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Potential Impact of Climate Change on Hydropower System in Malaysia

Nur Atirah Ibrahim[a], Sharifah Rafidah Wan Alwi[a,*], Zainuddin Abdul Manan[a], Azizul Azri Mustaffa[a], Siti Nor Azreen Ahmad Termizi[a], Kamarizan Kidam[b]

[a]Process Systems Engineering Centre (PROSPECT), Research Institute for Sustainable Environment (RISE), Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Malaysia
[b]UTM-MPRC Institute for Oil & Gas, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
syarifah@utm.my

Hydropower emerged as the predominant renewable source, constituting 83.3 % of the overall renewable electricity generated and contributing to 15.9 % of the total electricity output in Malaysia. The adverse effects of climate change, including extreme temperature and precipitation events, pose challenges to the performance and infrastructure of the hydropower plant. The main objective of this research is to investigate the potential ramifications of climate change on hydropower generation in Malaysia, with a particular emphasis on the projected impacts of temperature and precipitation changes. Data from ClimateAP software using global climate models are used to estimate the percentage changes in annual average temperature by 2070 under high emissions scenarios in comparison to baseline data from the end of the 20th century. The heat map was used to show the projected maximum temperature and precipitation across Malaysia under the Radiative Concentration Pathways 8.5 scenario. The hydraulic power generated formula was modified to determine the relationship between climate change and power generation. The findings reveal that an increase in temperature reduces power generation while an increase in precipitation increases energy production. Enhancements, additional analysis, and validation of these findings would help mitigate climate change and provide valuable insight into hydropower systems.

1. Introduction

Climate change is a worldwide phenomenon that encompasses various effects. According to Tang (2019), these impacts extend beyond extreme weather events and include changes in precipitation patterns, wind speeds, temperature changes, and sea level rises over the last ten years. Climate change impacts and extreme weather will affect the energy system. Failure to address climate change mitigation and adaptation could result in serious short and long-term problems, such as partial or total blackouts due to disruptions in energy supply (Ibrahim et al., 2022).

The role of hydropower is expected to grow significantly in Malaysia as the country strives to achieve its energy and climate targets. Hydropower currently accounts for approximately 17% of total electricity generation in the nation (Energy Information Administration, 2021) with annual hydropower energy production rated at 4.5 Mtoe/y (Tang, 2020). Malaysia possesses a considerable amount of hydropower resources, although their distribution across the country is uneven, with more significant concentrations found in Sabah and Sarawak. The initial significant hydropower infrastructure, specifically Chenderoh Dam with a capacity of 27 MW, was constructed in 1930. Over the subsequent decades, the systematic development of Malaysia's natural resources has resulted in an annual energy generation of over 27,300 GWh from an overall installed capacity of 6,240 MW (Othman, 2020).

Based on projections, climate change is expected to have a range of effects on ecosystems associated with rivers (Vliet et al., 2013). Even in the absence of changes in precipitation patterns, the increasing temperatures are predicted to elevate evapotranspiration rates, leading to a reduction in river flow.

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Under climate change scenarios, several studies have observed a potential decrease in future hydropower production. This decline is attributed to various factors, including changes in precipitation patterns, rising temperatures, the transition from solid atmospheric precipitation to rain, earlier snowmelt, and reduced snow reservoirs in mountainous areas. It is crucial to acknowledge that the impact of climate change on hydroelectricity generation is contingent upon the specific region and warrants the conduction of local studies.
For instance, Beheshti et al. (2019) assessed the effects of climate change on precipitation, temperature, and stream flow, which are the key factors influencing hydropower generation in Karun III dam, Iran. The projections indicate that the Karun-III dam catchment is likely to become warmer and receive more rainfall. The study suggests that hydropower generation is expected to grow more in the near future compared to the far future, as predicted by both scenarios. In a review conducted by Obahoundje and Diedhiou (2022) on the historical and projected impacts of climate change, land use, and land cover changes on hydropower generation in West Africa, it was revealed that numerous hydropower plants in Africa have encountered recurrent power disruptions over the past thirty years due to the influence of climate change and variability.
Since very little research has specifically examined the potential impact on hydropower in Malaysia, despite the rising global temperatures and the attention given to climate change by researchers, this research gap inspired the authors to investigate the impact of climate change on hydropower. This study examines the potential implications of temperature and precipitation changes due to climate change on hydropower generation in Malaysia. Hydropower plants are typically equipped with forebay or upstream sources, trash rack, penstock, turbine, generator, surge chamber, power house and electrical system (Kadier et al., 2018). In this study, only four components were considered to investigate the potential impact of climate change on hydropower infrastructure which are forebay, penstock, turbine and generator other than power generation and efficiency.

