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19th International Conference on
Thermal Science and Engineering of Serbia

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Energy – Efficiency – Ecology

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The Economic Impact of Climate Change on the HPS Mavrovo

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Abstract: Due to the stochastic character of climate change, the hydropower plants work with great uncertainty, especially as a result of hydrological variability. The magnitude of the climate change impact largely depends on the hydrological capacity of the existing power plants' storages and hence on the economy of a country. Having into account a fact that many factors have a significant impact on climate change, long-term estimates, analysis, and prediction of future hydrology is not easy and could not be quite precise. However, the opportunities offered by various meteorological models have strongly contributed to better understandings of climate change and its physical effects, thus raising global awareness of the need to better adapt and optimize the operation of hydropower plants.In this paper, the authors use the hydropower system (HPS) Mavrovo as a model to explain the expected economic impacts of climate change on this HPS and on the local electricity markets. It has been shown that the expected climate change has an ambiguous impact on energy generation and economy of operation. The cost of electricity and the system operation are changing, increase during dry weather conditions and decrease under average wet or extreme wet weather conditions. Finally, some analysis and protection measures for climate change mitigation are also given.

Keywords: Hydropower, Climate change, Economic impact assessment.

1. Introduction

Hydropower has a major role in global electricity production and still is the most widely used source of renewable energy. The interaction of the hydrology and energy system, known as the water-energy link, has received more attention in the past decade in research and political debates.

Hydropower is an important part of power systems in many countries. Not only does it play an important role in mitigating climate changes, but it is also a subject to climate change impacts. Climate changes have also an impact on the economy of hydropower, so it can reduce electricity production an also provide an unstable power system. In the future, a significant increase in electricity consumption, as well as increase climate changesare expected, so analyzes and methods for reducing climate changes must be done as much as possible along with providing electricity for the needs. In this paper, our research focus will be set on the impact of climate change on HPS Mavrovo, and as well on how it affects the local electricity market. This modeling approach enables not only to cover the possible quantitative effects of changes in water availability and variations in potential production but also to calculate expected electricity production and revenues for hydropower operators under market constraints. Furthermore, the repercussions between the changes in the hydrological potential on the one hand and the prices on the electricity market and the costs of the system, on the other hand, are given.

2. Climate, climate changes and their impact of the hydrology

Climate is the statistics of weather over long periods of time. Besides the statistical weather information, climate also includes information about the range of weather extremes for a certain location. Climate can often be mistaken with the weather, although the weather only describes the short–term conditions of the certain weather variables, such as temperature, humidity, atmospheric pressure, wind, and precipitation for a given region. By assessing the patterns of variation on these and other meteorological variables, one can measure climate in a given region over a longer period of time.

In general, the climate system is comprised of five interacting parts, the atmosphere (air), hydrosphere (water), cryosphere (ice and permafrost), biosphere (living things), and lithosphere (earth's crust and upper mantle). The climate of a location is affected by its latitude, terrain, and altitude, as well as nearby water bodies and their currents. Climates can be classified according to the average and the typical ranges of different variables, most commonly temperature and precipitation. The most commonly used scheme for this purpose was Koppen climate classification [1]. Apart of the Koppen climate classification, it is important to mention the Thorntwaite system, in use since 1948 and the Bergeron and Spatial Synoptic Classification system, of which, the first one incorporates evapotranspiration along with temperature and precipitation information, and the second one focuses on the origin of air masses that define the climate of a region [1].

Climate change in the world can be caused by various activities. When climate change occurs, temperatures could change dramatically. The Earth receives nearly all of its energy from the sun, with a relatively tiny amount from earth's interior. Also, Earth gives off energy to outer space, thus the Earth's energy balanceis determent by the balance of incoming and outgoing energyand the energy transfer through differentparts of the climate system. This means that we have two cases:

- if more energy comes in, the Earth’s energy balance is positive and the climate system is warming;
- if more energy goes out, the Earth’s energy balance is negative and the climate system is cooling.

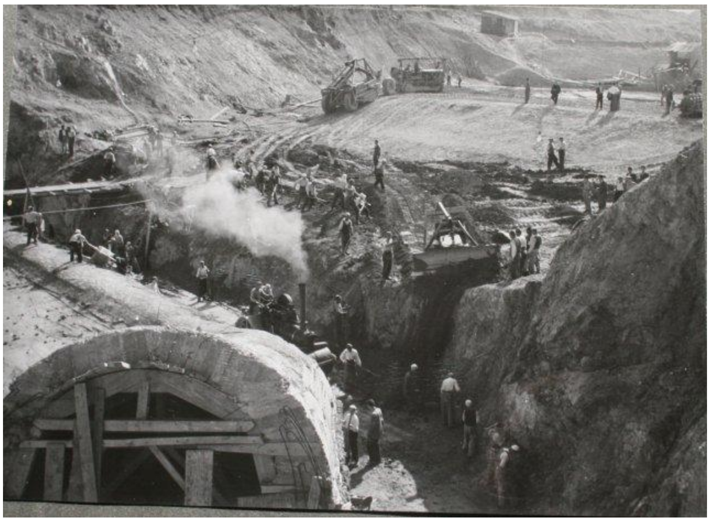
The terms internal variability i.e. cyclical ocean patterns such as El Nino Southern Oscillation, Pacific Decadal Oscillation, and Atlantic Multi-Decadal Oscillations, and external forcing such as changes in solar output and volcanism, refer to natural processes and also contribute for such changes known as "climate change". It is very important to acknowledge that the change of climate can also be caused by human activities causing so-called “effect of global warming”. Water with its resources is essential and necessary, playing a very important part of all ecosystems, industrial processes, and agricultural production. However, as a consequence of human and natural factors, water shortages are a major problem in many countries, and the future of availability of water resources becomes very difficult to guarantee. Finally, the consequences of climate change on water resources should be expected, albeit different in a different ecological, socio-economic, and political context [2].

