WATER – ENERGY – FOOD NEXUS IN CLIMATE ADAPTATION MODELLING
Case Study Ohrid and Prespa Lakes in H2020 Funded Project Arsinoe

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Abstract
Water management has been facing new challenges, due to more intensive and uncertain climate change impacts, demographic trends and economic growth, resulting in more intensive resource demands. These affect water management in all related and water dependent sectors (economy, energy, environmental systems). Traditional approaches based on isolated sectoral analytics, planning and forecasts, along with conventional management and planning approaches are no longer sustainable under these circumstances and cannot provide in long term reliable water sources. There is a need to develop and deploy comprehensive, multidisciplinary and complex analytical approaches with having capacity of a correct identification and setting of water issues, enabling decision making under deep uncertainty and including all affected sectors in solving solutions. This is particularly of importance in case of water deficit and scarcity, under conditions of transboundary share of the same water resources

IWaMM is an integrated water manegement model across sectors (climate – water –energy – food). It calculates and presents results of simulation of a complex hydro system behavior under superposed climate and socio – economic scenarios. It integrates hydrological processes, climate changes, and use of water in economic sectors and environmental ecosystems, hydropower generation and agriculture, at a hydrological unit (basin, region) scale. Simulation includes BAU as well as adaptiveness scenarios, applied in form of measures / actions for rationale and effective use of water across sectors, thus ensuring water availability within the analyzed time frame.

During the first half of project ARSINOE (https://arsinoe-project.eu/) runtime, the model has been deployed in the Case Study of Ohrid and Prespa Lakes, shared by three countries (North Macedonia, Albania and Greece) to provide an improved representation of integrated transboundary water management under climate change scenarios.
The paper presents the adaption of the model for the needs of the Case study and results provided by its first run.

Key words: Integrated cross sectoral water management, transboundary model, climate resilience and adaptiveness, water scarcity

1. Introduction

IWaMM Is an integrated water manegement model across sectors (climate – water –energy – food). It calculates and presents results of simulation of a complex hydro system behavior under superposed climate and socio – economic scenarios. It integrates hydrological processes, climate changes, and use of water in economic sectors and environmental ecosystems, hydropower generation and agriculture, at a hydrological unit (basin, region) scale. Simulation includes BAU as well as adaptiveness scenarios, applied in form of measures / actions for rationale and effective use of water across sectors, thus ensuring water availability within the analyzed time frame.

The model can estimate a long-term water balance under conditions of climate impacts (affecting both supply and demand side of the system), demographic changes and economic sectors' foreseen growth (agriculture, industry, seasonal sectors as tourism) and energy generation (hydropower), while taking in consideration environmental constrains (water needs and dependence of environmental ecosystems). It integrates hydrological, meteorological, climate changes and socio –economic processes and impacts thereof to water availability and couples multi sectors water use to provide equilibrium and fair water allocation among water users, in long term.

The core loop is the mass balance as the governing equitation set for a hydro system that includes a reservoir (natural (lake) or artificial – dam impounded), supply and demand side, as well as losses, optimizing water preservation in terms of providing a long term availability and preventing overflows as well as water deficit. Calculations include water stocks and flows across sectors, in discrete time steps (mean monthly), identifying deficits (and time spots of occurrence) that may appear as a result of climate influence or / and sector policy.

The model uses nationally or regionally available data related to climate and economy parameters.

During the first phase of the project ARSINOE (https://arsinoe-project.eu/) runtime, the model has been deployed in the Case Study of Ohrid and Prespa lakes, shared by three countries (North Macedonia, Albania and Greece) to provide an improved representation of integrated transboundary water management under climate change scenarios

2. DESCRIPTION OF THE MODEL

2.1. Background of the model

The model was developed during a previous research project: *Development of an integrated multi criteria numerical model for environmental – economy assessment of complex hydro systems*, Funded by Ministry of Environment and Physical Planning of North Macedonia, 2015 – 2016. The purpose of the model is to identify and optimize climate adaption strategies of multiple coupled sectors, applying WEF nexus, under relevant combinations of SSP and RCP scenarios.

2.2. Basic features of the model

Area coverage: River basin / Watershed scale
Time coverage: 1980 – 2100
Reference/calibration data: Against measured hydrological and climate indicators data in the watershed.