2. Data and Methods

2.1 Climate trend analysis

The present study employed the ClimateAP software to project climate data, drawing upon global climate models derived from the Coupled Model Intercomparison Project Phase 6 (CMIP6). These models, featured in the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC), offer estimations concerning forthcoming temperature variations and precipitation. The reference dataset for ClimateAP consist of the most reliable interpolated climate data accessible for the 1980-2010 timeframe. In order to derive scale-free point data, the baseline dataset underwent down sampling from a moderate spatial resolution, employing dynamic local elevation adjustments (Wang et al., 2017).
This study focuses on examining the impact of climate-related variables, namely temperature and precipitation, on the hydropower sector in Malaysia and translated into heat map.

2.2 Potential impact analysis

This section presents a significant analysis that focuses on estimating the performance implications and physical damage caused by temperature change and precipitation due to climate change on various infrastructure components of hydropower systems.
In order to assess the implications of projected temperature and precipitation changes on performance of hydropower plants, a structural calculation scheme has been modified based on established hydraulic power plant generated formula (Unya et al., 2022). Assumptions were made during calculation such as reference of ambient temperature at 25°C and 90 % of turbine efficiency. Table 1 tabulates the characteristics and climate data by selecting five significant hydropower plants in Malaysia as the case study.

Table 1: Characteristics and climate data of five hydropower plants in Malaysia

Hydropower station	Max Power (MW)	Capacity (million m^3)	Discharge capacity (m^3/s)	Operating system	Temperature		Precipitation	
					Historical	Projected	Historical	Projected
Bakun, Sarawak	2,400	44,000	-	Reservoir	30.9	33.2	449	476
Murum, Sarawak	944	12,043	-	Reservoir	29.1	31.3	438	449
Pergau, Kelantan	600	62.6	2,470	Reservoir	29.7	32.6	347	373
Kenyir, Terengganu	400	13,600	7,000	Reservoir	32.4	35.2	508	532
Ulu Jelai, Pahang	372	2.57	2,300	Reservoir	30.1	32.9	327	357

Hydropower plants rely on the utilization of waterfalls to generate electricity. Stream flow serves as the fuel for these plants, and the continuous availability of water is essential for uninterrupted power generation. The hydraulic power generated (Ph) by the flowing water is expressed in Megawatt (MW) as shown in Equation 1 where ρ is water density (1,000 kg/m^3), g is acceleration due to gravity (9.81 m/s^2), h_n is net head and Q is discharge in m^3/s.

$$P_h = \rho g Q h_n \quad (1)$$

The present study adapted the above equation which measures the impact of climate change in terms of change of temperature (P_T) and precipitation (P_P) variables based on Equations 2 and 3 respectively.

$$P_T = P_h + \rho g Q h_n \alpha(\Delta T) \quad (2)$$

$$P_P = P_h + \rho g Q h_n \beta(\Delta P) \quad (3)$$

Where ΔT and ΔP represent the percent change in forecast temperature and precipitation as compared to the historical based-line value for specific location of hydropower, respectively. The coefficient α is the dimensionless parameter represents the rate of decline in power generation influenced by extreme temperature and variations in ambient temperature, -0.0273 (Markoff and Cullen, 2008). β is a dimensionless positive coefficient of power generation in a specific timeframe which is generated based on change of precipitation and extreme rainfall, 0.0091 (Chilkoti et al., 2017). Other potential impacts on infrastructure of hydropower plant were studied using qualitative data from published sources and previous case studies.

