Hybridization modelling (power-to-hydrogen)

Session 17: Digital solutions for operation and maintenance of existing hydropower

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[TECHNOLOGY CENTRE] CARTIF

148

Ongoing projects

International projects

55 %

Projects with companies

38 %

National and Regional projects

7 %

247

Projects in main international programmes

Framework Programmes

161 Projects (**31** coord.)
63,2M€

INTERREG

20 Projects (**5** coord.)
3.3M€

LIFE

34 Projects (**16** coord.)
7.4M€

Iberoamericans

32 Projects (**8** coord.)
1,6M€

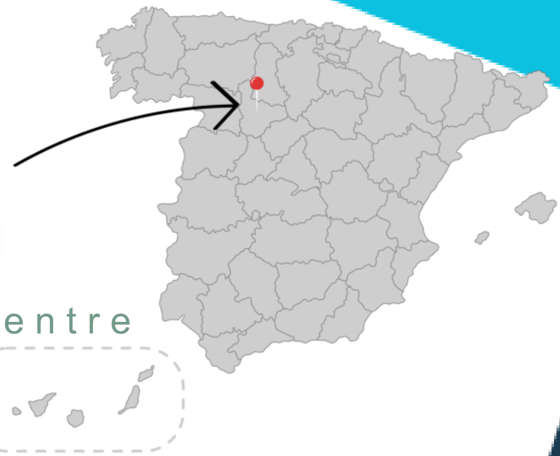
228

Customers

209

Staff

37 PhD´s



CARTIF Technology Centre

47151 Valladolid, España

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Energy Efficiency

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Energy Systems

Smart Grids

Energy and Climate Policies

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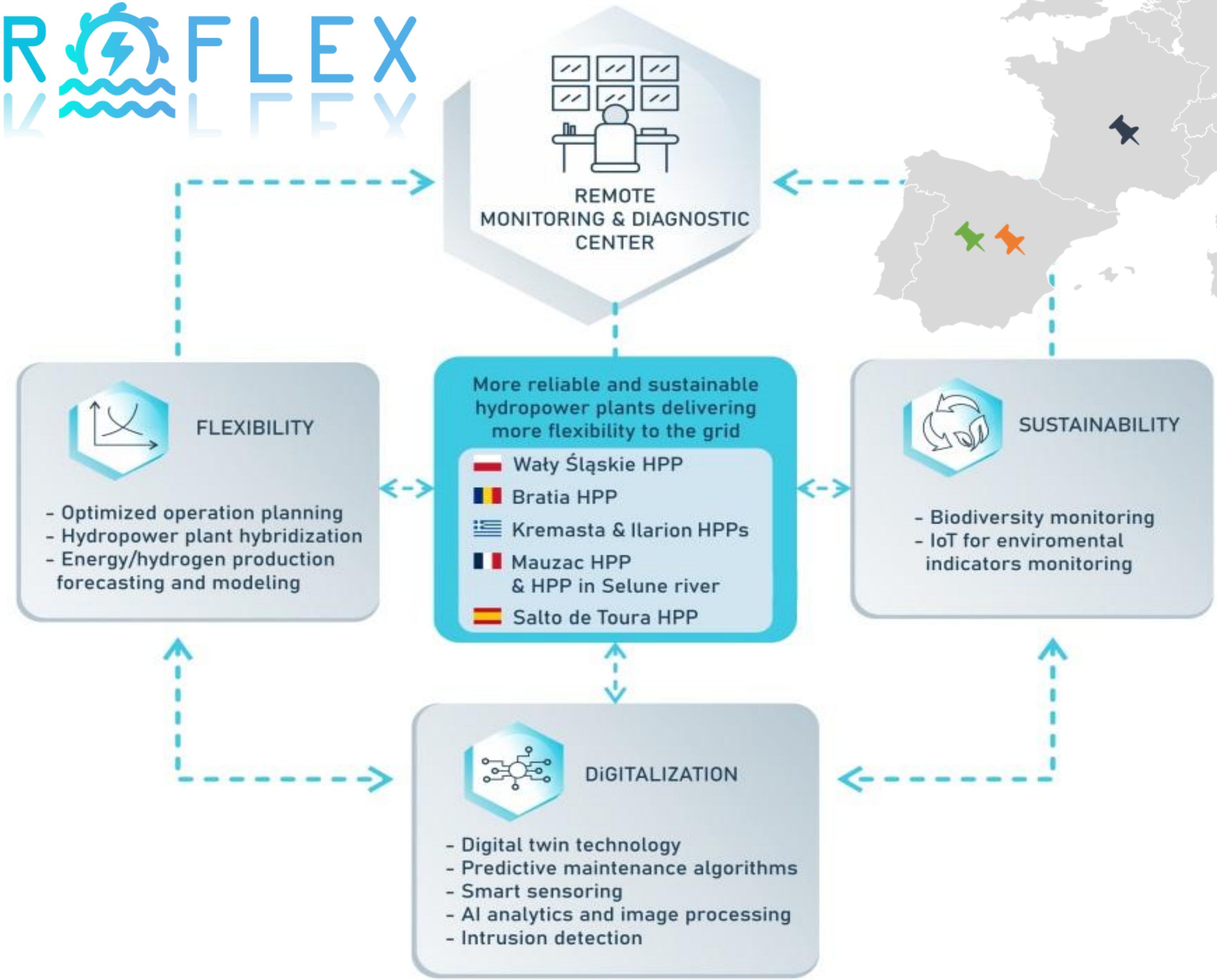
D-HYDROFLEX


