iAMP-Hydro

Date: 3rd July 2024

Location: Online

Prof. Aonghus McNabola

PEN@Hydropower – WG1

Hydropower digitalisation in Southern Europe: Opportunities and challenges for increased flexibility and flow forecasting

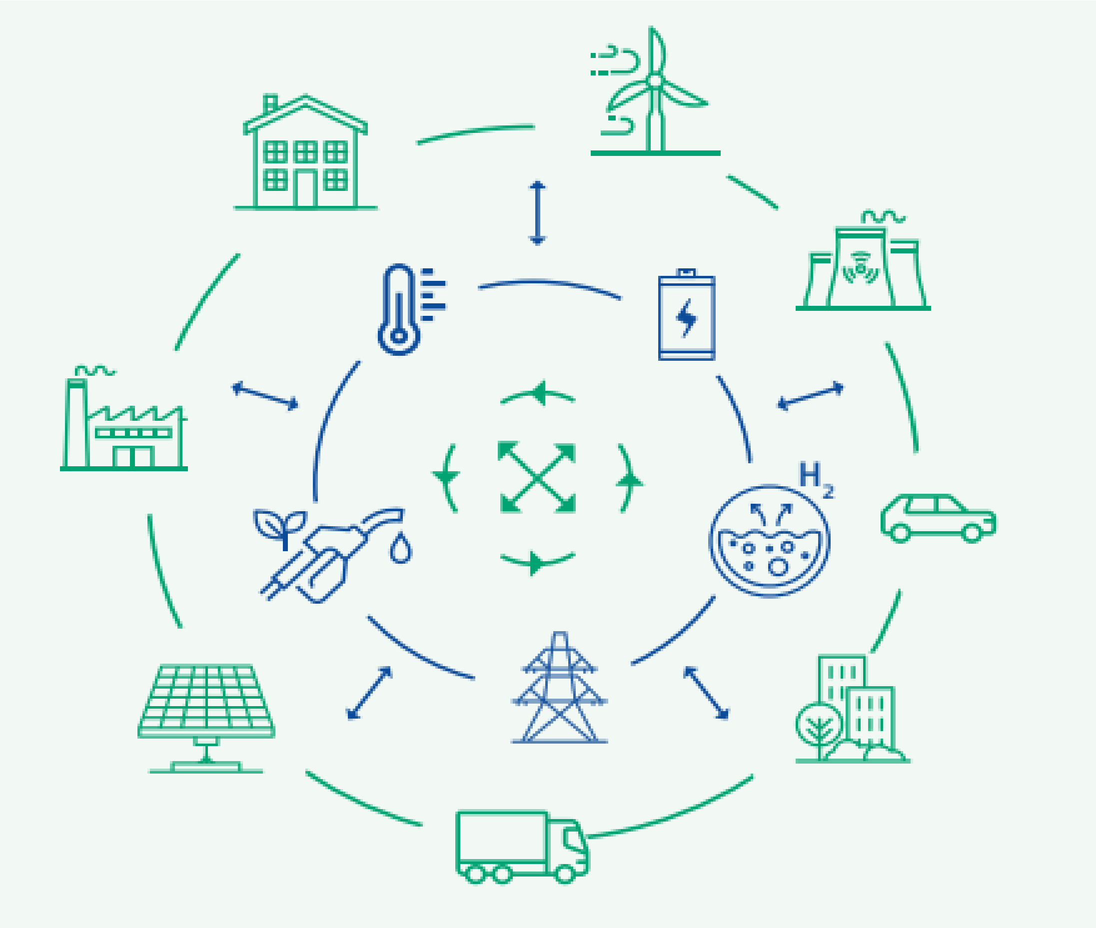
Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. 101122167.

Introduction

Digitalisation of the energy system

- EU electricity sector undergoing a fundamental change with the increase of digitalisation
- Digitalisation means embedding sensors, data collection and amassing big data resources for the optimisation of energy systems
- Hydropower Digitalisation has implications for increasing energy storage capacity:
    - More efficient use of water resources
    - Sensors, Digital Twins & Forecasting Systems
    - Increased flexibility and predictability of storage capacities



Introduction

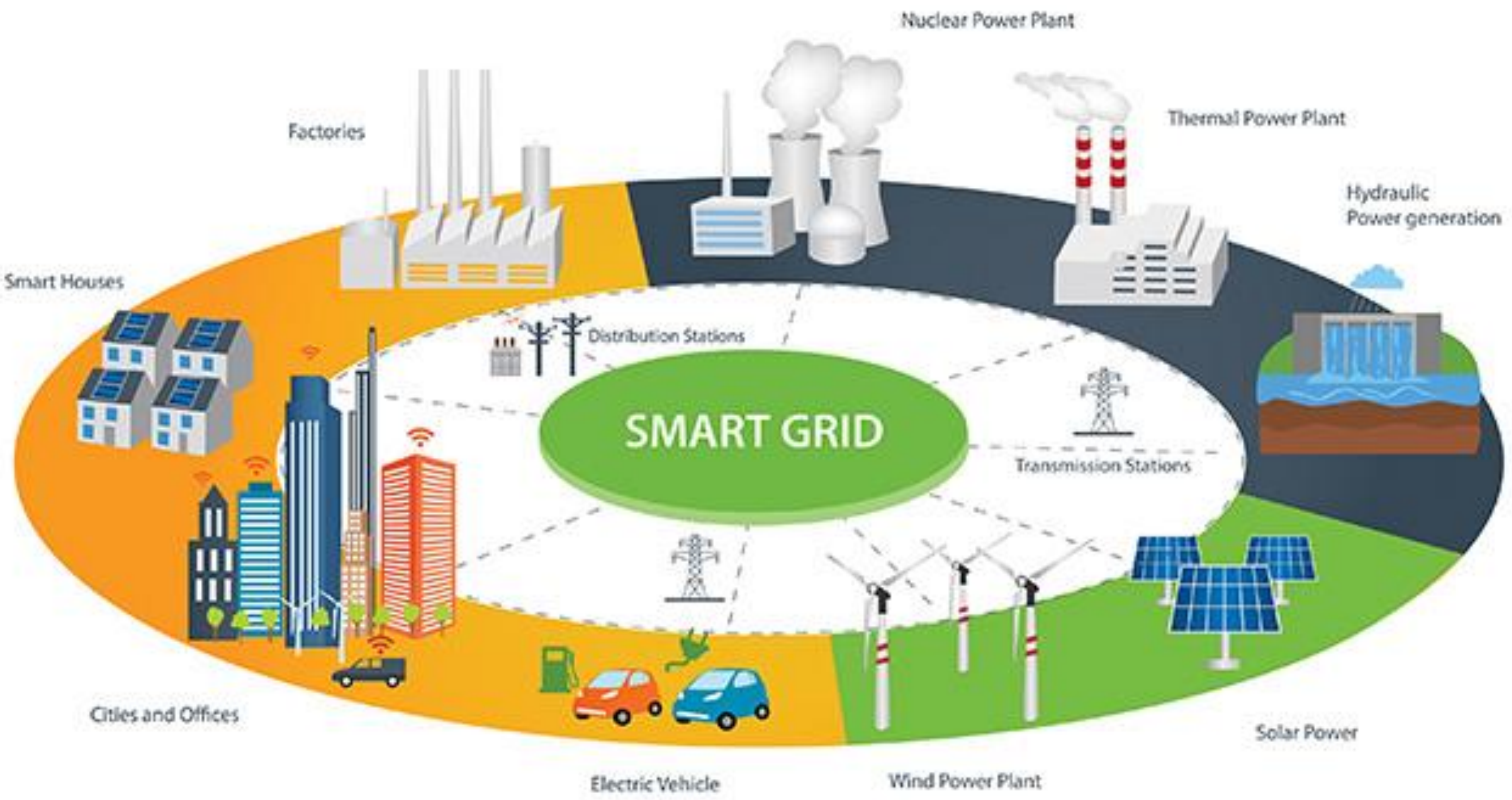
Grid Flexibility, Renewable Energy & Electrification

Challenge

- More variable source renewables
- Less conventional sources
- Greater demand for electricity

Hydropower

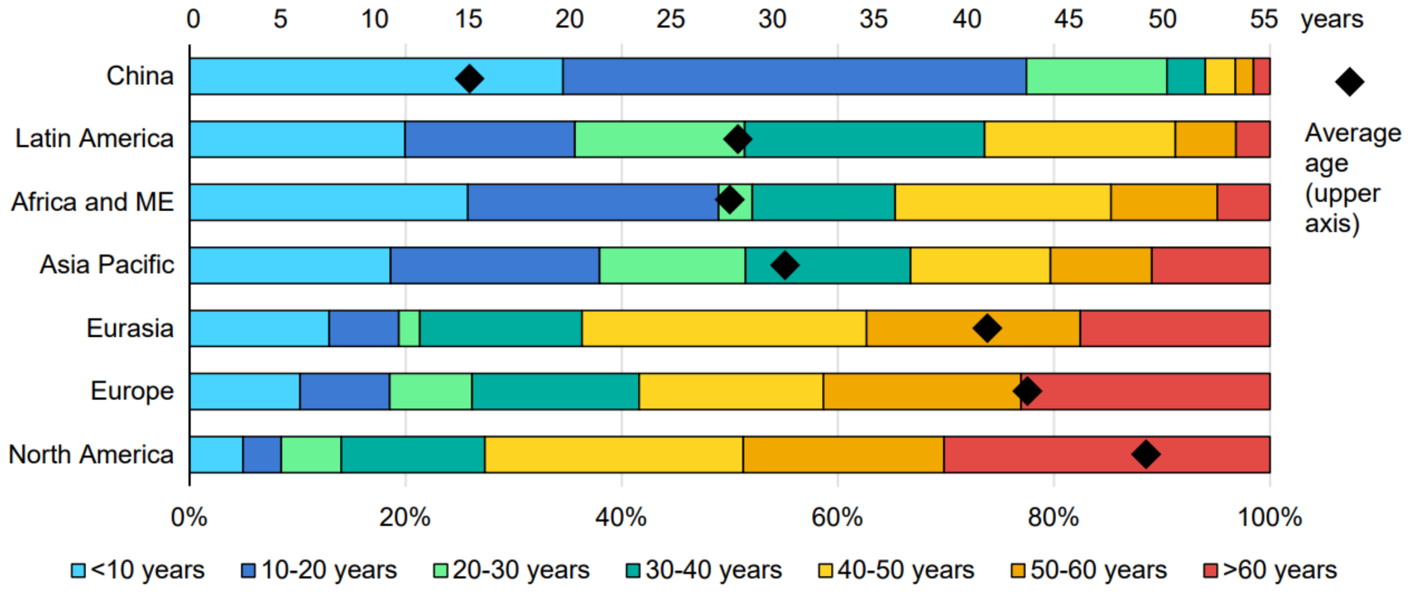
- Start/stop quickly (dispatchable)
- Energy Storage
- Predictable / less variable
- More off-design operation
- More hydro-peaking
- Climate change challenges



Introduction

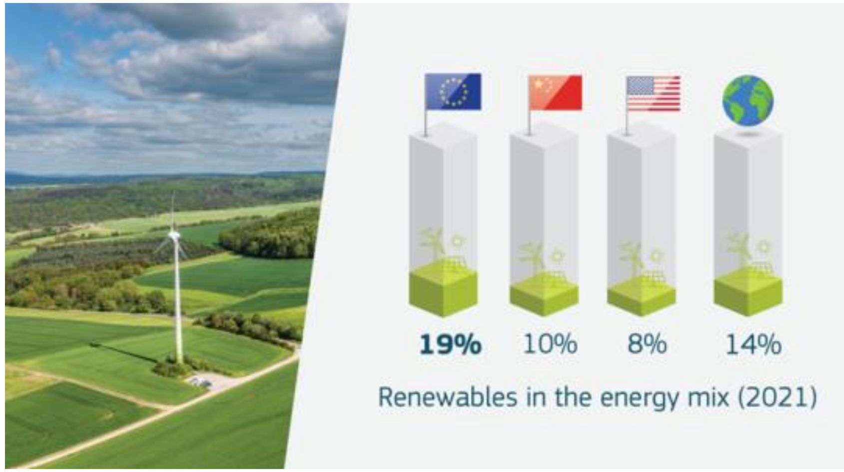
Hydropower & Digitalisation

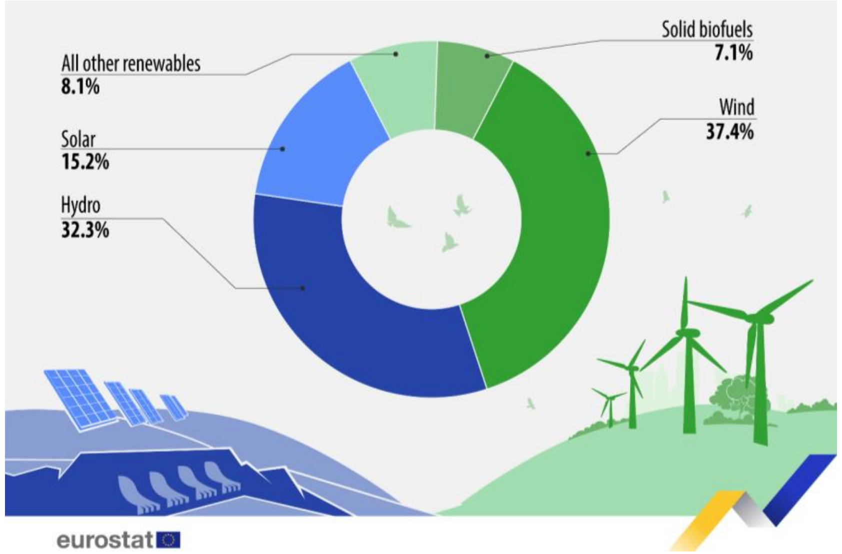
- Hydropower represents one sixth of global electricity generation
- Provides significant contribution to grid flexibility and security
- However the fleet is aged and requires significant modernisation works



