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"Water Availability for Energy Production by the Proposed Pocem Dam in the Vjosa River Basin under the Effect of Climate Change"

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ABSTRACT : *Vjosa river (Aoös in Greece), being one of the largest wild rivers in existence, not only in Albania, but also in Europe, has not been yet subject of any large hydropower development. All climate scenarios for Vjosa River basin show that this area is expected to become warmer, with increasing minimum and maximum values in annual and seasonal temperature trends. [5]. Therefore, the Vjosa river basin is increasingly under the influence of climate change, threatening human lives, ecosystems and the weak economies of the poor communities that are living in these beautiful but badly managed areas of Albania in terms of water resources. Recently, due to irregular rainfall patterns, floods are the most frequent disasters befalling this area. There is no adequate early warning system for this important river basin which is increasingly seen as key factor for reducing these impacts, especially from the flooding events that are happening almost every year in the lowlands of the Vjosa basin. A project, implemented at IGEWE, was focused on creating a hydropower development scenario for Pocem Hydro Power Plant (HPP) via utilizing the Water Evaluation and Planning (WEAP) software. The start of the construction of Pocem Hydro Power Plant, initially planned in 2016, was never implemented due to mass protests objecting the likely negative environmental impacts. This study will, hopefully, bring a better understanding of some of the water resource issues related to the building of the proposed dam, under the effects of climate projections extending until the year 2050.*

KEYWORDS: *Hydropower dam, operational rules, flow requirements, etc.*

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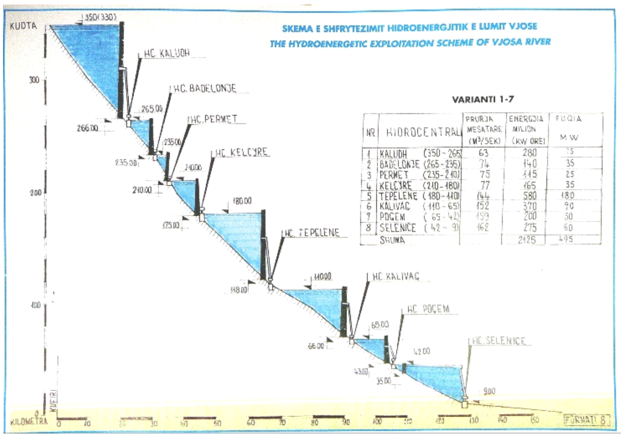
I. INTRODUCTION

The Vjosa River is the second most important of Albanian rivers in terms of hydroenergetic potential. Different studies are conducted by several Albanian institutions with regard to its hydroenergetic exploitation over the past 30 years. As shown in the Fig. 1, the exploitation scheme of Vjosa River foresees construction of eight hydro power plants with installed power of 490.000kW and an annual production of electric power of approximately 2.130 billion kWh (in the year 1999, before the data period of 2001-2008 considered for this study) [12]. Actually, there are many reservoirs in the Vjosa basin, but most of them are not located on the main river body. The streamflow data for the above mentioned Vjosa project were available for only the main branch and the two biggest tributaries, Drinos and Shushica. Because of that, other smaller river tributaries are not considered in the Vjosa WEAP model, neither are reservoirs situated far from the main river body. There are only two out of several proposed reservoirs taken into consideration in the model: Pocem and Kalivac dams. The most complete data gathered was that about the Pocem HPP. Due to the fact that the data for Kalivac reservoir was not available in the timeframe of the project, the cost-benefit analyses was completed only for Pocem hydropower plant. However, it is possible that the Kalivac reservoir, together with other reservoirs (not considered here) in the Vjosa River Basin, can be part of the modeling in the future when the appropriate data will be in place.



VARIANTI 1-7

NR	HIDROCENTRALI	PRURJA MESATARE (M³/SEK)	ENERGJIA MILION (KW ORE)	FUQIA MW
1	KALUDH (350 - 265)	63	280	75
2	BADELONJE (265 - 235)	74	140	35
3	PERMET (235 - 210)	75	115	25
4	KELCYRE (210 - 180)	77	165	35
5	TEPELENE (180 - 110)	144	580	180
6	KALIVAC (110 - 65)	152	370	90
7	POÇEM (65 - 42)	159	200	50
8	SELENICE (42 - 9)	162	275	60
	SHUMA		2125	495

Fig. 1. Hydroenergetic exploitation scheme of Vjosa River. Source: Shoqata e Veprave HidroenergjitiketeShqiperise, 1999.

II. STUDY AREA

The Vjosa river is the second largest crossborder river in Albania, shared with Greece (Fig. 2). It transcends southwestern Albania and northwestern Greece, originating at 2.600 m a.s.l from Mavrovouni Mountain in Greece, within Pindos mountain range. The total length of the river is about 275 km, and the total area of the basin is 6,808 km2, one/third of which belongs to Greece and two/thirds to Albania. In Greece, the river catchment intersects with three prefectures: Ioannina, Kastoria and Grevena, with a combined population estimated to be around 70.000 inhabitants [4]. In Albania, the Vjosa catchment has a mean elevation of about 855 m, and it is shared among five prefectures: Gjirokastër, Vlorë, Fier, Korçë, and Berat. At the timeframe of the project, the Albanian population living within the Vjosa basin is estimated to be about 200.000 inhabitants [3]. According to the Census data there is a decline in the overall population alongside Vjosa basin because of the domestic and international migration [6]. Vjosa river finally flows into the Adriatic Sea, creating the Narta lagoon in the north region of Vlora city. The Vjosa catchment is estimated to be the least influenced by the anthropogenic activities, being the less contaminated among other important rivers of Albania. The Vjosa river basin exists under a typical Mediterranean climate with a dry and hot summer, and a mild and wet winter.

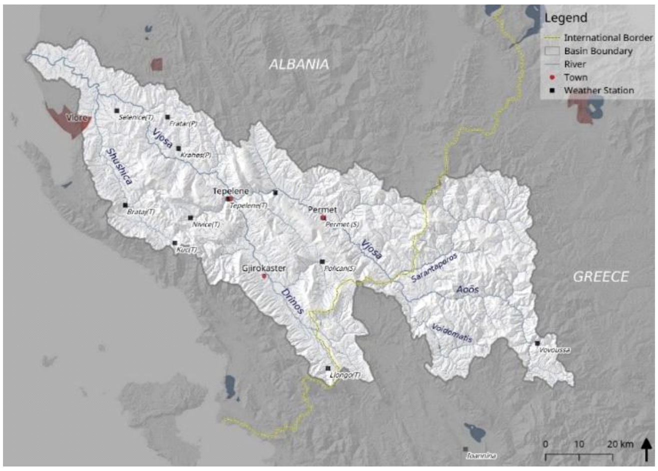


Fig. 2. The study area; source: Wickel, 2017.

Rainfall ranges from 950 to 1.600 mm, and the precipitation in Vjosa river basin, specifically in Drino and Shushica sub-basins, is usually higher than the average value for Albania. For the Greek part of the basin, the climatic conditions range from Mediterranean to Mid-European in lowlands, and towards higher altitude it is characterized by an alpine climatic condition [5].