Table 1: Main characteristics of the model applied in ARSINOE CS Ohrid and Prespa Lakes

<table>
<tr><th>Model input parameter(s):</th><th colspan="2">Source:</th><th>Resolution:</th></tr>
<tr><td>Meteorological forcing
Temperature, Precipitation
Hydrological data (inflows)
Climate scenarios</td><td colspan="2">Reference data (interpolated hydrological and meteorological stations measurements)
GCM data (CORDEX)</td><td>1 month
12 km; statistically downscaled from climate model grids</td></tr>
<tr><td>Static information on land use (agriculture) and water use</td><td colspan="2">Regional surveys and studies</td><td>Static, periodic updates</td></tr>
<tr><td>Information on water consumption by users (households, agriculture, industry, hydro power)</td><td colspan="2">Municipalities (water management utilities), Power Generation Utilities</td><td>Static, periodic updates</td></tr>
<tr><th colspan="2">Output parameter(s):</th><th colspan="2">Resolution:</th></tr>
<tr><td colspan="2">Water level in the lakes</td><td colspan="2">Monthly time series of mean values</td></tr>
<tr><td colspan="2">Precipitation, temperature, radiation, humidity, wind</td><td colspan="2">0,11’, 11 km</td></tr>
<tr><td colspan="2">(Water consumption per type of consumers</td><td colspan="2">Mean monthly values (million m^3)</td></tr>
<tr><th colspan="4">Analysis objectives:</th></tr>
<tr><td colspan="4">The model was used in the Ohrid and Prespa watersheds to provide:
- changes in the course, magnitude and seasonality of water balance terms
- drought dynamics and relevant indicators
- impact assessment of new adaptation strategies (altered land use, agricultural practices, water withdrawal (irrigation, transfer), etc.)</td></tr>
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The Figure 1 presents the block diagram of the model.

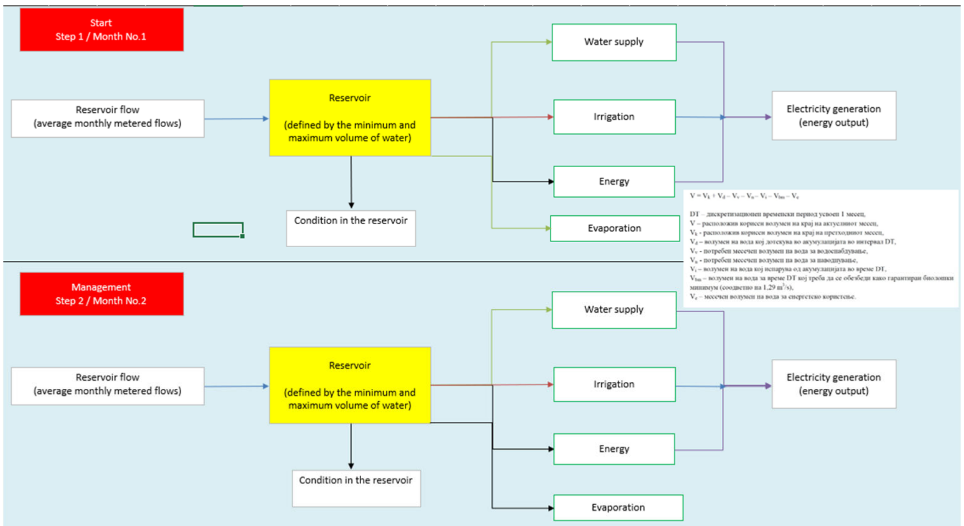


Figure 1: Block diagram of the model

2.3. Case study Ohrid / Prespa lakes in the project ARSINOE

This CS aims at improving climate resilience of environmental, economic and social sectors related to water use, by providing an intelligent comprehensive innovation set of long-term planning solutions, allocation and use of sufficient quantity and of adequate quality water for all users, respecting their interests in order to improve human health, food production, conservation of natural environmental systems, clean energy production and sustainable growth of all sectors. Water availability have been analysed in the wider transboundary region of the lakes

Ohrid/Prespa, to propose a new water governance management framework, adapted to climate change challenges. This CS will contribute to secure a balanced use of available water resources and bridge the gap between social and economic aspect facing the climate changes impacts on a transboundary surface and ground water systems of Ohrid and Prespa lakes. optimal water allocation and climate adapted usage and management thereof.

