Renewables & Energy Storage

Hybrid hydro and solar PV microgrid for rural electrification

International Hybrid Power Systems, Madeira – PT, April 26 -27, 2022

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company presentation - fields of activity

- **POWER SYSTEMS**
  - OFF - GRID SYSTEMS
    - Solar Photovoltaics Systems
    - Wind Power Systems
    - Energy Storage Systems
    - EV charging Systems
    - Diesel, Petrol and Gas Generators systems
  - GRID CONNECTED SYSTEMS
    - Solar Photovoltaics
    - Wind Power Systems
    - Small and Large hydroelectric systems
    - Co-generation systems
    - Energy Storage Systems
    - EV charging System

- **SERVICES SUPPLIER**
  - ENGINEERING SERVICES
  - FINANCING SERVICES
  - DUE DILIGENCE SERVICES

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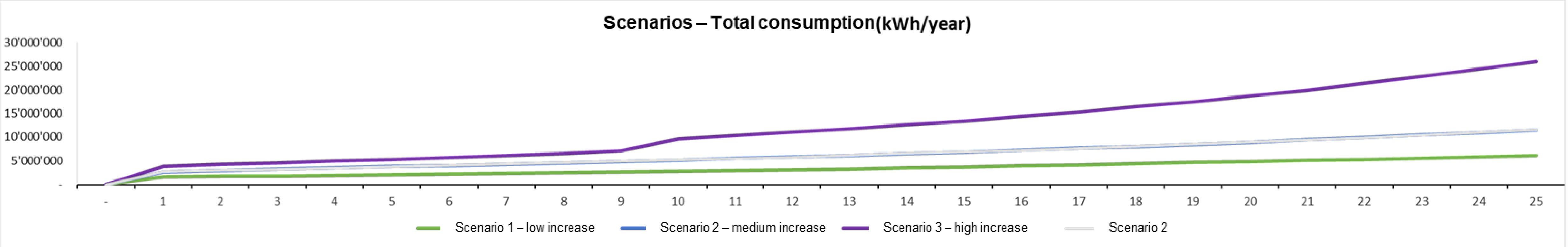
Project context

- Project characteristics
  - **Rural electrification** project in **Sub-Saharan Africa**
  - Very **remote** area
  - **~ 9’000** connections
  - **100 km** of medium voltage (**MV**) distribution grid
  - **Hydroelectric plant** is the **main electricity generation asset** (developed before demand identification)
  - Densely **forested** and **cultivated** area
  - Pronounced **geomorphology** with very few flat areas
  - High level of **subsidies** from donors for **CapEx**

- Project challenges
  - **Water inflows** important **seasonality**
  - High **CapEx** of **hydroelectric plant** with **reservoir dam**
  - **Restricted area availability** for solar **PV** installation
  - **Difficult access** to the sites
  - **Elongated system**

Demand characteristics

- Demand characteristics
  - ~ 9’000 connection
  - ~ 30’000 population
  - **90 villages** in **22** village **groups** with important variation in size of villages and number of villages per group
  - **Area** of **30 km long x 20 km** width
  - **100 km** of **MV distribution grid**
  - **25** years time horizon



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Generation characteristics 1/2

- Hydroelectric power plant

  - Reservoir dam
    - Installed capacity: 1’350 kW
    - Reservoir capacity: ~ 9 MWh
    - Generation variation: 10% to 100%
    - Life duration: 35 years
    - **CapEx: ~ 8.5 M EUR**