REMOTE
MONITORING & DIAGNOSTIC
CENTER
More reliable and sustainable hydropower plants delivering more flexibility to the grid
Wały Śląskie HPP
Bratia HPP
Kremasta & Ilarion HPPs
Mauzac HPP
& HPP in Selune river
Salto de Toura HPP
FLEXIBILITY
- Optimized operation planning
- Hydropower plant hybridization
- Energy/hydrogen production forecasting and modeling
SUSTAINABILITY
- Biodiversity monitoring
- IoT for enviromental indicators monitoring
DIGITALIZATION
- Digital twin technology
- Predictive maintenance algorithms
- Smart sensoring
- AI analytics and image processing
- Intrusion detection

Why Hybridisation?

Green Hydrogen

- **Key vector for decarbonizing** sectors that are difficult to electrify (transport, industry).
- Functions as long-term **storage and a bridge** between renewable production and energy demand.

Global Advances

- Projects around the world demonstrate **the viability** and economic competitiveness of hybrid systems.
- In Europe, the **D-Hydroflex** project modernizes hydroelectric plants by integrating hybrid hydrogen systems.

Current Energy Context

- **Manage** the increasing integration of renewables and the variability of electrical demand.
- Grid flexibility is crucial to **stabilize systems** with intermittent sources.

Relevance of Hydroelectric Plants

- **Strategic nodes in hybrid systems**, combining generation and hydrogen storage.
- They leverage water resources and renewable surpluses to **maximize grid flexibility and stability**.

Hybridisation
Two Scenarios

- **Objective:** Evaluate the profitability of integrating hydrogen production and storage systems in hydroelectric plants.
- **Common Systems:** Photovoltaic plant and hydrogen system (electrolyzer and storage).
- **Key Differences:** Technology and scale of the selected hydroelectric plants.

Small hydroelectric power plant *(SCENARIO 1)*

- Power: **35 kW.**
- Located at a Drinking **Water Treatment Plant** (DWTP).
- Implements a **Pump as Turbine (PaT)** to recover energy from a pressure reducing valve.
- Constant and **continuous water flow**, generating stable energy.
- **Optimizes resource** use in the industrial sector.

Seasonal hydroelectric power plant *(SCENARIO 2)*

- **2.1 MW** dam-peak hydroelectric plant.
- Average annual production of **2 GWh**.
- Reservoir of **102.6 hm^3** in a dry tropical climate.
- **Operates seasonally with a Francis turbine (flows from 0.8 to 4.8 m^3/s).**
- Hybridization allows storing and producing energy during **periods of low water demand or grid injection restrictions.**

Parameters and components

PaT Turbine *(Scenario 1)*

Based on operational data, fitted with a 2nd-degree polynomial
Minimum Operating Flow: **0.119 m³/s**

Photovoltaic Solar System

Capacity: **500 kW**
Approximately 4,500 m² of panels to complement hydroelectric generation.

Francis Turbine *(Scenario 2)*

Obtained through 10th-degree polynomial ridge regression
Operating Flow: **0.8 and 4.8 m³/s**

Hydrogen Storage System

3 stage H_2 compressor post-electrolyzer
5 m³ tank with a maximum pressure of **200 bar**

High-Pressure Alkaline Electrolyzer

Nominal Power: **500 kW**
Hydrogen Production: **243.75 kg/h**
Configuration: 20 electrolyzer of 25 kW each