Water assets: The mean annual discharge of the river at the border with Albania is 70 CMS, including the discharge of Saradaporos river [4]. Vjosa River has a mean annual discharge of approximately 195 CMS, and the minimum discharge in the summer period is about 33 CMS. Drinos River is the biggest tributary of Vjosa River with a mean discharge of about 39 CMS, followed by the Shushica River with 19 CMS. The Vjosa river basin is characterized by many springs coming by deep karsts aquifers, maintaining a regular baseflow in the river especially during the summer period when lower precipitation occurs. In the Greek side, the three biggest hydrological units of Timfi, Amarantos, and ArenonGrammou contribute with an average annual water volume of approximately 169 MCM. In Albanian side of the Vjosa River basin around 30% of the total discharge comes from the groundwater in the dry period. Different reservoirs and wells, dispersed into the Vjosa River basin, are used to meet the household needs, irrigation and some small industrial needs [2].

III. MATERIALS AND METHODS

Hydropower Plant Data: The Hydropower Development Scenario was created with the intention to study the impacts of the Pocem HPP in the water resources of the Vjosa River, under the effects of the climate change predictions up until the year 2050. Different categories of data types were needed to build the Vjosa hydrological model and calibrate it, such as physiographic/spatial data, meteorological data, water use/demand data, etc. The catchment was delineated using ArcGIS software with the Hydro Tools extension and a digital elevation model (DEM), resulting in the final Vjosa watersheds shape files that will be used in the WEAP model for further analysis as shown in Fig. 3.

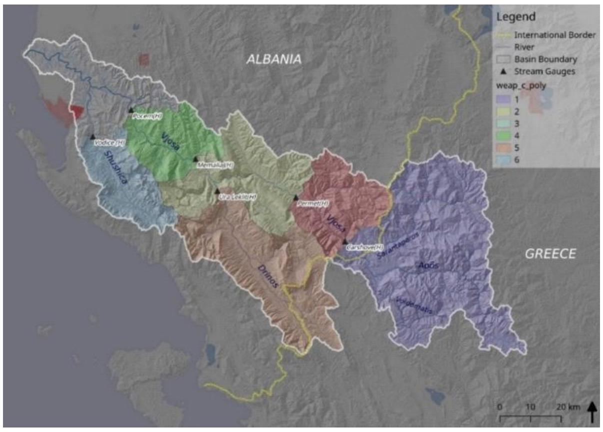


Fig. 3. Vjosa delineated catchments for the WEAP model; source: Wickel, 2017.

Precipitation data is one of the most important inputs for the WEAP rainfall-runoff model. This study includes compilation of data from meteorological stations in both the Albanian and Greek parts of the basin. For Albania, complete datasets for the years 2002-2008 came from nine precipitation stations as shown in Table I and Fig. 2. In Greece, precipitation data came from stations Vovoussa (in the Vjosa basin) and Ioannina (which is about 15 km south of the basin).

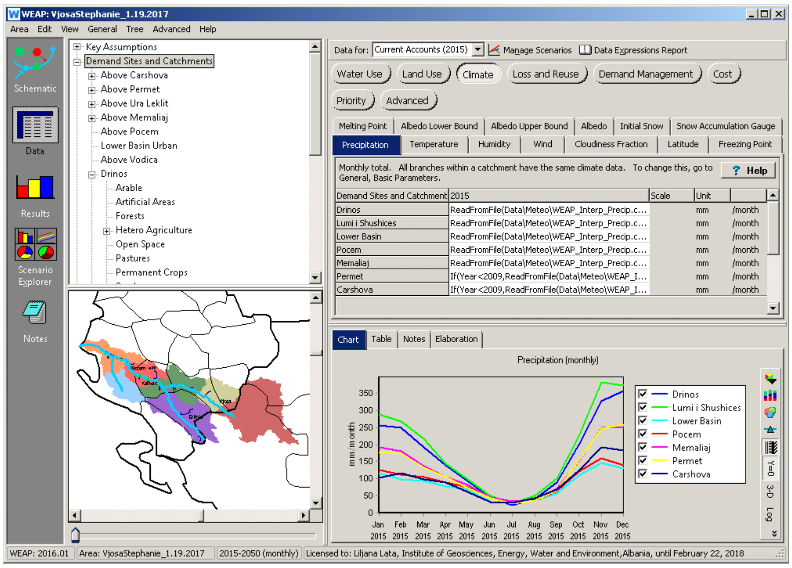
Table I. Chosen Meteorological Stations WGS84; source: IGEWE archive.

ID	*NAME*	*Latitude*	*Longitude*	*Precipitation*	*Temperature (Tmax, Tmin)*	*Relative Humidity*
1	Brataj(T)	40.27	19.67	x	x	
2	Fratar(P)	40.51	19.81	x		
3	Kelcyre(T)	40.31	20.19	x	x	
4	Krahes(P)	40.43	19.85	x		
5	Kuc(T)	40.18	19.84	x	x	
6	Llongo(T)	39.84	20.37	x	x	
7	Nivice(T)	40.24	19.89	x	x	
8	Permet (S)	40.24	20.36		x	x
9	Polican(S)	40.13	20.35		x	x
10	Selenice(T)	40.53	19.64	x	x	

11	Tepelene(T)	40.29	20.02	x	x

Name Label Description
T -there are data for Temperature and Precipitation
P - there are data only on Precipitation
S - there are data available for Temperature, Precipitation and other parameters (humidity, etc.)

The sub-basins of the Vjosa WEAP model were determined by the streamflow gauges (hydrometric stations) used for calibration points (Table II and Fig. 3). The average discharge data by month for all the hydrological stations that were calibrated (Permet, Pocem, and Ura e Leklit) was prepared for the study period (2002-2008). Then, the prepared data was entered in the Vjosa WEAP model (Fig. 4).



Data for: Current Accounts (2015)

Monthly total. All branches within a catchment have the same climate data. To change this, go to General, Basic Parameters.

Demand Sites and Catchment	2015	Scale	Unit	
Drinos	ReadFromFile(Data\Meteo\WEAP_Interp_Precip.c...		mm	/month
Lumi i Shushices	ReadFromFile(Data\Meteo\WEAP_Interp_Precip.c...		mm	/month
Lower Basin	ReadFromFile(Data\Meteo\WEAP_Interp_Precip.c...		mm	/month
Pocem	ReadFromFile(Data\Meteo\WEAP_Interp_Precip.c...		mm	/month
Memaliaj	ReadFromFile(Data\Meteo\WEAP_Interp_Precip.c...		mm	/month
Permet	If(Year<2009,ReadFromFile(Data\Meteo\WEAP_I...		mm	/month
Carshova	If(Year<2009,ReadFromFile(Data\Meteo\WEAP_I...		mm	/month

WEAP: 2016.01 | Area: VjosaStephanie_1.19.2017 | 2015-2050 (monthly) | Licensed to: Liljana Lata, Institute of Geosciences, Energy, Water and Environment,Albania, until February 22, 2018

Fig. 4. View of the monthly Interpolated Precipitation data in the Vjosa WEAP model.

Table II. Chosen Hydrological Stations WGS84; source: IGEWE archive.