Figure 2: Location of Ohrid and Prespa Lakes

Figure 3: Lake Prespa current status of water level

2.4. Challenges in adaptation to CS4 needs

1. Two natural reservoirs (lakes), hydraulically connected in a unique way – through groundwater below mountain.
2. Lack of sufficient data for modelling
3. Transboundary dimension (three countries sharing the same water resources, with possibly different policy, economic and environmental priorities and perspective).

2.5. Adjustment for the purpose of CS4

Adjustment of the model had to be made, more specifically:

- Integration of different sets of input data (for both supply and demand side),
- Harmonization of decided SSP and RCP scenarios and adjustments of data inputs accordingly,
- Modification of supply and demand patterns and data series
- Interpretation of natural hydrogeological connection and interdependences of two separate hydro systems,
- Prioritization of water users, and their requirements
- Planning horizon selection,
- Setting consensually relevant objectives and criteria for MCDM module,
- Identification of feasible alternatives for climate resilience improvement,
- Quantification of criteria / sub-criteria indicators for evaluation of adaptiveness strategies.

3. METHODOLOGY

3,1, Hydro - climate modelling method

The hydro - climate modelling was done through a seven - step methodology**:**

Step 1: Setting the baseline

Step 2: Development of MMEs (dynamical downscaling of RCMs (CORDEX database))

Step 3: Development of filtered MMEs
Step 4: Weighted average sum of model ensembles
Step 5: Linking historical and projected series; bias estimation
Step 6: Development of hydro – climate models up to the projecting horizon
Step 7: identification, ranking and selection of adaptiveness strategies of water use across sectors

Step 1: Setting the baseline

1.1. Establish the current water balance of the two lakes;

Establish the water balance equation for the two watersheds, mathematical representation of relation between the lakes (groundwater outflow – inflow through karstic masses), water demand per sectors; calculating mean annual water levels

1.2. Collect and process historical (measured) data

- Measured (historical) data for the two climate indicators (temperature and precipitation) were provided:
- Ohrid : Two meteorological stations, one in Mk, one in AL, for 1961 -2020 and 1980-2020, respectively
- Prespa: Two meteorological stations, one in Mk, one in AL, for 1981 -2020
- At the moment of setting the baseline, there weren't data in sufficiently long time series available from the Greek part of the Prespa watershed
- Data on water consumption per sectors were provided by analysis of available studies and report, as well as by a field research (municipalities and local water utilities)

1.3. Select climate indicators (precipitation and air temperatures, as the most influential ones for the water balance calculation)

1.4. Select time of projections (2021 to 2100)

1.5. Select climate scenarios (RCP 2.6, RCP8.5), in compliance with SIA applied in the course of the project

1.6. Select time resolution (mean monthly values, to correspond to seasonal character of the largest consumers – irrigation, tourism, population)

1.7 Select spatial coverage (the two watershed boundaries, in the three countries)

Step 2: Development of MMEs (dynamical downscale of GCM, RCMs)

Method of development of projections (climate modelling) consists of:

- Select RCMs models from MCIP5
- Make projections of the climate indicators (downscale mean monthly values from the RCMs, In the spots of locations of sources of measured data)
- Develop an ensemble formed of all the applied RCMs – MMEs – multi model ensembles
- Present the ensemble as time series of projected data (mean monthly values) for the subject climate indicator (air temperature, precipitation), in the time period selected for climate modelling (2021 – 2100)
- Compare the ensemble data with observed data time series

Step 3: Development of filtered MMEs

3.1. Reduce the number of source RCMs;
3.2. Exclude RCMs with extreme values that are not in compliance with historical data,
3.3. Select the most relevant RCMs to compile the ensemble

Step 4: Weighted average sum ensembles

4.1. Apply weighted average method to ensemble reduced number of RCMs
4.2 Produce new ensembles

Step 5: Linking observed and projected data series

5.1. Link the average and the trend line of projections with the observed data series
5.2. Calculate the bias by linear regression method

Step 6: Hydro – climatic model development

Application of the projected values of mean monthly sums of precipitation and mean monthly air temperature in the lake water balance equation.