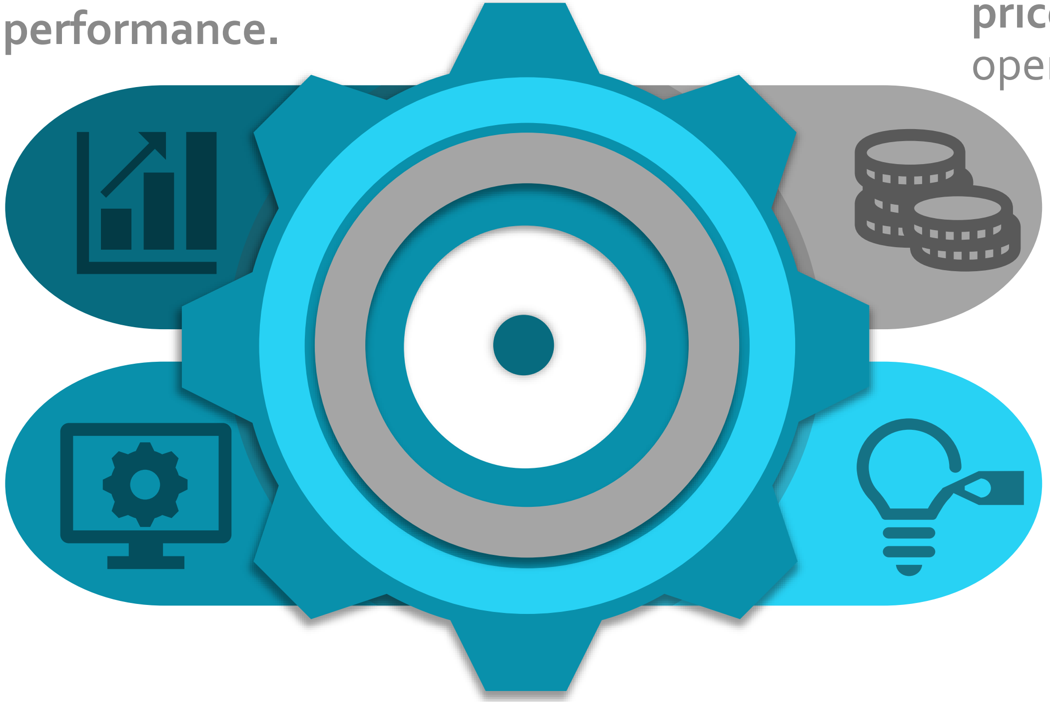
PEM Fuel Cell

Electrical Power: **250 kW**
Proton Exchange Membrane
Configuration: 125 units of 2 kW each

Operational conditions

General Objective:

Operate components to maximize sales and ensure optimal system performance.



Control Rules:

➢ **Price Thresholds:**

Stop Price: €60/MWh. Injection stops, and hydrogen is produced.

Activation Price: €130/MWh. The PEM fuel cell is activated to sell electricity.

➢ **Compliance with Grid Restrictions:** Ensure that energy is not injected when there are operator prohibitions.

Electricity Market:

➢ **Use of Spain's SPOT prices** to simulate real conditions.

➢ **Hourly wholesale market prices** determine control and operation strategies.

Grid Restrictions:

➢ **Operator signals** allow or prohibit the injection of energy into the grid.

➢ **Prohibitions** due to excess renewable energy, low demand, maintenance, etc.

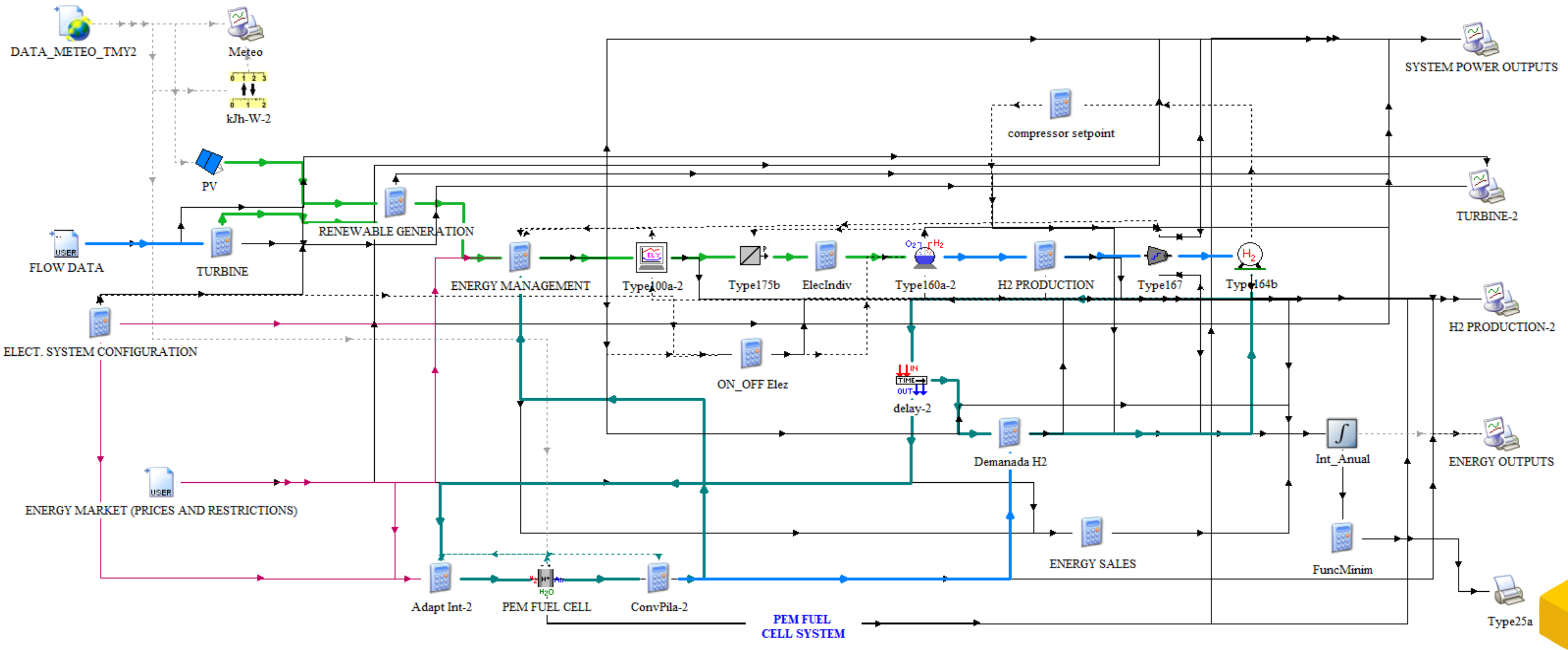
➢ **During prohibitions**, the system produces and stores hydrogen for future use.