3. Result and discussion

3.1 Hydropower in Malaysia

Hydropower can be classified based on power output into five categories which are large (> 10 MW), small (1-10 MW), mini (100 kW – 1 MW), micro (5 – 100 kW) and pico (< 5 kW) (Kadier et al., 2018). Three types of operating system of hydropower consist of run of river type, reservoir type and pumped storage type. The run of river type does not control the river's flow but uses the natural water flow to generate electricity. It faces water scarcity during dry seasons and excessive water during rainy seasons. The majority of large hydropower plants in Malaysia use reservoir types to store a significant amount of river water, and they modify their power output in response to seasonal demand. Meanwhile, the pumped storage system utilizes off-peak electricity or power to facilitate the elevation of water from a lower-level water reservoir to a higher level within the reservoir (Kadier et al., 2018).

Figures 1a and 1b represent the heat map of historical and projected maximum temperature for different locations of hydropower in Malaysia. Meanwhile, Figure 2a and 2b shows the heat map of historical and projected of maximum monthly precipitation of hydropower in Malaysia.

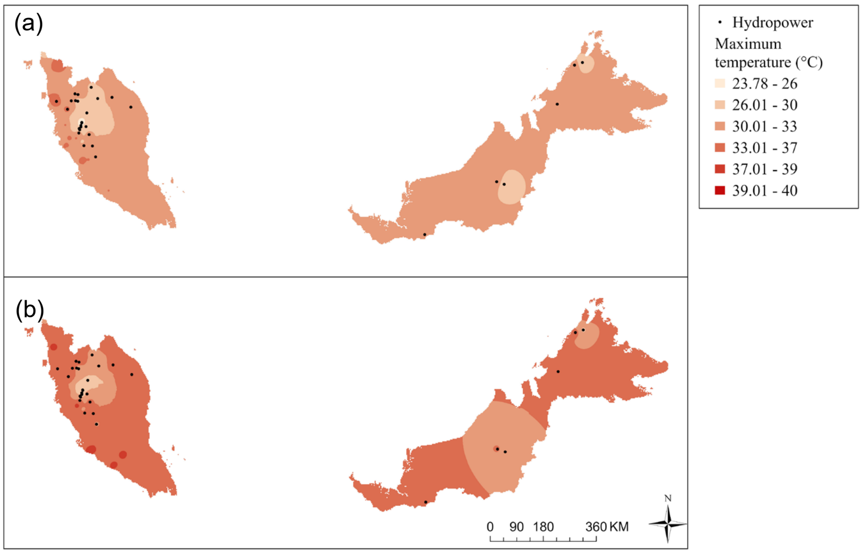

Figure 1: Heat map of (a) historical maximum temperatures, (b) projected maximum temperatures for different hydropower

These maps only consider large and small hydropower with capacity above 1 MW. According to previous research (Tang, 2019), the average annual temperature in Malaysia typically ranges from 25 °C to 28 °C. By using projections derived from the ClimateAP software, it is estimated that by the year 2070, under the RCP 8.5 high emission scenario in Figure 1, it can be seen that the average of maximum temperature in Malaysia will experience hotter ambience with an increase of approximately 7 to 10 °C. The monthly precipitation map in Figure 2 shows that rainfall will increase by roughly 20% in 2070 as indicated by the darker colours at certain locations near hydropower plants.