$S_t+(P+Q_{in}+G_{in})-(E+ET+Q_{out}+Q_{ws}+Q_{ir}+G_{out})=S_{t+\Delta t}$

S_T - Initial water storage in the watershed at the beginning of the analyzed period

P – Input water in the watershed due to precipitation = *f(mean sum of precipitations)*

Q_{IN} – Input water in the watershed from another watershed

G_{in} – Groundwater inflow

E – Output water due to evaporation from free surface water = *f(mean air temperature)*

ET – Output water due to evapotranspiration = *f(mean air temperature)*

Q_{OUT} – Outflow water to another watershed

Q_{WS} – Used water for population and industry and water supply

Q_{IR} – Used water for irrigation

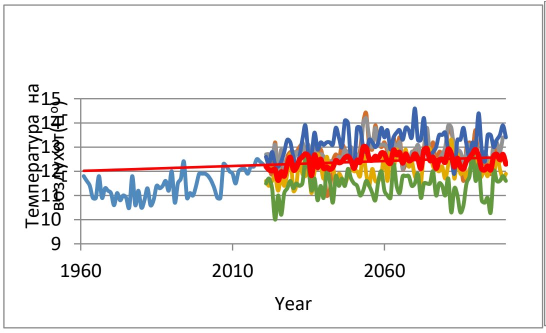
G_{OUT} – Groundwater outflow

$S_{t+\Delta t}$ - Water storage in the watershed at the end of the analyzed period

4. RESULTS

4.1. Hydro – climate model results

Results of coupling observed and projected climate and hydrology data, as per the method described above, are presented on the Figures 4,5, and 6.



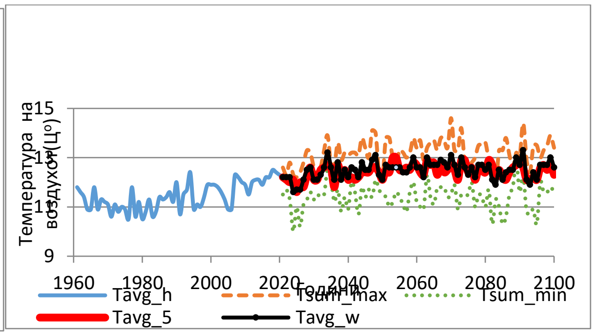


Figure 4. Common graph of observed and projected data of mean annual air temperatures for Ohrid and Pretor, with MMEs of selected 5 RCMs for Ohrrd and 7 RCMs for Pretor, RCP 2.6.; Figure 5. Common graphs of observed and projected data of compounded mean annual temperature with weighting coefficients, 2021-2100,RCP 2.6.

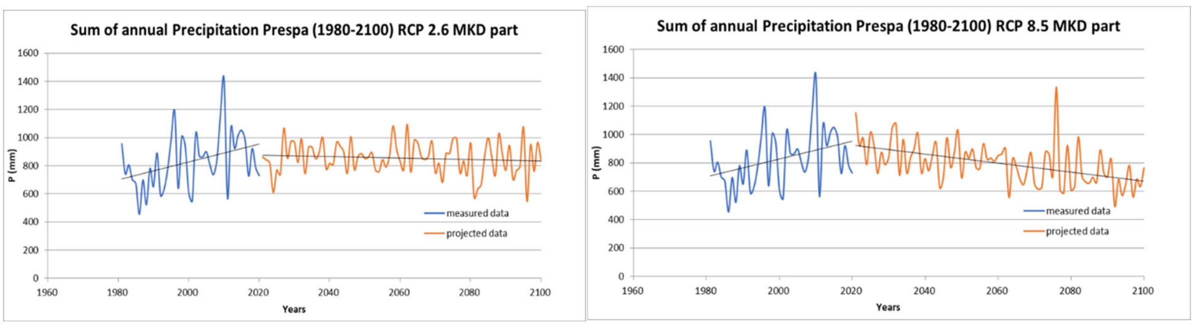


Figure 6. Sum of annual Precipitation Prespa (1980-2100) RCP 2.6 MKD part

Bias identification and adjustment was carried out by using the method of linear regressions by an Excel tool developed by Wageningen university it was applied for the most representative scenario, for precipitation projections, in Prespa, for RCP 8.5.

