ETIP HYDROPOWER

TRANSFORMING SECTORIAL LARGE-SCALE IRRIGATION INFRASTRUCTURES INTO A FLEXIBLE INNOVATIVE HYDROPOWER-BASED STORAGE SYSTEM

THE AGISTIN PROJECT

AGISTIN

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the European Union

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Josep Arévalo

Carla Cinto

Sergi Costa

Pau Garcia

Oriol Gomis

Paula Muñoz

Carlos Olives

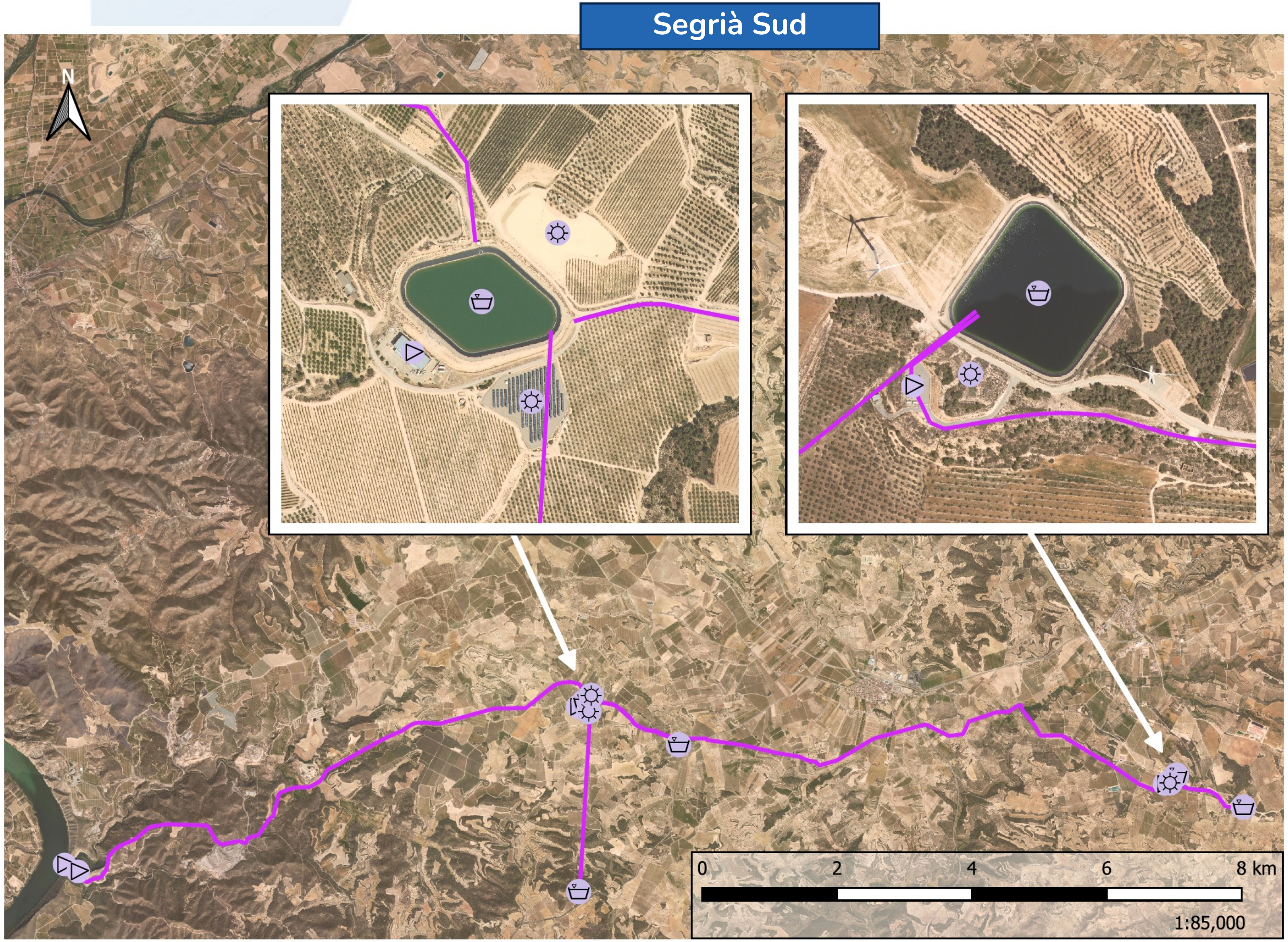
Context

- Large-scale **agricultural irrigation facilities are highly present in Spain**
- Focusing on the area of Catalonia, the **number of irrigation communities (IC) is > 200**
- A typical infrastructure is **a multi-reservoir system**, connected through **pumping stations**
- They are **intensive both in water and energy usage**, therefore it is crucial to **optimize their operation**
- These systems have great **implicit energy storage capacity** (water reservoirs) that is only exploited from the irrigation perspective
- We consider this an excellent opportunity to **expand their use-cases** to incorporate energy storage services
- Let's see an example!

Irrigation communities map (~80 communities included)
Source: Catalan association for irrigation communities (ACATCOR)

The Segrià-Sud irrigation community

- The **Segrià-Sud** irrigation community facilities composes **5 reservoirs with 3 pumping stations** connected to the large-scale Riba-Roja reservoir
- The community annually **consumes electricity in the GWh range**
- **70% of their operational costs** is electricity consumption
- The **pumps** used **range** between **hundred-kW** and **low-MW scale**
- The **irrigation periods** are
  - **High irrigation**: May-Aug
  - **Low irrigation**: Jan-Mar and Sep-Dec
- They have started **installing PV generation systems** to reduce their energy costs (considering both grid-connected and off-grid options)