NAME	*Lat*	*Long*	*Begin date*	*End date*	*Correlation*
Carshove	40.11	20.54	01/01/1993	31/10/2008	0.8
Memaliaj	40.35	19.97	01/03/2003	31/10/2008	0.86
Permet	40.24	20.35	01/01/1992	31/10/2008	0.82
Pocem	40.49	19.73	01/01/1992	30/06/1993	0.69
			01/01/2003	31/10/2008	
UraLeklit	40.26	20.06	01/03/2001	31/10/2008	0.84
Vodice	40.42	19.58	22/07/1992	1/12/2006	0.33

Thereafter, depending on the different aspects of the water use, other data types were related to natural and artificial storage, dam operations, and environmental flow requirements. Among different development scenarios that are considered during the implementation of the project, this publication is focused in the potential expansion of hydropower capacity in the Vjosa river basin [2].

Data Source: The data types needed for the Hydropower Development Scenario are shown in the Table III. The main source of the information needed to build this scenario inside the WEAP Vjosa model was derived from the Pocem HPP data that was included in the Cinar San Group Company project reports [7]. Specifically, the Pocem reservoir characteristics and other important information were evaluated and then inserted in the WEAP model.

The work for the Pocem HPP was presumed to begin in 2016, and therefore, the year 2016 served as a start for Hydropower Development Scenario using the WEAP model.

Water demand data collected for the Vjosa WEAP model was structured around three main datasets: Urban demand, Agricultural, and Industrial. While some data had not been available, estimates are made based on additional parameters such as land cover, population census data and the existing knowledge in per capita water use following the guidelines on Data Requirements to compute the indicator 6.4.2 on Water Stress, Target 6.4 in SDG 6 [13]. The format of this data must fit the subdivisions of the model divided according to the subcatchments. Normally, WEAP allocates water to various demand site according to their priority. No information about the priorities of the water demand in the Vjosa project was available. This priority was ranked solely on the basis of their supply requirements. As there was no additional information about the allocation priorities of the water demand, it was supposed that all water demands were of equal significance and had the same priority; according to this a smaller water demand may be of the same importance as a larger one. The main water demands that are taken into consideration in the Vjosa project, the assumptions, and the data processing done before entering the water demand data into the WEAP model, were evaluated with the intention of preparing and comparing the different scenarios that are described in details in the main report of the Vjosa project [2].

***Table III. Data Requirements for Pocem dam located in Vjosa Catchment; source: WEAP Tutorial*.**

Data Name	*Units*	*Description*
Location		Geographic position of storage reservoirs
Storage capacity	MCM	Total capacity of the reservoir
Volume elevation curve	MCM, m	The relationship between reservoir volume and elevation
Net Evaporation	mm/month	Monthly net evaporation rate (evaporation minus precipitation on reservoir surface)
Observed volume	MCM	Monthly reservoir storage data (historic)
Storage operation information	NA	NA

The climate scenarios taken in considerations are developed applying the 'Representative Concentration Pathways' (RCPs) for the climate science assessment ('Working Group I') of the Fifth Assessment Report (IPCC AR5, 2014), by using SimCLIM 2013 [5]. Using these data, five climate scenarios are constructed to examine possible climatic futures in the Vjosa WEAP model:

- RCP2.6: Median precipitation, and average of median minimum and maximum monthly temperatures;
- RCP4.5: Median precipitation, and average of median minimum and maximum monthly temperatures;
- RCP8.5: Median precipitation, and average of median minimum and maximum monthly temperatures;
- RCP8.5 Drought: Low (10%) precipitation, and average of median minimum and maximum monthly temperatures; and
- RCP8.5 Hot Drought: Low (10%) precipitation, and average of high (90%) minimum and high (90%) maximum monthly temperatures.
-

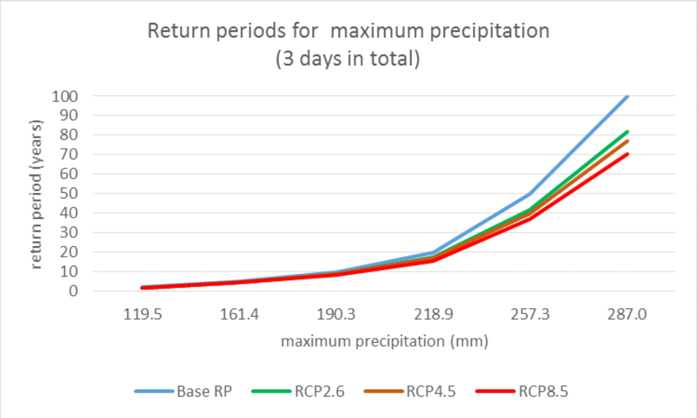


Fig. 5: Expected changes in average Tmax, Vjosa basin. Median estimates are given as full thick lines and the variation (lower and upper bound) given as dotted line; source: Mucaj, L, 2016.

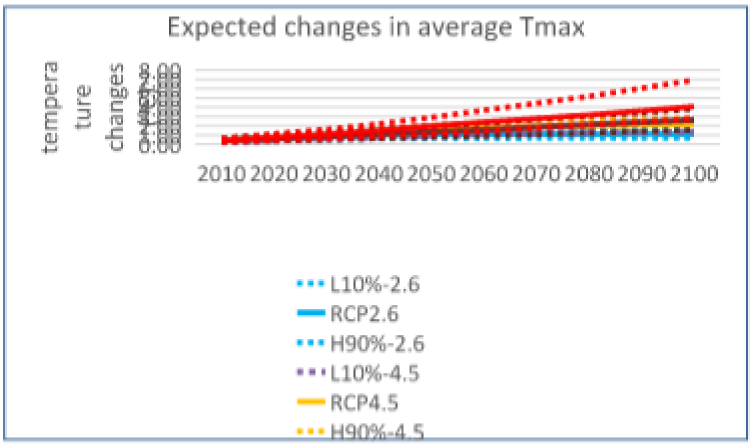
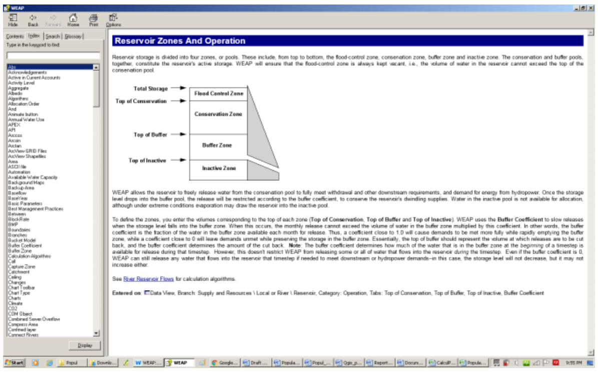


Fig. 6: Return period for 3 days with maximum precipitation. Permet; source: Mucaj, L, 2016.

Methodology on the Data Evaluation and Processing of the Energy Water Demand

Reservoir Zones and Operation-The available information selected from the main reports of the Pocem HPP project that was supposed to be implemented by the Cinar San Group company is related to the main characteristics of the Pocem HPP. This information was assessed, and adapted for the WEAP model, following the instructions of the WEAP Tutorial [8]. Some of the considered aspects are described in the below paragraphs: Reservoir storage was divided into four zones (See Fig. 7) specifically, from top to bottom, the Flood-Control Zone, Conservation Zone, Buffer Zone and Inactive Zone. The conservation and buffer zones, create the reservoir's active storage. WEAP makes sure that the Flood-Control Zone is always kept empty, as, normally, the volume of water in the reservoir cannot surpass the Top of Conservation zone.