This means that climate changes, for example, higher air temperatures resulting in intense evaporation and changes in the amount of water that are generated by the melting snow, will have serious consequences on water resources anywhere in the worldhaving different socio-economic and ecological aspect. Therefore, a huge effortmust be done to mitigating these problems. Changes in the snow cover and the snow melting will affect the amount of energy produced in hydroelectric power plants, which will affect water supply in cities, flood protection and commercial and recreational fishing. This will have political consequences; there will be more competition for water resources, and the management of these resources will become a very sensitive issue.

The expected climate changes could play an important role and have a strong effect on the water resources in the Republic of North Macedonia in the middle and especially on long-term periods. In addition, human health and safety might also be harmed without taking appropriate protection of the existing water resources. Thus, to accomplished effective mitigation of expected climate changes, an integrated approach to protect water resources must be done in cooperation withvarious involvedparties[3], [4].

3. Hydropower system (HPS) Mavrovo – location and historical information

With the total accumulation of 275 million [m^3] water, HPSMavrovo is one of the largest and most complexes HPS in the Macedonian power system. It is located in the Municipality of Mavrovo - Rostushe and with its three hydropower plants: HPP Vrutok, HPP Raven and HPP Vrben account for almost42% of the total installed hydropower capacity in Macedonia. This HPS utilizes the waters from National park Mavrovo for electricity production over several decades. Several hydropower stations, artificial lakes, and extensive piping and tunneling systems have been built as early as the 1940s. The operation of the hydroelectric plants is done by the Joint Stock Company ‘Elektranina Severna Makedonija’ (JSC ESM).



Source: *Power plants of North Macedonia [5]*

Figure 1. Construction of the Hydro System Mavrovo

The first phase of the construction of the HPS Mavrovohad begun in 1947. In order to increase electricity production, the construction of the second phase of the system called Mavrovo 2 was initiated in 1969. During this phase, the new and additional water supply system called “SharskiVodi” was constructedbringing additional waters from the nearby Shar Mountain. In 2014, the realization of the second phase of the revitalization of hydroelectric plantsincluding HPS Mavrovo was done by JSC ESM. This project, worth more than 37 million EUR, enabled the extension of the lifespan of hydropower plants and their accompanying buildings, as well as increasing their safety [5].

Source: *Power plants of North Macedonia [5]*

Figure 2. The current appearance of the hydro-power Mavrovo.

The main benefits of the revitalization of the HPS Mavrovo system were:

- The increase in the capacity of the Mavrovostorage for additional 32.55 million [m^3] of water with an additional water storage capacity of 20 million [m^3/year];
- The increase in installed capacity for additional 18.58 [MW], or increase the total installed capacity of all three hydropower plants to 200 [MW], and
- The increase in the annual electricity generation for 40 [GWh/year] in total.

The structure of the HPS Mavrovo is shown in a schematic diagram in Figure 3. As shown in Figure 3, the HPS Mavrovo is a cascade system comprised of three interconnected HPPs:

- HPP Vrben – run-of-the-river power plant with two units and a total installed capacity of 2x6.4=12.8 [MW]. The average electricity generation 38 [GWh/year] withthe average annual flow of 107 million [m^3] of water.
- HPP Raven – run-of-the-rive power plant with three units and a total installed capacity of 3x7=21 [MW], and the average electricity generation 42 [GWh/year].

- HPP Vrutok – water storage power plant with four units and a total installed capacity of 4x41.4=165.6 [MW]. The average annual electricity generation 350 [GWh/year] with the average annual flow of 278 million [m^3] of water.

The whole HPS is interconnected through power lines to the national power grid.