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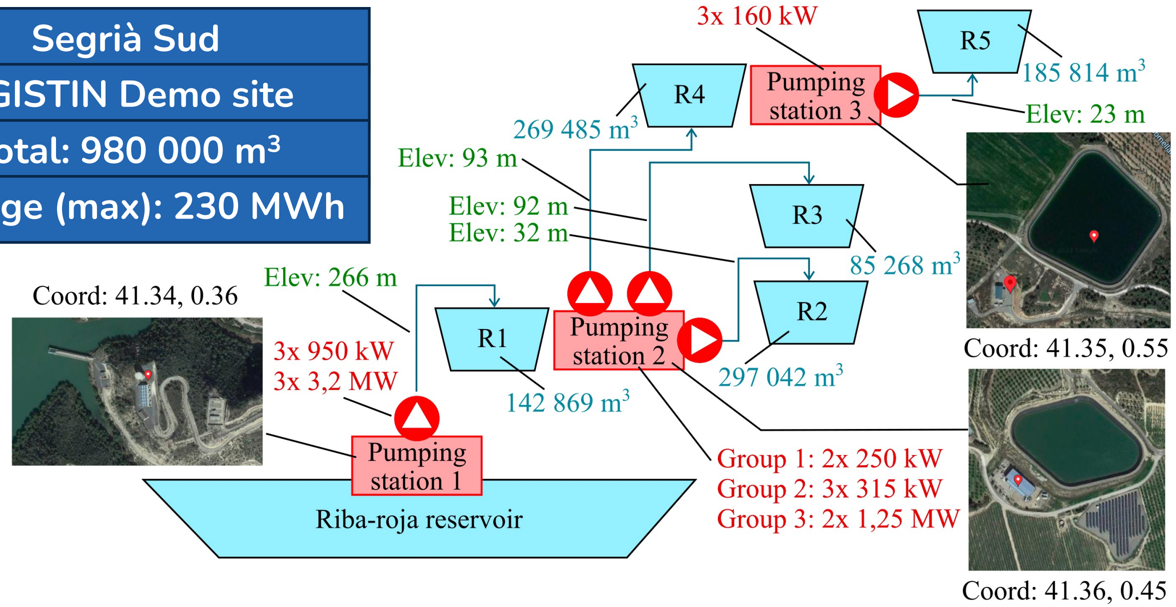
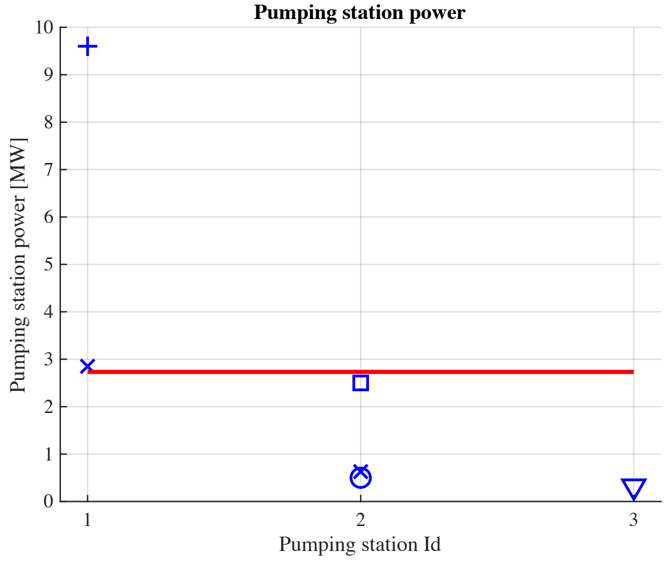
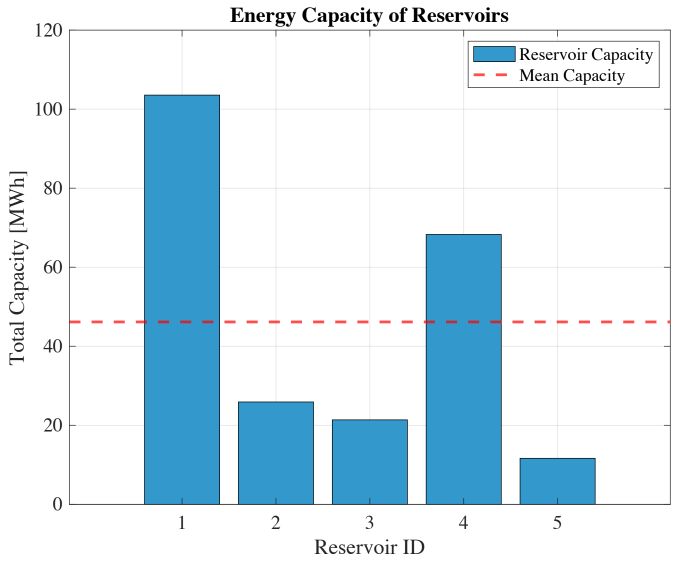
Storage potential

- How much **power/energy** do we have **available in Segrià-Sud**?
- **Reservoirs capacity (Energy and power)**
    - Capacity ranging between **10-100 MWh**
    - **Pumps power** ranging between **160 kW and 3,2 MW (x3)**
- **Initial points:**
    - The potential storage capacity is evident
    - Clearly, the infrastructure is not used at its maximum potential (from the energy point of view)
- Key **research questions**:
    - Can we **add extra energy storage related use cases** for these installations, while prioritizing irrigation purposes and improving its operation?
    - How should we **transform the infrastructure** to unleash such **storage-related use-cases**?

Segrià Sud
AGISTIN Demo site
Total: 980 000 m³
Storage (max): 230 MWh







The AGISTIN project

- Within AGISTIN, we aim to provide an answer to both questions, through the following **key objectives**

Transform sectorial large-scale irrigation infrastructures into a flexible innovative hydropower-based storage system	
Blend storage at different time scales	
Long-term storage **Multi-reservoir hydro**	**Short-term storage** **Different alternatives**
Enable **innovative services** for **End-users** and **network operators**	**Maximize renewable power usage** + **hydropower generation**
Validate the irrigation canal-based energy storage system	
Demo site **Real pumping station (Segrià-sud) + other replicas (CEDER, Les Planes, etc.)**	
Optimal technical economical installations' upgrade while **respecting and potentially improving the main water irrigation use case**	Set the bases for **deployment of the concept** across similar installations across EU

How are we doing it?

How should we transform the system to enable such storage services?

We have to disaggregate the problem

Long-term storage Multi-reservoir hydro	Short-term storage Different options (Li-ion, Redox, etc.)

Sizing problem definition

- Multi-year investment problem
- Seasonality considered
- Hourly resolution (real data available)
- Sizing of different assets
  - Hydraulic assets (turbine, Pump as turbine operation, etc.)
  - Storage assets
  - Electrical assets

Sizing problem definition

- Multi-year investment
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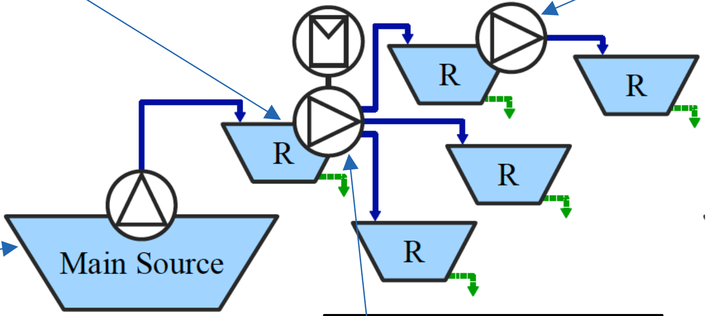
How are we doing it?

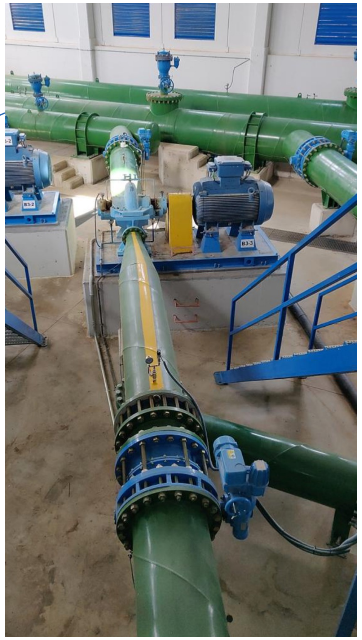
Long-term optimal design tool | **AGISTIN DEMO SITE**

Multi-reservoir system example – Segrià-sud installation

Current status

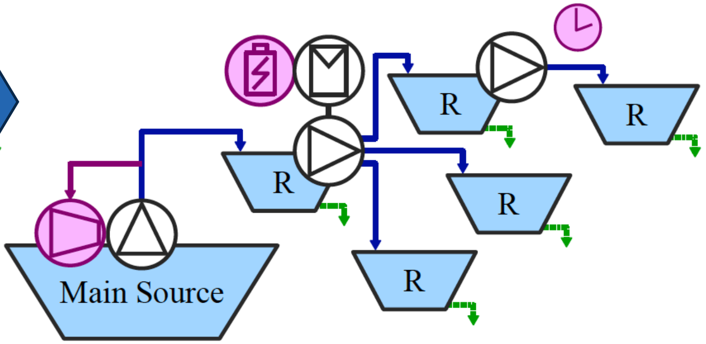
- Devices: reservoirs, pumps, PV
- Services: irrigation, water storage





System redesign

- Devices: + turbines, batteries ...
- Services: + grid services (energy storage, flexibility ...)