Reservoir Zones And Operation

Reservoir storage is divided into four zones, or pools. These include, from top to bottom, the flood-control zone, conservation zone, buffer zone and inactive zone. The conservation and buffer pools, together, constitute the reservoir's active storage. WEAP will ensure that the flood-control zone is always kept vacant, i.e., the volume of water in the reservoir cannot exceed the top of the conservation pool.

WEAP allows the reservoir to freely release water from the conservation pool to fully meet withdrawal and other downstream requirements, and demand for energy from hydropower. Once the storage level drops into the buffer pool, the release will be restricted according to the buffer coefficient, to conserve the reservoir's dwindling supplies. Water in the inactive pool is not available for allocation, although under extreme conditions evaporation may draw the reservoir into the inactive pool.

To define the zones, you enter the volumes corresponding to the top of each zone (**Top of Conservation**, **Top of Buffer** and **Top of Inactive**). WEAP uses the **Buffer Coefficient** to slow releases when the storage level falls into the buffer zone. When this occurs, the monthly release cannot exceed the volume of water in the buffer zone multiplied by this coefficient. In other words, the buffer coefficient is the fraction of the water in the buffer zone available each month for release. Thus, a coefficient close to 1.0 will cause demands to be met more fully while rapidly emptying the buffer zone, while a coefficient close to 0 will leave demands unmet while preserving the storage in the buffer zone. Essentially, the top of buffer should represent the volume at which releases are to be cut back, and the buffer coefficient determines the amount of the cut back. **Note**: The buffer coefficient determines how much of the water that is in the buffer zone at the *beginning* of a timestep is available for release during that timestep. However, this doesn't restrict WEAP from releasing some or all of water that flows into the reservoir *during* the timestep. Even if the buffer coefficient is 0, WEAP can still release any water that flows into the reservoir that timestep if needed to meet downstream or hydropower demands--in this case, the storage level will not decrease, but it may not increase either.

See River Reservoir Flows for calculation algorithms.

Entered on: Data View, Branch: Supply and Resources \ Local or River \ Reservoir, Category: Operation, Tabs: Top of Conservation, Top of Buffer, Top of Inactive, Buffer Coefficient

Fig. 7. A schematic view of the reservoir zones; (Source: WEAP Tutorial).

The Storage Capacity represents the total capacity of the reservoir, while the Initial Storage is the amount of water initially stored in the reservoir at the starting point of the first month of the Current Accounts year. WEAP keeps up a mass balance to truck the monthly storage volume created by the monthly inflows and outflows in the reservoir.

Furthermore, WEAP system has the capability to convert between volume of water and elevation. This function calculates the evaporation values and the energy production from hydropower plant, and is presented by the points of the Volume-Elevation Curve. All the values that stand between the points are interpolated. The most important element of this curve is the total storage capacity of the reservoir. If the reservoir is modeled as a box with straight sides, no other points are needed.

The monthly evaporation rate is determined by the difference between evaporation and precipitation on the reservoir surface, a parameter that can assume negative or positive values. A negative (positive) net evaporation shows a net gain to (loss from) the reservoir.

Losses from infiltrations from a reservoir can also be important; to model these losses a groundwater node and associated flow parameter should be specified for every timestep. Net gains from groundwater to the reservoir should be inserted as negative values.

Normally, the reservoir can release water from the conservation zone to meet all the downstream requirements (for agriculture, etc.) and the demand for energy production from the hydropower plant. When the storage water level declines into the buffer zone, the water release will be limited, depending on the buffer coefficient to manage the supplies of the reservoir. The quantity of water in the inactive zone is not for allocation, but it could happen that in very hot weather conditions (with very high values of evaporation) the reservoir can become dry. The values of Top of Conservation, Top of Buffer and Top of Inactive fields define the characteristic zones of the reservoir, each of them corresponding to the top of every zone. Buffer Coefficient is used in the WEAP system to limit the water releases when the water level drops into the buffer zone. Therefore, in this case the water released for one month can be less than the water volume of the buffer zone multiplied by the Buffer Coefficient. So, this coefficient represents the volume of water in the buffer zone that is available each month for release. Buffer Coefficient values range from 0 to 1: when the values tend to be close to 1, that means that water demands can be fulfilled at a higher level, whereas the buffer zone can go rapidly empty when the coefficient is close to 0. In other words, the water release will be cut back when the water level in the reservoir reaches the Top of Buffer and the coefficient represent the quantity of the cut back.

There is a minimum value of the monthly water discharge downstream the river to make possible that the requirements such as water quality, wildlife, fish, recreation, etc. are met. This minimum flow is called Minimum Flow Requirement. According to priority criteria, a flow requirement can be fulfilled before other demands on the river, at the same time or after other demands are satisfied. A Priority in this case refers to the priority for supply of the flow requirement, in comparison with all other demands in the system [8].

Hydropower Development Scenario Setup: The Fig. 8 displays a partial schematic of the Vjosa cascade with the proposed Pocem HPP and upstream Kalivac HPP. Data of Pocem HPP has been entered into the WEAP model for the Vjosa river basin (see Fig. 9 and Fig. 10) based on the available information about the reservoir's characteristics as below:

- Power generated: 99.5 MW, that is the maximum power that can be generated by the Pocem HPP. The plant will not work constantly, therefore the power output is not presumed to be a constant parameter.
- Total Storage Capacity of the reservoir: 295 MCM
- Reservoir Capacity at its normal water level of 70 m: 250 MCM
- Active Storage of the Reservoir: 112 MCM (from 70 m to 64 m)
- Surface of the Reservoir: 21.6 km2
- Investment cost: ≈ 135 Million Euro. As WEAP accepts it in UDS, it corresponds to a value of 141,145,084 UDS [7].

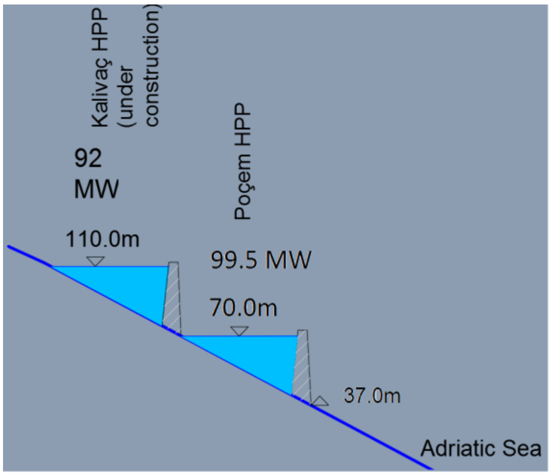


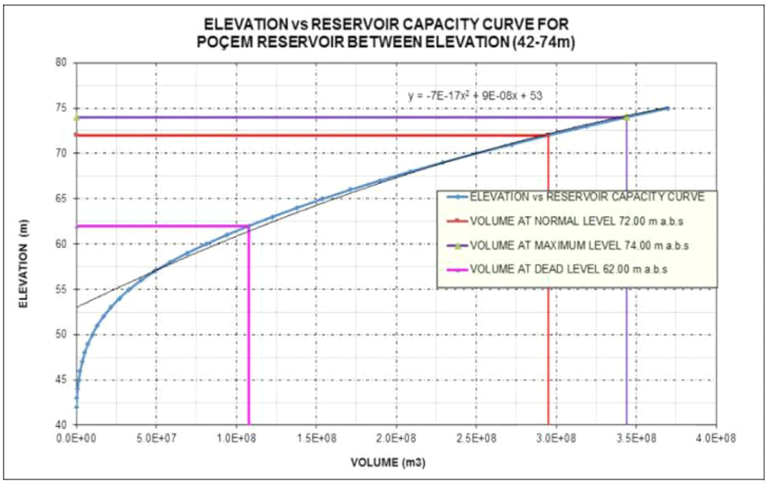
Fig. 8. Partial longitudinal profile of the Vjosa River with Pocem HPP and non-functioning Kalivac HPP; Source: Cinar San. 2015.