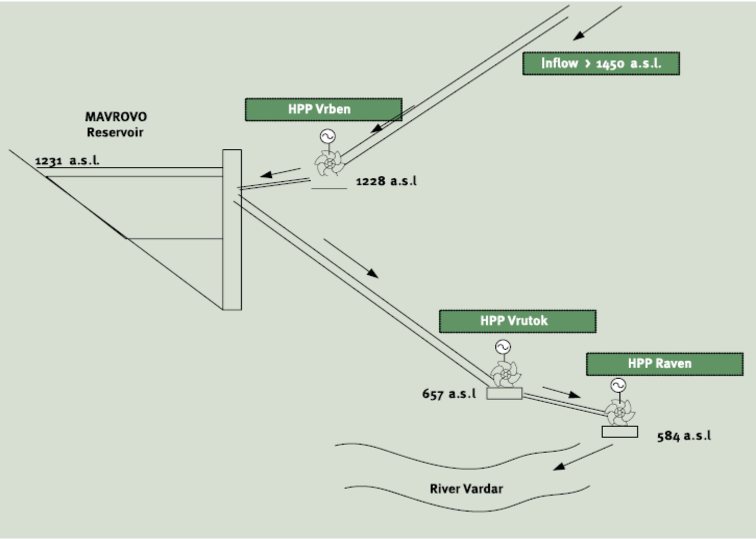


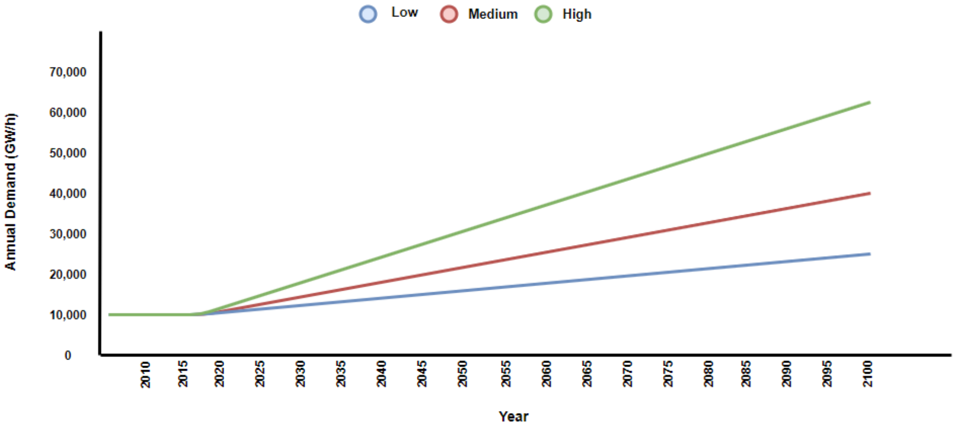
Figure 3. Schematic diagram of HPS Mavrovo

4. The Economic impacts of climate change on the hydropower sector: A case study of the HPP Mavrovo

4.1. Definition of Base Case Scenario and future trends

In order to make a comparison and evaluate the impact of the expected climate change on the hydropower sector, initially, the so-called Base Case scenario had to be established. For that, the Base Case scenario was set to coincide with the current climatic conditions and the existing electrical loads of the system, thus the year 2010 was set as a base year where the annual electricity needs were 9.500 [GWh] with the peak load of 1.700 MW (in December 2010).

The future load profile for electricity demand in the country was estimated based on the historical consumption patterns obtained by using the database for past electricity load consumptions. Using these patterns, three future electricity load demands (low, medium and high) were predicted. The growth rate and annual electricity demand for the three scenarios are shown in Figure 4in a different color, depending on expected growth rate: (blue line for low, red line for medium and green line for high). The growth rates used in these projections are higher until 2030 (1.5%, 2.0% and 2.5%) and after that the growth rates are lower until 2100 (1.0%, 1.5% and 2.0%), respectively.These predictions were made based on the economic development studies for the country and on the National energy strategy of 2010[6].



Source: *Assessing the economic impact of climate change - National Case Studies [8]*

Figure 4. Projections of annual electricity demand for 2050 and 2100. Mavrovo

According to these predictions, the Base Case climate scenario was assumed to remain constant over all periods (current period, 2050 and 2100). The databases of all HPPs consisted of average monthly inflow based on the water inflow of around 60 years (from 1946 until 2007). The inflows were divided into three hydrology categories:

- Low runoff – dry hydrology with 14% of the driest years;
- Average/Medium runoff – average hydrology with 74% of the average years; and
- High runoff – wet hydrology with 12% of the wettest years.

The previously stated hydrology categories for the entire system are shown in Figure 5.

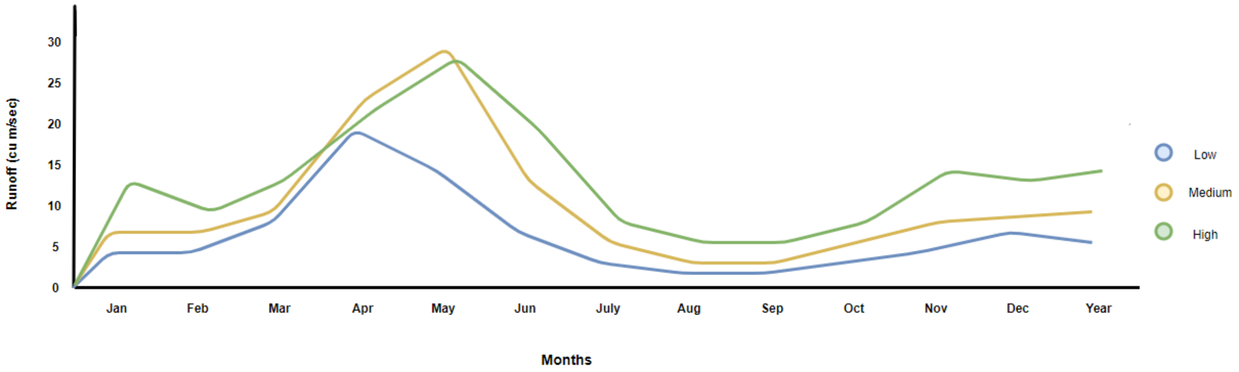


Figure 5.Monthly runoff for the Base Case (current climate) for low, average (medium) andhigh precipitation conditions