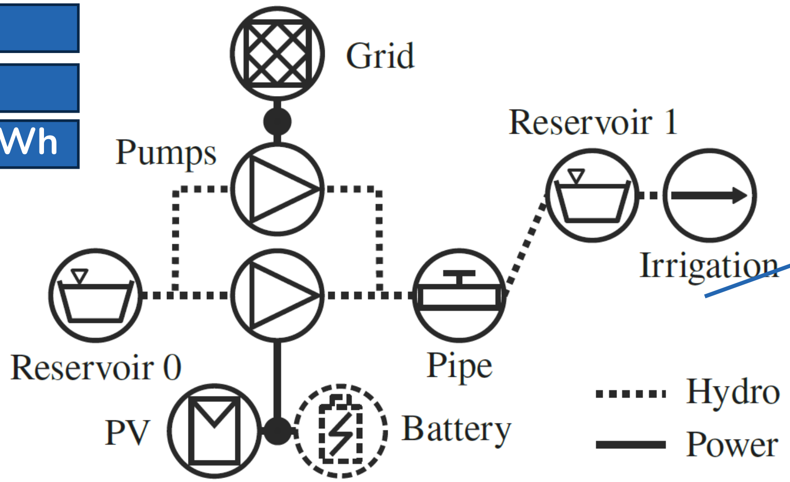
How are we doing it?

Long-term optimal design tool

Two-reservoir system example – Les Planes i Aixalelles installation

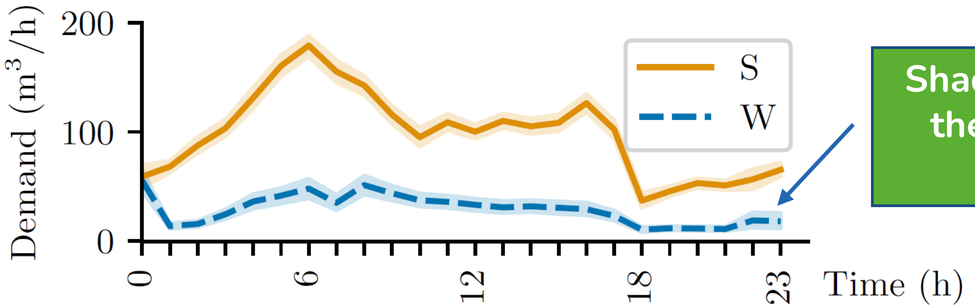
Real case: Les Planes i Aixalelles

Les Planes
Total: 13 000 m^3
Storage (max): 3,58 MWh



Profile-based optimization (24 h)

Two seasons → Summer → high water demand; Winter → low water demand

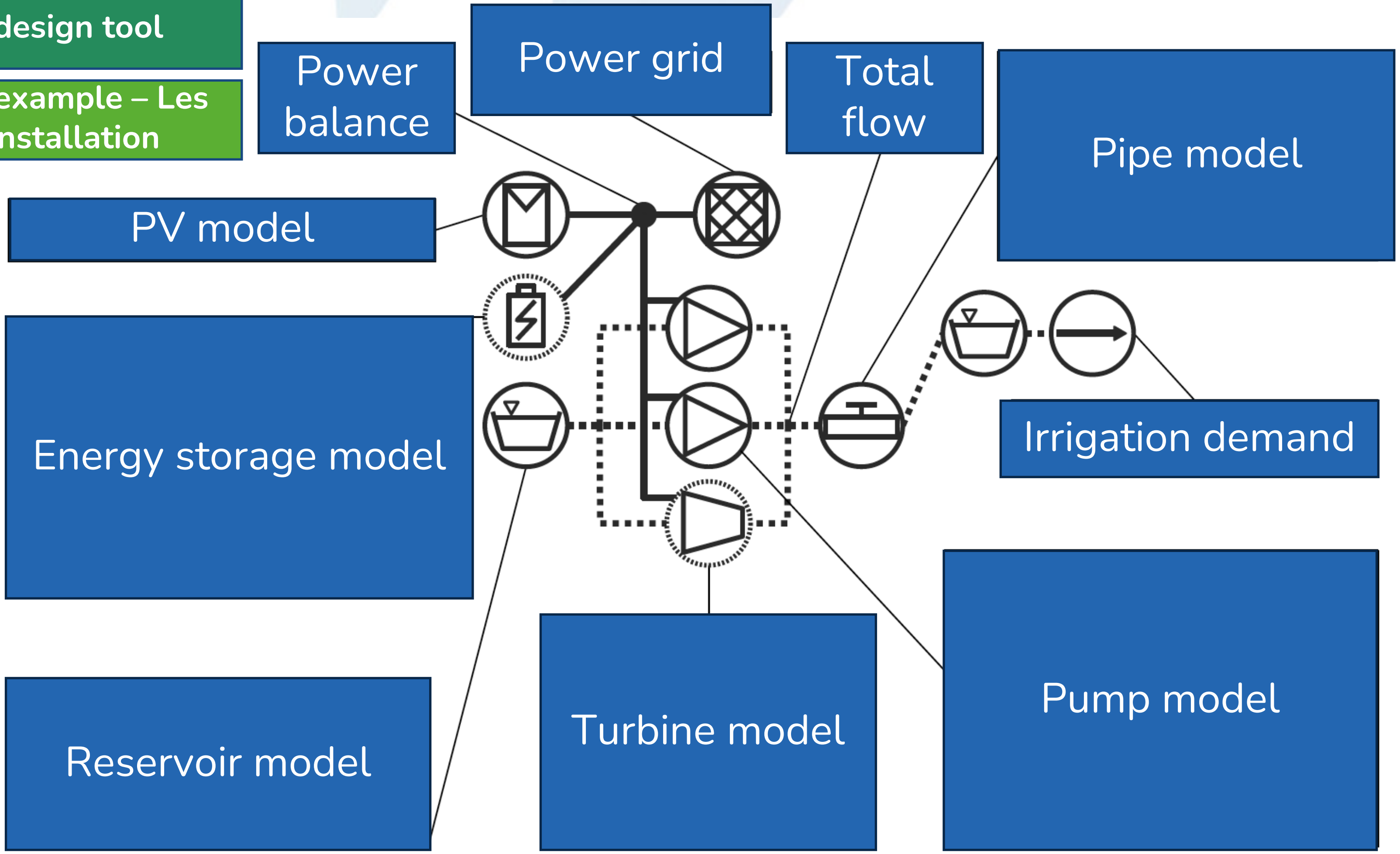


Shadow 95% of the irrigation profiles

How are we doing it?