Model

TRNSYS has been used to model the complete system, implementing the control strategies.

Three main systems: **solar generation, hydraulic generation** with the two turbines**, and the hydrogen system.**

Parametric variation of critical design variables: **hydrogen storage capacity, photovoltaic production capacity, the configuration of strings and arrays of the solar field, or the number of electrolyzers**



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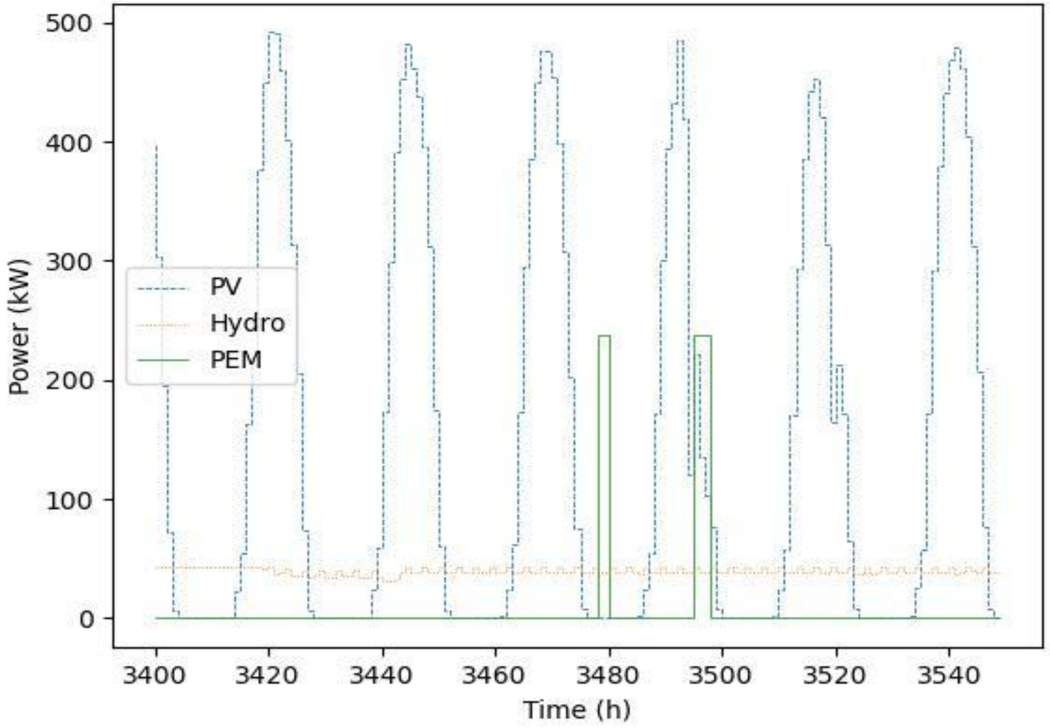
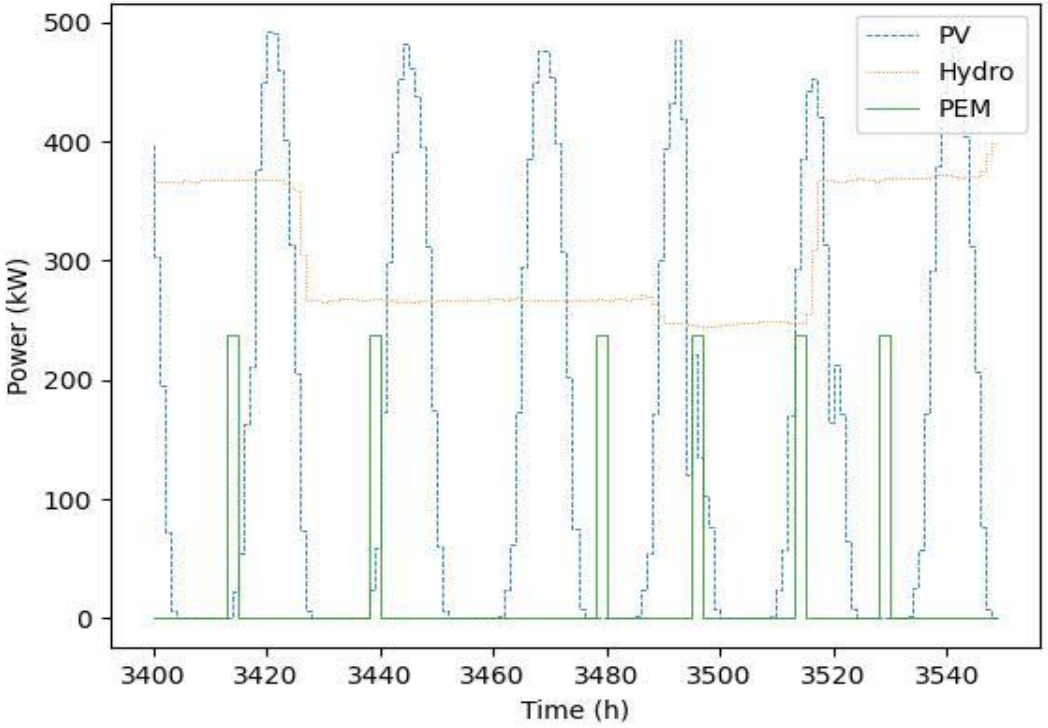
Results