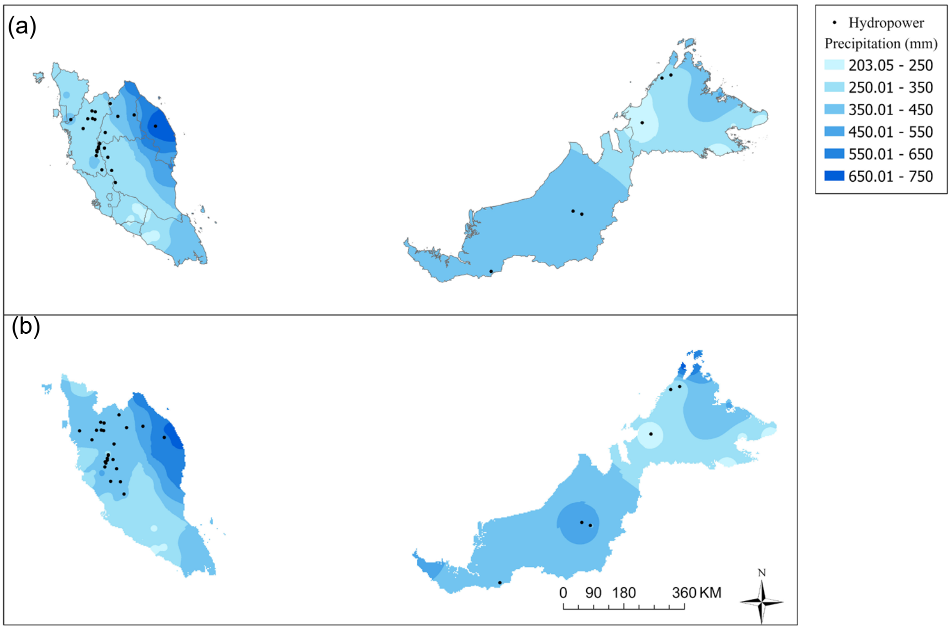

Figure 2: Heat map of (a) historical maximum monthly precipitation, (b) projected maximum monthly precipitation for different hydropower

3.2 Performance and other potential impacts on hydropower

The phenomenon of climate change poses significant impacts for prospective hydropower plant. Changes of precipitation patterns and rise in temperature contribute to disruptions in river stream patterns, adversely impacting hydropower generation, performance and infrastructure.

Table 2 shows the data and impact assessment results of the five hydropower production plants in Malaysia. The result is represented in Figure 3 to illustrate the impact of climate change (temperature and precipitation) in 2070 on the five hydropower production plants in Malaysia. Normal condition represents the amount of hydropower that can be produced within 24 h based on historical ambient temperature and precipitation. The impact of temperature and precipitation is represented by the percent rise of temperature and precipitation in 2070 for specific hydropower location. From Figure 3, it can be seen that the power generation dropped as the temperature increases. This is due to the higher evaporation rate from the surface of the reservoir as the ambient temperature rises. It will reduce reservoir capacity and subsequently reduce power production. The empirical relationship between evaporation and ambient temperature had been studied by Beheshti and team (Beheshti et al., 2019).

In contrast, the increase of precipitation amount will lead to a slight increase in their capacity for generating electricity. This is due to increment of runoff and stream flow resulting in the rate of turbine-water-flow to operate at maximum rate which will produce higher power generation (Lammers et al., 2020). In general, the production of hydropower exhibits a strong correlation with precipitation patterns. A rise in precipitation levels is directly associated with an upsurge in power generation. Prolonged periods of diminished or absent precipitation result in a decline in power generation.

Table 3 summarizes the potential impact due to climate change on hydropower plant. In general, minor increases in ambient temperature and precipitation may not cause significant physical damage unless extreme weather occurs. Higher temperature and reduced precipitation for a long duration may lead to heatwave and drought, while higher precipitation will result in flooding. During periods of flooding, the capacity of the reservoir may impede effective management of the amplified water inflow. This does not only lead to energy wastage through spill-overs but also jeopardizes the safety of the dam. Conversely, during prolonged drought periods, reducing the water level in the reservoir can result in degradation of water quality characterized by elevated algal biomass and increased turbidity (Ibrahim et al., 2022).