Age profile of installed hydropower capacity, 2020

(Source: Hydropower Special Market Reports, International Energy Agency)



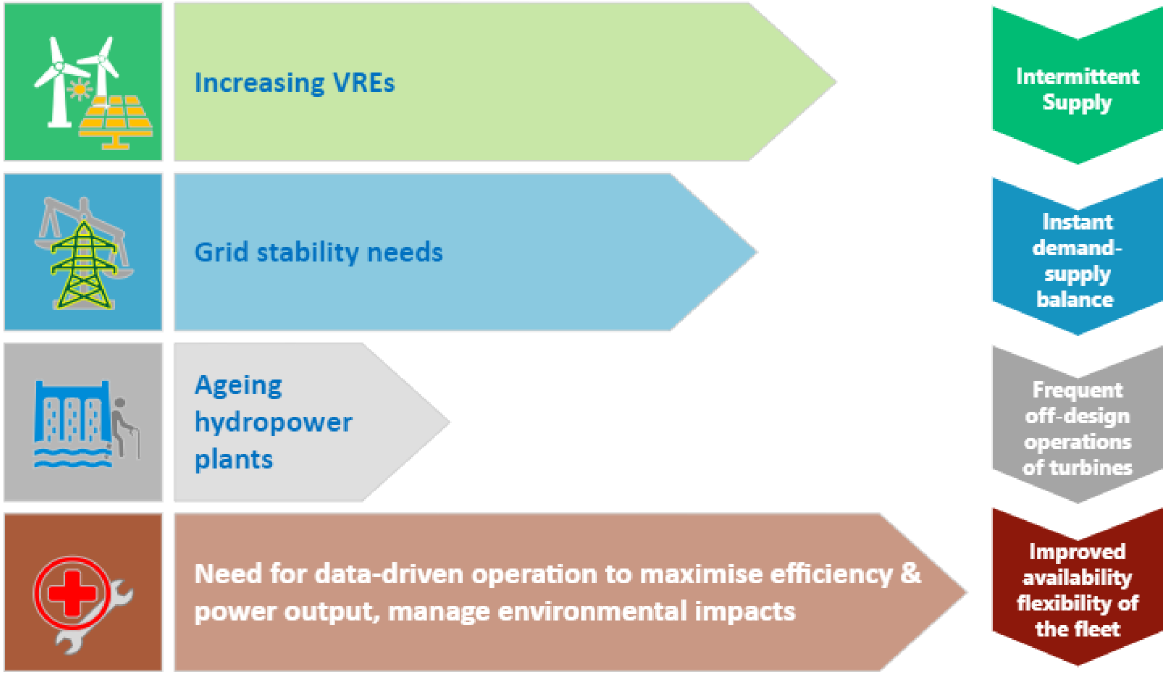


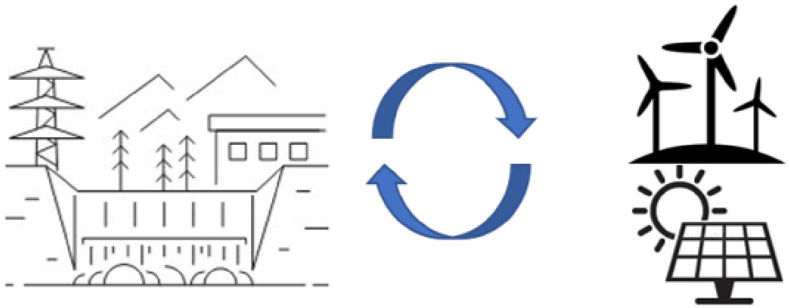
Sources of renewable energy in gross electricity consumption, EU 2021

Problem Statement

- Digitalisation required to increase grid flexibility, environmental and socio-economic sustainability and to foster the green and digital transitions in Europe.

- The digitalisation of the world's 1225 GW of existing hydro could increase annual production by 42 TWh, amounting to 5 billion USD in annual operational savings and significant reductions of greenhouse gas emissions





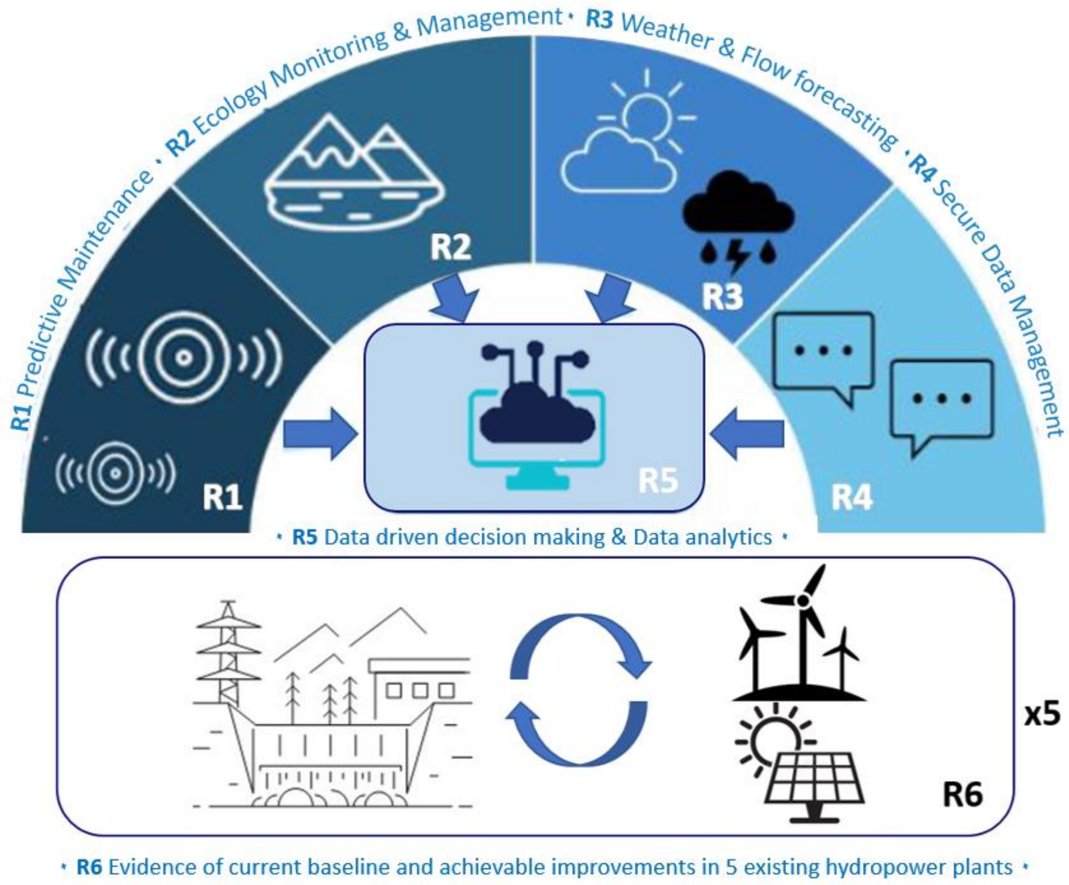
Project Objectives

1. **Co-develop** and **validate** novel condition monitoring and predictive maintenance digital solution at TRL5 for hydromechanical and electrical equipment.

2. **Co-develop** and **validate** advanced sensors and models for the monitoring of biodiversity parameters for an ecologically optimised hydropower operation to improve biodiversity, environmental and socio-economic sustainability of existing plants

3. **Co-develop** and **validate** enhanced weather and flow forecasting models for improvement in reservoir inflow, outflow and water balance prediction accuracy

intelligent Asset Management Platform



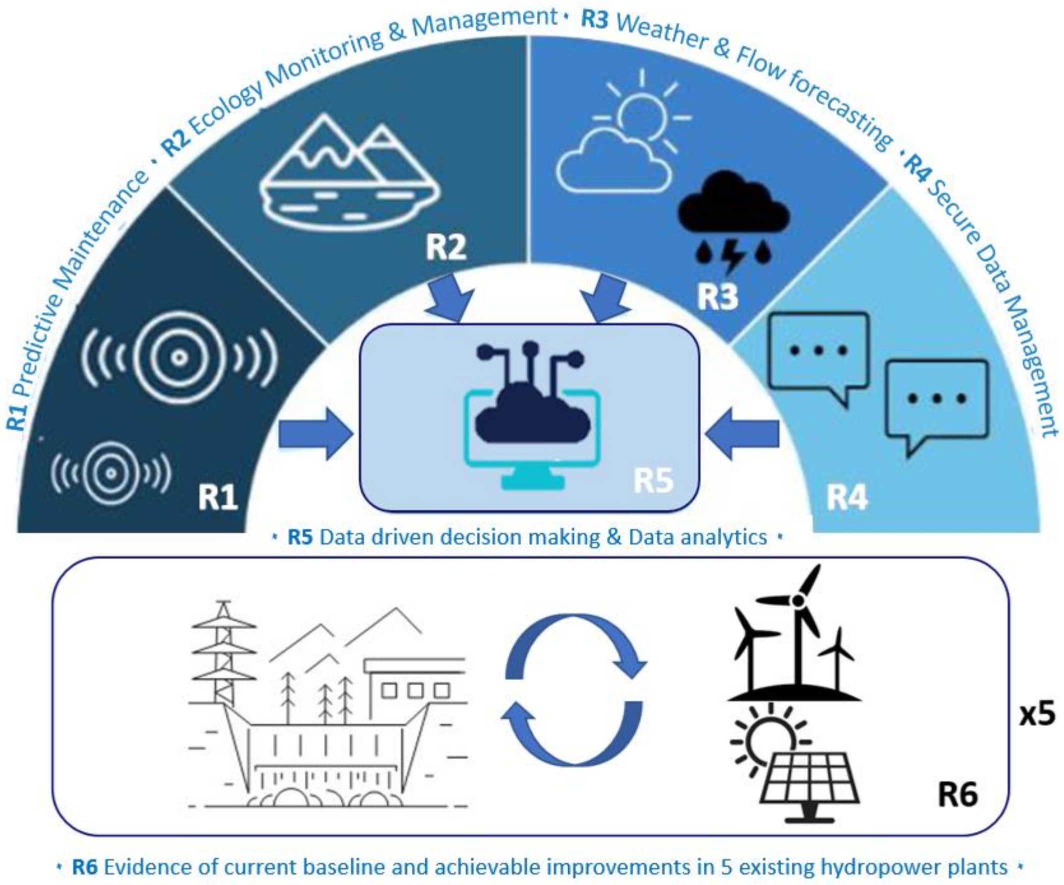
Project Objectives

intelligent **A**sset **M**anagement **P**latform

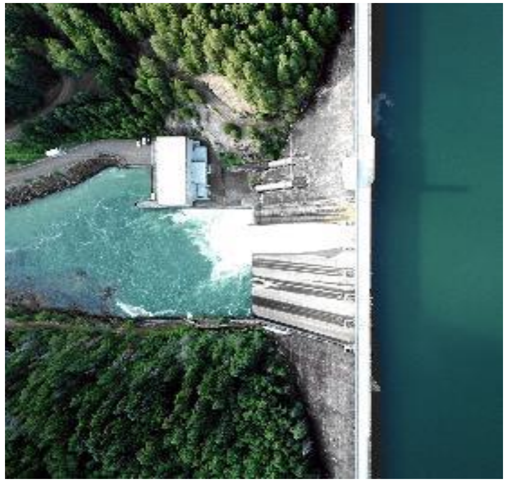
4. **Co-develop** secure data collection, communication, storage and sharing protocols and standards to enable trusted data-driven operation and maintenance, and interoperability between hydro operators, and with other renewable energy sources

5. **Co-develop** and **validate** iAMP decision-making algorithms for data-driven O&M, including integration of operations with other renewable energy sources to increase flexibility and optimise hydro positioning in energy markets

6. Widespread dissemination and communication of the potential benefits of digital solutions & gathering evidence for policy makers



iAMP-Hydro Validation Site



Berchules (0.8 MW)

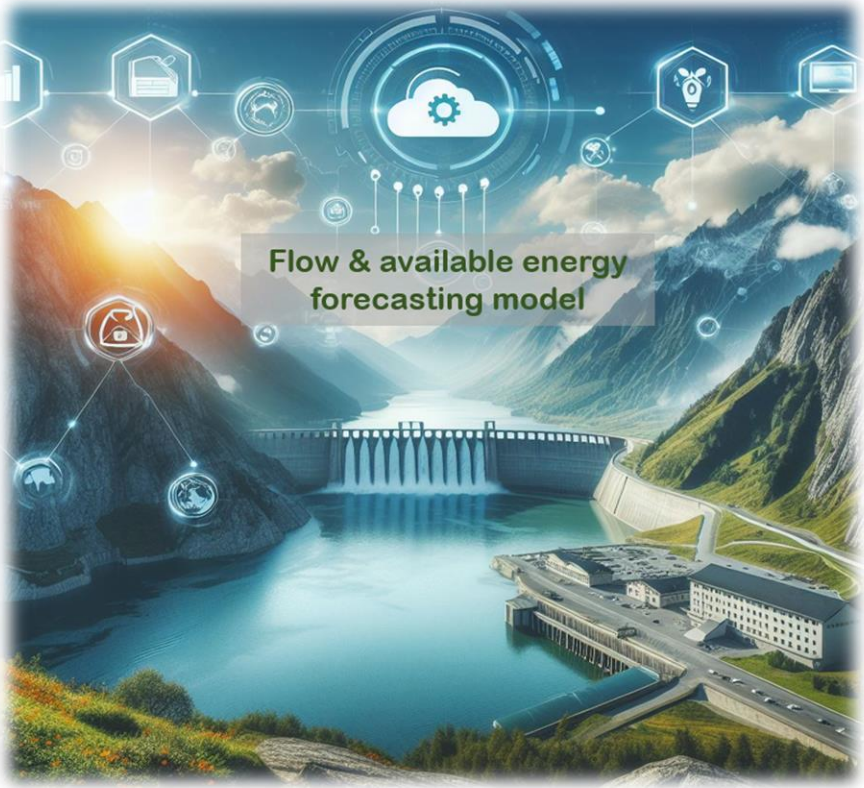
Bermejales (2.1 MW)

