Scenario Analysis of the Low Carbon Power System in Zambia by Using an Integrated Energy Demand-Supply Modeling Approach

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SCENARIO ANALYSIS OF THE LOW CARBON POWER SYSTEM IN ZAMBIA BY USING AN INTEGRATED ENERGY DEMAND-SUPPLY MODELING APPROACH

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ABSTRACT

This study applies an integrated energy supply-demand modeling framework designed to develop reliable and policy-sensitive forecasts by retaining the link between both the demand and supply sectors in the energy system and utilizing cost-effective future energy planning policies in Zambia.

KEYWORDS

Zambia, Integrated energy system modeling; cost-minimization approach, GHG emissions, Seasonal Autoregressive Integrated Moving Average.

1. INTRODUCTION

Zambia has experienced a severe electricity supply shortage since 2016. Zambia is in Sub-Saharan Africa, where the average population has limited access to electricity. The World Bank indicators show 44.52% of the people in Zambia have access to electricity[1]. There is an urgent need to improve the capacity factor of the power sector to reduce the chronic energy deficit in Zambia. To help assist in policymaking, this study develops an integrated modeling approach to analyze the effects of different scenarios compared to a baseline (2019) scenario on energy demand and supply. The model's objective is to choose the optimal combination of resources and technologies, subject to satisfying techno-economic and environmental constraints. On the demand side, the study uses time series analysis to forecast future electricity demand in Zambia. Using the cost-minimization approach, the supply-side energy model identifies the optimal combination of resources and technologies needed to satisfy exogenously specified electricity demand levels. The baseline scenario results revealed the power outages in Zambia, especially at peak times, which have been attributed to reliance on imported fuel for power generation, slow-paced integration of renewable resources, and not fully utilizing resource potential for the supply side. To overcome the power outages and meet the electricity demand in 2035, a comprehensive scenario analysis was conducted, including the main scenarios of 30% integration of renewable energy, no coal power generation, and low emission targets (10%, 20%, 30%, 40%, and 50% reduction from the baseline) in 2035.

2. INTEGRATED ENERGY DEMAND-SUPPLY MODELING FRAMEWORK

The proposed energy demand model is based on the Seasonal Auto-Regressive Integrated Moving Average (SARIMA) time series method. The seasonal ARIMA model consists of modeling the number of yearly observations while considering both the non-seasonal part of model and the seasonal part of the model, which can be expressed as follows [2]:

$$\left(1-\phi_1 A-\cdots-\phi_p A^p\right)\left(1-\Phi_1 A^s-\cdots-\Phi_P A^{sP}\right)(1-A)^c\left(1-A^s\right)^C D_t^0 = \left(1-\theta_1 A-\cdots-\theta_q A^q\right)\left(1-\Theta_1 A^n-\cdots-\Theta_Q A^{nQ}\right)d_t \quad (1)$$

In the equation above, the D_t^0 represents the fitted historical monthly electricity demand at time t. In addition, the non-seasonal autoregressive and moving average elements are represented by polynomials $\phi_p(A)$ and $\theta_q(A)$ of trend orders p and q. The parameters $\Phi_P(A)$ and $\Theta_Q(A)$ refer to seasonal autoregressive and moving average elements of trend orders P and Q. c and C represent the corresponding non-seasonal and seasonal difference components. A represents the backward shift operator. d_t refers to the error term, with a significance of mean 0 and variance 1. n is the number of periods per season. ϕ and Θ are the model coefficients.

The Model for Energy Supply Systems and their General Environmental Impact (MESSAGE)[3] was used as the energy supply model to find the optimal plausible combination of the energy supply technologies to satisfy the forecasted electricity demand. Figure 1 shows the Overall concept of an integrated energy model for Zambia.