Power production *(SCENARIO 1)*

- It allows understanding the operational dynamics of the micro-hydroelectric system.
- It shows the variability and interaction with hydrogen storage.

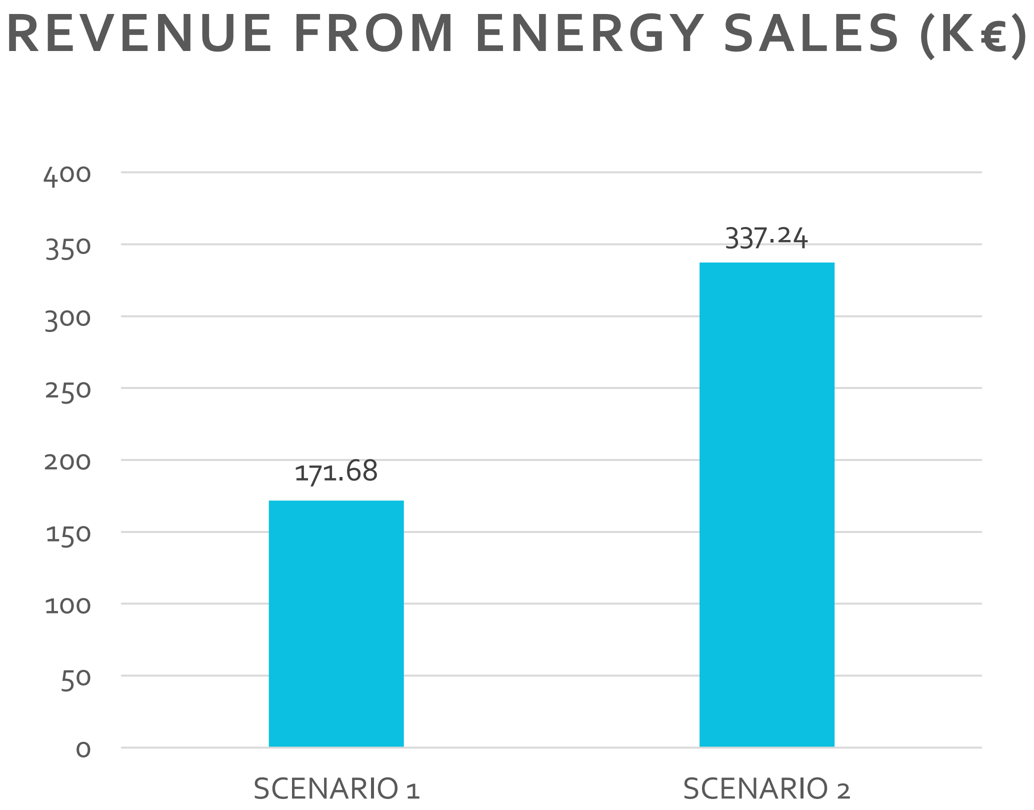
Power production *(SCENARIO 2)*

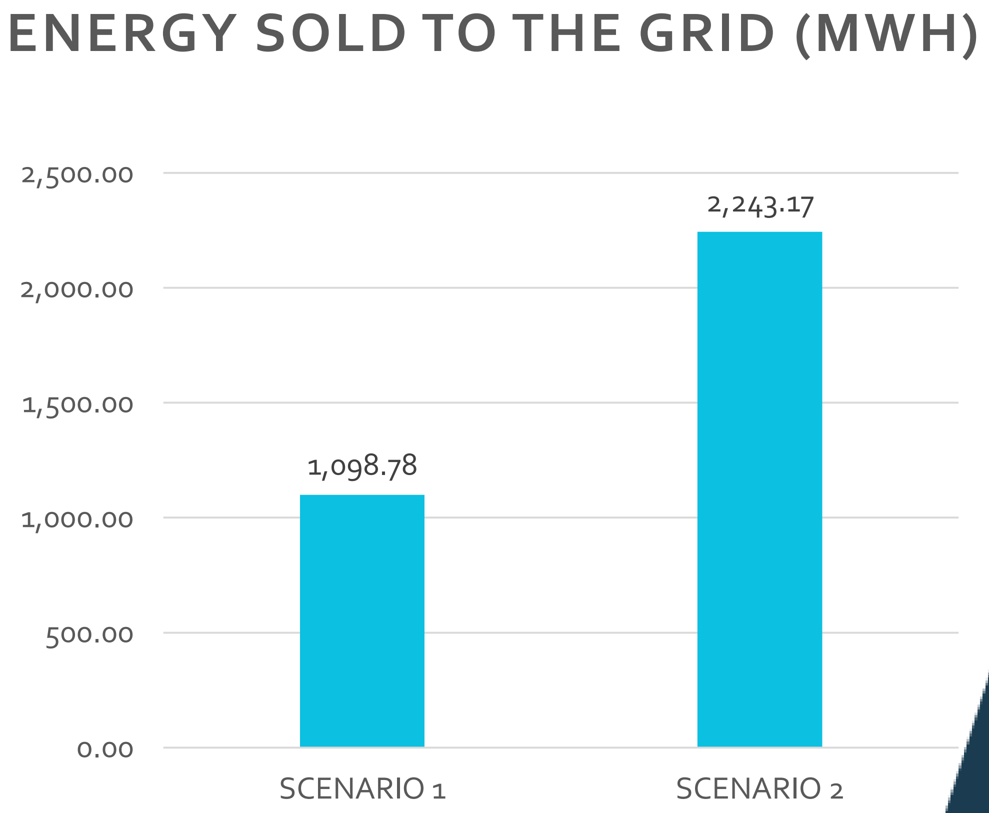
- It demonstrates greater stability in hydraulic generation.
- It reflects the influence of the larger capacity and size of the plant compared to Scenario 1.

Evaluation of Scenarios

Evaluated KPIs:

- **Energy Sold to the Grid:** Total energy that each hybrid system exports to the electrical system, including hydroelectric generation, photovoltaic generation, and production from the PEM fuel cell.