La Vega (2.4 MW)

Makrochori (10.8 MW)

Asomata (108 MW)

Better flow forecasting

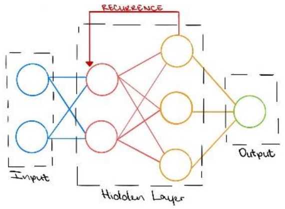


WP6 & WP7 objective

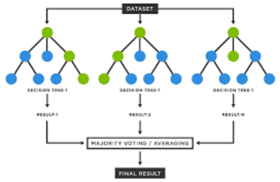
Co-develop **enhanced weather and flow forecasting models** using operational data from power plants and open source data in differing climates, with differing power capacities and flow regimes **achieving >23% improvement** in reservoir inflow, outflow and water balance **prediction accuracy**, from hourly up to **7-day time horizons**

Flow forecast modelling approach

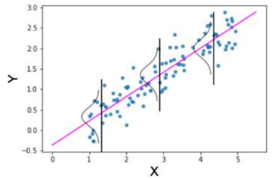
- AI-based: Deep learning (DL): recurrent neural networks (RNN) → Long Short-Term Memory (LSTM) networks



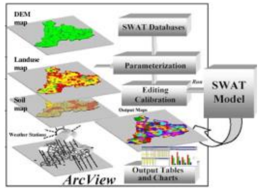
- AI based: Machine learning (ML): classification algorithms → random forest (RF) or support vector machine



- General linear model

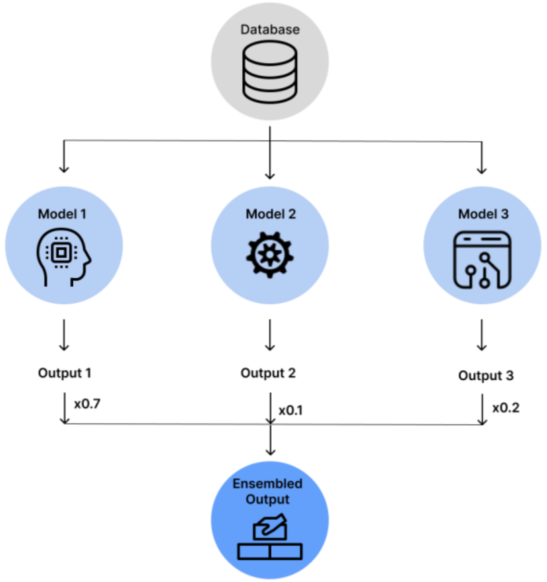


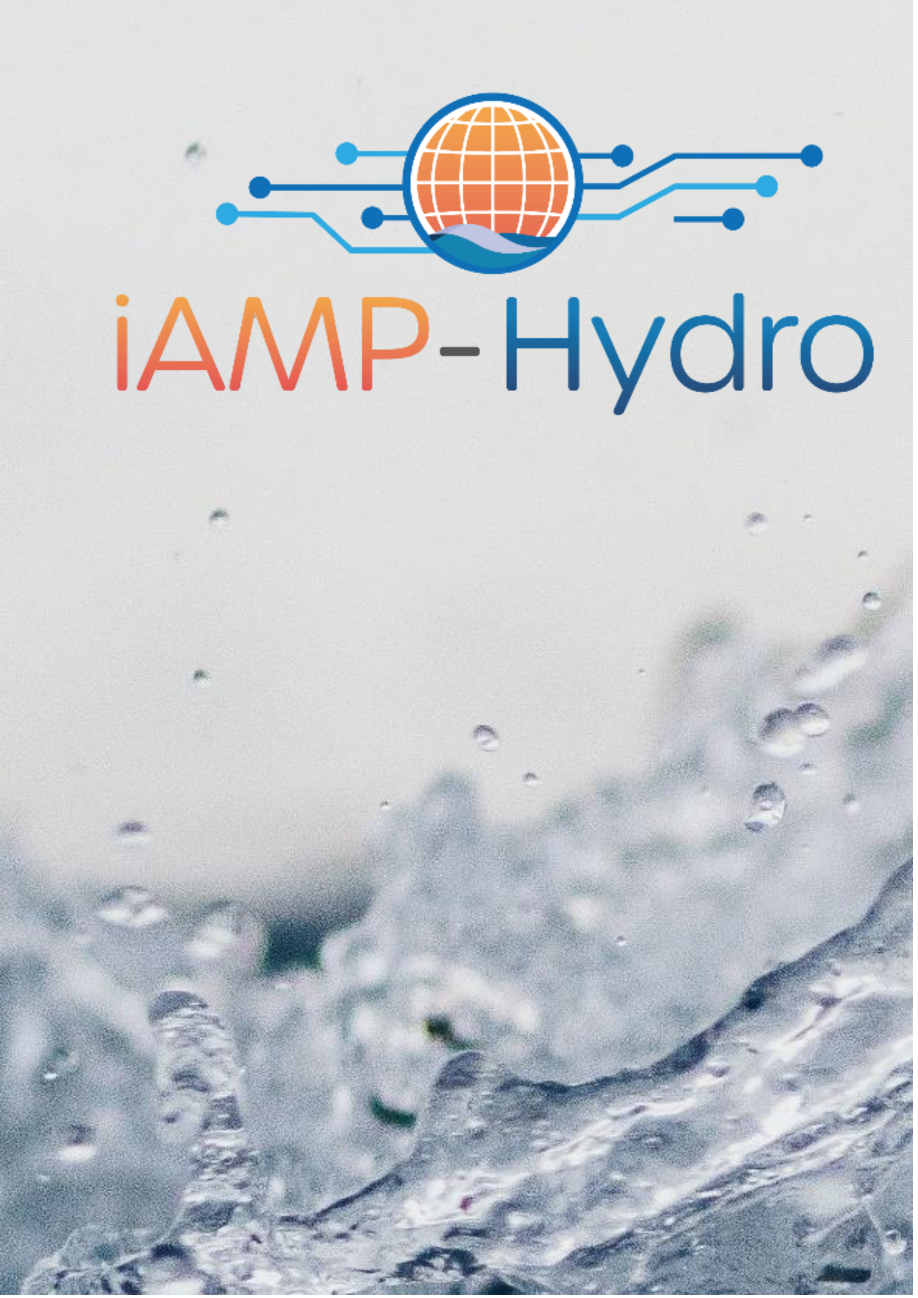
- Existing physical models (SWAT, HBV)