4.2. Results for Climate Change Analysis

4.2.1. Runoff and Electricity Generation

For projecting the available water resources for the HPS Mavrovo, it must be taken into account the fact that due its location (northwesternmostly mountainous part of the country), the main water comes from melting snowfall of the Shara and the Korab Mountains:

- in the Spring (April, May, and June) the water inflow into the lake Mavrovo, that acts as water storage for the HPS Mavrovo, is mainly because of snowmelt;
- in the Winter (from December until March) the water inflow into the lake Mavrovo is mainly from snow precipitation, not snowmelt;
- in the remaining parts of the year, the water inflow into the lake Mavrovo is mainly from rainfall.

The closest meteorological station to the Shara Mountain watersheds is the PopovaShapka weather station, located in a sub-alpine climate. The projected runoff values for 2050 and 2010 for the low, average/medium and high precipitation conditions were determined by normalizing the changes in precipitation at this site as projected by Bergant in [7].

4.2.2. Climate Change Impacts on Runoff

Climate Change is expected to impact the runoff depending on the period of the year. This means that runoff in March, April and May is projected to increase, or at least not decrease in 2050 and 2100 relative to the Base Case. Because of the large amount of runoff that occurs during this period, it could result in a positive effect on annual reservoir storage and the net effects could be bigger. The runoff for all of the remaining months of the year is projected to decrease due to climate change in 2050 and 2100 relatively to the Base Case. Because of the less amount of runoff that occurs during this period, it will result in a not so favorable net effect. In fact, the projected change in average monthly and annual runoff is actually positive for 2050 under high precipitation conditions. This makes sense because if the soil becomes increasingly dryer due to decreased precipitation, the free flow waters become lesser and the percentages of water that infiltrated the soil and later evaporated or percolated to groundwater becomes higher.

The projected water runoff changes for 2050 and 2100 are shown below for the low runoff scenario, the average/medium runoff scenario,and for the high runoff scenarioin Figures 6, 7, and 8, respectively. For the case of comparison, the Base Case values are also shown in each of the projections [8].

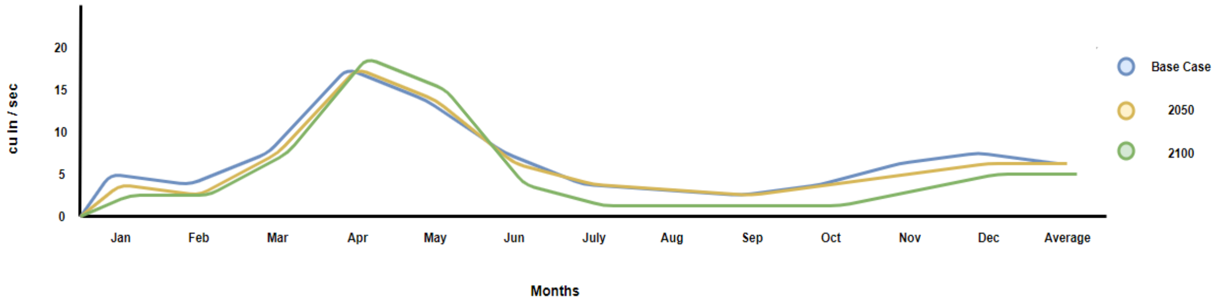


Figure 6.Monthly runoff for Mavrovo reservoir for low precipitation conditions in 2050 and 2010 (With climate change) Compared to the Base Case (without climate change)[8]

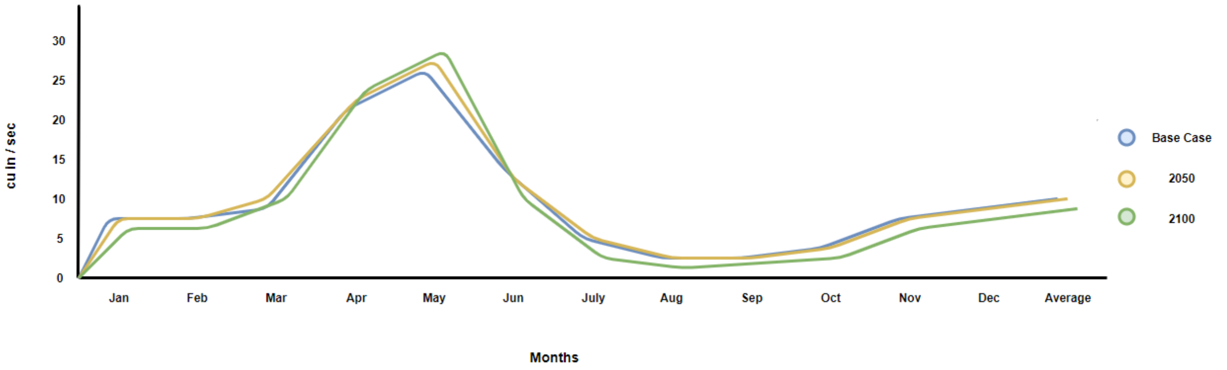


Figure 7.Monthly runoff for Mavrovo reservoir for medium precipitation conditions in 2050 and 2010 (with climate change) compared to the Base Case (without climate change) (m^3/sec)[8]