- **Revenue from Energy Sales**: Economic benefits obtained from the sale of energy, calculated according to the SPOT prices of the electricity market.





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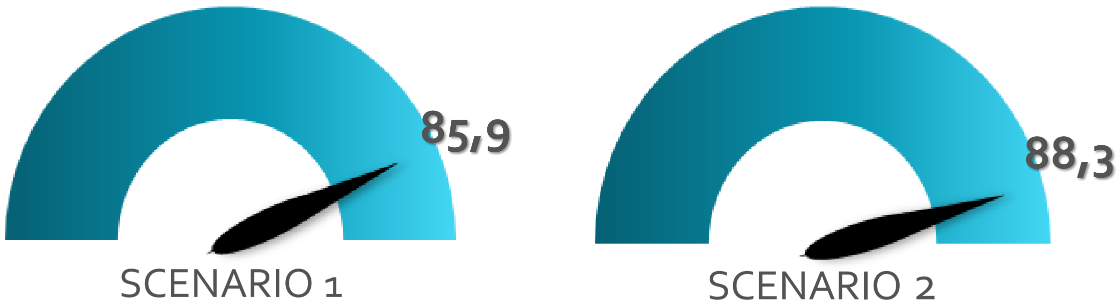
Evaluation of Scenarios

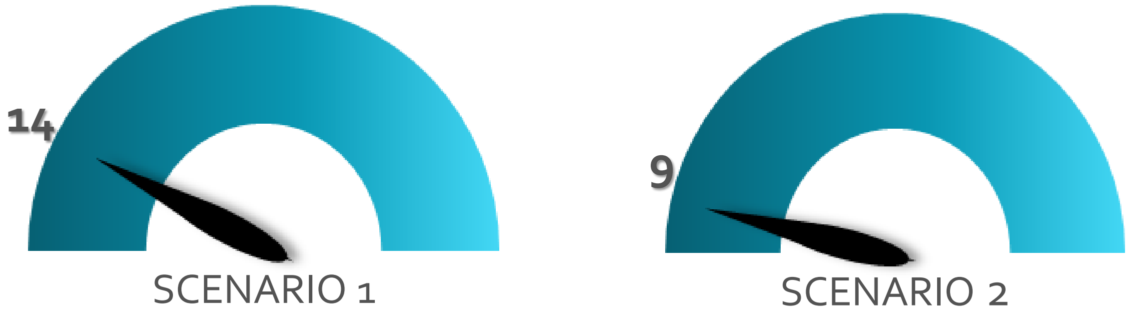
Evaluated KPIs:

- **Energy Sold vs. Potentially Generable Energy:** Percentage of energy actually sold compared to the theoretical maximum generation capacity, indicating operational efficiency.
- **Distribution of Generated Energy:** Proportion of energy allocated to sales, self-consumption, or storage as hydrogen, reflecting operational decisions to optimize resources.