Hybrid Flow forecasting models

Ensemble





Bermejales

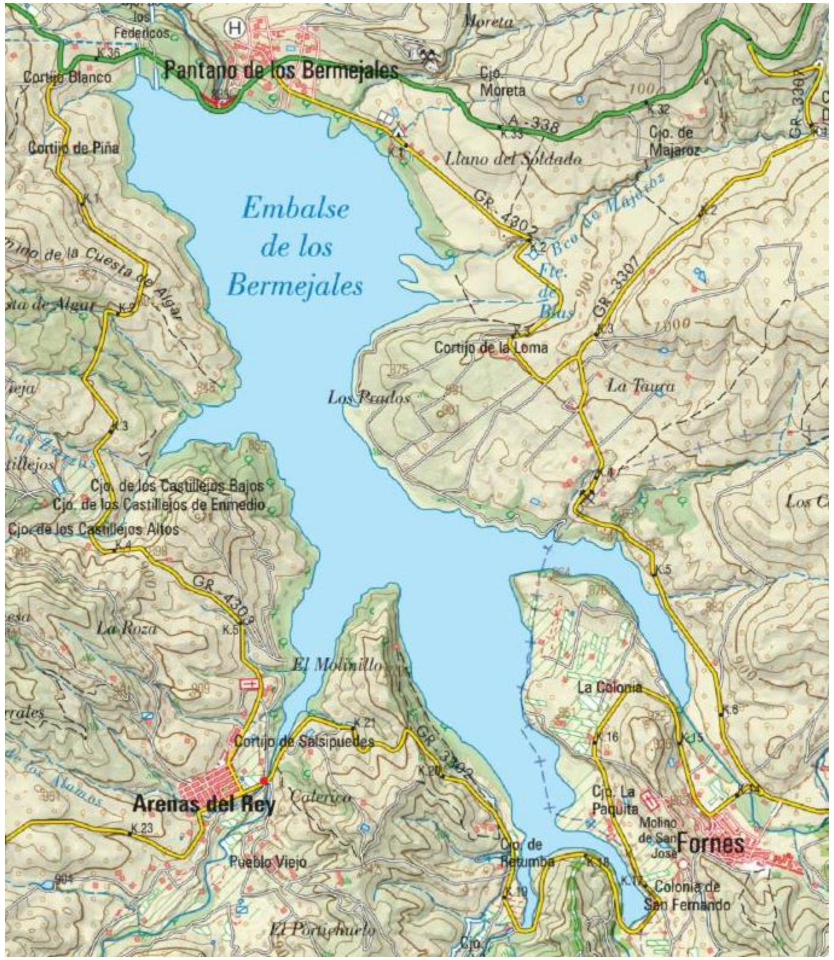
CUERVA, CARTIF

Cuerva
Energía Transparente

CENTRO TECNOLÓGICO CARTIF

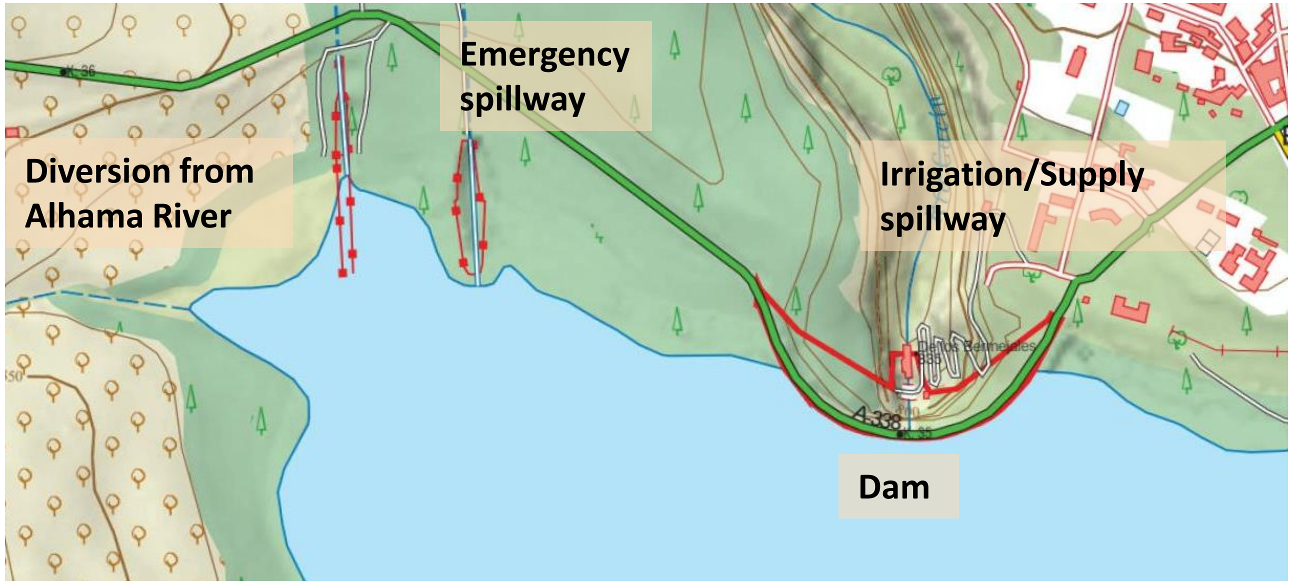
Bermejales

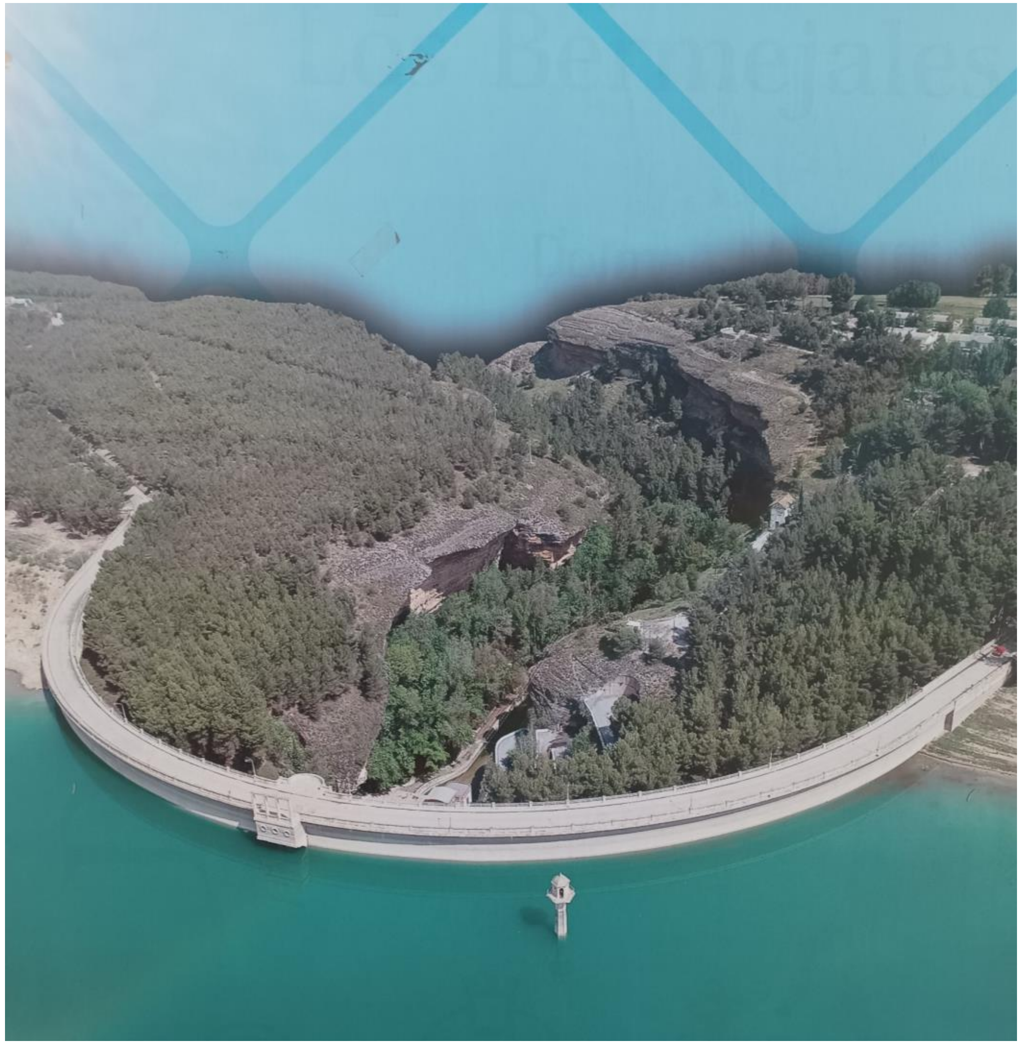
Plants	**Bermejales**
Nominal Power (MW)	2.1
Type	Dam base
Location	Arenas del Rey (Granada)
Net head (m)	56.5
Mean Flow (m^3/s)	0.8-4.8
Capacity (hm^3)	102.6
Nominal speed (rpm)	750
Type of turbine	Francis
Principal use	Irrigation



Source: https://www.ign.es/iberpix/visor

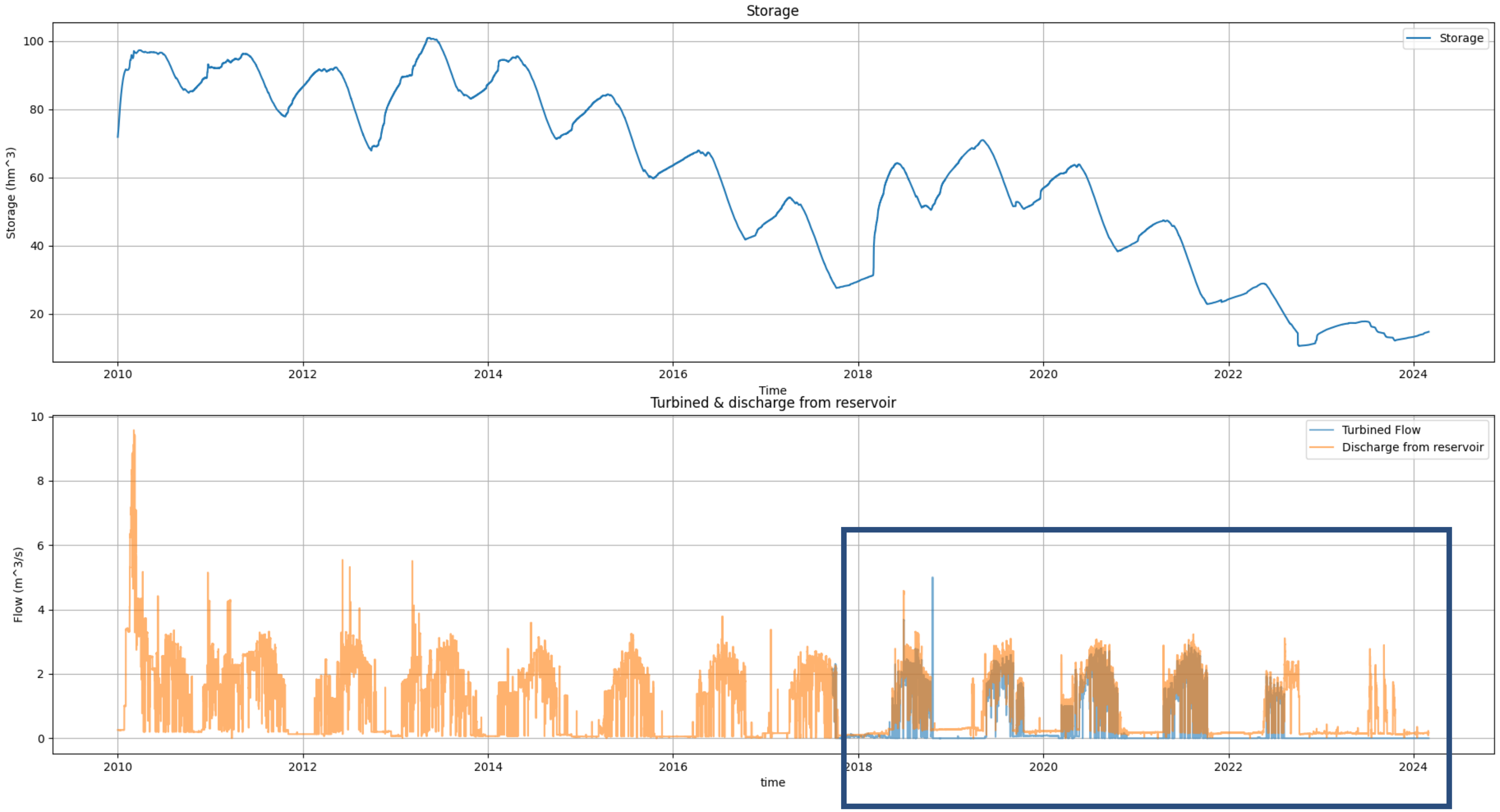
Bermejales


Emergency spillway
Diversion from Alhama River
Irrigation/Supply spillway
Dam



Bermejales

Bermejales



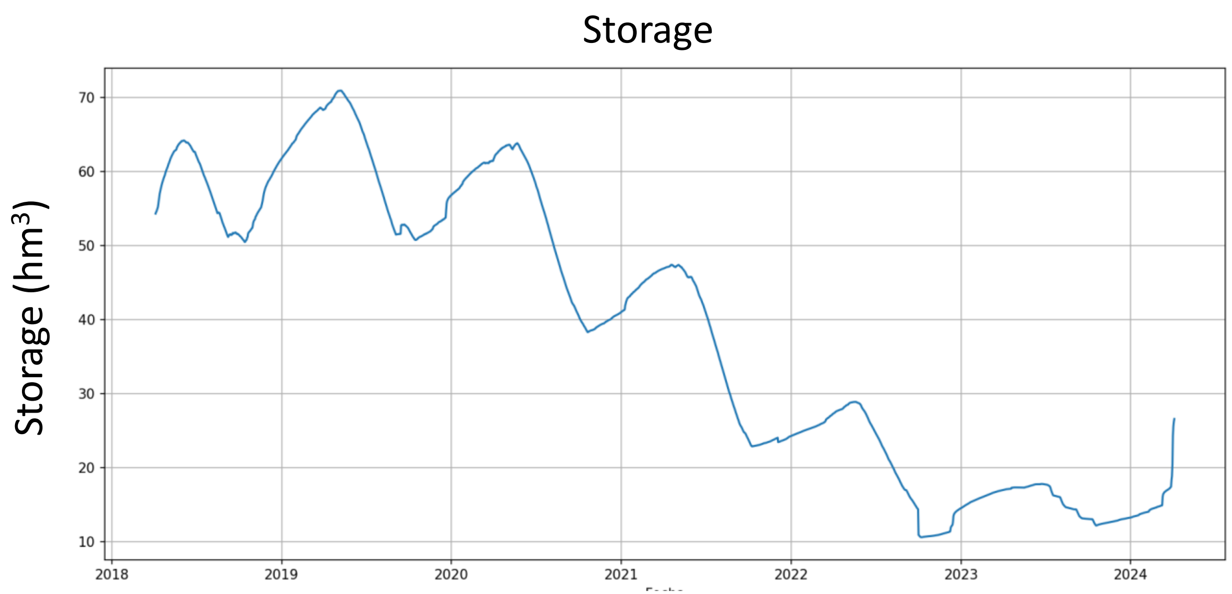
Since 2010, the **total volume in the reservoir** has decreased from 100 hm^3 to 20 hm^3: Severe drought and change in the irrigation scheme:

Discharge (for **downstream irrigation**):
2010-2021: 9 months (March to Nov).
2022: 5 months (June – Oct).
2023: 4 months (July – Oct, 10 days per month)

Turbined Flow:
2018- July 2022: 5 years of operation of the HPP
August 2022-2023: out of operation

Source: Sistema automático Información hidrográfica (SAIH) : https://www.chguadalquivir.es/saih/EmbalGR.aspx

Bermejales



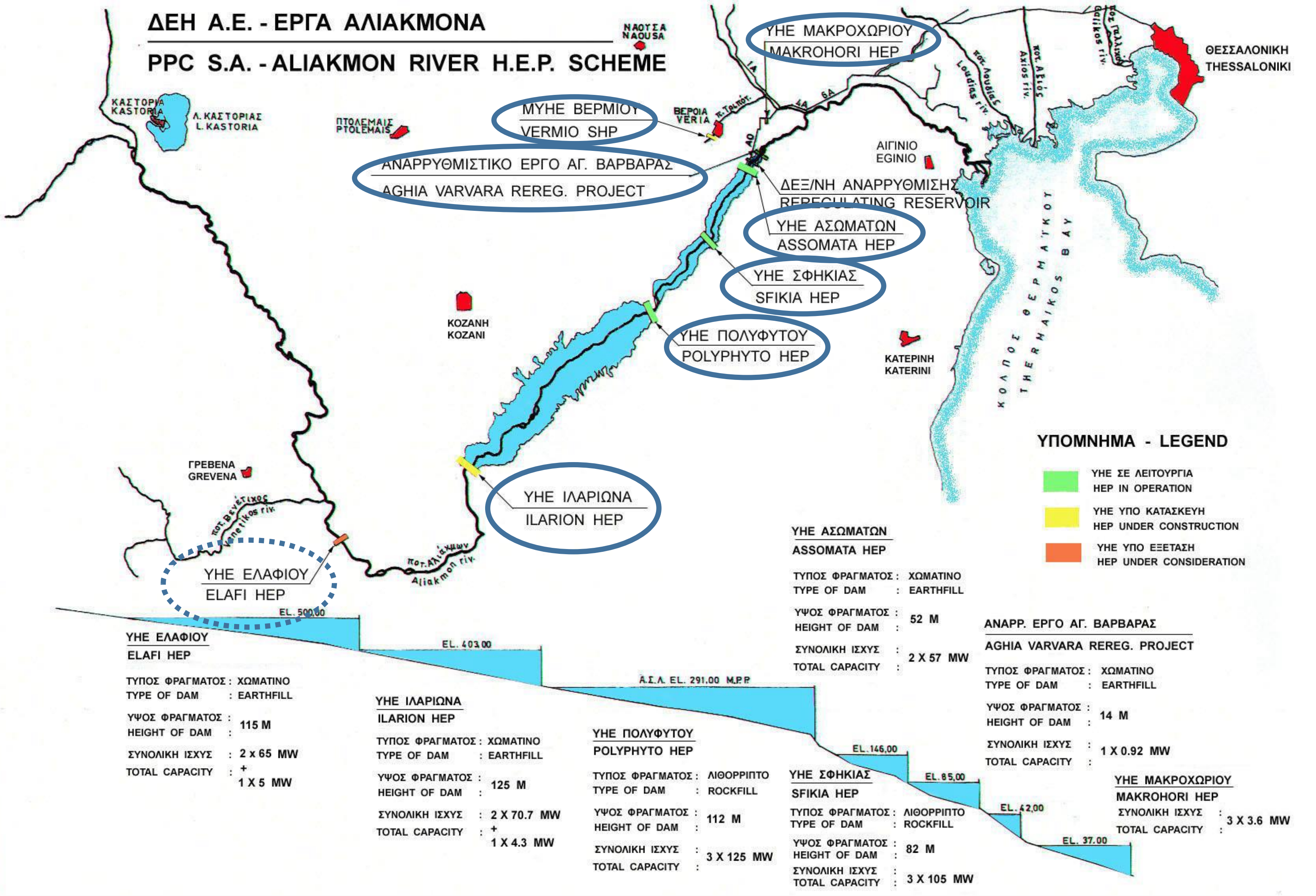
Conclusions:
- ✓ Drought & Irrigation impacting available Flow
- ✓ New smaller turbine required to avail of reduced storage capacity