4.2. Water balance results

By applying hydro – climate model outputs in the water balance equation, projections of the water level fluctuations on monthly basis, by 2100, were estimated, for each of the lakes, under the two selected scenarios: RCP 2.6 and RCP8.5.

In summary, Lake Prespa is expected to suffer further lowering of the water level, which shows to be more intensive under RCP8.5

The Lake Ohrid would preserve the current span of water level fluctuations, but the regulated discharge for the needs of hydro power generation would decrease under RCP8.5

4.3. Energy generation modelling

The energy module was used to calculate the impacts of climate change on lowering of the regulated discharge from the lake Ohrid, on power generation, and therefrom, on power generation in the cascade of seven HPPs (two in North Macedonia and three in Albania).

The results showed that under RCP 8.5, the contribution of Ohrid Lake discharge will affect the power generation in HPPs Globocica and Shpilje, by aapproximately 50% of decrease, whilst the impact on the other three HPPs, downstream, will be significantly smaller (about 2%).

Табела 1 Прогнозиран придонес на истекот во Охридско Езеро во средномесечно производство во ХЕЦ Глобочица период 2021-2100 година (GWh)

месец	1	2	3	4	5	6	7	8	9	10	11	12	Просек
просек	12.22	11.30	12.00	11.76	11.32	11.65	10.64	10.04	8.03	7.80	7.71	9.85	124.33

Табела 2 Прогнозиран процентуален придонес на истекот во Охридско Езеро во средномесечно производство во ХЕЦ Глобочица во период 2021-2100 година (%), Сценарио RCP 2.6

месец	1	2	3	4	5	6	7	8	9	10	11	12	Просек
просек	67.06	66.06	60.16	56.35	55.90	71.60	78.73	82.80	76.21	70.27	69.35	62.65	67.06

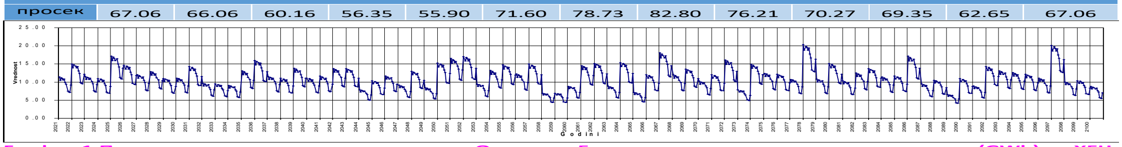


График 1 Прогнозиран придонес на истекот на Охридско Езеро во вкупно месечно производство (GWh) во ХЕЦ Глобочица во период 2021-2100 година, Сценарио RCP 2.6

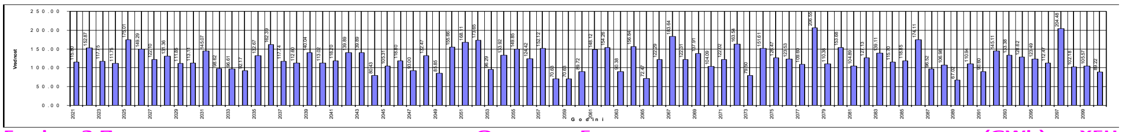


График 2 Прогнозиран придонес на истекот од Охридско Езеро во вкупно годишно производство (GWh) во ХЕЦ Глобочица во период 2021-2100 година, Сценарио RCP 2.6

График:

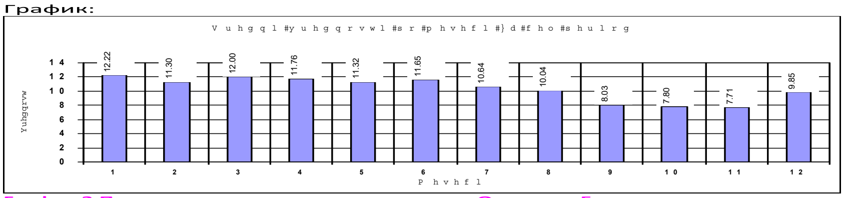


График 3 Прогнозиран придонес на истекот од Охридско Езеро во вкупно месечно производство (GWh) во ХЕЦ Глобочица во период 2021-2100 година, Сценарио RCP 2.6

Figure 7. Extract from results of energy modelling

4.4. Socio - economic modelling methodology

The data gathered from the SSP database were subjected to the method of downscaling. Statistical downscaling, foresees and explains the statistical relationship is established from observations between large scale variables. The statistical method that is used is linear method. Linear methods are very straightforward and widely used, and they can be applied to a single predictor-predictand pair or spatial fields of predictors-predictands.

