The Zambian Energy Transition (ZET): A Case Study for OsemOSYS and FlexTool

Kumbuso Joshua Nyoni (✉ kumbujosh@gmail.com)
University of Edinburgh  https://orcid.org/0000-0003-3831-8981

Research Article

Keywords: Energy Transition, FlexTool, Osemosys, Flexibility, Emissions Reduction, Cost Effective Generation, Net Zero

Posted Date: December 13th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-2368899/v1

License: ☇️ This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License
Abstract

This paper presents a Zambia study case for the application of Osemosys and Flextool. Three scenarios are explored assessing Zambian energy transition outlook (2022 – 2063) which include the business as usual (BAU), integrated resource plan (IRP), and Net Zero prospects to align with agenda 2063 for Africa. The output of Osemosys simulation modelling comprises detailed results providing capacity expansion planning of the generation assets to meet the anticipated demand for a specific range of future years (2022 – 2063). Based on the performance of the energy mix (i.e., hydro, thermal and renewable energy generation projects), the simulation assesses the adequacy of the available assets and identifies new capacity to be added at the least cost. Thereafter, the flexibility of the power system is assessed using FlexTool. To contextualise, FlexTool was used to assess the flexibility of the defined specific year of the capacity expansion plans produced in Osemosys. The writeup delved into analysis of three key assessment indicators for the various scenarios which include cost-effective generation, emissions reduction, and flexibility assessment outcome.

Background And Modelling Questions

According to the estimates developed based on studies undertaken in the past, Zambia has a potential for hydropower generation of more than 6,000 MW, and only 2,398 MW out of that has been developed so far. While solar and wind mapping has been undertaken in recent years, the potential of solar power is estimated at close to 1300 MW, several times more than the 100 MW currently commercially utilised. The use of wind energy is in its initial stages, but the overall potential is estimated to be about 920 MW. Based on the indigenous coal resources in Zambia, another 1300 MW of new coal-fired generation potential is estimated in the short and medium term. Geothermal resources have not been fully estimated, but projects of about 320 MW can be implemented in the country. Similarly, biomass and waste-to-energy projects of about 240 MW could be completed in Zambia (ERB, 2021).

Electricity supply in Zambia grew by 49.6% over ten years (2005 to 2015), while consumption grew by 51.31% over the same period. The total installed generation capacity is 2,981.23 MW, a large proportion (about 80%) of which comprises hydropower, and the remaining capacity includes thermal units and renewable energy plants. Since 2015/2016, Zambia has had a poor rainfall pattern (climate change impact) compared to the previous years, and hydrogenation has been severely impacted. Overall generation in 2016 in Zambia declined by about 15% compared to 2015, causing great distress among the electricity customer groups, especially domestic, mining and manufacturing customers. In 2019, the largest electricity consumer, according to the ERB Sector Report of 2019, is the mining industry, with a share of 51% (6,359 GWh) of the total energy consumption, followed by the domestic sector, which consumed 33% (4,023 GWh). The remaining sectors account for 16% (2,144 GWh). In 2018, 34% of the Zambian population had access to electricity, 69% of which were in urban areas and 8% in rural areas (Energy, 2022a; ERB, 2021; Nyoni et al, 2021).
To ensure a consistent demand and supply match, a renewables-based energy transition promises to deliver vast socio-economic benefits to countries across Africa, improving energy access, creating jobs and boosting energy security. To realise these benefits, African countries have an opportunity to leapfrog fossil fuel technologies to a more sustainable, climate-friendly power strategy aligned with the Paris Agreement and low-carbon growth. Zambia intends to reduce its greenhouse gas (GHG) emissions by at least 47% by 2030. At the same time, improving energy access remains a priority, as only 43% of the population has access to electricity. The government has identified energy efficiency as a priority in the country’s nationally determined contributions (NDCs) under the Paris Agreement to meet growing energy demand. Zambia’s National Development Plan includes plans to increase geothermal, wind and solar electricity generation by 2030 (Energy, 2022b; Nyoni, 2022).

In March 2021, the government of the republic of Zambia launched a K40 million Integrated Resource Plan (IRP) for the development of the electricity sector in the country, to among others, ascertain Zambia’s electricity investment needs, improve the reliability, affordability of electricity supply, reduce costs for delivering electricity services and minimise environmental and climate change impacts. The IRP process was finalised in May 2022, which proposed several capacity expansion projects (i.e., generation, transmission and distribution) to meet local and regional demand in 2026, 2030, 2040 and 2050 (Nyoni, 2022).