Data needs:
1. Operation range of the current Francis turbine
2. Irrigation schemes by the River basin Authority

Forecast of **the annual water storage** in the short-medium term (2030), depending on:
- ✓ Different irrigation schemes: 5 months, 4 months (10 days per month), others
- ✓ Different precipitation scenarios

Asomata Reservoir / HPP
Agia Varvara Reservoir / Makrochori SHPP

PPC / PPCR, POLI



ΔΕΗ Α.Ε. - ΕΡΓΑ ΑΛΙΑΚΜΟΝΑ
PPC S.A. - ALIAKMON RIVER H.E.P. SCHEME
ΝΑΟΥΣΑ
NAOUSA
ΥΗΕ ΜΑΚΡΟΧΩΡΙΟΥ
MAKROHORI HEP
ΘΕΣΣΑΛΟΝΙΚΗ
THESSALONIKI
ΚΑΣΤΟΡΙΑ
KASTORIA
Λ. ΚΑΣΤΟΡΙΑΣ
L. KASTORIA
ΠΤΟΛΕΜΑΙΣ
PTOLEMAIS
ΜΥΗΕ ΒΕΡΜΙΟΥ
VERMIO SHP
ΒΕΡΟΙΑ
VERIA
ΑΝΑΡΡΥΘΜΙΣΤΙΚΟ ΕΡΓΟ ΑΓ. ΒΑΡΒΑΡΑΣ
AGHIA VARVARA REREG. PROJECT
ΑΙΓΙΝΙΟ
EGINIO
ΔΕΞ/ΝΗ ΑΝΑΡΡΥΘΜΙΣΗΣ
REREGULATING RESERVOIR
ΥΗΕ ΑΣΩΜΑΤΩΝ
ASSOMATA HEP
ΥΗΕ ΣΦΗΚΙΑΣ
SFIKIA HEP
ΚΟΖΑΝΗ
KOZANI
ΥΗΕ ΠΟΛΥΦΥΤΟΥ
POLYPHYTO HEP
ΚΑΤΕΡΙΝΗ
KATERINI
ΚΟΛΠΟΣ ΘΕΡΜΑΙΚΟΥ
THERMAIKOS BAY
ΥΠΟΜΝΗΜΑ - LEGEND
ΥΗΕ ΣΕ ΛΕΙΤΟΥΡΓΙΑ
HEP IN OPERATION
ΥΗΕ ΥΠΟ ΚΑΤΑΣΚΕΥΗ
HEP UNDER CONSTRUCTION
ΥΗΕ ΥΠΟ ΕΞΕΤΑΣΗ
HEP UNDER CONSIDERATION
ΓΡΕΒΕΝΑ
GREVENA
ΥΗΕ ΙΛΑΡΙΩΝΑ
ILARION HEP
ΥΗΕ ΕΛΑΦΙΟΥ
ELAFI HEP
ποτ. Αλιάκμων
Aliakmon riv.
EL. 500,00
EL. 403.00
Α.Σ.Λ. EL. 291,00 M.P.P
EL. 146,00
EL. 85,00
EL. 42,00
EL. 37.00
ΥΗΕ ΕΛΑΦΙΟΥ
ELAFI HEP
ΤΥΠΟΣ ΦΡΑΓΜΑΤΟΣ : ΧΩΜΑΤΙΝΟ
TYPE OF DAM : EARTHFILL
ΥΨΟΣ ΦΡΑΓΜΑΤΟΣ : 115 M
HEIGHT OF DAM :
ΣΥΝΟΛΙΚΗ ΙΣΧΥΣ : 2 x 65 MW
TOTAL CAPACITY : + 1 X 5 MW
ΥΗΕ ΙΛΑΡΙΩΝΑ
ILARION HEP
ΤΥΠΟΣ ΦΡΑΓΜΑΤΟΣ : ΧΩΜΑΤΙΝΟ
TYPE OF DAM : EARTHFILL
ΥΨΟΣ ΦΡΑΓΜΑΤΟΣ : 125 M
HEIGHT OF DAM :
ΣΥΝΟΛΙΚΗ ΙΣΧΥΣ : 2 X 70.7 MW
TOTAL CAPACITY : + 1 X 4.3 MW
ΥΗΕ ΠΟΛΥΦΥΤΟΥ
POLYPHYTO HEP
ΤΥΠΟΣ ΦΡΑΓΜΑΤΟΣ : ΛΙΘΟΡΡΙΠΤΟ
TYPE OF DAM : ROCKFILL
ΥΨΟΣ ΦΡΑΓΜΑΤΟΣ : 112 M
HEIGHT OF DAM :
ΣΥΝΟΛΙΚΗ ΙΣΧΥΣ : 3 X 125 MW
TOTAL CAPACITY :
ΥΗΕ ΑΣΩΜΑΤΩΝ
ASSOMATA HEP
ΤΥΠΟΣ ΦΡΑΓΜΑΤΟΣ : ΧΩΜΑΤΙΝΟ
TYPE OF DAM : EARTHFILL
ΥΨΟΣ ΦΡΑΓΜΑΤΟΣ : 52 M
HEIGHT OF DAM :
ΣΥΝΟΛΙΚΗ ΙΣΧΥΣ : 2 X 57 MW
TOTAL CAPACITY :
ΥΗΕ ΣΦΗΚΙΑΣ
SFIKIA HEP
ΤΥΠΟΣ ΦΡΑΓΜΑΤΟΣ : ΛΙΘΟΡΡΙΠΤΟ
TYPE OF DAM : ROCKFILL
ΥΨΟΣ ΦΡΑΓΜΑΤΟΣ : 82 M
HEIGHT OF DAM :
ΣΥΝΟΛΙΚΗ ΙΣΧΥΣ : 3 X 105 MW
TOTAL CAPACITY :
ΑΝΑΡΡ. ΕΡΓΟ ΑΓ. ΒΑΡΒΑΡΑΣ
AGHIA VARVARA REREG. PROJECT
ΤΥΠΟΣ ΦΡΑΓΜΑΤΟΣ : ΧΩΜΑΤΙΝΟ
TYPE OF DAM : EARTHFILL
ΥΨΟΣ ΦΡΑΓΜΑΤΟΣ : 14 M
HEIGHT OF DAM :
ΣΥΝΟΛΙΚΗ ΙΣΧΥΣ : 1 X 0.92 MW
TOTAL CAPACITY :
ΥΗΕ ΜΑΚΡΟΧΩΡΙΟΥ
MAKROHORI HEP
ΣΥΝΟΛΙΚΗ ΙΣΧΥΣ : 3 X 3.6 MW
TOTAL CAPACITY :

Asomata reservoir & HPP

Energy for everyone

Aliakmon Hydroelectric Scheme

Assomata HPP

<u>Location</u>: Central Macedonia, Imathia prefecture
<u>Purpose</u>: hydropower, irrigation
<u>Commercial operat.</u>: 1985
<u>Installed power</u>: 108 MW (2x54)
Francis type turbines
<u>Mean an. Product.</u>: 130 GWH
<u>Dam</u>: earthfill, 52 m height
<u>Reserv. net cap.</u>: 10 m.c.m.

Public Power Corporation S.A. 28

Agia Varvara reservoir

Makrochori SHPP

Principle of operation describe Makrochori as a run of the river (RoR) SHPP.

[MAKROHORI SHPP TECHNICAL DESCRIPTION rev.pb.pdf]

Energy for everyone

Aliakmon Hydroelectric Scheme

Makrochori small HPP

Location: Central Macedonia, Imathia prefecture
Purpose: hydropower, irrigation, water supply
Commercial operat.: 1992
Installed power: 10,8 MW (3x3,6)
Caplan tubular S type turb.
Mean an. Product.: 30 GWH

Public Power Corporation S.A. 30

Agia Varvara reservoir / Makrochori SHPP (PPCR)

Data from PPCR - Daily values for the period 2008-2023 for:

Agia Varvara reservoir: level, volume [th.m3], variation of volume, total inflow, overflow, outflow from Asomata, ecological flow, water supply for Thessaloniki, for irrigation, irrigation before and after Makrochori, drainage water into the river, natural inflow;

Makrochori: Energy generation [MWh] per unit and total, Aux cons, Net prod, Max power, Hours of operation and out of availability per unit, No of starts, overflow, used for energy generation, specific consumption, efficiency.

PUBLIC POWER CORPORATION

ΜΗΝΑΣ : January 2008

SHPP MAKROCHORI I — ΜΗΝΙΑΙΟ ΔΕΛΤΙΟ ΣΤΑΘΜΟΥ — peak : 9.2 MW

date	Production (MWh) UNITS I	II	III	Total	Aux. Consumption (MWh) Grid	net production (MWh)	peak (MW)	operation hours Unit I	II	III	hours out of availability Unit I maintenance ΣΤΑΘ	ΕΞΩ	Unit I failure ΣΤΑΘ	ΕΞΩ	Unit II maintenance ΣΤΑΘ	ΕΞΩ	Unit II failure ΣΤΑΘ	ΕΞΩ	Unit III maintenance ΣΤΑΘ	ΕΞΩ	Unit III failure ΣΤΑΘ	ΕΞΩ	Number of starts UnitNo I	II	III	comments
1	6.3	0.0	0.0	6.30	1.30	5.0	1.5	4.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5	0	0	
2	2.8	2.7	8.5	14.00	2.00	12.0	4.9	1.90	1.20	5.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2	2	3	
3	0.0	0.0	9.2	9.20	1.20	8.0	1.5	0.00	0.00	6.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	5	
4	0.0	0.0	10.8	10.80	1.80	9.0	1.5	0.00	0.00	6.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	7	
5	5.3	0.0	3.7	9.00	1.00	8.0	1.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3	0	2	
6	10.8	0.0	0.0	10.80	1.80	9.0	1.5	10.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8	0	0	
7	7.5	0.0	0.0	7.50	1.50	6.0	1.4	4.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4	0	0	
8	10.4	0.0	0.0	10.40	1.60	8.8	2.3	6.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5	0	0	
9	8.5	0.0	0.0	8.50	1.50	7.0	1.5	5.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3	0	0	
10	47.5	40.2	0.0	87.70	1.60	86.1	6.8	16.40	11.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3	1	3	
11	27.0	5.7	16.9	49.60	1.60	48.0	5.5	13.00	2.20	10.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4	1	2	
12	18.1	2.9	3.4	24.40	1.40	23.0	4.7	10.10	1.20	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4	1	1	
13	8.5	0.0	4.7	13.20	1.20	12.0	1.6	5.80	0.00	2.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4	0	1	
14	36.9	28.6	28.6	94.10	2.10	92.0	8.8	15.90	10.60	10.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4	2	2	
15	21.3	21.0	20.3	62.60	1.20	61.4	8.9	8.80	8.70	7.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3	2	3	
16	35.4	35.7	31.9	103.00	2.00	101.0	9.2	14.40	13.40	11.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2	1	1	
17	28.9	22.7	22.4	74.00	1.10	72.9	7.4	14.00	9.50	9.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3	1	1	
18	5.4	12.7	19.1	37.20	1.20	36.0	7.6	3.00	5.50	9.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1	1	2	
19	5.8	0.0	0.0	5.80	1.60	4.2	1.4	3.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4	0	0	
20	2.0	0.0	2.9	4.90	1.20	3.7	2.1	1.40	0.00	1.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2	0	0	
21	0.0	0.0	5.5	5.50	1.50	4.0	1.8	0.00	0.00	3.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	5	
22	0.0	0.0	6.1	6.10	1.30	4.8	2.4	0.00	0.00	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	4	
23	8.5	10.1	14.7	33.30	1.30	32.0	6.8	3.80	4.20	7.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1	1	4	
24	23.0	26.0	33.1	82.10	1.80	80.3	7.4	10.00	10.80	15.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1	1	4	
25	24.6	25.5	35.0	85.10	1.10	84.0	8.0	10.70	10.40	16.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1	1	5	
26	0.0	0.0	5.8	5.80	1.80	4.0	1.5	0.00	0.00	3.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	4	
27	0.0	0.0	6.9	6.90	1.40	5.5	1.5	0.00	0.00	4.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	4	
28	9.7	6.8	13.0	29.50	1.50	28.0	7.1	4.70	2.90	6.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2	1	4	
29	2.7	5.7	12.2	20.60	1.40	19.2	6.7	1.20	2.80	6.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1	1	4	
30	8.3	6.6	15.2	30.10	1.10	29.0	8.1	4.00	2.50	7.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1	1	4	
31	15.9	9.1	18.0	43.00	1.90	41.10	9.0	7.40	3.30	8.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2	1	4	
ΣΥΝΟΛΑ	381	262	348	991	46	945	9.2	182.5	101.0	167.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	73	19	79	

PUBLIC POWER CORPORATION — Monthly Report of Hydrological Data — MONTH January 2008