The average annual flow of the Vjosa River is approximately 150 CMS. It can vary from 84.2 CMS, a typical value in a dry year (1990), to 210.42 CMS, a value that is characteristic for a wet year (1979) [2]. According to the Pocem HPP project [7] the proposed restrictions for the water use are as below:

For irrigation: 2 CMS will be released from 15th May to 15th September. It will not be used for energy production from Pocem HPP.

According to Albanian Law No.111, dt. 15.12.2012 regarding "Integrated Management of the Water Recourses", the downstream ecological flow requirement for the Pocem dam that will be inserted into the WEAP model is evaluated to be 22.2 CMS (specified as a flow for 355 days). This estimate is calculated from the duration curve for the average year with a return period of two years (50% probability). This ecological flow will be released from the Pocem reservoir continuously throughout the year. This value is entered into WEAP as a flow requirement node with a constant number of 22.2 CMS.

Other typical parameters of the Pocem reservoir are as follows: Top of Conservation equal to 70 m that characterize the normal water level of the reservoir functioning; Top of Buffer equal to 64 m, that represent the minimum water level of functioning; The vertical distance in which the reservoir normally works is: 70 – 64 = 6 m. The data of Volume Elevation Curve [7], (shown in the Fig. 9a, b) is entered into WEAP in order to help us evaluate the evaporation from the reservoir volume over time.



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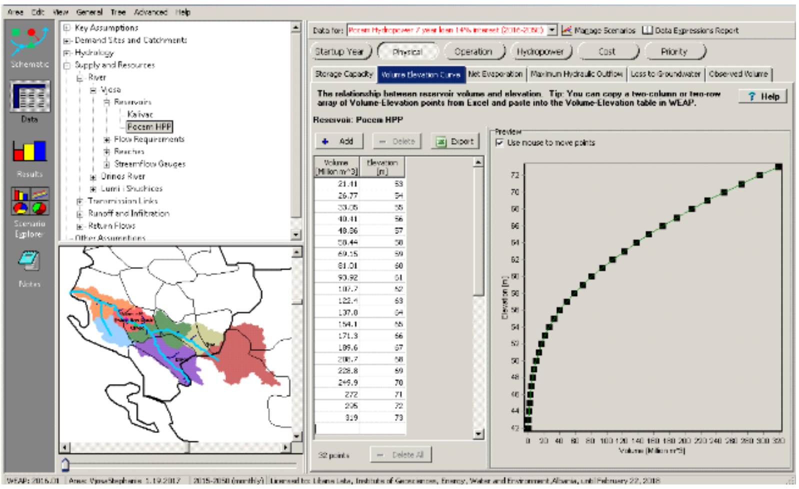


Data for: Pocem Hydropower 7 year loan 14% interest (2016-2050)

The relationship between reservoir volume and elevation. Tip: You can copy a two-column or two-row array of Volume-Elevation points from Excel and paste into the Volume-Elevation table in WEAP.

Reservoir: Pocem HPP

☑ Use mouse to move points

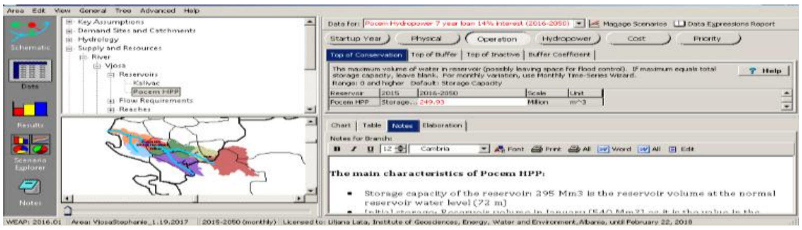
Volume [Million m^3]	Elevation [m]
21.41	53
26.77	54
33.05	55
40.41	56
48.86	57
58.44	58
69.15	59
81.01	60
93.92	61
107.7	62
122.4	63
137.8	64
154.1	65
171.3	66
189.6	67
208.7	68
228.8	69
249.9	70
272	71
295	72
319	73

32 points

WEAP: 2016.01 | Area: VjosaStephanie_1.19.2017 | 2015-2050 (monthly) | Licensed to: Liljana Lata, Institute of Geosciences, Energy, Water and Environment, Albania, until February 22, 2018

b)

Fig. 9. a) Volume elevation curve for Pocem HPP; Data Source: Cinar San 2015.
b) Volume Elevation Curve displayed in Vjosa WEAP system; source: own elaboration.



Data for: Pocem Hydropower 7 year loan 14% interest (2016-2050)

The maximum volume of water in reservoir (possibly leaving space for flood control). If maximum equals total storage capacity, leave blank. For monthly variation, use Monthly Time-Series Wizard.
Range: 0 and higher Default: Storage Capacity

Reservoir	2015	2016-2050	Scale	Unit
Pocem HPP	Storage...	249.93	Million	m^3

Notes for Branch:

Cambria 12

The main characteristics of Pocem HPP:

- Storage capacity of the reservoir: 295 Mm3 is the reservoir volume at the normal reservoir water level (72 m)

WEAP: 2016.01 | Area: VjosaStephanie_1.19.2017 | 2015-2050 (monthly) | Licensed to: Liljana Lata, Institute of Geosciences, Energy, Water and Environment, Albania, until February 22, 2018

Fig. 10. Entering the main characteristics of Pocem HPP in WEAP model; source: own elaboration.

According to the Pocem HPP project, four Kaplan Adjustable Vertical Turbines were planned to be used initially, with an individual capacity of 85 CMS. At a later time, a fifth turbine with a capacity of 22.2 CMS was included in planning, in order to fulfill the environmental downstream flow requirements for the dam (Fig. 11). All five turbines generate an overall possible output of 362.2 CMS.

During the implementation of the Vjosa project, no data related to water demand priorities for all other demands in the Vjosa water system was available. No data was in place even for underground losses.

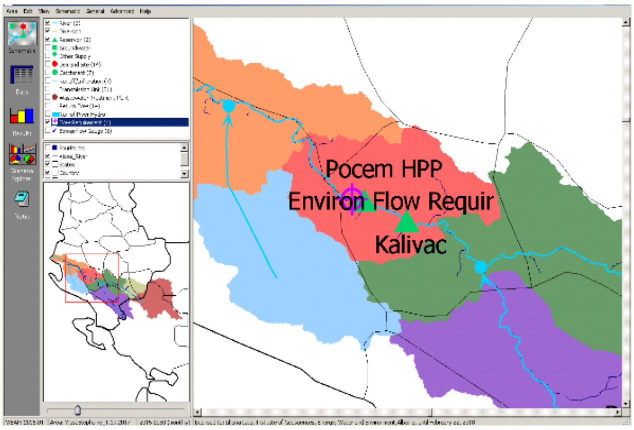


Fig. 11. Editing the Minimum Flow Requirement in WEAP; source: own elaboration.