Therefore, this research explores the energy transition outlook for Zambia through scenario analyses which include the business as usual (BAU), integrated resource plan (IRP), and Net Zero prospects to align with agenda 2063 for Africa and considered the following research question:

1. Can Zambia attain Net Zero by 2063 to align with Agenda 2063 for Africa?
2. Does the proposed IRP & Net Zero aid in emissions abatement?
3. What is the cost of electricity generation under the IRP and Net Zero? Is it pragmatic?
4. Is the existing (2022) power system flexible?
5. Under the IRP, will the system be flexible in 2030 and 2050 without additional investments?

The key indicators for scenario assessment under consideration were cost-effective generation, emissions reduction and flexibility assessment outcome.

**Materials And Methods**

Using the Osemosys and FlexTool, the investigated scenarios are illustrated in Table 1.
Table 1

Summary of study scenarios and key assumptions (Nyoni, 2022)

<table>
<thead>
<tr>
<th>Scenario Label</th>
<th>Scenario Description</th>
<th>Key Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAU</td>
<td>Business as usual (BAU) - Baseline scenario without any integrated resource plans (IRP)</td>
<td>Baseline for targets/scenarios below</td>
</tr>
<tr>
<td>IRP (2022–2050)</td>
<td>Zambia targets to add about 3.2GW, 2.1GW, 1.2GW, 4.5GW generation capacity in 2026, 2030, 2040 and 2050 respectively. This will have a mix of hydro, coal, biomass, geothermal, solar and wind</td>
<td>Financing feasible, cost-reflective tariffs, firm SAPP regional integration</td>
</tr>
<tr>
<td>Net Zero Future (by 2063)</td>
<td>Domestic production and imports of fossil fuels and biomass gradually decline to 0 in 2063, beginning in 2023. A gradual increase of renewable capacity commencing 2023 (aligned with pragmatic attainable resources)</td>
<td>Fuel switching and energy efficiency assumption adopted from Appendix of the starter kit (Allington et al, 2022; Cannone et al, 2022a; Cannone et al, 2022b; Howells et al, 2021)</td>
</tr>
</tbody>
</table>

Long-term expansion planning using Osemosys requires modelling of several associated matters and availability of quantitative data. For example, to adequately represent the operation of the hydro-generation plants, hydrological (river basins, ecological zones) and climate change models are needed to represent the future outcomes based on historical data. Macroeconomic analysis is required to establish the path of economic growth in Zambia for the long term. Global models are necessary to establish climate targets and set country-specific goals. While some Zambia-specific modelling has been undertaken recently, most of them are incoherent in terms of underlying assumptions adopted. In the absence of specific outputs, several key assumptions were made in this study.

A significant challenge of long-term energy planning pertains to an inadequate cost database for different generation technologies and locations in Zambia (investment cost, fixed and variable operations and maintenance (O&M) cost, un-served and spill-over cost of electricity, emission cost, etc.). Wherever Zambia-specific cost data was unavailable, the starter data kit was utilised.

A flexibility assessment was also conducted for the existing power system, and investment needs were identified. Flexibility issues were also identified in the IRP 2030 and 2050 scenarios. Zambia was divided into five nodes to perform detailed flexibility, each serving two provinces as listed below.

A. North Node → Northern & Luapula provinces with 16.6% of total national electricity annual demand
B. East Node → Muchinga & Eastern Provinces with 16.8% of total demand
C. Central Node → Lusaka & Central Provinces with 24.3% of total demand
D. South Node → Southern & Western Provinces with 20.9% of total demand
E. West Node → Copperbelt & Northwestern Province with 21.4% of total demand

FlexTool is an optimization tool able to solve economic dispatch and capacity expansion. The primary objective of FlexTool was to assess the flexibility of the capacity expansion plans simulated in Osemosys software. Identification of least cost additional investments and sensitivity analysis on high shares of...
variable renewable energy sources were treated as secondary and tertiary objectives, respectively. FlexTool model had no uncertainty of the future and assumed perfect foresight. FlexTool knew the characteristics of the simulation at the start of the simulation run such as demand. This is an assumption that was required for linear programming optimization.

The flexibility attributes for the power generators in this study adopted typical literature values since actual attributes were not readily available.

**Discussion Of Results**

The output of Osemosys simulation modelling comprises detailed results providing capacity expansion planning of the generation assets to meet the anticipated demand for a specific range of future years (2022–2063). Based on the performance of the energy mix (i.e., hydro, thermal and renewable energy generation projects), the simulation assesses the adequacy of the available assets and identifies new capacity to be added at the least cost. Thereafter, the flexibility of the power system is assessed using FlexTool. To contextualise, FlexTool was used to assess the flexibility of the defined specific year of the capacity expansion plans produced in Osemosys. Therefore, some Osemosys data after relevant unit conversion formed as part of the inputs in FlexTool such as specified annual demand, reserve margin, efficiency of power plant technologies, variable cost of fuel and technology, fixed cost, capital cost, operation life, discount factor, availability factor, emission activity ratio, total capacity annual and resource potential. To optimise the computation run time, a time slice reduction was done from 96 to 8 for profile aligned inputs in Osemosys (i.e., technology capacity factors). However, Renewables Ninja was used to determine the hourly capacity factors for wind and solar photovoltaics as inputs in FlexTool with particular focus on Zambian sites.