Long-term optimal design tool

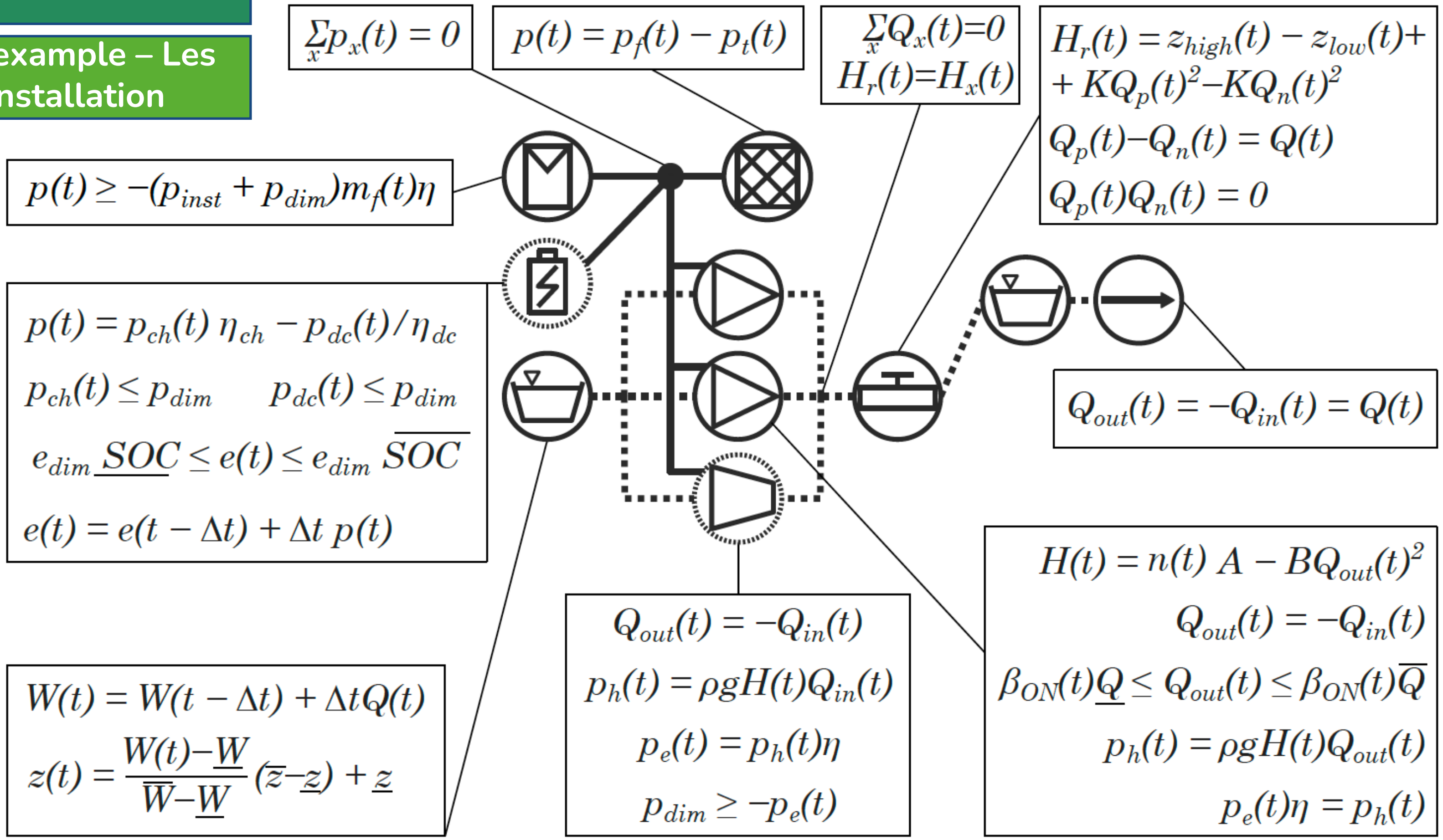
Two-reservoir system example – Les Planes i Aixalelles installation



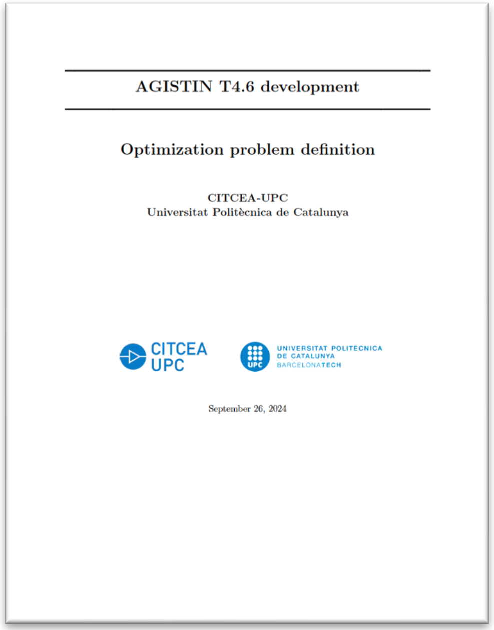
How are we doing it?

Long-term optimal design tool

Two-reservoir system example – Les Planes i Aixalelles installation



Optimization tool Manual


AGISTIN T4.6 development

Optimization problem definition

CITCEA-UPC
Universitat Politècnica de Catalunya

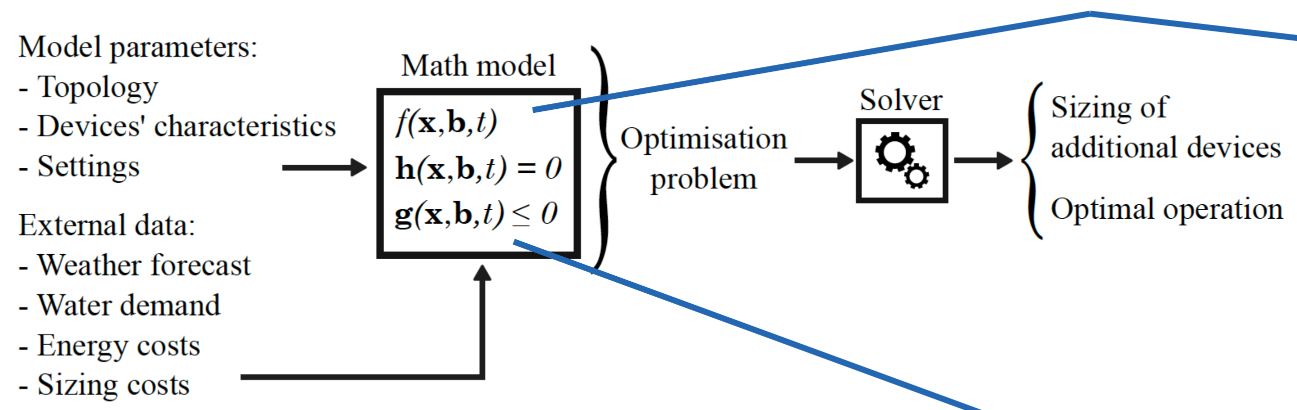
September 26, 2024

Available on demand

How are we doing it?

Two-reservoir system – Long-term optimization tool application

Optimization tool

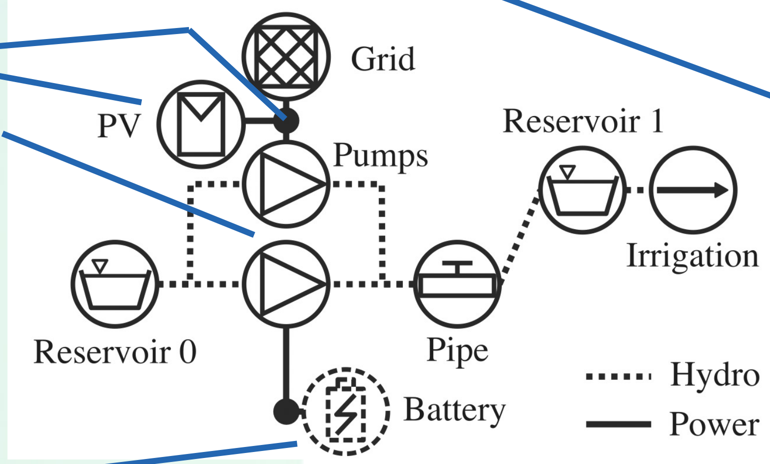


Objective function

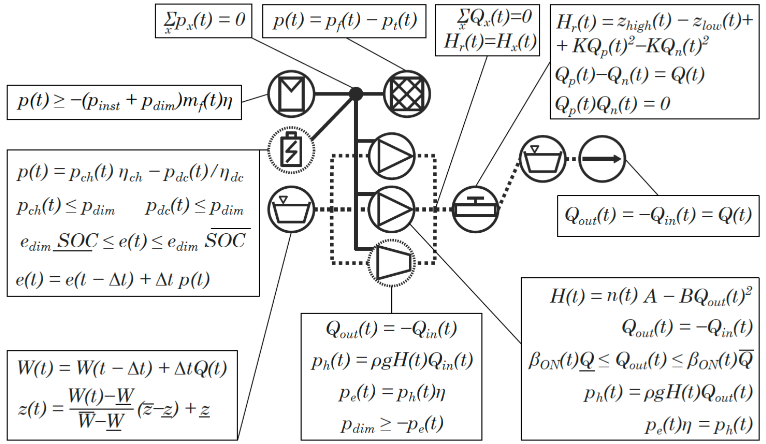
$$f(\cdot) = \sum_{t=t_0}^{t_f} \left[p_{f,g}(t)\, c_{buy,g}(t) - p_{t,g}(t)\, c_{sell,g}(t) \right] \Delta t + $$
$$+ p_{dim,PV}\, c_{p,PV} + p_{dim,turb}\, c_{p,turb} + $$
$$+ p_{dim,bat}\, c_{p,bat} + e_{dim,bat}\, c_{e,bat}$$

Network services can be added!