The Pocem HPP was planned to operate 3,070 hours/year, or 35.05% of the time, (the number entered in the WEAP model as the “Plant Factor”). The efficiency of the generated power was 89% [7]. The evaporation value from the reservoir was entered as the previous month’s evaporation calculated by WEAP for the Pocem catchment.

The Hydropower Development Scenario starts in 2016, which was the year when the reservoir reached full capacity, according to the Pocem HPP project reports [7].

IV. RESULTS

According to the different climate scenarios, the Vjosa streamflow necessary for electricity production varies with time as shown in the Fig. 12. The worst climate scenarios (RCP8.5Drought and RCP8.5HotDrought) show a decreasing streamflow until the year 2050, and this does influence the reservoir storage that decreases also. During the best climate scenarios (the Reference, RCP 2.6, RCP 4.5 and RCP8.5), the almost constant streamflow allows for an almost full reservoir storage.

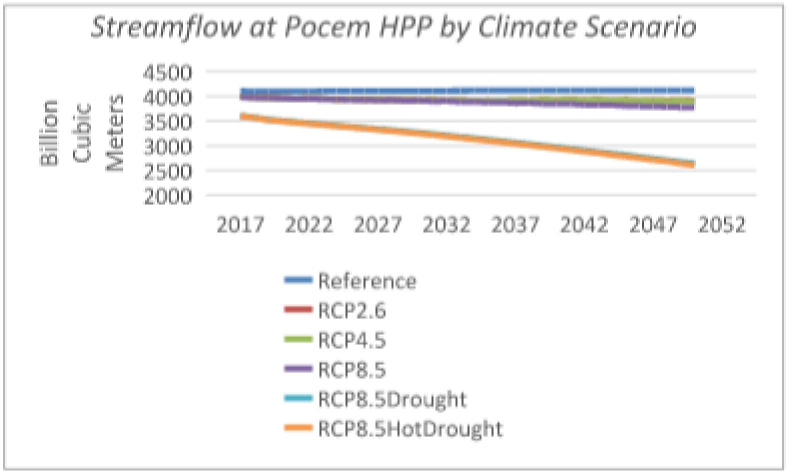


Fig. 12. The annual total streamflow at Pocem HPP according to climate scenarios (2017- 2050); source: Wickel, 2017.

The monthly streamflow volumes also change between the climate scenarios, specifically from around 70MCM in September for the worst climate scenario (RCP8.5HotDrought), to around 700 MCM in February for the best-case scenario (Poçem Hydropower/Reference scenario) (Fig. 13).

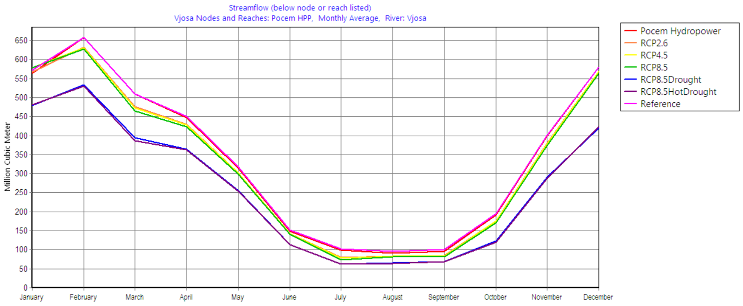


Fig. 13. Average monthly streamflow at Pocem HPP site (2015-2050); source: Mucaj, 2016.

Predictably, the normal value of storage volume of the reservoir of 250MCM, for the worst scenarios (RCP8.5Drought and RCP8.5HotDrought) drops during the summer, reaching values somewhat less than 100%. It does not decrease in the best-case scenarios (Fig. 14 and Fig. 15).

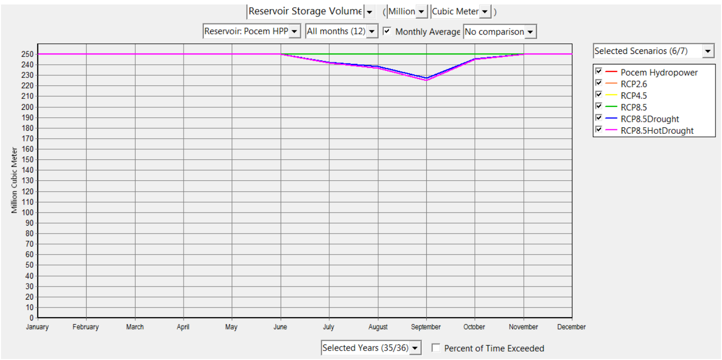


Fig. 14. Monthly average storage volume of Pocem HPP by climate scenario (2015-2050).

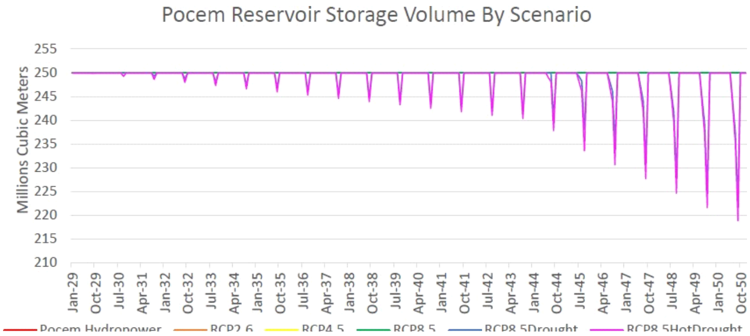


Fig. 15. Storage volume in Poçem Reservoir, all scenarios, 2029-2050.

Because of the changes in the streamflow volume, for each of the climate scenarios, there are distinct variations in the electricity production (in MW), for the full operation years, beginning in 2016 (Fig. 16); as indicated previously this is the first year when the reservoir operates under full capacity and the Pocem HPP becomes operational.

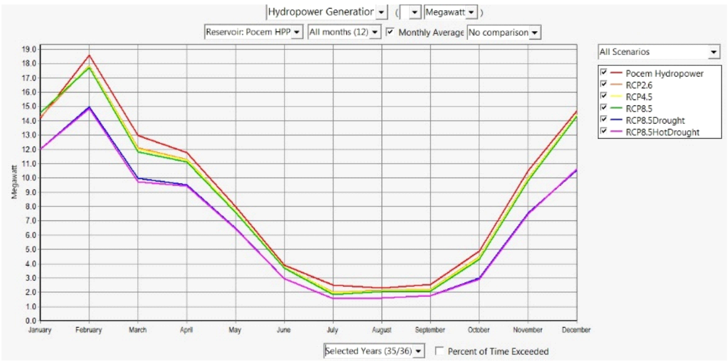


Fig. 16. Average monthly hydropower generation for Pocem HPP by climate scenario (2016-2050).