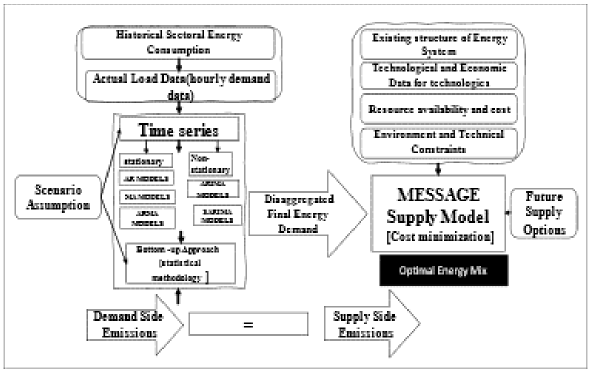

Figure 1. Integrated energy model for Zambia.

3. RESULTS AND DISCUSSIONS

The developed SARIMA model was used to predict the future electricity demand in Zambia, which is shown in Figure 2.

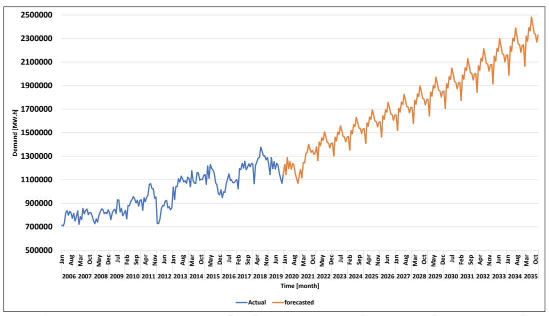

Figure 2. Projected electricity demand in Zambia

Figure 3 shows the optimal selection of the power generation technologies for the baseline scenario with integrated demand with future dominance of Oil (FO) to meet the electricity demand.

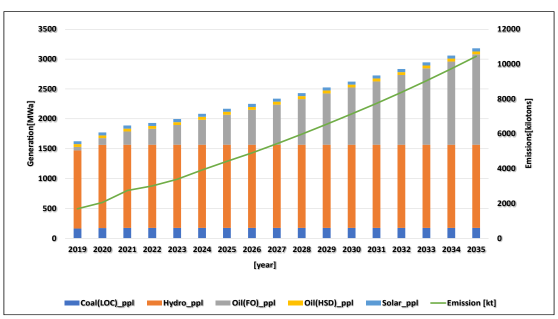

Figure 3. Electricity generation and emissions under the baseline scenario.

Table 1 summarizes emission reductions, cost, and renewable shares in the different scenarios. Each scenario, excluding the baseline, has shown efforts in decarbonization measures such as extensive use of renewable resources.

Table 1. Summary of analysis of scenarios on the Supply side in 2035.

Scenario	Annual emissions [kt]	LCOE [Cents/kWh]	RE share [%] *
Baseline (BL)	104,44.4	7.68	45.40
Renewable Scenario (RE)	5,059.8	8.02	73.80
No Coal (NC)	9,357.8	7.82	50.84

*RE includes solar, wind and hydro

Figure 4 shows the results of the baseline, renewable, and no coal scenario.

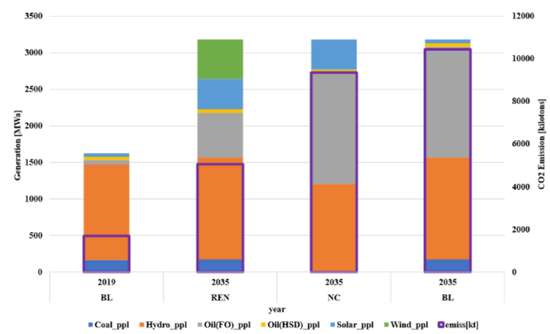

Figure 4. Comparison between the renewable, No coal Scenario and Baseline scenarios.

4. CONCLUSION

The modeling results conclude a lack of self-sufficiency in the country to meet future electricity. The baseline scenario results revealed an alarming oil (FO) rate estimated on the horizon. The available generation capacity against peak demand recorded an average deficit of 623MW from 2023 to 2035. The No Coal scenario contributes to about 50.84 percent of the renewable share in the energy system. The emission target scenarios constrain the use of fossil fuels by using more renewable energy while still meeting the demand of the country. The 50% emission reduction scenario shows a 65.03% renewable share contribution in 2035.

5. REFERENCES

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[2] Malehmirchegini L, Farzaneh H. Demand response modeling in a day-ahead wholesale electricity market in Japan, Energy Reports.