4.2.3.Climate Change Impacts on Electricity Generation

The changes of power generationare the reflection of and vary accordingly with the changes of the water runoff patterns, as one could expect. Firstly, the water runoff changes for medium and high precipitation were investigated. In such scenarios either a small increase in power generation during the March-May period and a small reduction or even no reduction in power generation relative to Base Case in the remaining months, could be observed. In these two cases, the climate change show patterns of changes of the seasonal distribution of waters and reservoir operators, increase inflows during spring months and decrease inflows for the rest of the year. Fortunately, the existing reservoirs are sufficiently large to accommodate these larger water inflows as a result of theseclimate change patterns.Under medium precipitationcondition, the system does not have to reduce power generation relativeto the Base Case and under high precipitation conditions; the system can actually increasepower generation under the projected climate changes in 2050 and 2100.

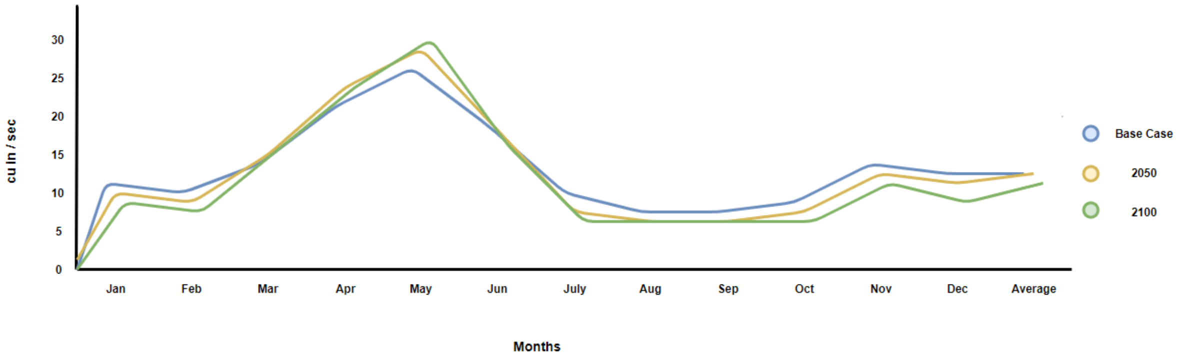


Figure 8.Monthly runoff for Mavrovo reservoir for high precipitation conditions in 2050 and 2010 (with climate change) Compared to the Base Case (without climate change)[8]

Table 1. Projected runoff for low, medium and high precipitation conditions for the Base Case (no climate change) and 2050 and 2100 (with climate change) [8]

Case	**Monthly Average Runoff (m^3/sec)**	**Change [%]**
	Low	
Base	6,03	-
2050	5,81	- 3,53 %
2100	5,45	- 9,58 %
	Medium	
Base	9,66	-
2050	9,51	- 1,52 %
2100	9,12	- 5,56 %
	High	
Base	13,15	-
2050	13,24	0,63 %
2100	12,96	- 1,45 %

Next, the low precipitation case scenario was investigated. As expected, results showed a decrease in the power generation all year aroundrelative to the Base Cases, irrespectively of the season in 2050 and in 2100. In this case, even during the March-May period when the reservoir was achieving its highest peaks, the water inflows were less than those during the other two precipitation cases, the medium and the high precipitation cases. Additionally, as a result of this low precipitation condition, the power generation was decreasing during all months in the year.

The projected changes in electric power generation for low precipitation, medium/average precipitation conditions, and for high precipitation scenariosare shown in Figures 9, 10, and 11, respectively, whiletabulated resultsof these changes are given in Table 2. For comparison, the Base Case values are also shown in each of the projections [8].

For better understanding, the clime change impact on the electricity generation, derived from results given in Table 2, the percentages of decrease/increase of the generated electricity relative to the Base Case for the HPS Mavrovo are given in Figures 12 and 13. Figure 12 shows in the changes in power production relativeto the Base Case in absolute values [GWh/year], while Figure 13 shows the relative changes in percentage [%] compared with the Base Case Scenario.

