2023 ENGINEERING INSTITUTION OF ZAMBIA SYMPOSIUM

AN ASSESSMENT OF CLIMATE CHANGE ADAPTATION IN HYDROPOWER STATIONS IN ZAMBIA – A CASE STUDY OF KAFUE GORGE UPPER HYDROPOWER STATION

PRESENTER : Musekwa Mimba

DATE : Friday 21st April 2023

Avani Victoria Falls Resort, Livingstone, Zambia

PRESENTATION OUTLINE:

- Introduction
- Objectives
- Methodology
- Results
- Discussion
- Conclusion and Recommendations

Introduction

- Electricity is essential for domestic and national economic growth.
- Zambia utilizes approximately 80% hydropower for electricity generation.
- Hydropower relies on water resources availability for electricity generation.
- Climate change threatens water resources, potentially affecting hydropower generation.
- Climate change leads to changes in the hydrological regime including increased variability and more frequent hydrological extremes such as floods and droughts.
- E.g. El Niño events in 2015-2016 caused electricity outages due to reduced rainfall.

Introduction

Response to climate change.

- Adaptation and mitigation are two complementary responses to climate change.
- Adaptation is defined as an adjustment in natural and human systems in response to actual or expected climatic stimuli or their effects (Stuart, 2017).
- These can further be categorized as structural and non-structural.
- Structural measures modify existing infrastructure like dams, reservoirs, spillways, and turbines.
- Non-structural measures integrate climate change considerations into hydropower generation management and efficient water resources management.

Introduction

Alto Rabagao Power Station - Portugal

- Pumped hydropower station with 68 MW installed capacity and average annual generation of 83 GWh.
- Located in the Iberian Peninsula.
- The peninsula has experienced increased temperatures and reduced rainfall.
- Experiences abundant solar in summer and reduced water availability.
- In 2017, integrated floating solar PV with hydropower.
- Covers 2500 m^2 area, and supports 840 PV modules.
- Floating solar PV installed capacity of 220 kW.
- Expected annual production of 300 MWh.

Introduction

Kafue Gorge Upper Power Station

- Located in Chikankata, Zambia along the Kafue River.
- Constructed in the early 1970s.
- Initial total installed capacity of 900 MW and later uprated to 990 MW.

No. of Generating Units	6
Generator capacity per unit	165 MW
Full Supply Level (F.S.L)	977 m
Storage at F.S.L	1178 mcm

Objectives

- Research data spanned over the period 2000~2020.
- Objective 1 - To investigate climate influence on hydropower generation.

- Rainfall and temperature data collected from the NASA climate website.

- Objective 2 - To investigate river flows and reservoir levels' influence on hydropower generation.

- Kafue River flow data obtained from WARMA.
- Hydrology and power generation data obtained from Zesco Ltd.

- Objective 3 – To identify and assess climate change adaptation measures implemented at Kafue Gorge Upper hydropower station.

- Data obtained from Zesco Ltd.

Methodology

- Mixed-Method research approach and utilized both qualitative and quantitative methods.
- Questionnaires distributed to KGU Power Station and Generation Directorate personnel.
- Hydrometeorological data was obtained and analysed to establish and identify any relationships between the datasets as per each research objective.
- Datasets were as follows:

- Climate data i.e. rainfall and temperature.
- Kafue river flows, KGU reservoir levels and KGU power generation.
- Trend analysis was used to describe relationships between the datasets.