Eventually, the estimated average annual energy production from Pocem HPP, according to different climate scenarios will be decreasing with time as expected (Table IV).

Table IV. Pocem HPP annual hydropower production (Thousand MWh) by climate scenario (2016-2050).

Climate Scenario	*MW production/year*
Pocem Hydropower (Reference)	106.8657
RCP2.6	102.1436
RCP4.5	102.078
RCP8.5	100.9321
RCP8.5Drought	81.94077
RCP8.5HotDrought	81.38992

For almost all scenarios except for the RCP8.5 extreme drought scenario, the MW production values are actually above the designed value of 99.5 MW/year. This fact points out that the 60% plant efficiency that was used during the WEAP model calibration might be a very low value, or that the climate records indicate an above average streamflow. All other factors that could influence higher streamflow values (and as a result higher power outputs), such as decreasing water demands from domestic demand sites etc., (see [2]), cannot guarantee high enough streamflow values, that in turn could generate the expected hydropower for the extreme climate scenarios (RCP8.5Drought and RCP8.5HotDrought). Such scenarios, becoming feasible during low precipitations and high temperature seasons, will result in lower energy productions and therefore decreased profits (Fig. 18).

WEAP uses the real values of dollars in the Current Account year of the model, meaning the value of the currency in future or past years is converted to the value in 2015 by adjusting for inflation. The Vjosa model, though, calibrated for the historic period 2002-2008, will run from 2015 as the Current Accounts year to 2050 as the last year of scenarios.

We can examine the net benefits of the hydropower plant over time in Million Real US Dollars. The Pocem HPP produces different results under different climate scenarios, and in the Fig. 17 are presented the results for the Reference Scenario (no climate change), RCP2.6 (mild climate change, 2°C world) and RCP8.5HotDrought scenario (4°C world), which takes the RCP8.5 scenario and uses the 10% percentile values for low precipitation as well as high temperature.

It was estimated that the costs of building the reservoir would not be paid off by the year 2050, indeed at that rate it would take an additional 28 years, or until 2078, to cover the costs of building the reservoir, not including the annual operational. The initial construction costs and the profits after year 2022 vary considerably, as related to streamflow by climate scenarios. Fig. 17 shows that the Reference has the lowest costs and highest benefits, while RCP8.5 Drought and HotDrought have the highest costs and lowest benefits (the Pocem Hydropower scenario represent the plant's construction in the Reference climate conditions).

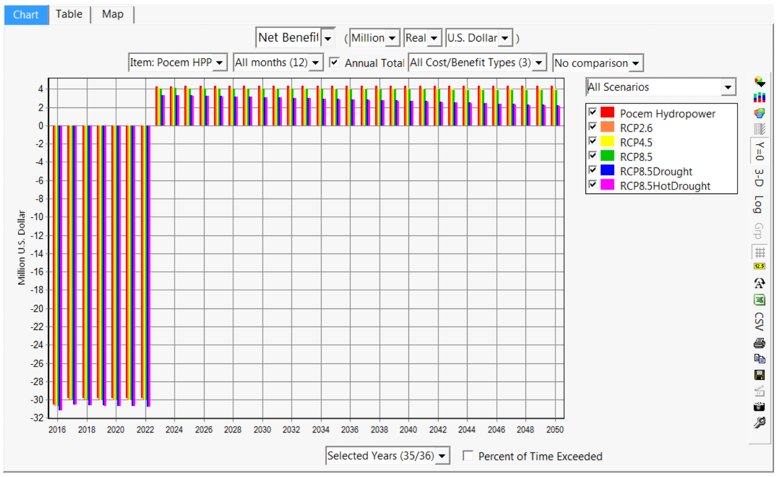


Fig. 17. Costs and benefits of Pocem HPP by climate scenario (2016-2050).

Obviously, the profits presented in Fig. 18 are relevant to the streamflow at the Pocem HPP site, shown in Fig. 12. The profits diminish according to the respective climate scenarios. In Fig. 18, the profits of the various climate change scenarios are noticeably lower than the Reference Scenario, with RCP2.6 and RCP4.5 being very close until year 2050, with a slight differentiation for RCP8.5 and major differentiations in profit for sustained low percentiles of precipitation and temperature in RCP8.5 Drought and RCP8.5 HotDrought.

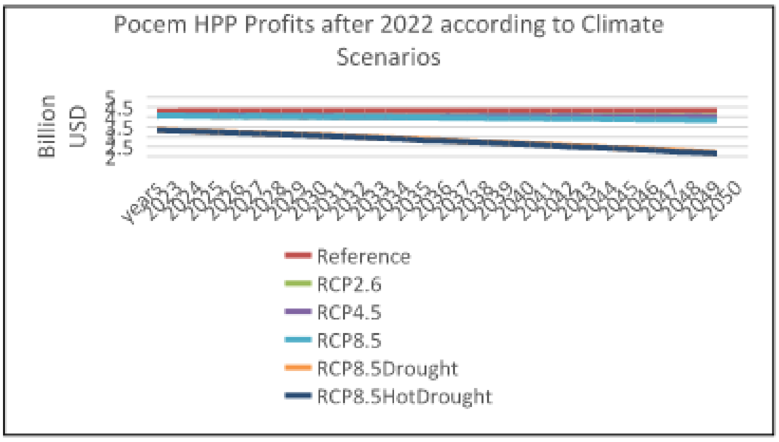


Fig. 18. Annual profits at Pocem HPP by climate scenario (2023-2050).

It is duly noted that whereas the addition of extreme temperatures to the drought scenario did worsen it, the difference was negligible compared to the differences made by using extreme precipitation values. Table V shows the payback period for each climate scenario, considering cost and benefit trends.

Table V. Estimated payback period for Pocem HPP according to climate scenario.

Climate Scenario	*End of Payback Period (year)*
Pocem Hydropower (Reference)	2071
RCP2.6	2075
RCP4.5	2075
RCP8.5	2077
RCP8.5Drought	Profits become negative in 2101, before the full cost has been paid back
RCP8.5HotDrought	

The results for the most dramatic climate scenario, RCP8.5 with high temperature and low rainfall suggest that the reservoir would not be profitable under these climate trends, though reference and climate scenarios (50th percentile values) have payback periods within six years of each other. Fig. 19 shows the monthly average energy production according to scenario. This shows minor differences between the 3 climate scenarios, but large differences between their respective values and the values for RCP8.5Drought and HotDrought.

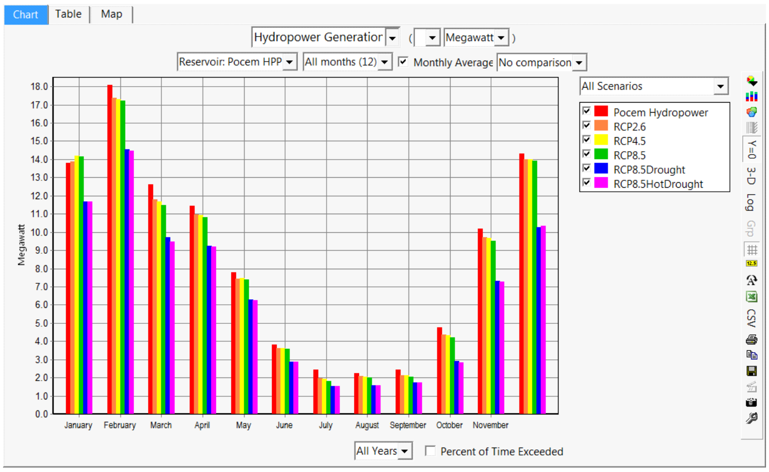

Hydropower Generation (Megawatt)
Reservoir: Pocem HPP
All months (12)
☑ Monthly Average
No comparison
All Scenarios
☑ Pocem Hydropower
☑ RCP2.6
☑ RCP4.5
☑ RCP8.5
☑ RCP8.5Drought
☑ RCP8.5HotDrought
All Years
☐ Percent of Time Exceeded

Fig. 19. Projected monthly average MW energy production by climate scenario at Pocem HPP (2016-2050).