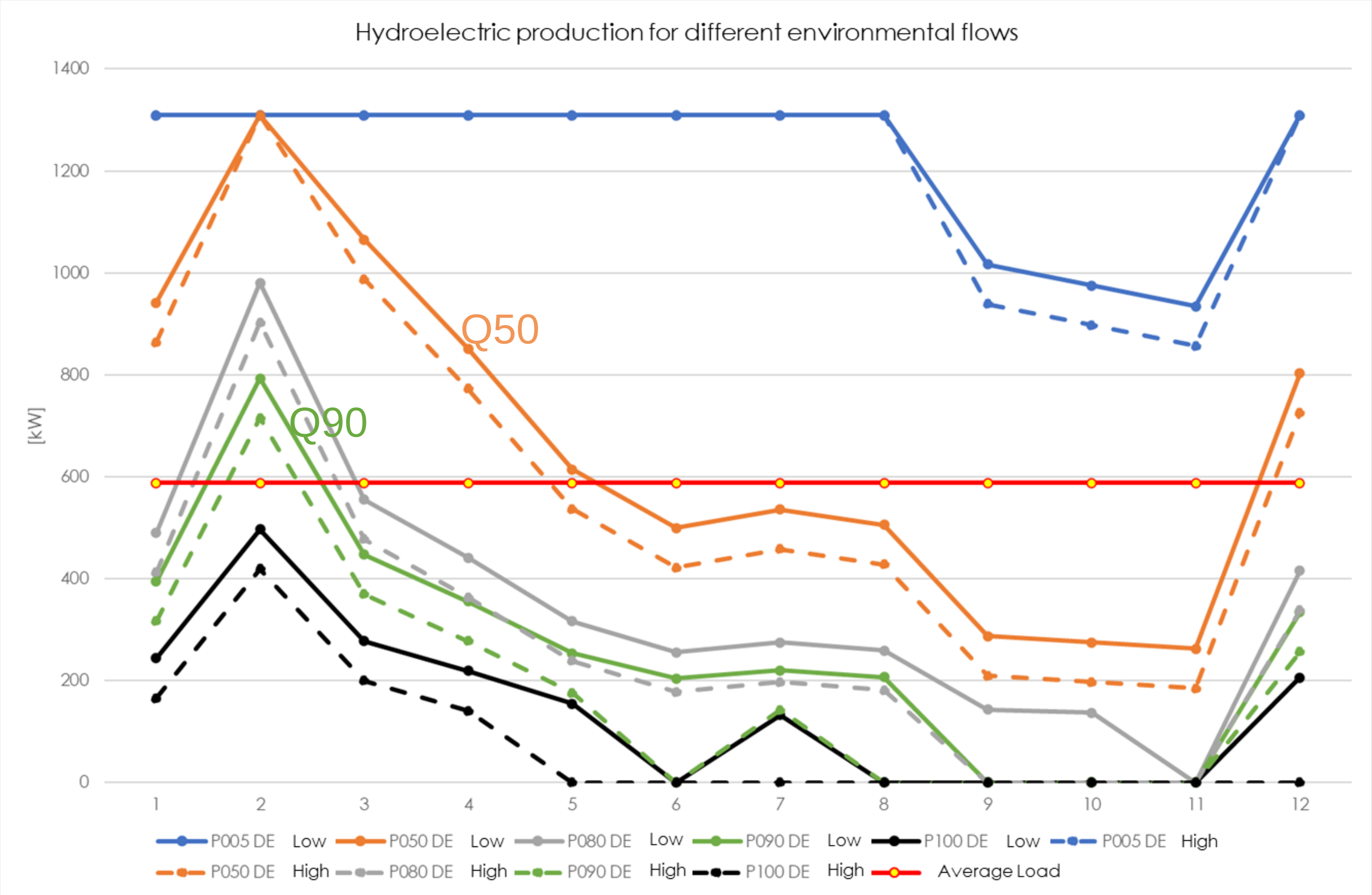
  - Run of River
    - Installed capacity: 1’350 kW
    - Reservoir capacity: 0 MWh
    - Generation variation: 10% to 100%
    - Life duration: 35 years
    - **CapEx: ~ 5.5 M EUR**

Generation characteristics 2/2

- Solar PV
  - PV + BESS
    - Installed capacity: to be calculated
    - Storage capacity: to be calculated
    - Generation variation: 0% to 100%
    - Life duration: 25 years (considering PCU replacement), 4’000 cycles battery
    - CapEx
      - PV: 1’000 EUR / kWp
      - Storage: 400 EUR/kWh
- Diesel
  - Diesel power plant
    - Installed capacity: 2 x 250 kW + 4 x 500 kW (to cover the entire load)
    - Storage capacity: 10 m3 of Diesel
    - Generation variation: 25% to 100%
    - Life duration: 15’000 hours
    - CapEx: 400 EUR/kW

Hydroelectric variability

- Hydraulic production can vary significantly from **one year to another** and for this reason it must be approached using a **stochastic** sizing methodology.
- Hydroelectric plants are characterised also by a **pronounced seasonality**.
- Q50: median
- Q90: system design inflows



Calculated energy mixes

- Several energy mixes were calculated and sized in order to compare the solution **with and without storage**, as well as select the **optimal solution**.
- The **reference** scenario was with **Diesel** gensets only.

Hydroelectric	Diesel gensets	PV	BESS
	X		
Reservoir dam	X		
Reservoir dam	X	X	Energy BESS
Run of river	X	X	Energy BESS

Calculation and sizing methodology

- Model characteristics
  - The model used and by extension the optimisation problem **formulated are linear deterministic**. However, **any non-linear characteristics** is approximated by a **piece-wise linear function**.
  - The optimisation problem is a **two stage minimisation of investment and operation cost**, calculated in **net present value** and solved using **Mixed Integer Linear Programming (MILP)**.
  - **Sensitivity analyses** (1'512 scenarios) were considered including:
    - Different **energy mixes**: 6 mixes
    - **Inflows**: 12 different inflow levels (P5 to P100)
    - **Environmental flows**: 7 different input levels (low to high)
    - **Diesel prices**: 3 price levels (current, q75 and q50 of the last 10 years)
- Decision variables (~12.5 M)
  - Diesel
    - Operational, economical
  - Photovoltaic power plant
    - Size (PV modules, inverters, batteries, converter), operational, economic
  - Hydroelectric power plant
    - Operational, economic
  - System
    - Operational, economical

Assumptions

- Horizontal assumptions

Horizontal assumptions		
Assumption	**Units**	**Value**
Project horizon	[Years]	25
Demand horizon	[Years]	10
Discount rate	[%]	12
Inflation rate	[%]	3
Non-served demand	[%]	2%
Modeling step	[-]	Hourly
Data base (Irr, temp)		NREL