Table 2: Impact assessment results of five hydropower plants in Malaysia

Hydropower station	Temperature rise (°C)	Precipitation change (%)	Average production (MW/day)	Temperature impact on power generation (MW/day)	Precipitation impact on power generation (MW/day)
Bakun, Sarawak	2.3	6.01	2,110	1,977	2,225
Murum, Sarawak	2.2	2.51	635	597	650
Pergau, Kelantan	2.9	7.49	150	138	160
Kenyir, Terengganu	2.8	4.72	165	152	172
Ulu Jelai, Pahang	2.8	9.17	48	44	52

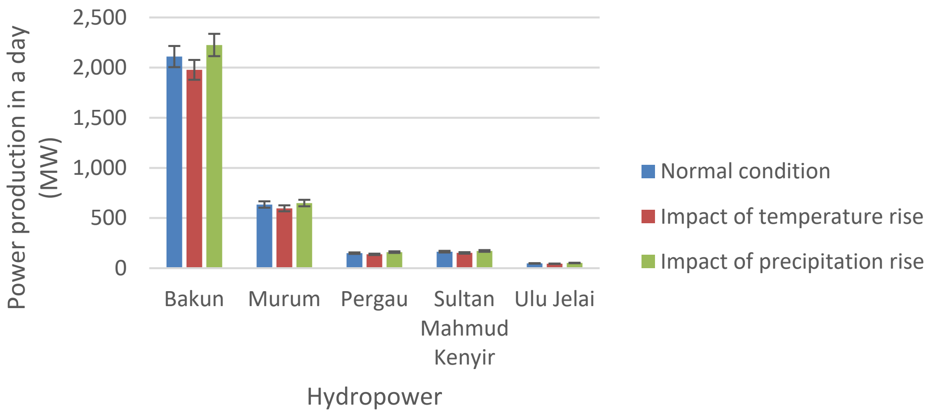

Figure 3: Impact of temperature and precipitation change in 2070 on hydropower production

Table 3: Potential impact due to climate change on hydropower plant.

Influencing factors		Climate scenario: Higher temperature and lower precipitation	Climate scenario: Higher precipitation	References
Performance	Power capacity	Reduce power output up to 50 %	Increase power generation by 39 %	(Chilkoti et al., 2017; Mekonnen et al., 2022)
	Efficiency	Low efficiency performance	Increase efficiency performance	(Mekonnen et al., 2022)
Physical damage	Forebay	May cause siltation and reduce water quality in reservoir due to low water level	Influence the streamflow variability	(Chuphal and Mishra, 2023; Mukheibir, 2013)
	Penstock	-	Excessive water flows may cause the penstock to burst	(Adamkowski, 2001)
	Turbine and generator	May cause siltation that can damage and reduce the turbine efficiency	Damaged turbine due to debris if flood happens	(Ebinger et al., 2011; Mukheibir, 2013)

*(-) means insignificant or uncertainty impact due to lack of information.

4. Conclusions

This study investigates the potential impact of climate change on hydropower in Malaysia using ClimateAP software to obtain the percentage increase in temperature and precipitation for specific hydropower location by 2070. By 2070, Malaysia will experience a hotter ambient temperature with an increase of roughly 7 to 10 °C and a rise in precipitation of about 20 %. Increased precipitation levels have a direct positive impact on power generation, while extended periods of reduced or absent precipitation correspondingly decrease power generation. Simultaneously, rising temperatures lead to a decrease in power generation due to the elevated evaporation rates from the reservoir's surface, triggered by higher ambient temperatures. Further research on extreme temperature and precipitation risks to hydropower plants, as well as design reviews, are required for future planning and assessing the relevance of existing plants.

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