Assets + grid connection to size



Optimization constraints

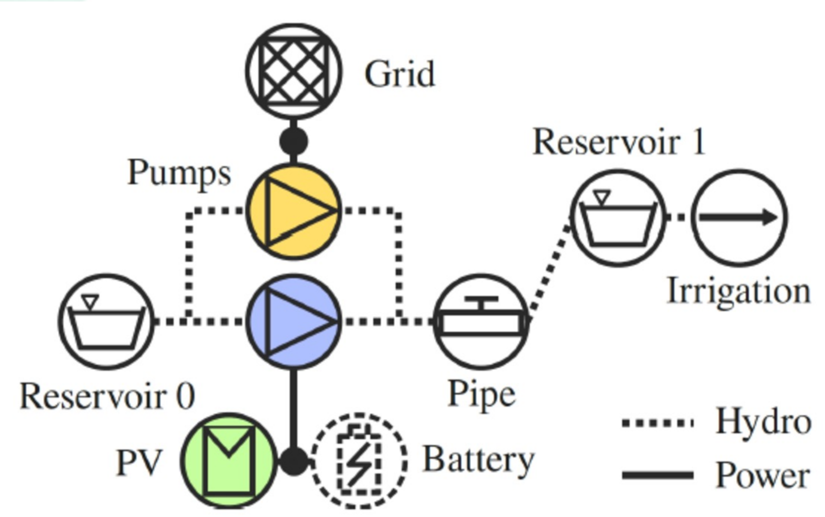


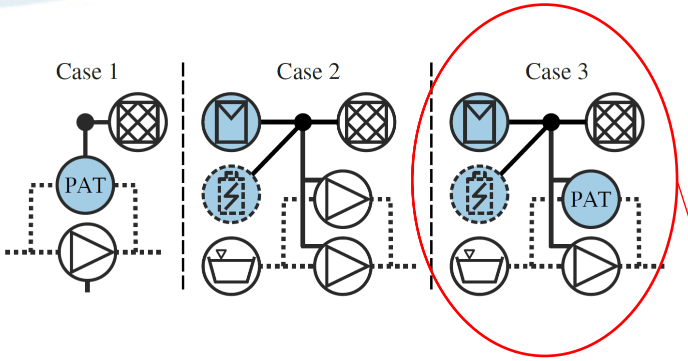
GitHub
python
PYOMO

How are we doing it?

Two-reservoir system – Long-term optimization tool application

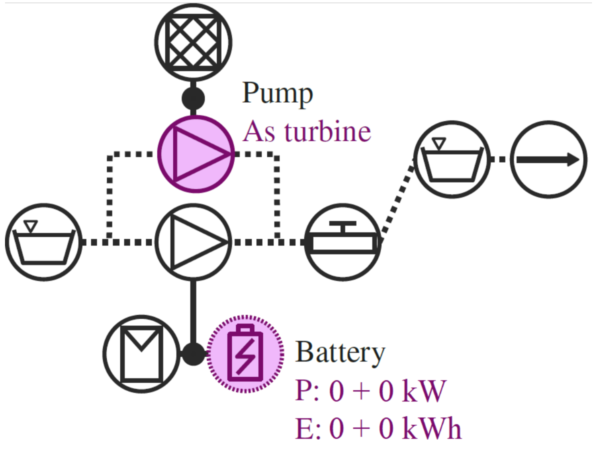
Real case: Les Planes i Aixalelles

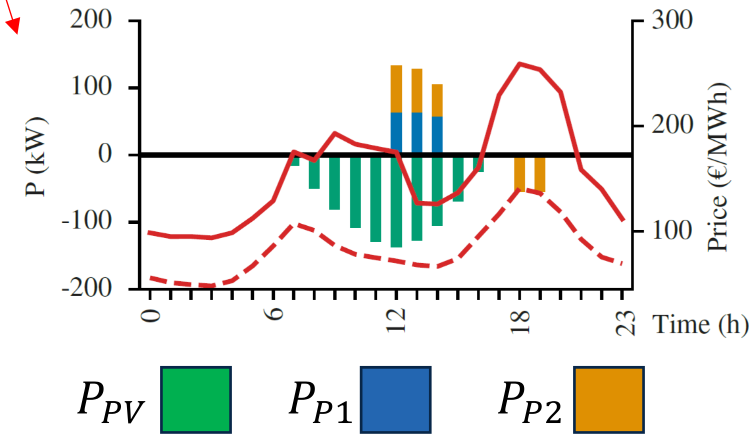




Results summary

- **No Li-ion battery sized** (it is not cost-effective)
- Utilizes **PV pumping**, then **turbines (PAT) during high price** periods





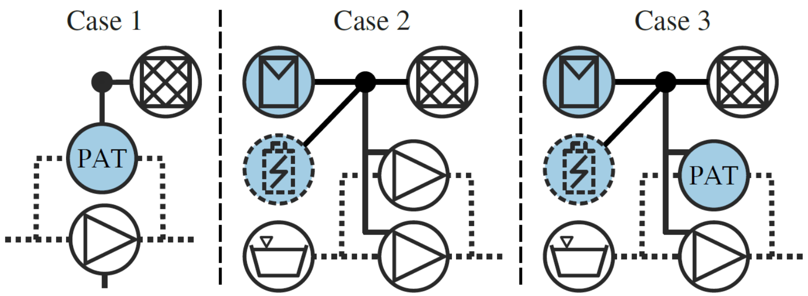
How are we doing it?

Two-reservoir system – Long-term optimization tool application

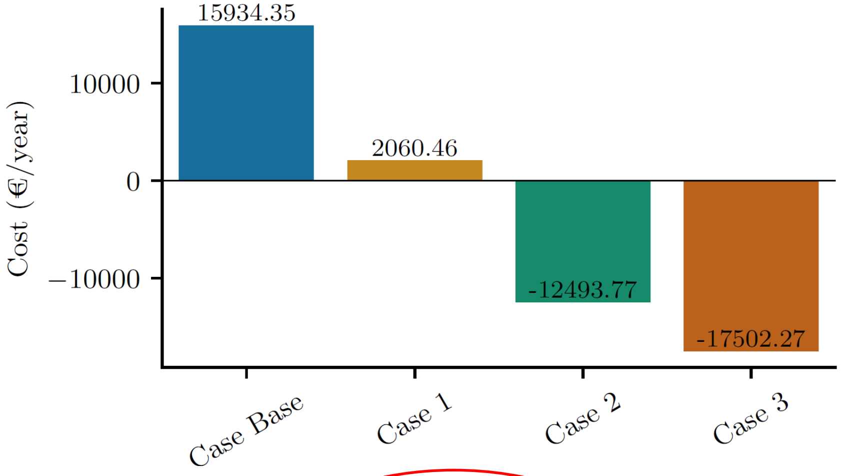
Simulation validation

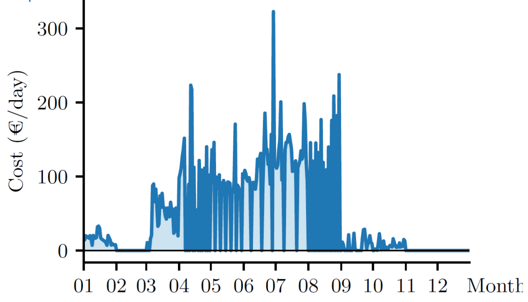
- Les Planes installation
- 365 days simulation of real operation
- Real data considered:
  - Irrigation profile considered
  - Network electricity costs
  - Weather data