VAgia-in=DVAgia+VM-spil+VAgia-spil+VM-en+VAgia-ec+VAgia-ir+VM-ir-before

VAgia-in-nat=VAgia-in-VAsom+Vlosses

SHPP MAKROCHORI I

date	Regulating lake of Agia Varvara: level 24:00 (m)	content (m3x10³)	level 8.00 (m)	content (m3x10³)	water saved in lake (DVAgia)	Catchment water inflow m3x10³ (VAgia-in)	Overflow: Flap Gate (Makrochori I) m3x10³ (VM-spil)	Overflow from lake's gates m3x10³ (VAgia-spil)	Used at M for en generation m3x10³ (VM-en)	specific consumption q=ε/energy generation (q)	efficiency nt=36697/ (Eff-tb)	water outflow from Asomata m3x10³ (VAsom)	ecological water (VAgia-ec)	water for Thessaloniki (VThe)	Irrigation Water: right bank irrigation m³x10³ (VAgia-ir)	before SHPP Mak irrigation m3x10³ (VM-ir-before)	after SHPP Mak irrigation m3x10³ (VM-ir-after)	drainage water to the river m3x10³ (VM-II-in-drainage)	Lake natural Inflow m3x10³ (VAgia-in-nat)	Losses m3x10³	comments
	40.65	703	40.50	648	α=δ(στ)	β=α+γ+δ+ε+ζ+η β=α+γ+δ+ε+AO+ζ+η	γ	δ	ε	m3x10³/MWh	/(q*H)	στ	m3x10³	m³x10³	ζ	η	θ	ι=ε-θ ι=ε+AI-AP-θ	κ=β-στ κ=β-στ+Losses		
1	40.35	592	40.60	685	-111	89	0	0	200	31.75	77.06	0	0	200	0	0	0	0	89	0	
2	41.20	907	40.10	500	315	803	0	0	400	28.57	85.63	785	88	260	0	0	0	140	19	1	
3	42.00	1,203	40.80	758	296	685	0	0	270	29.35	83.36	685	119	260	0	0	0	10	1	1	
4	41.05	851	41.60	1,055	-352	-1	0	0	340	31.48	77.71	0	11	260	0	0	0	80	1	1	
5	41.90	1,166	40.80	758	315	686	0	0	300	33.33	73.39	686	71	260	0	0	0	40	1	1	
6	40.80	758	41.70	1,092	-407	-1	0	0	380	35.19	69.53	0	26	300	0	0	0	80	0	1	
7	41.00	833	40.80	758	74	391	0	0	250	33.33	73.39	392	67	250	0	0	0	0	0	1	
8	42.00	1,203	41.60	1,055	370	1,420	330	0	330	31.73	77.10	1,421	390	260	0	0	0	400	0	1	
9	42.00	1,203	41.70	1,092	0	590	0	0	300	35.29	69.32	590	290	250	0	0	0	50	1	1	
10	42.00	1,203	42.00	1,203	0	3,625	0	650	2,585	29.48	83.00	3,626	390	260	0	0	0	2,325	0	1	
11	41.60	1,055	42.00	1,203	-148	3,283	0	0	3,240	65.32	37.45	3,283	191	260	0	0	0	2,980	1	1	
12	42.00	1,203	41.30	944	148	980	0	0	790	32.38	75.56	980	42	260	0	0	0	530	1	1	
13	40.90	796	41.90	1,166	-407	-1	0	0	400	30.30	80.73	0	6	200	0	0	0	200	0	1	
14	41.40	981	40.80	758	185	2,841	0	0	2,590	27.52	88.89	2,842	66	260	0	0	0	2,330	0	1	
15	41.80	1,129	41.20	907	148	1,960	0	0	1,790	28.59	85.56	1,960	22	250	0	0	0	1,540	1	1	
16	41.40	981	41.50	1,018	-148	3,282	0	400	2,850	27.67	88.42	3,283	180	260	0	0	0	2,590	0	1	
17	41.50	1,018	41.10	870	37	2,302	0	0	2,050	27.70	88.31	2,303	215	250	0	0	0	1,800	0	1	
18	41.50	1,018	41.20	907	0	1,028	0	0	1,020	27.42	89.22	1,029	8	300	0	0	0	720	0	1	
19	41.95	1,184	41.40	981	167	357	0	0	190	32.76	74.68	343	0	190	0	0	0	0	15	1	
20	41.60	1,055	41.80	1,129	-130	21	0	0	150	30.61	79.92	0	0	150	0	0	0	0	22	1	
21	42.00	1,203	41.30	944	148	1,028	0	200	170	30.91	79.15	1,029	510	170	0	0	0	0	0	1	
22	41.60	1,055	42.00	1,203	-148	42	0	0	190	31.15	78.54	0	0	190	0	0	0	0	43	1	
23	41.30	944	41.45	999	-111	739	0	0	850	25.53	95.84	686	0	300	0	0	0	550	54	1	
24	41.90	1,166	40.90	796	222	3,970	0	898	2,250	27.41	89.27	3,969	600	300	0	0	0	1,950	2	1	
25	40.80	758	41.70	1,092	-407	1,823	0	0	2,230	26.20	93.36	1,715	0	300	0	0	0	1,930	109	1	
26	40.25	555	40.70	722	-203	0	0	0	200	34.48	70.95	0	3	200	0	0	0	0	1	1	
27	40.00	463	40.20	537	-93	138	0	0	230	33.33	73.39	0	0	230	0	0	0	0	139	1	
28	41.30	944	39.90	426	481	1,371	0	0	840	28.47	85.92	1,372	50	300	0	0	0	540	0	1	
29	41.80	1,129	41.00	833	185	1,322	250	0	600	29.13	84.00	1,323	287	250	0	0	0	600	0	1	
30	41.45	999	41.80	1,129	-130	735	0	0	860	28.57	85.63	735	4	300	0	0	0	560	1	1	
31	41.50	1,018	41.20	907	19	1,372	0	0	1,220	28.37	86.23	1,372	133	300	0	0	0	920	1	1	
ΣΥΝΟΛΑ	41.41	986	41.23	917	315	36,877	580	2,148	30,065	30.34	80.64	36,409	3,769	7,780	0	0	0	22,865	498	30	

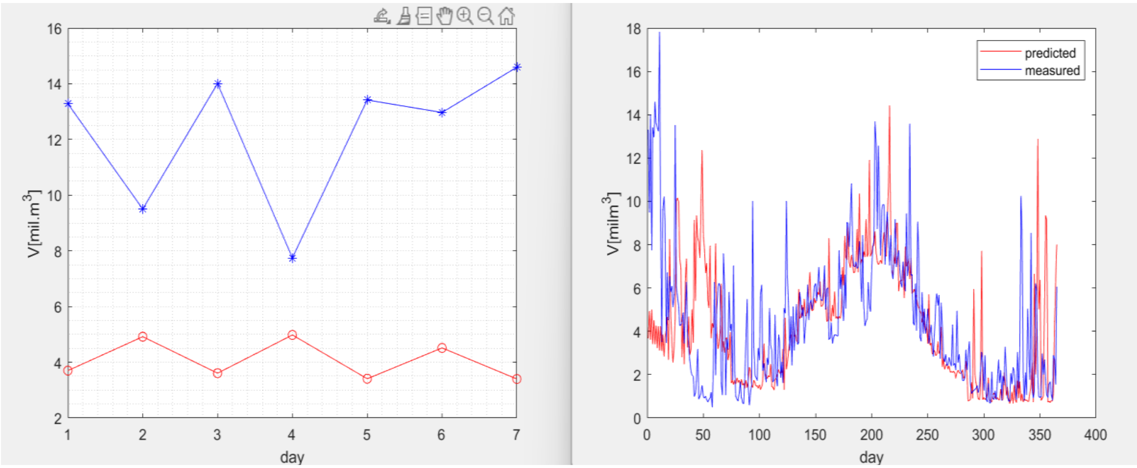
Agia Varvara reservoir / Makrochori SHPP (PPCR)

Ensemble Approach

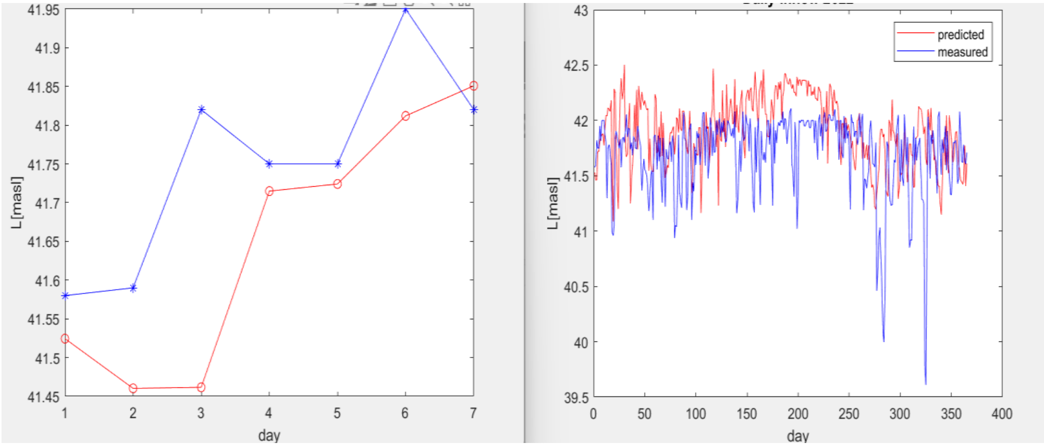
Investigating various statistical, AI and physical modelling methods:

- Time series forecasting: Autoregression & Moving
- Data: daily recorded values from 2010 to 2021 for reservoir **inflows, levels** and **energy generation**
- Forecast: for next 7 days and 365 days.

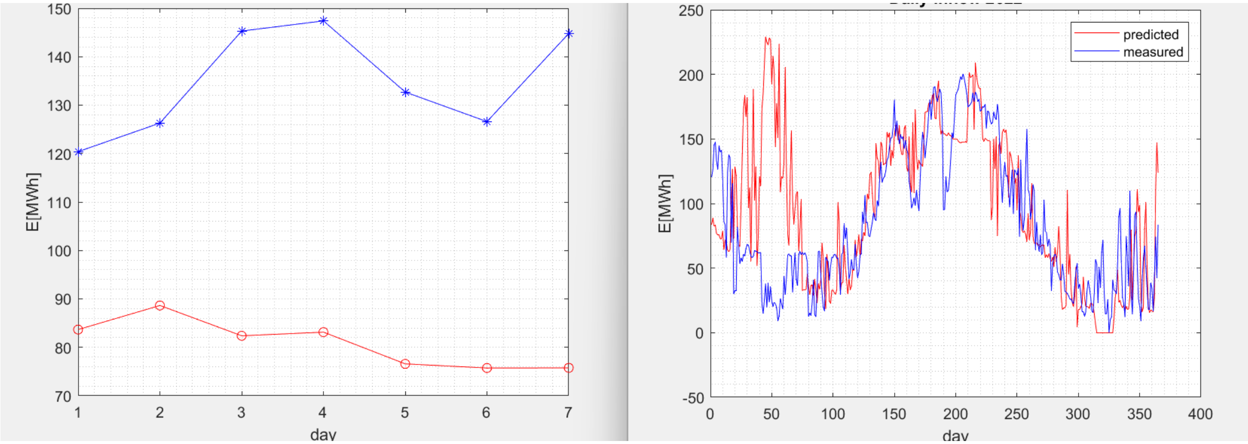
INFLOW, RMSE=21.53



LEVEL, RMSE=0.269



ENERGY, RMSE=142.71



Agia Varvara reservoir / Makrochori SHPP (PPCR)

Recurrent neural network LEVEL, L [masl]

Levenberg-Marquardt algorithm,

RMSE=0.3644 (KPI: RMSE–>0)

Scaled Conjugate Gradient,

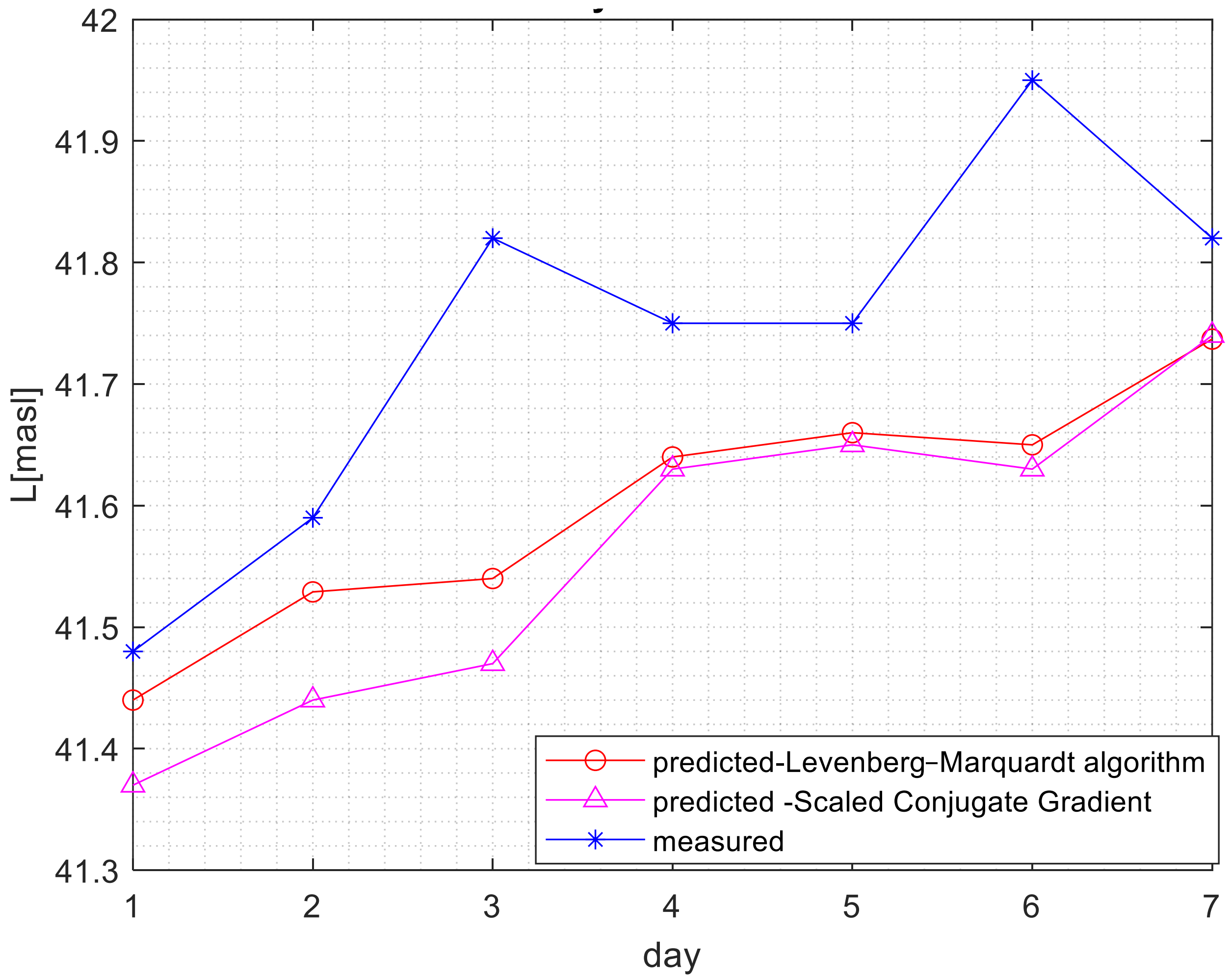
RMSE=0.4649 (KPI: RMSE–>0)