4.5. Water consumption modelling

Water consumption was observed in coupled water – energy – economy - food nexus. Water demands were projected for the following social and economic sectors: households, tourism, agriculture and industry. The consumption in 2020 was taken as a baseline, whilst the projections until 2100 were generated taking into account the outputs of socio – economic modeling, the GDP growth and the number of population change until the projection horizon. The results of water consumption and allocation are given in the figures below.

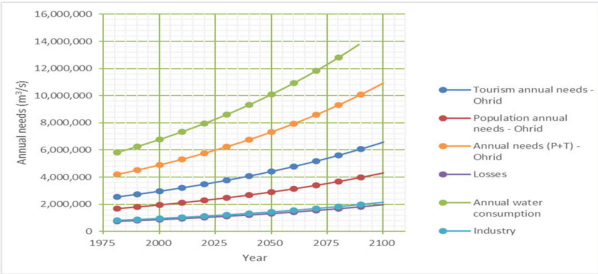


Figure 8. Total annual water needs-Ohrid, by 2100

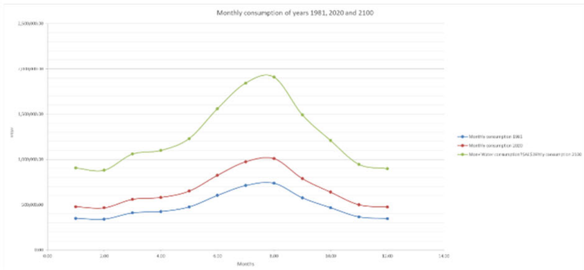


Figure 9. Monthly consumption of water for years 1981; 2020; 2100-Ohrid

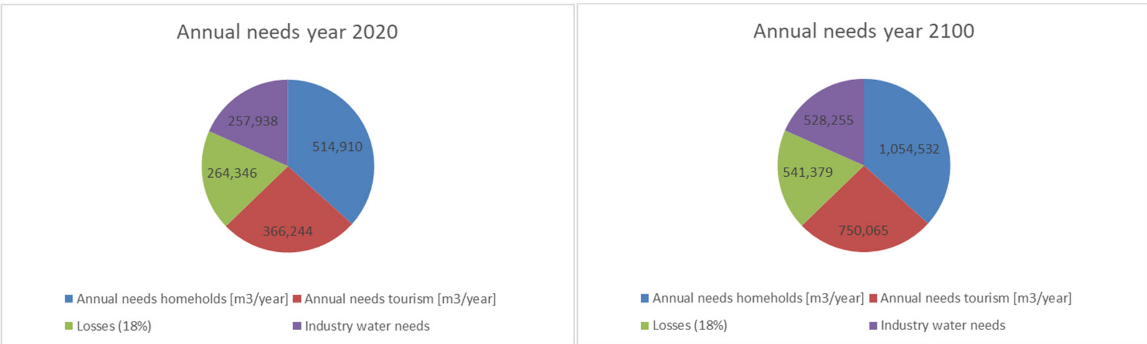


Figure 10. Annual distribution of water consumption for the year 2020-Resen

5. FINDINGS AND CONCLUSIONS

The methodological and mathematical model IWAMM has been applied in transboundary watershed area of Ohrid and Prespa Lakes, shared by three countries. Two boundary scenarios selected for analysis, including two RCPs and accompanied SSPs, showed that

1. Both lakes will be affected by the climate changes
2. Decrease of water level can be expected at Prespa Lake, in more severe way for RCP8.5
3. To maintain the water level of Ohrid Lake, regulation of discharge will have to be more limited.
4. The most affected sectors will be environment, agriculture, and energy sector.
5. Adaption strategies have to be developed in a WEF nexus approach, using multi – criteria analysis and decision making tool.
6. Cross - sectors and transboundary trade – offs will be further explored, leading to a consensual, sustainable, long term solutions of interest for all countries and sectors.
7. In the model further runs, Step 7 will be applied, for identification and selection of adaption strategies of sectors, by using multi – criteria analysis and decision making method.

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