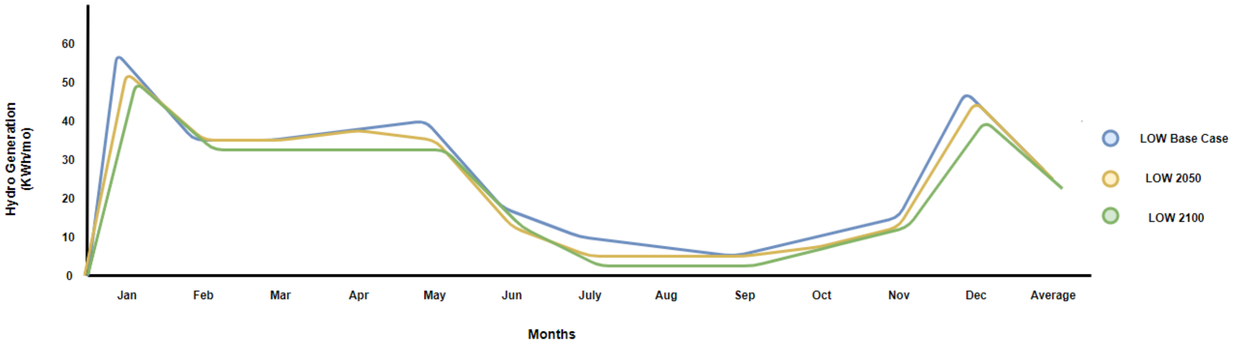


Figure 9.Monthly Hydro-electric power generation for Mavrovo for low precipitation conditions in 2050 and 2010 (with climate change) compared to the Base Case (without climate change) [GWh/month]

Figure 10. Monthly hydro-electric power generation for Mavrovo for medium precipitation conditions in 2050 and 2010 (with climate change) Compared to the Base Case (without climate change)

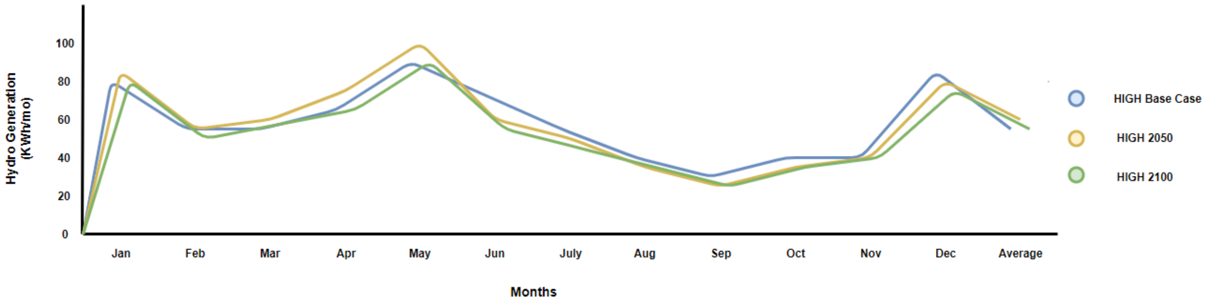


Figure 11. Monthly hydro-electric power generation for Mavrovo for high precipitation conditions in 2050 and 2010 (with climate change) Compared to the Base Case (without climate change)

Table 2.Projected hydropower generation for low, medium and high precipitation conditions for the Base Case (with no climate change), and 2050 and 2100 (with climate change) [8]

Case	Monthly Average Power Generation [GWh]	Annual Average Power Generation[GWh]	Change[%]
Low			
Base	26,28	315,32	-
2050	25,35	304,25	- 3,51 %
2100	23,98	287,70	- 8,76 %
Medium			
Base	42,22	506,62	-
2050	41,47	497,69	- 1,76 %
2100	39,68	476,18	- 6,01 %
High			
Base	57,37	688,39	-
2050	57,66	691,91	0,51 %
2100	56,46	677,54	- 1,58 %

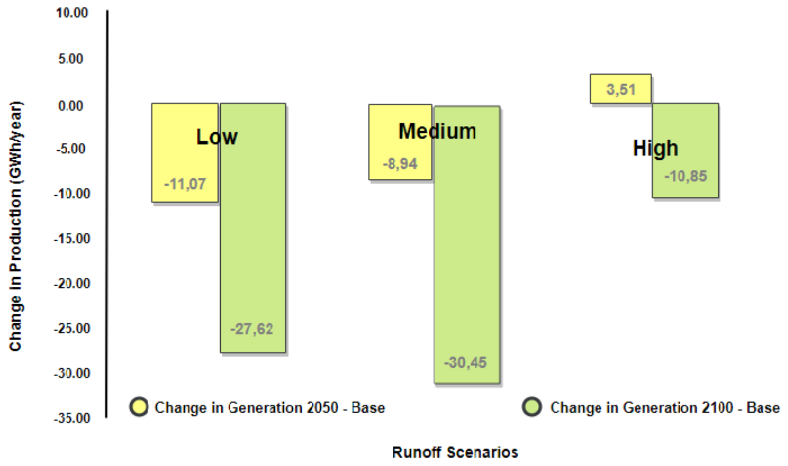


Figure 12. Change in annual hydro-electric power generation for Mavrovo for low, medium and high precipitation conditions in 2050, and 2100 (with climate change) compared to theBase Case (without climate change) in [GWh]