Cases studied

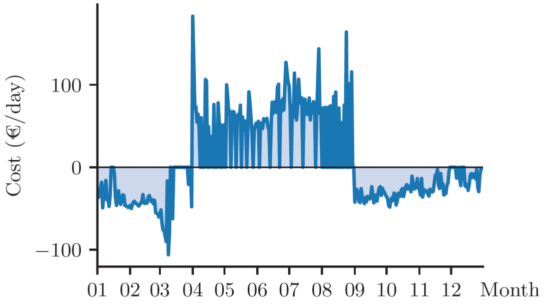


Simulation results

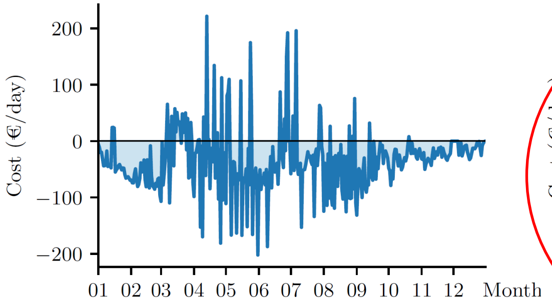




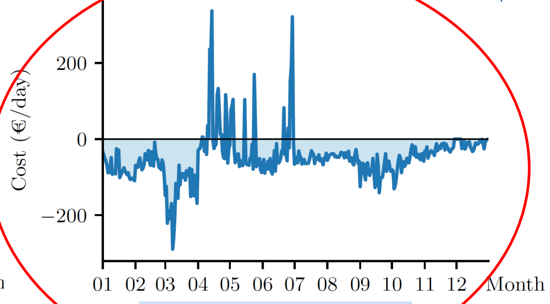
Optimized base case



Case 1



Case 2



Case 3

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- Hourly resolution
- Sizing of different assets
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  - Storage assets

Sizing problem definition

- Multi-year investment
- Yearly data considered (real data available)
- Minutes to seconds resolution
- Storage asset sizing

How are we doing it?

Short term storage: Energy storage to prevent water hammer on PV pumping

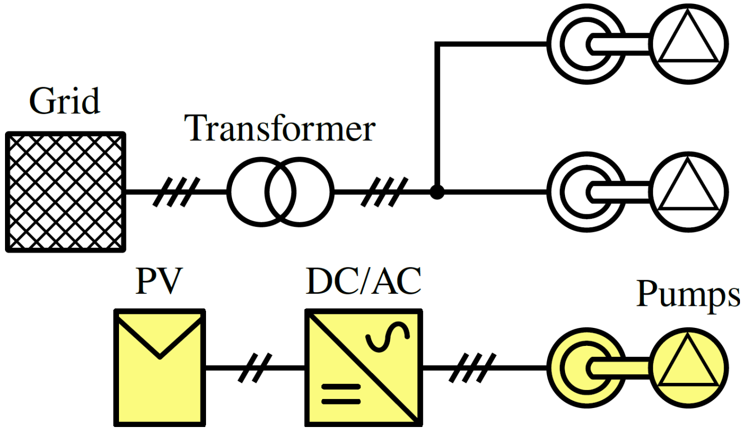
Problem description

- Irrigation communities have been recently installing **off-grid PV pumping systems**
- Clouds can stop the pump harshly (potentially causing water hammer effects)

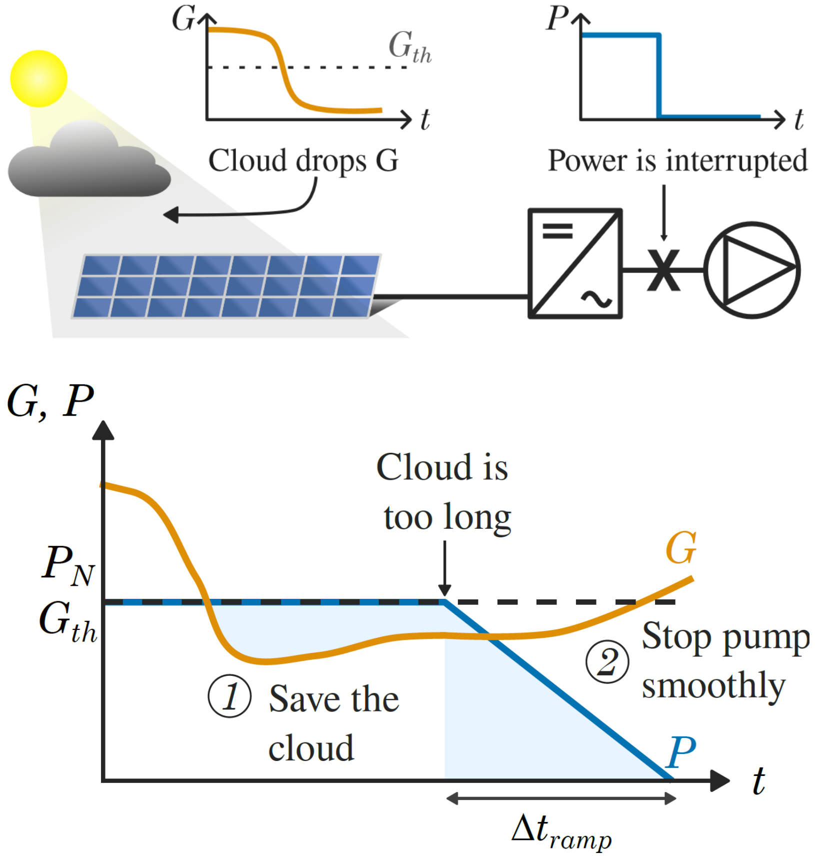
Main objectives

- **Size an energy storage system** to:
  1. Avoid stopping the pump
  2. Stop the pump smoothly

Current scenario



Cloud irradiance - Pump power



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How are we doing it?