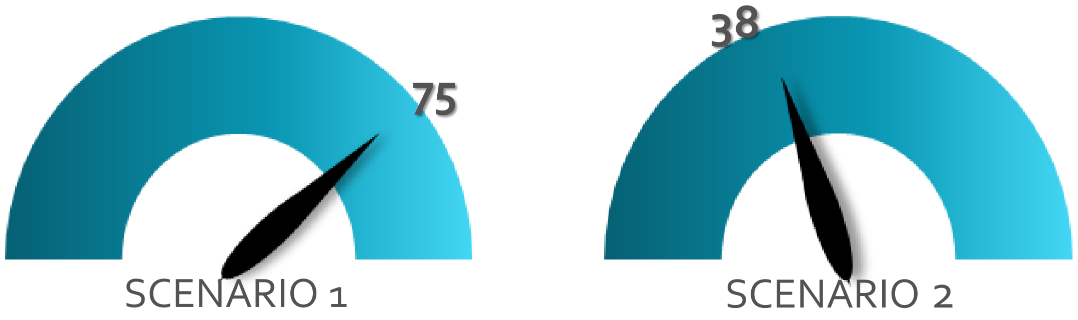
ENERGY SOLD VS POTENTIALLY GENERABLE ENERGY (%)



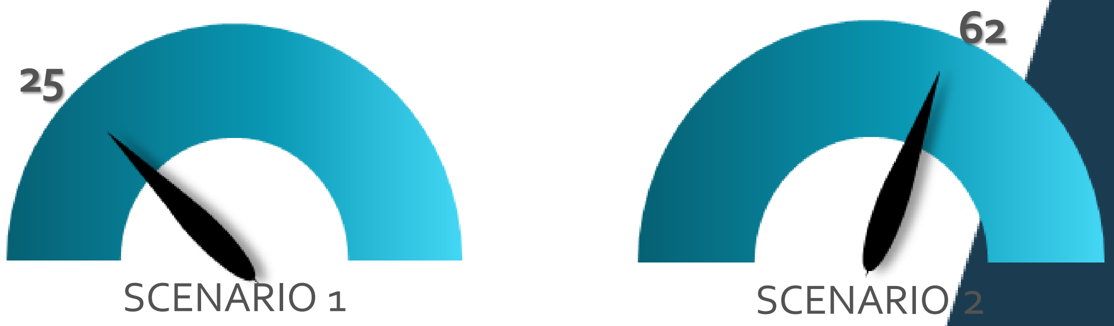
ENERGY CONSUMED BY ELECTROLYZER / RENEWABLE ENERGY PRODUCTION (%)



PV/TOTAL RENEWABLE (%)



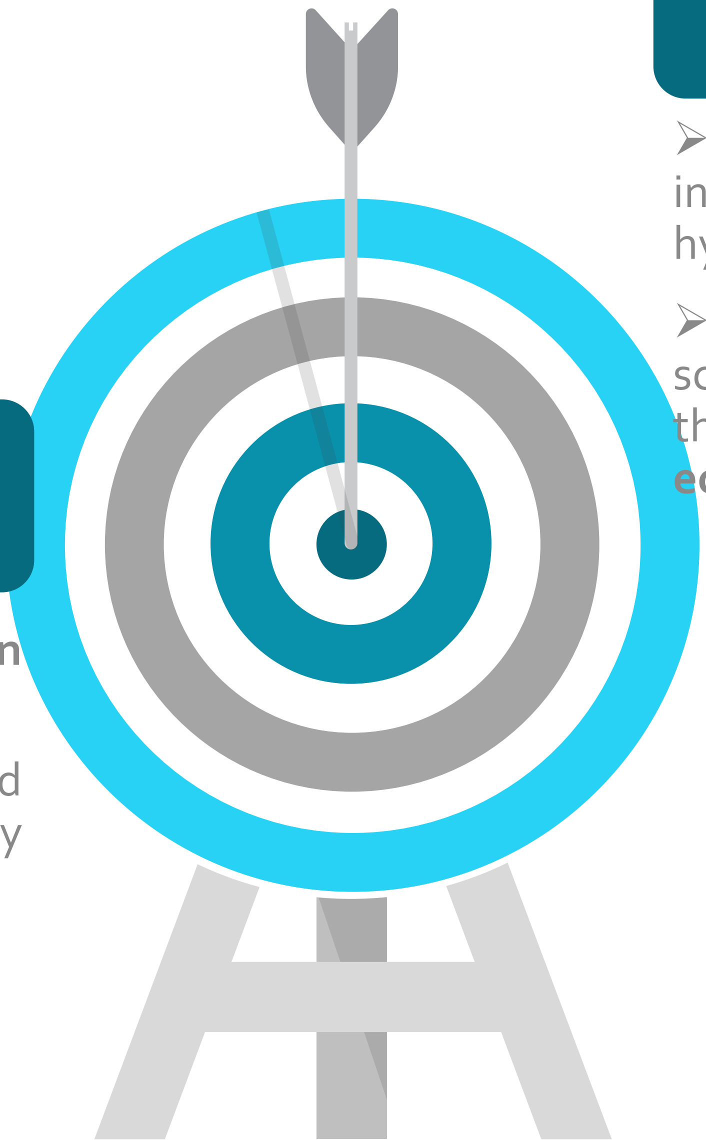
HYDRO/TOTAL RENEWABLE (%)