Input: daily values *x*(1:end–2)

Output: daily values *x*(3:end)

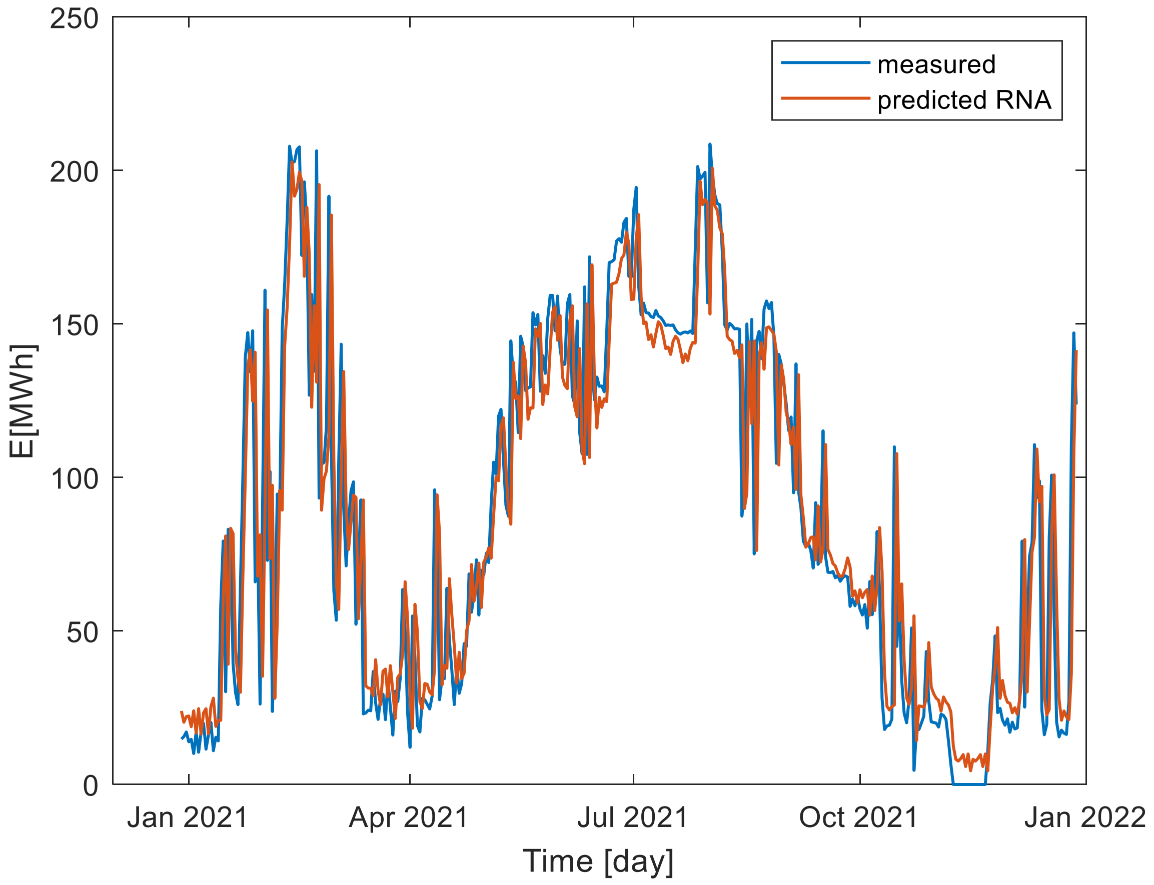
Hidden layer: 10 neurons

where: *x* = variable (inflow, level, energy)

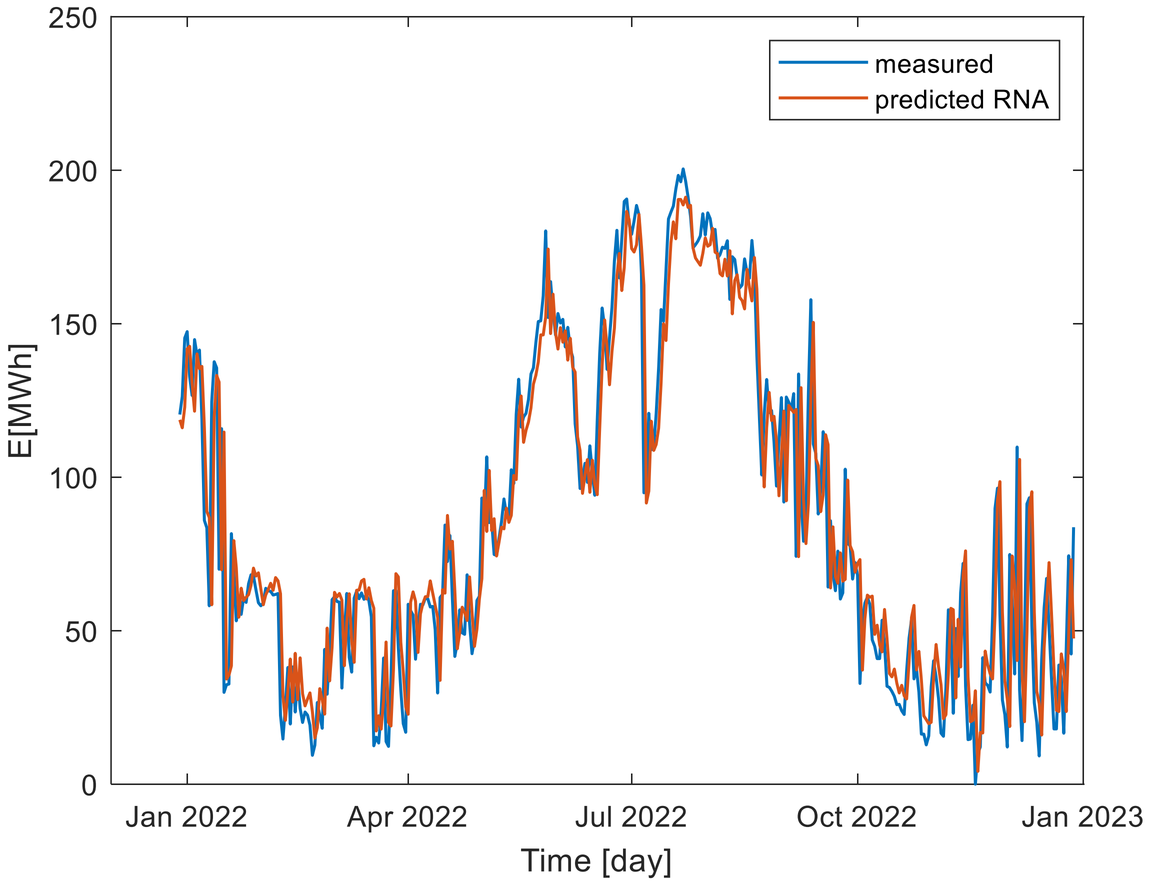


Agia Varvara reservoir / Makrochori SHPP (PPCR)

ENERGY, **2021**, RMSE=25 (for 365 days forecasting)

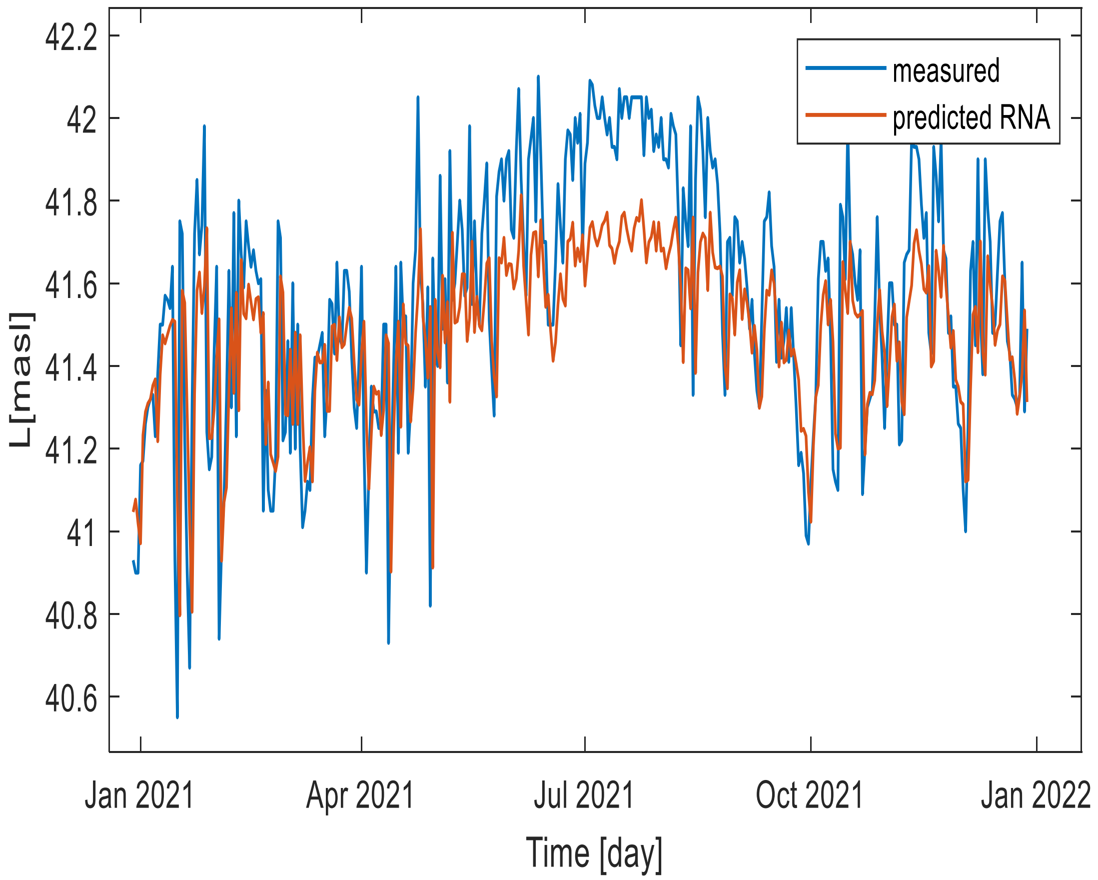


ENERGY, **2022**, RMSE=18.77 (for 365 days forecasting)

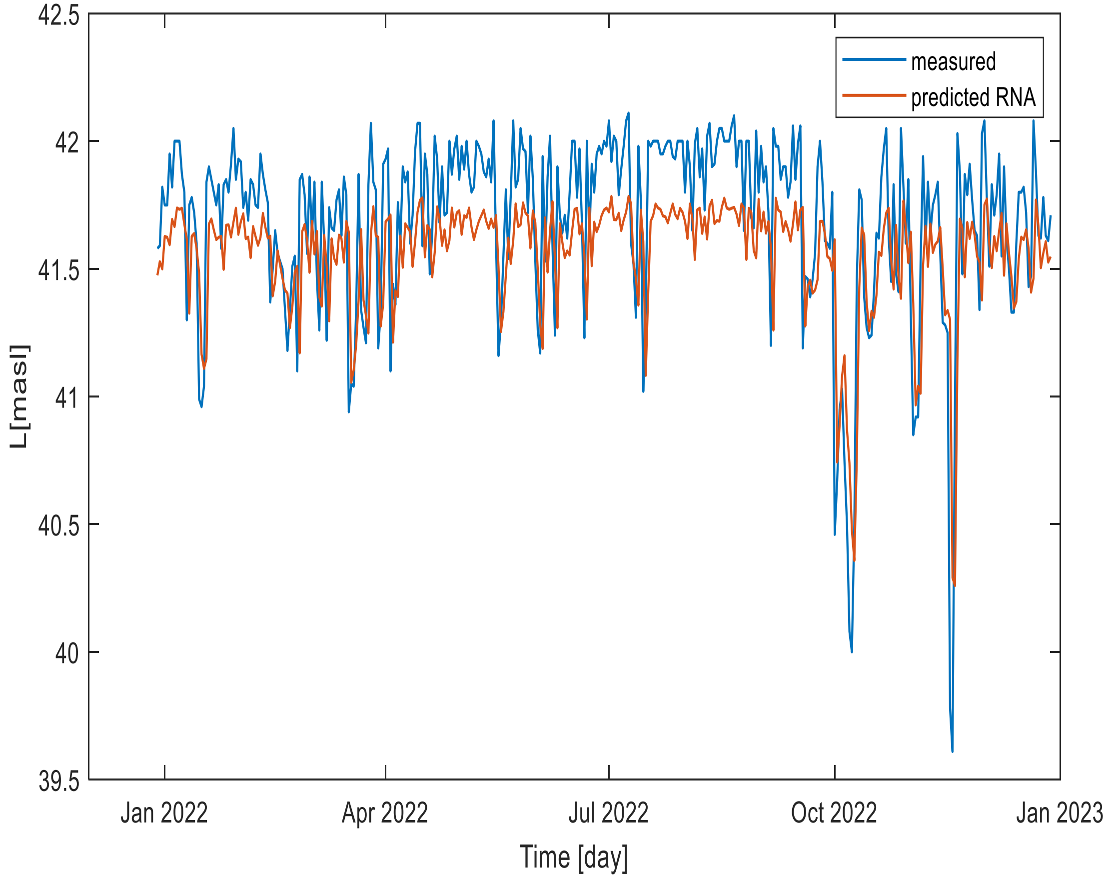


Agia Varvara reservoir / Makrochori SHPP (PPCR)