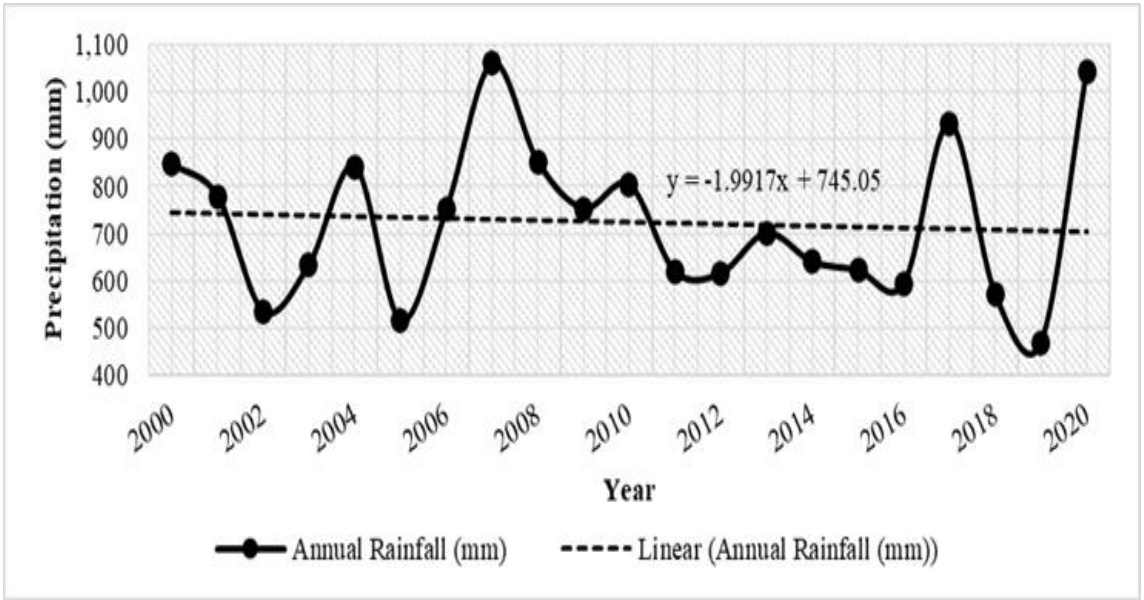
Results and Discussion

Objective 1 - Climate elements that influence hydropower generation.

- Data included rainfall and maximum temperatures over the coordinates latitude -15.81 and longitude 28.42.

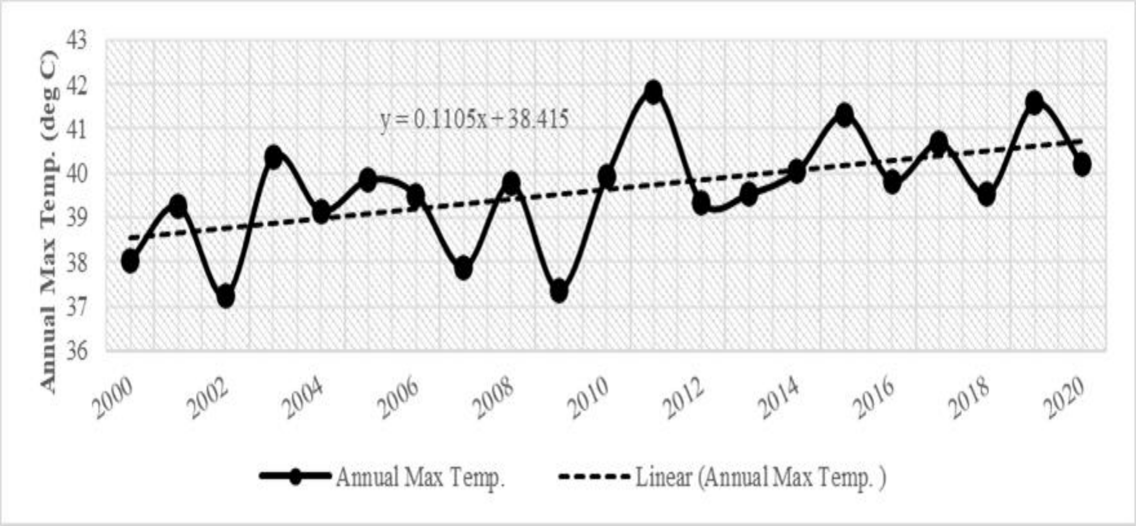
Rainfall:

- Negative trend observed.
- On average, the rainfall declined by approximately 7% or approximately 2 mm each year



Temperature:

- Upward trend observed.
- Overall, the temperature increased by approximately 0.11 ˚C each year an average change of 0.40% increase.