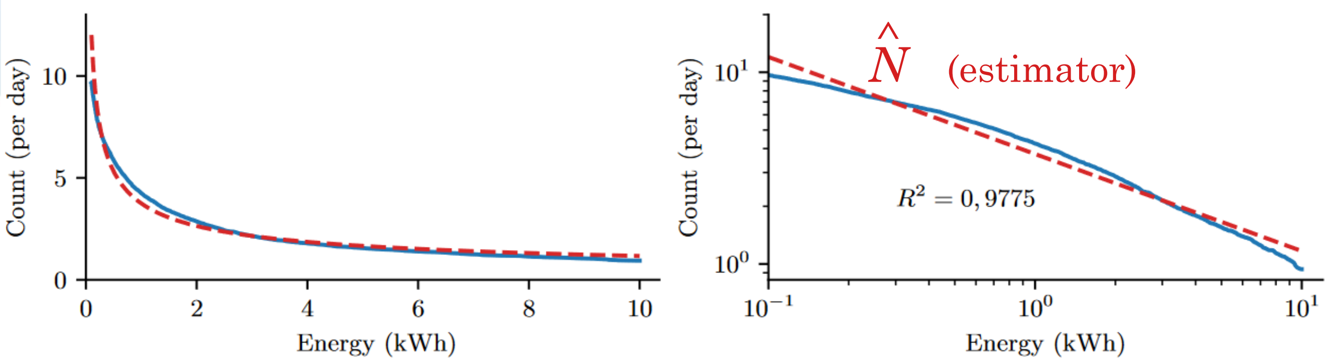
Short term storage: Energy storage to prevent water hammer on PV pumping

Methodology description

- Definition of clouds (from site data)
  N of clouds per day follows law of power

- Cost function C in terms of ESS capacity E
  - Cost of stopping the pump, i.e. pump not working (depends on N)
  - Energy capex
  - Variable opex (depends on N)
  - Power capex
  - Fixed opex (lifetime included)

- Optimization can be analytically solved



$$C(E_{(1)}) = c_{stop}\, Lifetime\, \hat{N}(E_{(1)}\, DOD) +$$
$$+\, opex_{var}\, Lifetime\, E_{(1)}\, (\overline{N} - \hat{N}(E_{(1)}\, DOD)) + capex_E\, E_{(1)}$$
$$+\, opex_{var}\, Lifetime\, E_{(2)}\, \hat{N}(E_{(1)}\, DOD) + capex_E\, E_{(2)} +$$
$$+\, opex_{fix}\, P + capex_P\, P,$$

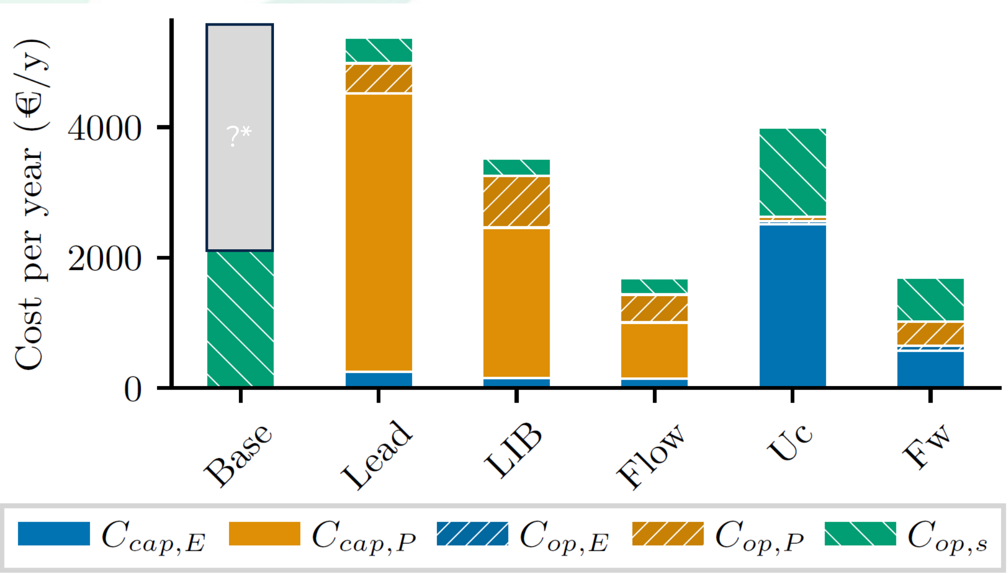
$$\frac{dC}{dE_{(1)}} = 0 \quad \Rightarrow \quad E_{(1)} = \left(\frac{-c_{cap,E,ESS}}{L_{ESS}\, c_{stop}\, D_{ESS}^{\alpha}\, K\, \alpha} \right)^{1/(\alpha-1)}$$

How are we doing it?

Short term storage: Energy storage to prevent water hammer on PV pumping

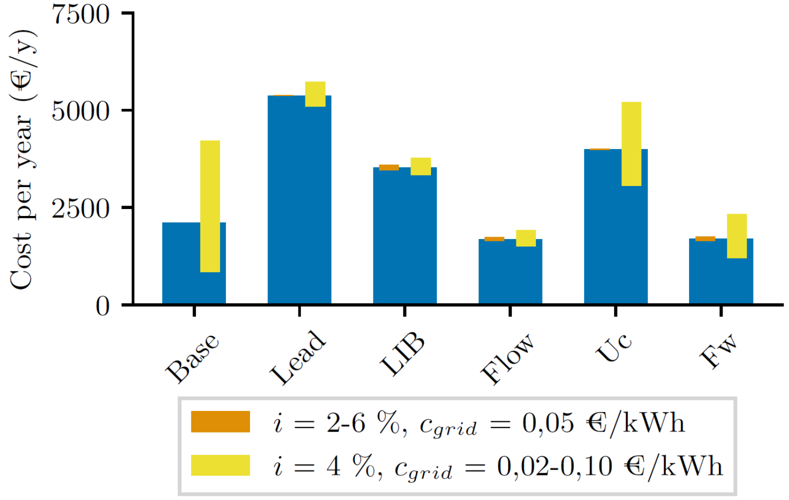
Methodology description

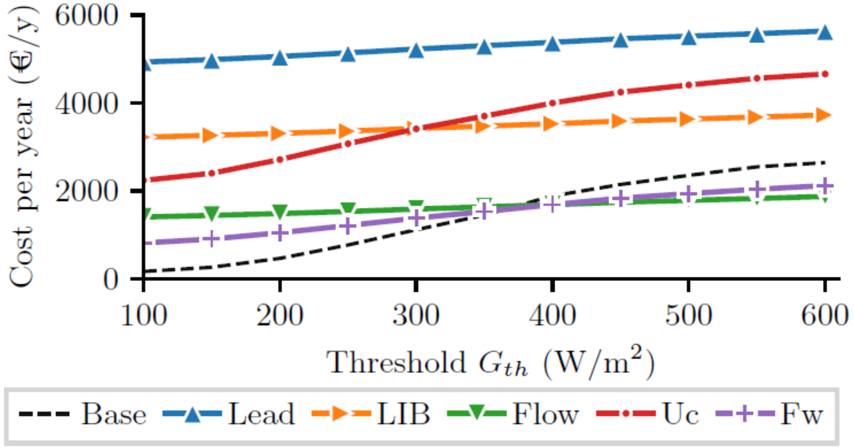
- Analysis for different technologies
  + base case (does not consider smooth stop)