**4.1. Annual Power Generation**

Figure 1 shows a predominance of biomass under the BAU in 2050 and 2063. IRP and Net Zero show a more sustainable generation mix. All scenarios had surplus demand in 2030.

**4.2. Annual Emissions**

Figure 2 shows the BAU with an emission increase of 80% in 2063 concerning 2022. The IRP is midway between the BAU and Net Zero in terms of annual emissions.

**4.3. Cost of Electricity Generation**

Figure 3 shows that the BAU will be cheaper to generate electricity in 2030 at $10.8/MWh. In 2050 the BAU and IRP will both cost $15.9/MWh. It also shows that Net Zero attainment will not come cheap as the scenario shows higher costs for the years under consideration.

**4.4. Flexibility Assessment**
Figure 4 shows a flexibility assessment for the existing Zambian power system as of 2022 and identified transmission investment needs between southnodeD and northnodeC of 1000MW transfer capacity coupled with about 250MW generation investment at the two respective nodes. Therefore, the coming online of the 2 x 150MW units from Kafue Gorge Lower in 2023 would help remedy this flexibility issue in the short term.

This study also identified flexibility issues under the IRP in the years 2030 and 2050, respectively. The robust and complementary combination of Osemosys and FlexTool in capacity planning and flexibility assessment respectively presented an opportunity to revisit the assumptions on network capacity planning under the IRP, whose main findings will be published by the ministry of energy before the end of 2022.

### Conclusions, Policy Insights And Future Work

The BAU utilises about 70% and 80% of the biomass in 2050 and 2063, respectively, translating into an unsustainable pathway. Emissions will increase by 96% in 2050 and 154% in 2063 concerning 2022. The flexibility of the current power system can be enhanced through transmission and generation investment between northern and southern nodes. To attain IRP targets, government or/and IPPs must invest in capacity expansion, and the cost of electricity will be 11.6, 15.9, and 15.6 $/MWh in 2030, 2050 and 2063, respectively. It is possible to attain Net Zero by 2063 with a gradual phase-out of fossil fuels. The generation cost will be 12.9, 18.1, and 16 $/MWh in 2030, 2050 and 2063, respectively.

The near-total dependence on hydro generation resources under inadequate rainfall (due to climate change events) severely tested the ability of ZESCO to operate these assets under optimal conditions as the country faced supply shortages. The dominance of hydropower generation puts the country at risk due to changes in climatic conditions, such as global warming leading to insufficient rainfall and drought. These challenges pose a risk of inadequate water resources available for hydropower generation.

Electricity generation projects generally require lumpy investments and long lead times. Barring small-scale projects (less than 50 MW), typical investments for a 200 MW power plant may run into several hundred million dollars and may require a completion time of 3 to 5 years, depending on the technology involved. Given these considerations and the growth in electricity demand (especially in countries like Zambia, where the access rate is low), there must be a pipeline of generation, transmission and distribution projects which could deliver reliable electricity supplies to the customers at an affordable and cost-reflective price. This also requires considering the uncertainties of the future and building adequate reserve margins in the power system to meet unforeseen supply shortfalls. Timely investments (public and private) and completion of projects as per plans is crucial. It is also essential to recognise that generation, transmission, and distribution constitute a single chain and projects in each of these three sub-sectors must be undertaken synchronised and timely.
There is a need to advocate for sustainable and coherent energy policies to attain IRP and Net Zero targets. Investment plans must start now for a flexible and low-emission energy system.

Finally, opportunities for future work include continuous model updates to align with technology learning rates, update flexibility assessment data and prices/costs for various technologies, resolve flexibility issues in the IRP 2030 and 2050 scenarios, and incorporate sector coupling (i.e., electric mobility in the flexibility assessment).

**Declarations**

**Declaration of competing interest**

The author declares that he has no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

**CRediT Author Statement**

Kumbuso Joshua Nyoni: Conceptualisation; Data curation; Investigation; Methodology; Software; Formal analysis; Validation; Visualisation; Writing – Original Draft.

**Acknowledgements**

This paper has been written with the support of the Climate Compatible Growth Programme (#CCG) about the Zambian energy system. The views expressed in this paper do not necessarily reflect the Zambian government’s official policies nor the final contents in the integrated resource plan (IRP) for Zambia.

**References**


**Figures**

Figure 1

Annual power generation for the three scenarios
Figure 2

Scenario annual emissions comparison
Figure 3

Scenario electricity generation cost comparison

Figure 4

Flexibility assessment and investment for the 2022 system