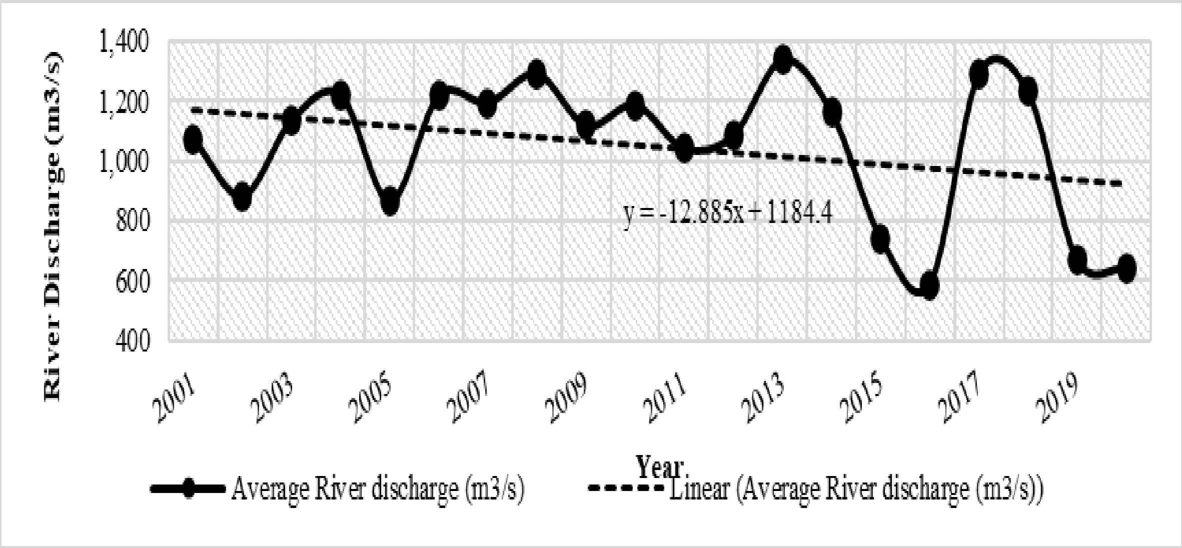


Results and Discussion

Objective 2 - The influence of river flows and reservoir levels on hydropower power generation.

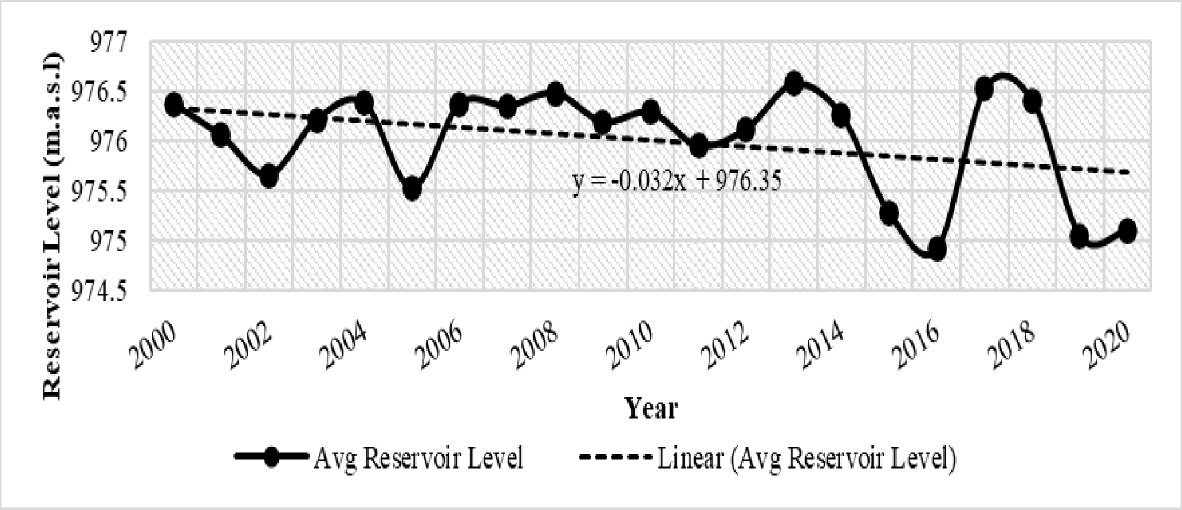
Kafue River flows:

- The average river flow rates decreased by approximately 13 m3/s per year and an average change of 2%.



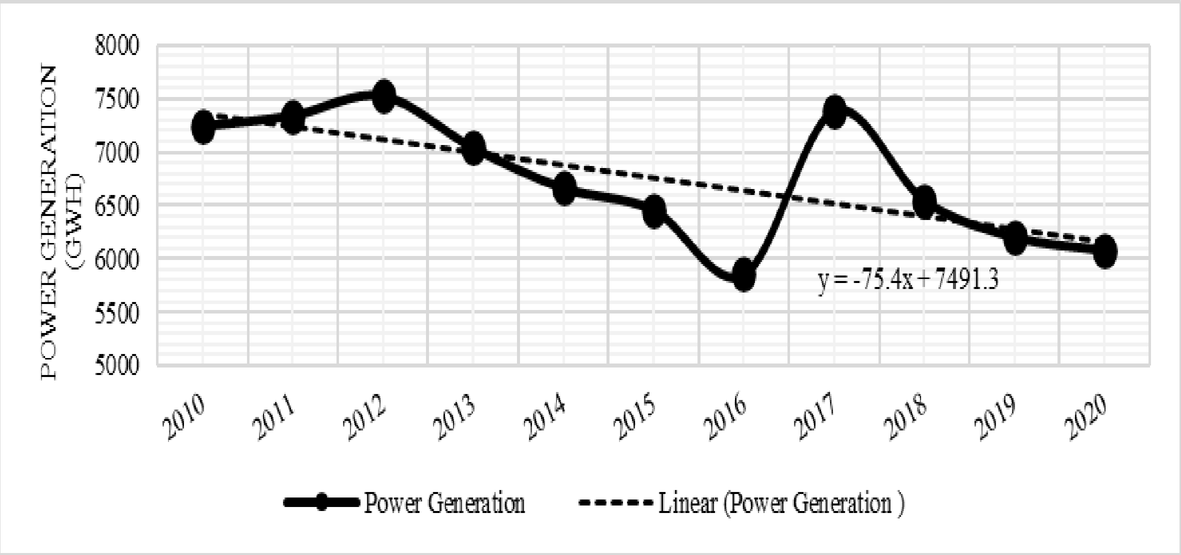
KGU Reservoir levels:

- Negative trend observed.
- This decrease translated to approximately 0.03 meters above sea level each year and a percentage decrease of 0.3%



Results and Discussion

- **Objective 2 - The influence of river flows and reservoir levels on hydropower power generation.**
- The study analysed power generation readings from 2010 to 2020 to determine the correlation between reservoir levels and power generation.
- It was observed that the period exhibited a negative trend.
- Power generation decreased by 75.40 GWh each year and at an average change of 3%.
- **Note:** Power generation data was only available from 2005~2020. The power station also underwent a rehabilitation project in 2005~2009. Therefore, the period under consideration is 2010~2020