Eventually, for RCP8.5Drought and HotDrought climate scenarios, the streamflow at Poçem HPP and resulting energy production is noticeably lower.

V. DISCUSSION

The Vjosa river, as one of the last remaining wild rivers in Europe has not yet been subject of big engineering developments such as damming and channeling. Nevertheless, the plans for dam development for this river are in place due to future developments in the Albanian energy sector and flood risk management scenarios. This analysis does not consider the development of small-scale hydropower plants in the small tributaries that feed the river (the plans are already in process).

This manuscript analyses the Pocem Hydropower Plant on the main watercourse of the Vjosa River, whose construction was initially scheduled to start since 2016 by the Cinar - San Group, a Turkish company interested in energy production from renewable resources [7]. According to the proposal at the proposed time of the project implementation in 2016, (the proposal still needs the approval of Albanian government) the Vjosa cascade would be improved through energy production using a novel and environment-friendly technology that would consider the social - economic effects by adapting various mitigating measures and flood risk management for the flood prone areas below Pocem site. (The most recent important floods were observed in February of 2015, and in December 2017).

Water management infrastructure with regard to development of large dams for power generation and storage can bring great benefits, but it can also be highly vulnerable to climate change scenarios, especially when assumptions on hydrological conditions are only based on (limited) historic observations.

When attempting to provide adaptation priorities, it is nevertheless critical to evaluate mal- adaptive developments. According to this study, the Poçem hydropower plant development appears to be a good example of a project that has a high potential for mal-adaptation and that requires a full evaluation of climate risk. Modeling results indicate that, using the best available information, the Poçem hydropower project is unlikely to be cost effective for a very long time even before factoring in the climate change factors, given its long cost recovery period (See Table V).

Considering the fact that a high level of uncertainty is associated with the impacts of sediment – an aspect that was beyond the current scope of this project - in one of Europe's most sediment loaded rivers, special efforts should be made in future evaluations to capture the linkage between increased peak flows, as a distinct likelihood under all future climate change scenarios and increased erosion and sediment transport by the river.

In additional to the sensitivity demonstrated by the construction's loan terms, the WEAP cost- benefit analysis may have some bias due its simulation of the streamflow at the Pocem HPP site. The Pocem site is located significantly downstream of the model's two upstream calibration points, Permet and Drinos, and industrial and domestic demand are removed from the river prior to reaching the Pocem HPP site. The closest calibrated gauge to the Pocem site is the model's Pocem gauge, which measures the river volume after industrial and domestic demands for the Pocem region have been removed from the river and their unconsumed portion (10% and 88% respectively) is returned to the river (Fig. 19).

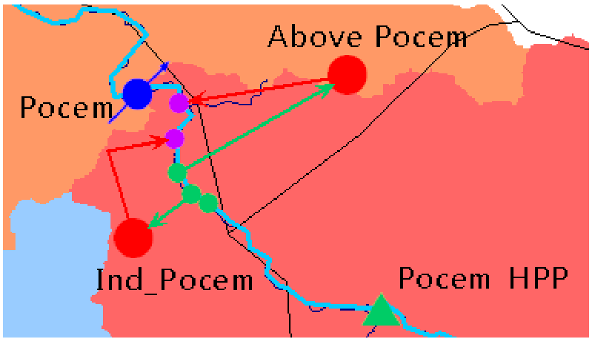


Fig. 19. Pocem HPP site located upstream of the calibrated Pocem gauge.

As indicated in Fig. 19, the overall water consumption of the two intervening demand sites are quite small: Pocem Industrial consumption is 0.014 MCM/year, and the average domestic consumption of water between the years 2002-2008 for Pocem domestic users was 0.213 MCM. The sum of these values (0.227 MCM) is small compared to the annual average streamflow at the Pocem gauge of 3,976 MCM/year (2002-2008, modeled streamflow). Therefore, despite these intervening demands, the accuracy of the streamflow at Pocem HPP can be inferred by the accuracy of the streamflow at the Pocem gauge.

VI. CONCLUSION

Climate change is supposed to modify meteorological and hydrological regimes, most likely resulting in diminished water availability in the Vjosa basin. The SimClim2013 model is run through the year 2050 to simulate the likely changes in precipitation. A reduction in total precipitation combined with an increasing water demand would result in a diminished run-off to the river and eventually lower river flow [5].

The expected maximal precipitations are increasing, resulting in higher flood frequency during the wet season (Fig. 6). Furthermore, the predicted values for minimal precipitation will result in a higher frequency of droughts during the dry period. Thus, the hydrology of Vjosa river catchment, the water demand, and the presence of snow pack will be affected.

This will likely affect sediment transportation and stream temperatures in the Vjosa River and have significant impacts on the high biodiversity of the river and specifically on the Narta Lagoon, located close to its delta. Simulations using climate projections show that the flows could be altered further, severely limiting the ability to sustain environmental flows and significantly reducing the capacity of species and ecosystems to adapt to climate change.

It is important that the impacts of this project on stream temperatures due to reduced flows, but also increasing air temperatures as well as sediment transport implications are studied further.

The Pocem Hydropower plant development has been an integral part of the Vjosa river development plans for several years (Fig. 1). Despite the fact that this development scenario was finalized as of December 2016 using the WEAP model, the construction is yet to start. Potential climate change impacts in the Vjosa Basin raise serious questions about the viability and profitability of the reservoir as an investment. Both, the relatively low cost of electricity and the uncertain future of streamflow in the Vjosa river mean that the large capital costs of the development project will likely not be recouped before the year 2078 (with no climate change scenario); taking into account the severity of various climate change scenarios, would largely add to the uncertainty of development cost recuperation.

The Poçem hydropower project will significantly alter the flow regime of the Vjosa river. As a consequence, these likely effects will increase the coastal region's vulnerability, making the Disaster Risk Management (DRM) and adaptation measures vital for long-term development strategies [5]. A critical vulnerability of the Vjosa basin – flooding – is not currently well-captured in the WEAP model because the time step is too large (monthly). With more detailed temporal data available, it might be possible to study the occurrence and impact of flooding in the Vjosa basin.

The scheme of hydroelectric exploitation of Vjosa River must be seriously studied, and common decisions should be made by Albanian and Greek governments after conducting a proper Strategic Impact Assessment study. In September of 2019, the upstream of Vjosa River Basin received National Park status from the Albanian government. There are further efforts by different national and international environmental organizations to extend the National Park status over the entire Vjosa river, as this river is considered unique in its kind within European borders [11].

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