**Maintenance not considered*

- Sensitivity analysis: irradiance threshold, real interest rate, cost of energy





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AGISTIN Demo site

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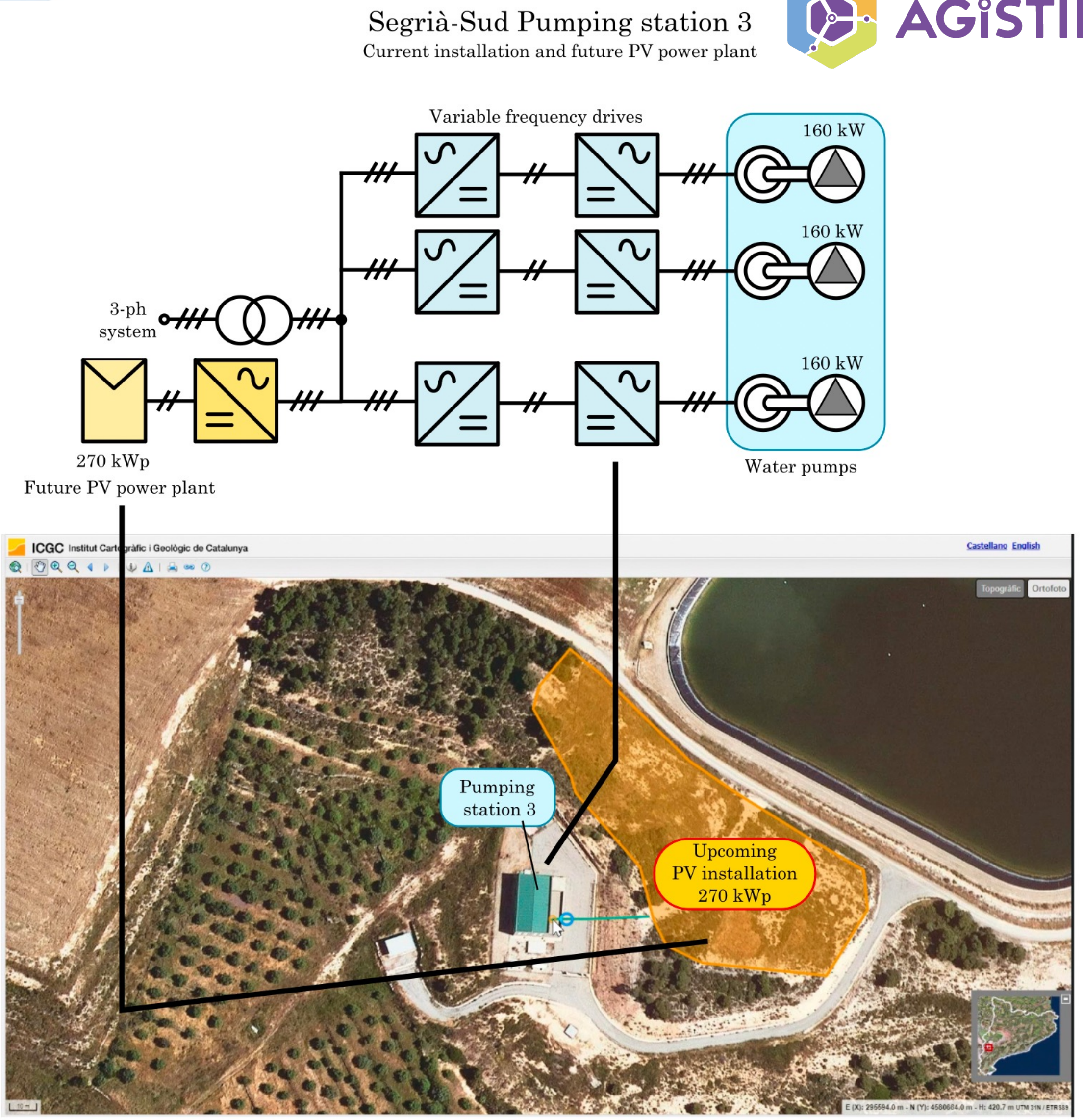
Segrià-Sud Pumping Station 3 current status

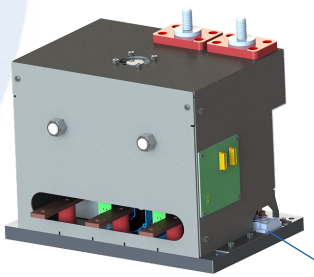
- 3 pumps (2+1 structure) -160 kW
- variable frequency converters in place (Power electronics SD700)
- Upcoming PV installation of 270 kWp via AC/DC inverter and a grid connected installation
- Network connection: Elèctrica Seroense (local DSO)

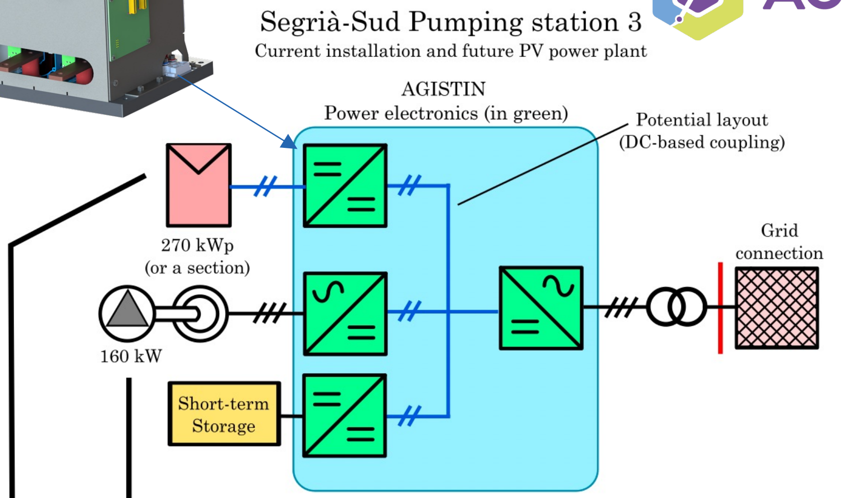
Upgrades are required to extract the full potential of the installation

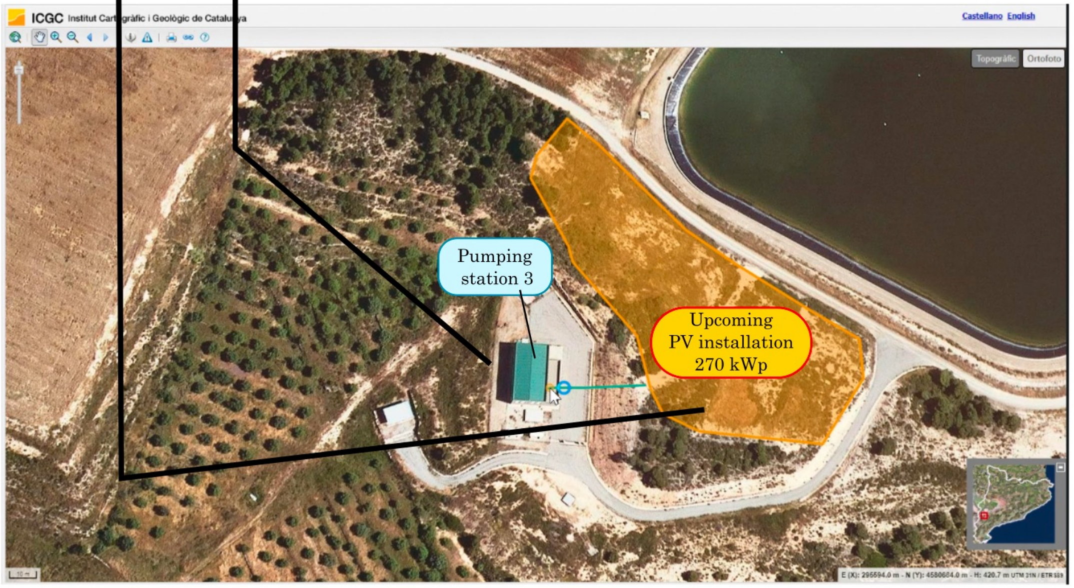


AGISTIN Demo site

Converter







Segrià-Sud Pumping Station 3 key upgrades

- A multiport converter (AGI – Advanced Grid Interface) enabling a DC link to interconnect all assets (pumps, PV and storage)
- An ECR battery (Geyser batteries). High power, ~30s → 1 min capacity
- This setup allows to optimize the AC grid connection power
- Possible off-grid operation
- Enables innovative services from the AC/DC converter (e.g. grid-forming).

Long-term sizing

Short-term sizing

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Main takeaways

Large-scale irrigation systems can be transformed to take advantage of their own long-term storage capacity to optimize their operation

Short-term storage can support the operation of irrigation systems in presence of variable renewable energy PV generation

Additional energy storage services could be enabled, adding extra use-cases to the infrastructure

Regulation should be revisited to enable the operation of such infrastructures

THANK YOU!

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