Results and Discussion

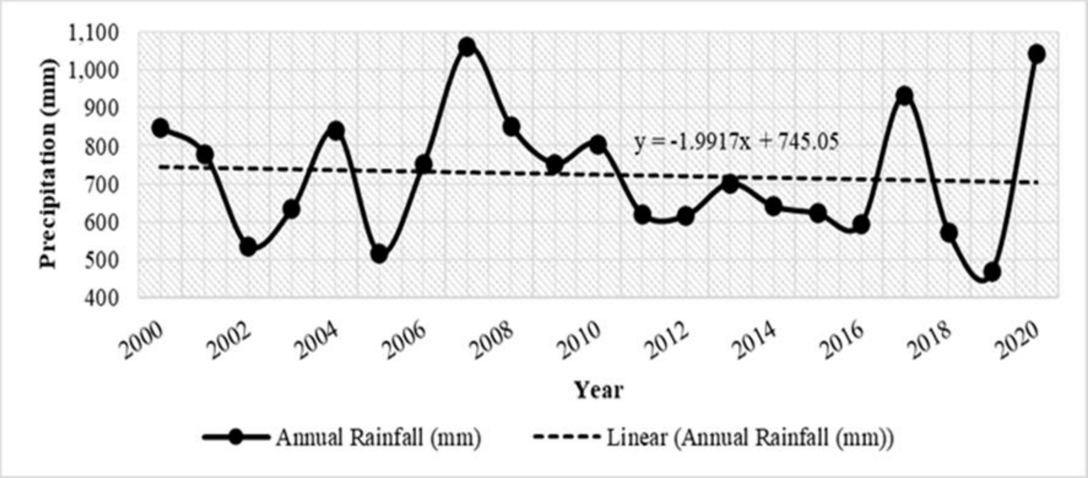


Fig. 1 Annual Rainfall

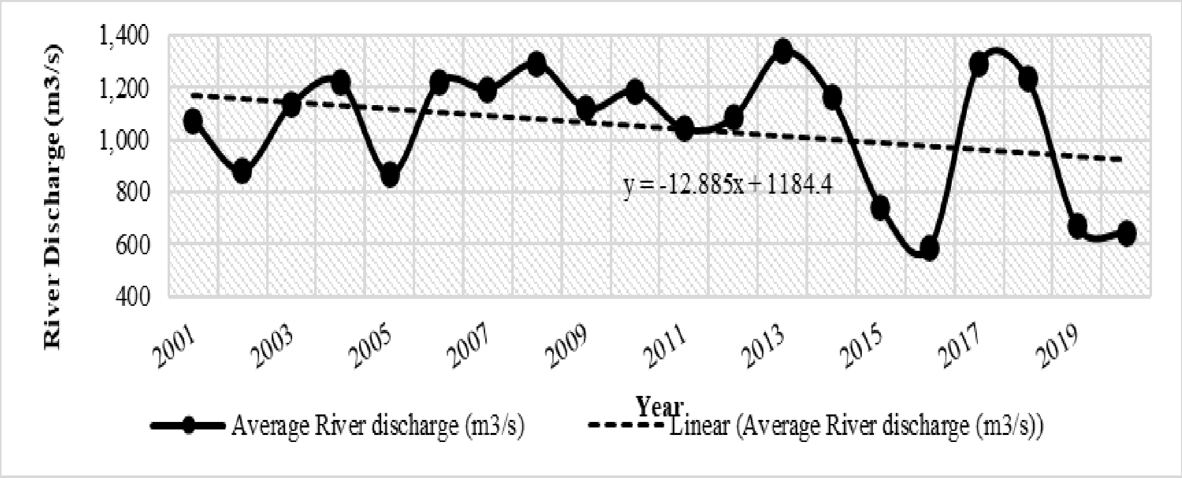


Fig. 2 Average River Discharge

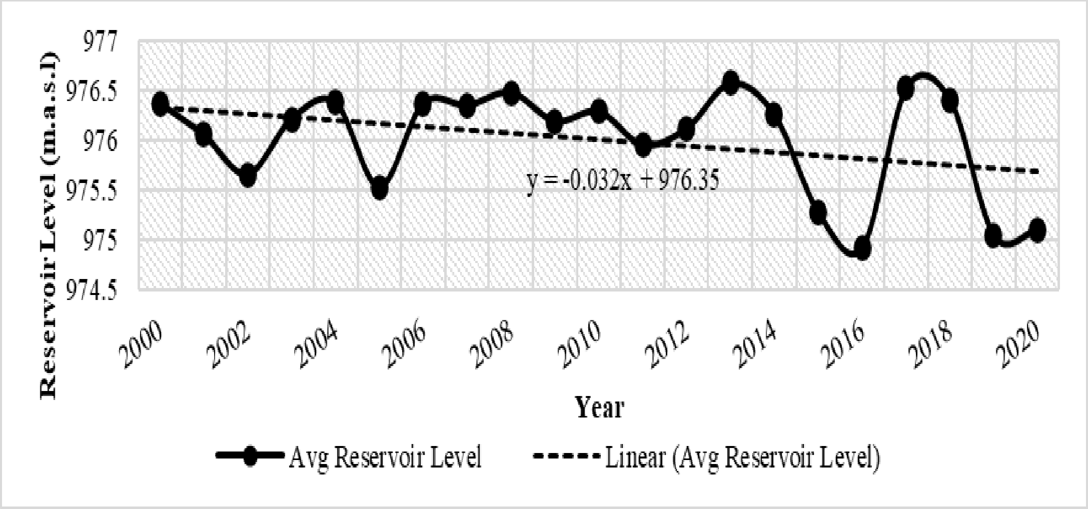


Fig. 3 Average Reservoir Level

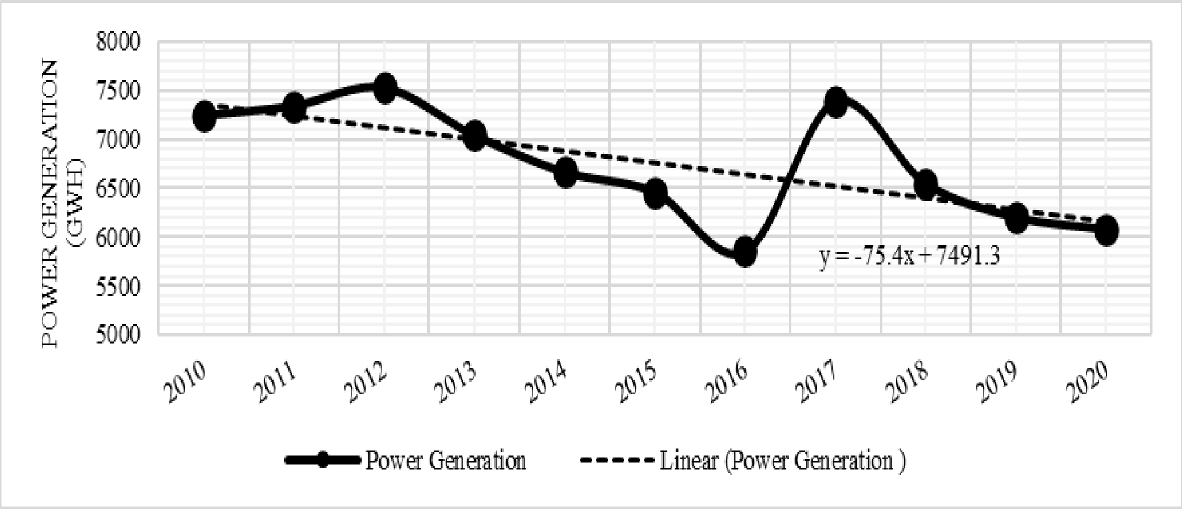


Fig. 4 Power Generation

Results and Discussion

- **Objective 2 - The influence of river flows and reservoir levels on hydropower power generation.**
- Further analysis of the influence of hydrometeorological changes on power station's generation capacity using the Pearson correlation analysis.
- The R-value or coefficient is 0.74.
- This indicates a close positive relationship between river flows and power generation.
- Therefore, river flows can impact power generation capacity by increasing or decreasing, indicating that changes in river flows can significantly impact the capacity of a system.