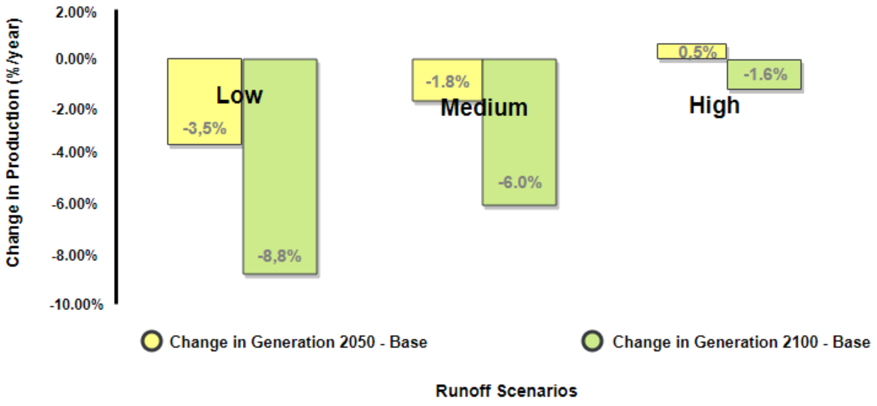


Figure 13. Change in annual hydro-electric power generation for Mavrovo for low, medium and high precipitation conditions in 2050, and 2010 (with climate change) compared to the Base Case (without climate change) in [%]

4.2.4. Cost Analysisof the Projected Climate Change Impact

For evaluating the climate change impacts due to runoff reductions atthe HPS Mavrovo, calculation of the replacement cost for the lost hydropower generation in 2050 and 2100 relative to the BaseCase was used.Replacement cost was divided in accordance with the type of power plants and used fuels, the classical fossil-fueled ones and the renewable ones, separately. That wasdone using the annualized life-cycle cost data given in Tables3 and 4 for various types of electric power generation plants.

Table 3.Annualized life-cycle generation and total cost estimates for different types of power plants in the NorthMacedonia in 2010Plant-Type Generation [6]

Plant type	Generation cost (EUR/kWh)	Total cost (EUR/kWh)
Coal – Fired	0,04	0,100
Gas – Fired	0,058	0,118
Nuclear	0,053	0,115
Wind power	0,089	0,152
PV systems	0,260	0,350

***Source**: National energy plan*

Thus, for evaluating the annualized climate change damages in 2050 and 2100, two different methods were used: the first method was to assume that the lower power generation, relative to the Base Case, could bereplacedwith generating power from classical fossil-fueled sources, while in the second method the lower power generationcould be replaced by other renewable energy sources. At this point, it is important to notice that the prices for renewable sourcesreflected subsidized or so-called “feed-in” tariffswhich are much higher than the regular commercial price. However, it should be taken into account that these commercial pricesare expected to rise dramatically in the coming decade as currentcommercial prices do not reflect the economic price.

Two evaluation criteria were used to bound thecost of replacing the power that was lost as a result of reduced runoff due to climate change:the generation cost and the total cost. The generation cost includes investment, fuel, and operating andmaintenance costs. Total cost includes the generation cost plus the distribution and transmissioncost.

In general, the reductions in power generation by the HPS Mavrovowere surprisingly small incomparison to the Base Case. They show some impact in relative terms only for the dryprecipitation conditions when there are sharp reductions in precipitation during the wet season. During the low precipitation conditions, the projected reductions in average monthly power production were about3.5 [%] in 2050 and about 8.8 [%] for 2100, compared to the Base Case. The comparable projected changes in power generation at HPS Mavrovo under high precipitationconditions were an increase of about 0.5% for 2050 and a reduction of about 1.6 [%] for 2100.

Using the above-described methodology, the projectedvalue of climate change damages for 2050 ranged from a benefit of aboutEUR 140,000 per year to a cost of about EUR 1.3 million per year, depending on the type ofpower plant and precipitation conditions. For 2100 these projections ranged from a cost ofEUR 575,000 per year to about EUR 3.6 million per year. For the replacement with renewables,the same amount of reduced electricity could increase almost three times or could reach a cost of nearly EUR 10 million. The replacementcost from renewable is much higher compared with the same ones from baseload conventionalpower plants, mainly because of relatively higherproduction and feed-in tariffs forrenewables[6].

The estimated climate change damages for replacing the lost production with traditional sourcesof power and with renewable energy source are shown in Tables 4 and 5, respectively.

The calculations for the estimating climate change damages for 2050 and 2100 are shown in Table 6. As shown in Table 6, the projected climate change damages for 2050 could be between EUR 1.2 and 2.5 million per year, and between EUR4 and 7.1 million per year for 2100.

Table 4.Projected cost (10^6 EUR/year) of replacing lost hydropower production due to climate change with coal, gas and nuclear alternatives per year

Precipitation Condition	**2050**		**2100**	
	Generation	**Total**	**Generation**	**Total**
Coal				
Low	- 0,443	- 1,107	- 1,100	- 2,751
Medium	- 0,358	- 0,894	- 1,218	- 3,045
High	0,141	0,352	0,434	1,084
Gas				
Low	- 0,642	- 1,306	- 1,596	- 3,246
Medium	- 0,519	- 1,055	- 1,766	- 3,593
High	0,204	0,415	- 0,629	- 1,279
Nuclear				
Low	- 0,587	- 1,273	- 0,575	- 3,164
Medium	- 0,474	- 1,028	- 1,614	- 3,502
High	0,141	0,405	- 0,575	- 1,247

Table 5.Projected cost (10^6 EUR/year) of replacing lost hydropower production due to climate change with renewable energy alternatives per year