Conclusions

Energy Efficiency and Optimization:

- Both scenarios show **high efficiency in the utilization of the generated energy**.
- Reflects effective management and distribution of the available energy resources



Impact of the Scale of the Hydroelectric Plant:

- **The capacity of the plant** significantly influences the economic results of hybridization with hydrogen systems.
- **Scenario 2** demonstrates that larger-scale plants increase the energy sold and the revenues, making **better use of economic benefits**

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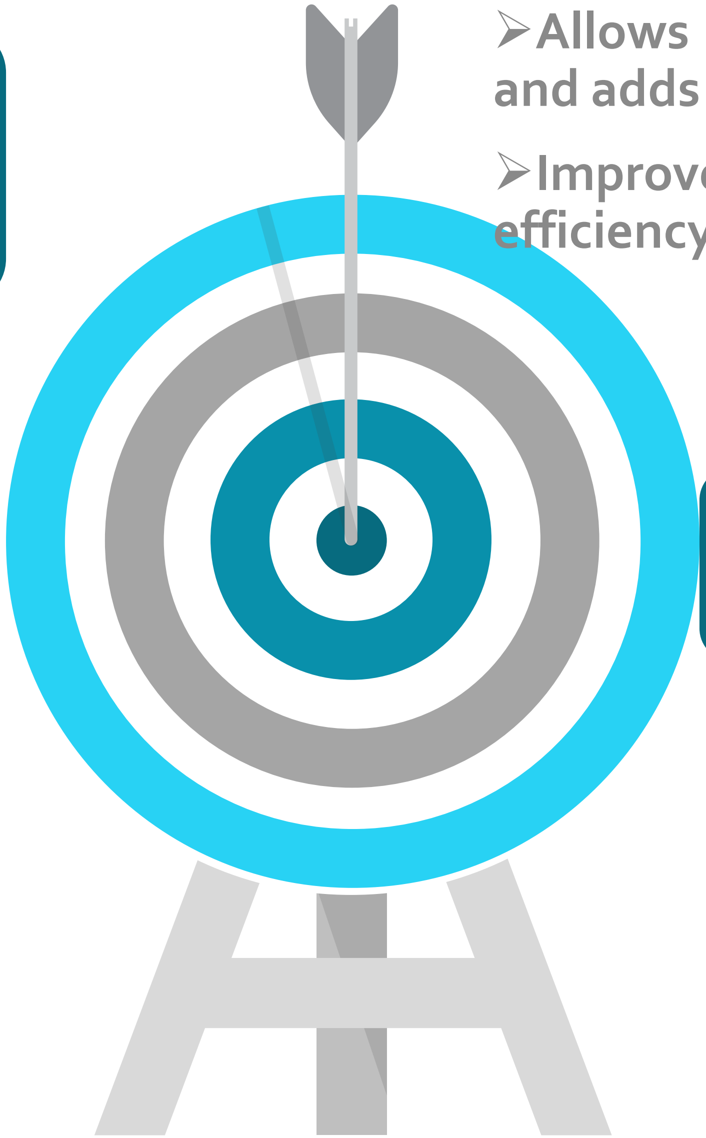
Conclusions

Diversification and Complementarity of Renewable Sources:

- **Hybridization facilitates adaptation** to the specific characteristics of each plant.
- **Scenario 1: Photovoltaic energy complements the micro-hydroelectric system.**
- Scenario 2**: The seasonal hydroelectric plant benefits from solar contribution** during periods of low hydraulic generation.



Key Role of Hydrogen:

- **Allows storing energy surpluses and adds flexibility to the system.**
- **Improves the stability and overall efficiency of the hybrid system.**

Applicability and Environmental Benefits

- Strategy applicable from **small industrial** installations **to large energy infrastructures.**
- **Contributes to reducing greenhouse gas emissions and promotes sustainable development**.

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Next steps

Optimization

Perform a **parametric optimization** to determine the **optimal sizes** of the involved technologies, considering **CAPEX and OPEX**

Real-Time Control

Develop/implement **a real-time control system** that connects the hydroelectric plant with the optimization algorithms

Technologies

Explore various **turbine technologies** and types of hydroelectric plants to evaluate their **impact.**

Implementation and Validation

Implement pilot projects to validate theoretical results and adapt models to real-world conditions.

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Thank you!

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