		River Inflows	**Power Generation**
River Inflows	Pearson Coefficient	1	0.74
	N	120	120
Power Generation	Pearson Coefficient	0.74	1
	N	120	120

The Engineering Institution of Zambia

Results and Discussion

Objective 3 - Adaptation measures to withstand climate change

- Measures specifically in response to climate change have not been implemented by the power station during the period under consideration.
- Proposed measures to counter the effects of climate change include:
- diversification of the energy mix,
- installation of low-water-level turbines,
- introduction of cascaded hydropower generation systems,
- implementation of mini hydropower stations,
- improved government policies and government-driven funds for renewables.

Conclusion

- The changes in rainfall and temperature in the Kafue River catchment area associated with the hydropower station influenced the changes in the Kafue River flows.
- Changes in the Kafue River flows influenced changes in the water level of the reservoir of the hydropower station.
- As a result, hydropower generation was also affected by reservoir level fluctuations.
- The study was consistent with the literature review - temperatures increased, whilst rainfall and river flows decreased.
- It also agreed that these changes would influence hydropower generation.
- The hydropower station has not implemented countermeasures specifically to tackle climate change impact.

Recommendations

- **Structural Adaptation - Solar PV integration**

- Solar PV energy can be integrated into the power station for electricity generation.
- This enhances power plant output capacity and ensures efficient use during low reservoir levels or minimal rainfall.
- Nyirenda's 2019 study showed an average annual irradiation of 5.5 kWh/m2/day, sufficient for electricity production.

- **Non-structural Adaptation - Development of a real-time hydrometeorological data system**

- Inputs hydrometeorological data from Zesco Limited, WARMA, and Meteorology Department.
- Software tools to analyse the data and model it for purposes of optimizing operations and maintenance of the power station.

References

- Adegbehin, A. B., Yusuf, Y. O., Iguisi, E. O. & Zubairu, I., 2016. Reservoir inflow pattern and its effects on hydroelectric power generation at the Kainji Dam, Niger State, Nigeria. *WIT Transactions on Ecology and The Environment*, 203(1), pp. 233-244.
- Barnes, D. F. & Samad, H., 2018. *Measuring the Benefits of Energy Access A Handbook for Development Practitioners.* Washington, D.C: Inter-American Development Bank.
- Basnyat, D. B. & Watkiss, P., 2017. *Adaptation to Climate Change in the Hydro-electricity Sector in Nepal*, s.l.: Nepal Development Research Institute (NDRI).
- Hamududu, B. & Killingtveit, A., 2012. Assessing Climate Change Impacts on Global Hydropower. *Energies*, 5(2), pp. 305-322.
- Kaunda, C., Kimambo, C. Z. & Nielsen, T. K., 2012. "Hydropower in the Context of Sustainable Energy Supply: A Review of Technologies and Challenges". *International Scholarly Research Network Renewable Energy*, Volume 2012.
- Nyirenda, E., 2019. "Conjunctive Operation of Hydro and Solar PV Power with Pumped Storage at Kafue Gorge Power Station (Zambia)". [Online] Available at: https://www.diva portal.org/smash/get/diva2:1334218/FULLTEXT01.pdf [Accessed 31 2021 August].
- Water Resources Management Authority, 2020. *Kafue Catchment.* [Online], Available at: http://www.warma.org.zm/catchments-zambia/kafue-catchment-2/. [Accessed 11 May 2020].
- ZESCO Limited, 2021. *ZESCO Limited.* [Online] , Available at: https://www.zesco.co.zm/projects/generation. [Accessed 11 December 2022].

The End

THANK YOU FOR YOUR ATTENTION.