Precipitation Condition	2050		2100	
	Generation	Total	Generation	Total
Wind power				
Low	- 0,985	- 1,683	- 2,458	- 4,198
Medium	- 0,796	- 1,360	- 2,710	- 4,629
High	0,312	0,534	- 0,965	- 1,649
PV systems				
Low	- 2,879	- 3,875	- 7,180	- 9,667
Medium	- 2,326	- 3,131	- 7,918	- 10,659
High	0,913	1,229	- 2,820	- 3,797

Table 6. Projected increase in annualized total system cost in 2050 and 2100 due to reductions in runoff from climate change for Mavrovo Hydro System under low, medium and high precipitation conditions

Precipitation Condition	2050 vs. Base (10^6 EUR)	2100 vs. Base (10^6 EUR)
Low	2,540	7,140
Medium	1,210	4,010
High	2,070	5,380

The estimated value of the climate change damages shown for the system cost method isroughly twice as high as the total replacement power cost calculations. To understand this discrepancy,one has to think about what happens when climate change reduces the generationof electricity by hydropower plants and replaces it with electricity generated by commercial sources or imports. The replacement cost method assumes that the only cost of closingthis gap is the increase in the cost of alternative fuels. This assumes no change in the cost ofhydropower production and that all of the substitutions, [kWh] from a fossil fuel plant for a [kWh]from a hydro plant, are all made at the same cost. Neither of these assumptions is necessarilycorrect and the results are telling us that these assumptions are indeed ***not*** correct, at leastif the system is modeled.

One example of this is the substitution of baseload plants for peaking load plants. In thecountry, the least-cost solution is to use fossil fuel plants to provide most of the baseload andfor hydro plants to provide most of the peak power. When climate change reduces this possibilityin 2050 and 2100 relative to the Base Case, then it costs more both to run the hydroplants as baseload plants and to run the fossil fuel plants as peak load plants. The costsof using both types of generating resources rise. This is reflected in the total systems cost estimateof climate change damages, but not in the replacement cost estimates. In other words,the replacement cost measure of climate change damages only reveals part of the picture andexcludes the cost of not using HPPs optimally as well as costs related to meetingpeak loads with baseload plants.

The analyzed study [8]tellsthat it is extremely difficult to accuratelyestimate the benefits and/or costsof any adaptation measures.

However, this does not mean that simulated adaptation was not correctly estimatedby this method. The fact that the analysis was conducted with a model that captured bothchanges in reservoir and power system operation in a least-cost optimization framework indicatesthat a great deal of adaptation was included in the analysis. In reality, the estimates ofclimate change damages that were developed in this study are actually estimates of residualdamages – that is the value of climate change damages that cannot be avoided by adaptation.The problem with estimating the net value of the climatedamages that can be avoided andthose that cannot is threefold:

- There is no single theory to suggest which adaptations should be included in the estimateof climate change damages and which should not. However, assuming that noautonomous adaptation will take place in response to climate, is simply wrong.

- The costs of adaptation are more difficult to calculate than most non-economists imaginebecause these costs include both changes in technology and behavior.
- There is a real lack of studies that estimate the basic engineering costs associatedwith adaptation technologies. This is not the kind of dirty work that economists like todo and engineers have different approaches to measuring costs than do economists.

Finally, in this analyzes the cost of emissions were not included. It is a fact that that in case the loss of hydropower generation had to be replaced with power generated by other power plants, especially those that use fossil fuel, the amount of emissions could increase that could on one side have negative influence on the environment, and on the other side could increase the cost of production due to imposed penalties for increased emissions of greenhouse gasses (GHG) such as CO_2, SO_X, NO_X, ash and small particles. These additional costs were not part of this investigation and it is not included in this paper. It could be part of some future work of the authors, especially having into account that only with the increased electricity production by 40 [GWh/year]as a result of the modernization and rehabilitation of the old HPP of the HPS Mavrovo done in 2014, the emissions of GHG in the country was annually reduced by 36.400 tons of CO_2.

5. Conclusion

The hydropotential works continuously in great uncertainty of climate variability due to its stochastic character. The magnitude of the climate change impact largely depends on the hydrological capacity of the existing water storages and hence on the economy of a country.

The HPS Mavrovo was selected for this paper for several reasons:

- The system is the largest in the country, consisting of three HPPs and a large storage reservoir.
- The hydrology and geomorphology of the Mavrovo basin are fairly typical of existing and potential hydro sites in the country.
- A simulation model of the HPS Mavrovowas available to use for the project.

This paper analyzes the impact of future changesinprecipitation on runoff and the resulting impact on power generation. It was expected that the decrease of precipitation and rise of the air temperatures would reduce runoff available to the HPPs and this, inturn, could result in reduced water storage and net head to drive the hydro turbines,resulting in a reduced capacity for electricity production. In such cases, the eminent lost of generation powerhaveto be replaced by either imported electricity or electricity generated by other types of powerplants, principally coal-, oil- or natural gas-fired plants.

The climate change is largely unreliable and cannot be quite precise for more exact prediction, taking into account many factors that it depends on. However, the opportunities offered by various meteorological models have contributed to a better understanding of the physical effects and thereby raising awareness of the need for adaptation on a global level, and selection of appropriate mitigation measures.

The stated constraints on climate change and hydro potential are indicative of the need for a wider and more efficient review of climate change in the area of hydro potential, in order to have stable and sustainable electricity generation.

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