LEVEL, **2021**, RMSE=0.1192 (for 365 days forecasting)

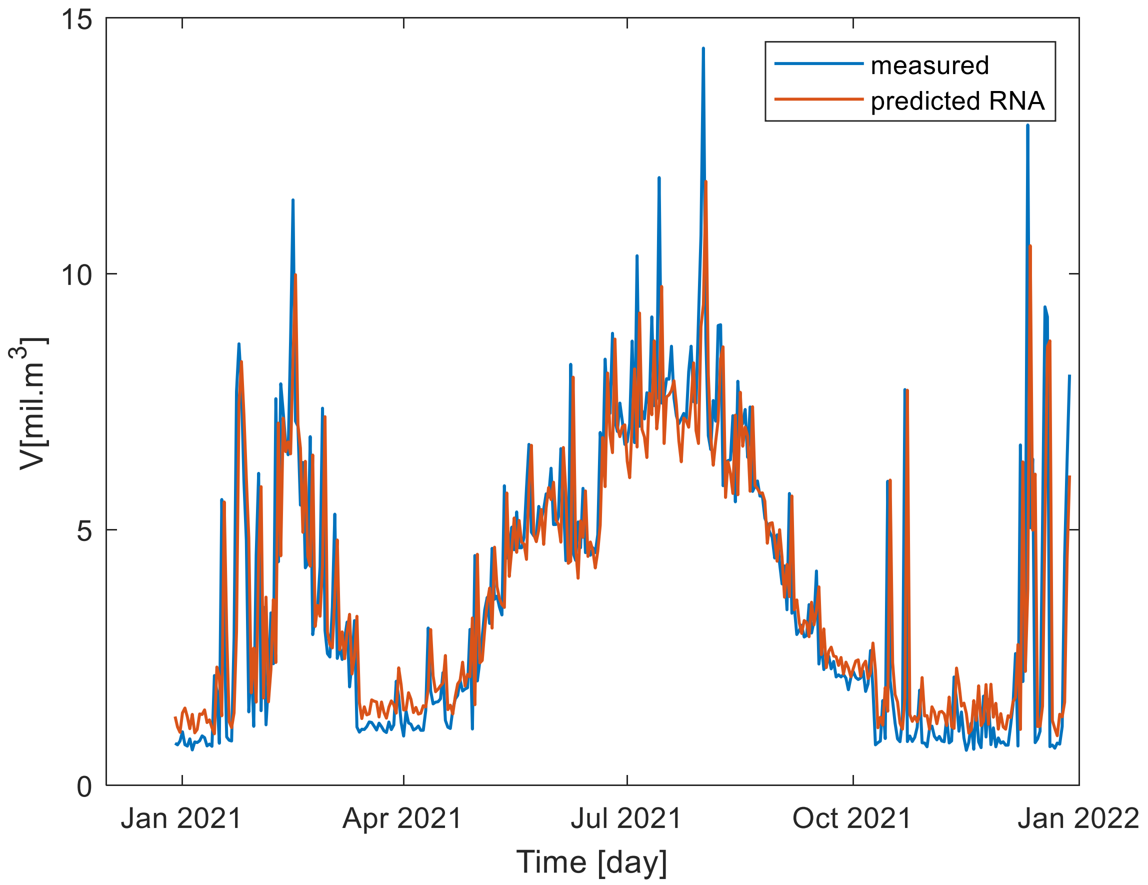


LEVEL, **2022**, RMSE=0.3020 (for 365 days forecasting)

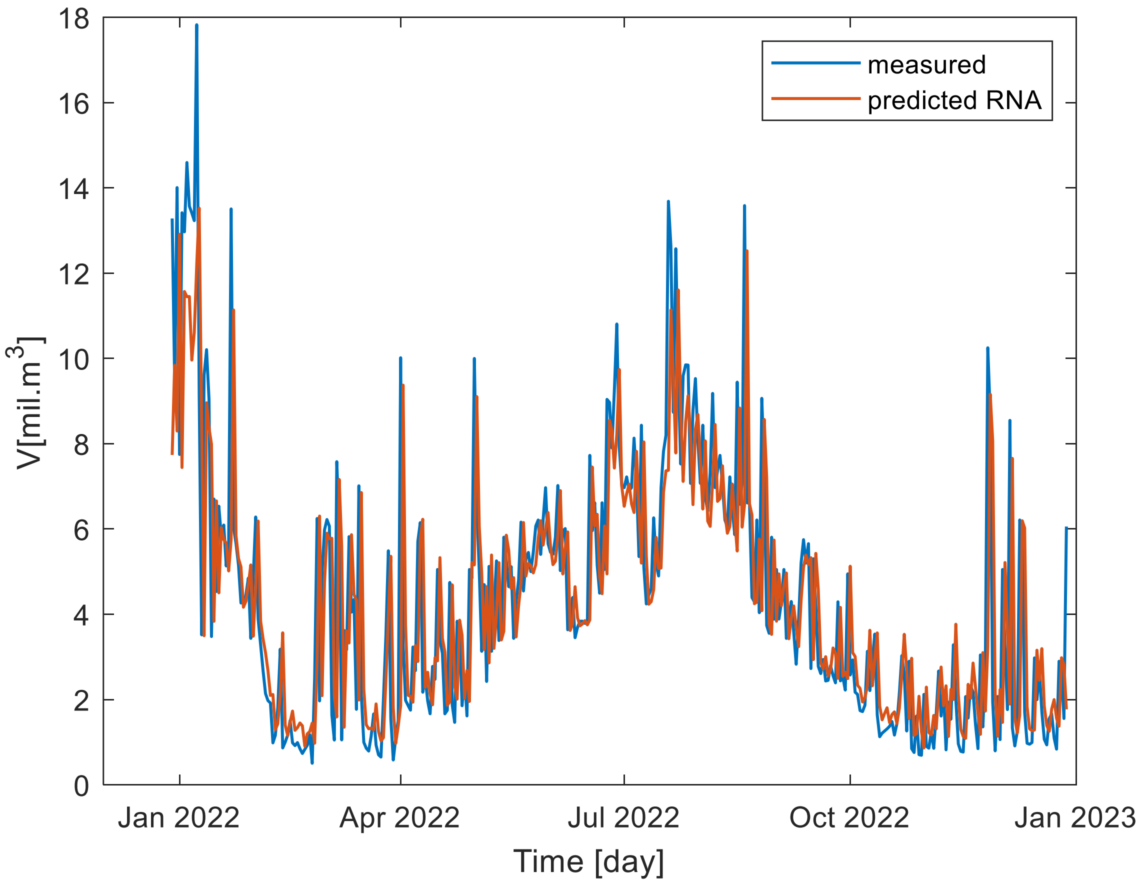


Agia Varvara reservoir / Makrochori SHPP (PPCR)

INFLOW, **2021**, RMSE=1.63 (for 365 days forecasting)



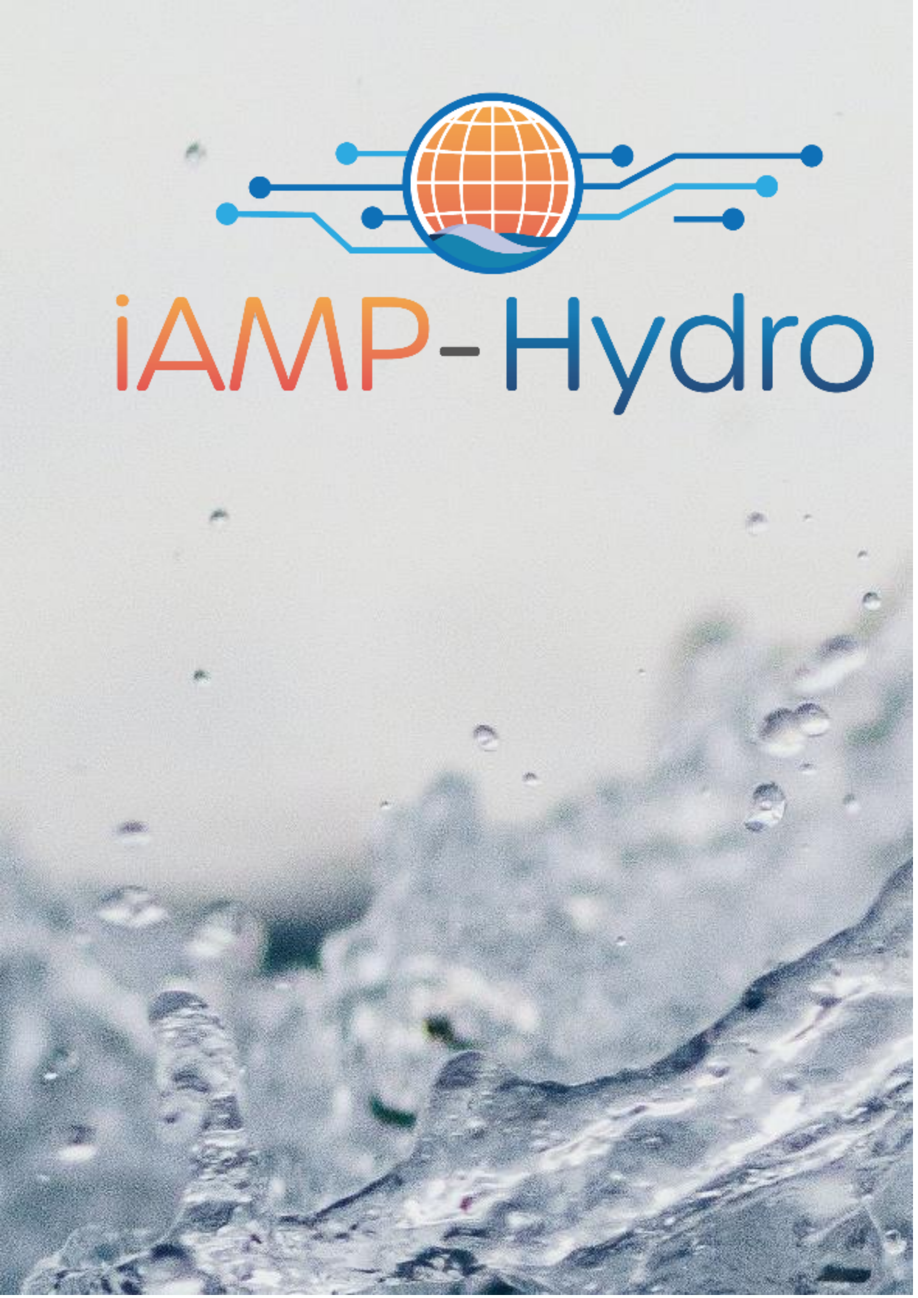
INFLOW, **2022**, RMSE=2.11 (for 365 days forecasting)



Conclusions

Work in progress

- iAMP-Hydro commenced in October 2023 – preliminary results of flow forecasting promising but much work to be done over the coming >2 years.
- Challenge of irrigation and drought in Southern Europe a recurring theme across our five pilot plants – solutions needed to adapt to these conditions.
- Other elements of digitalisation work ongoing (condition monitoring, biodiversity monitoring, secure data management, decision support, etc)
- Co-development workshops: keen to engage with stakeholders to co-develop solutions and showcase demo site. Next event on Artificial Intelligence in hydropower digitalisation in Dec 4th (Online Event)
- More details at www.iamp-hydro.eu



Thank you!

Contact

Prof. Aonghus McNabola

Professor in Energy and Environment,

Dept. of Civil, Structural and Environmental Engineering,

Trinity College Dublin,

Dublin, Ireland.

D02 PN40

amcnabol@tcd.ie

Partners

Trinity College The University of Dublin

Cuerva Energía Transparente

Suite5 We Deliver Intelligence

EasyHydro

Politehnica University of Bucharest

ΔEH

PPC Renewables Innovation • Development • Environment

NORCE

Centro Tecnológico CARTIF

WIP Renewable Energies

This project has received funding from the European Union’s Horizon Europe research and innovation programme under grant agreement No. 101122167.