investment cost above 1950 US$/kWh while keeping coal at 2300 US$/kWh or less, favouring coal power plants installed capacity shares growths. The rise of coal power plant investment cost to 2300 US$/kWh without similar rise of the investment cost for CCGT power plant to above 2000 US$/kWh will have negative impact on the coal power plant shares. In terms of coal and natural gas fuel variations, the observation on the sensitivity analysis suggests that gas fuel cost is less sensitive than that of coal. Furthermore, the variations of investment cost of coal and natural gas technologies do not influence renewable energy technologies penetration into electricity generation. The sensitivity analysis further reinterprets the influence of the market environment and the challenges on which

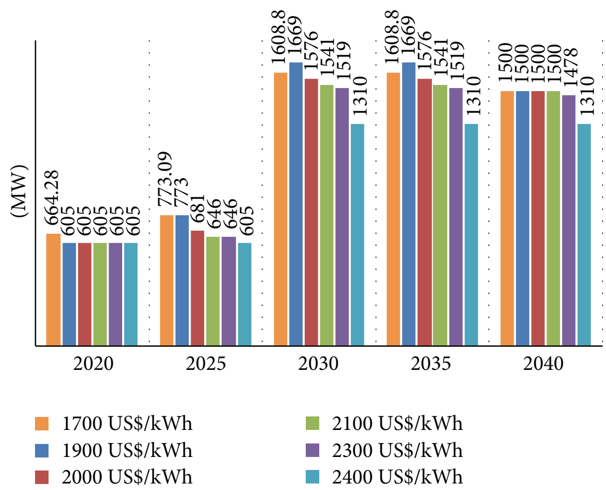

FIGURE 7: The installed capacity shares changes for coal power plants.

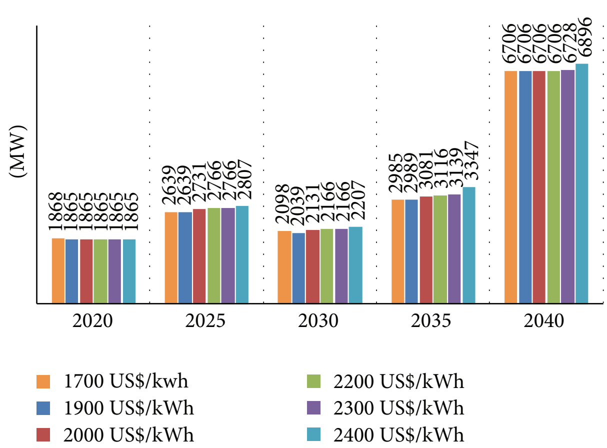

FIGURE 8: The installed capacity shares changes for CCGT power plants.

renewable energy technologies run into when trying to penetrate the generation mix.

4. Conclusion

The study presented a detailed analysis of the economics of renewable energy sources mixing into electricity generation in Tanzania. MESSAGE least-cost optimization results suggest that renewable energy sources and thus their technologies require compulsory policy measures to penetrate into the country's electricity system. Renewable energy technologies failures to fit in into the country's electricity system as suggested in the results were mainly due to technoeconomic competitiveness shown by conventional technologies under least-cost basis. Furthermore, the least-cost optimization results as considered in adopted scenarios of this study reflect the impact of the market environment and the challenges of renewable energy technologies explicitly wind and solar encounter in actuality. Mandatory penetration of renewable energy sources into electricity generation allows for realizing substantial reduction in primary energy supply, O&M costs, and CO_2 emissions. However, RE scenario is still more expensive than BAU scenario in terms of investment cost. It is concluded that economic feasibility of renewable energy sources into electricity generation depends much on research and development (R&D) of renewable energy technologies that should allow for the investment cost decline coupled with efficiency improvement. Moreover, the use of renewable energy sources increases country's energy security from disruptions of supply. The weaknesses of renewable energy incorporation into electricity generations are on the high cost of its implementation. Renewable energy mandatory incorporation into electricity generation as was shown in RE scenario requires more investments than the case in BAU scenario. An interesting result is that the RE scenarios support the view that it is possible to meet future electricity demand based on domestic resources in spite of the associated higher investments costs.

Competing Interests

The authors declare that they have no competing interests.

Acknowledgments

The authors would like to thank Arusha Technical College (ATC), Nelson Mandela African Institution of Science and Technology (NM-AIST), Tanzania Atomic Energy Commission (TAEC), and College of Engineering and Technology (CoET) of the University of Dar es Salaam (UDSM) for their enabling environment that allowed successful completion of this work.

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