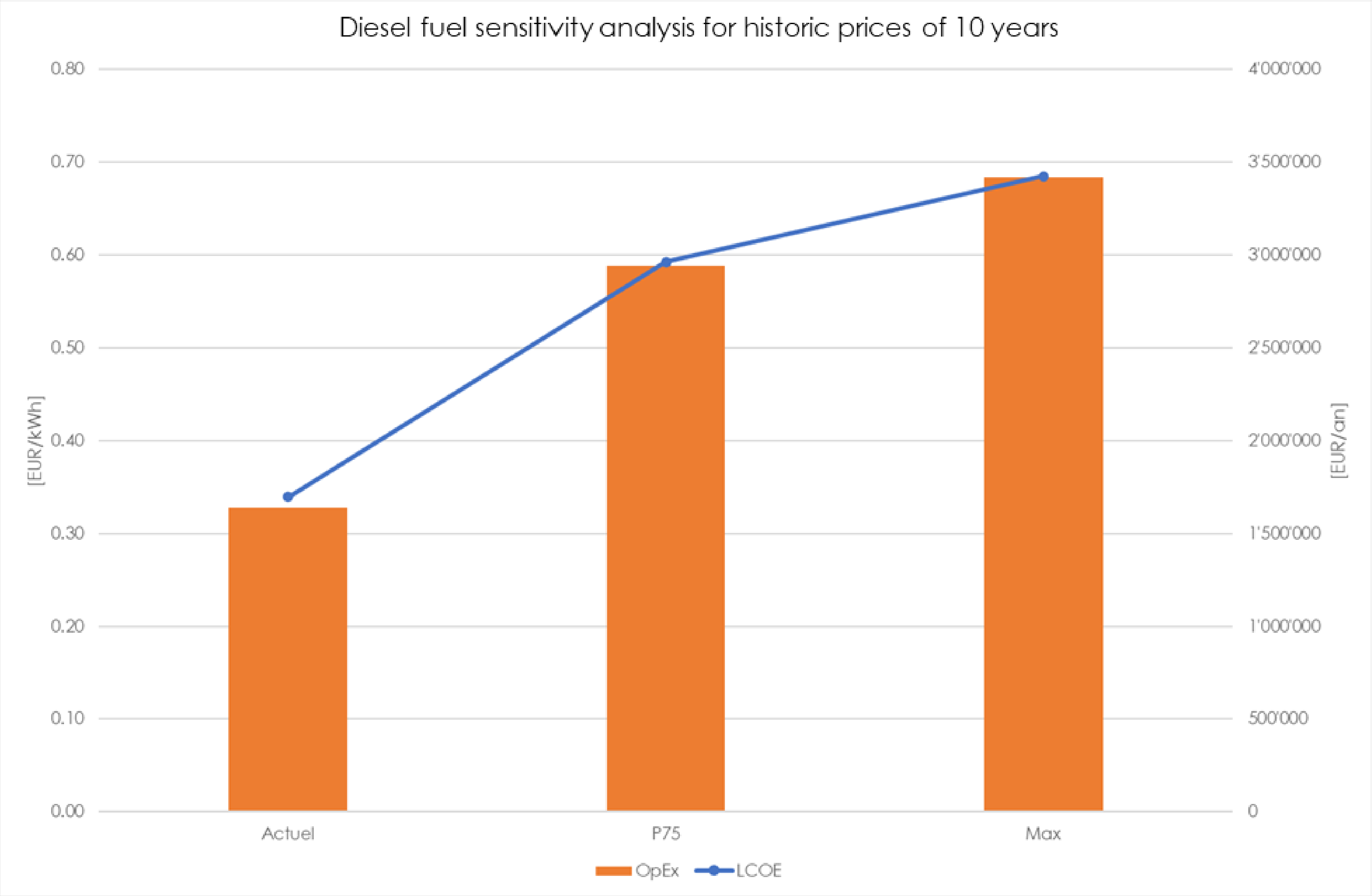
Differed investment horizon

Assumptions

- Computational tool assumptions
  - Stochasticity
    - The problem is solved for **each probability of hydraulic inflows** and then the **expected value** of the desired result is calculated.
    - This approach is **deterministic**, which is not correct because we indirectly apply the assumption that we make investment and operation decisions **under the perfect knowledge of the future** (Decision using Perfect Information).
    - The decision under the perfect knowledge of the future and by extension these calculated optimal results of the model, **represent an ideal situation**.
    - The results are an **undervaluation of future costs** (or an overvaluation of future revenues, depending on the problem) because the decision was **made with perfect knowledge of the future** (expected value of perfect information - EVPI).
  - BESS
    - The **battery storage** system is modelled through a function which takes into account the **losses** according to the **charge-discharge**, the **external temperature**, the **aging** and defines the **battery life** through the energy which crosses it.
    - An approximation is made at the level of **microcycles** where we consider that **their sum is equal to a complete cycle**.

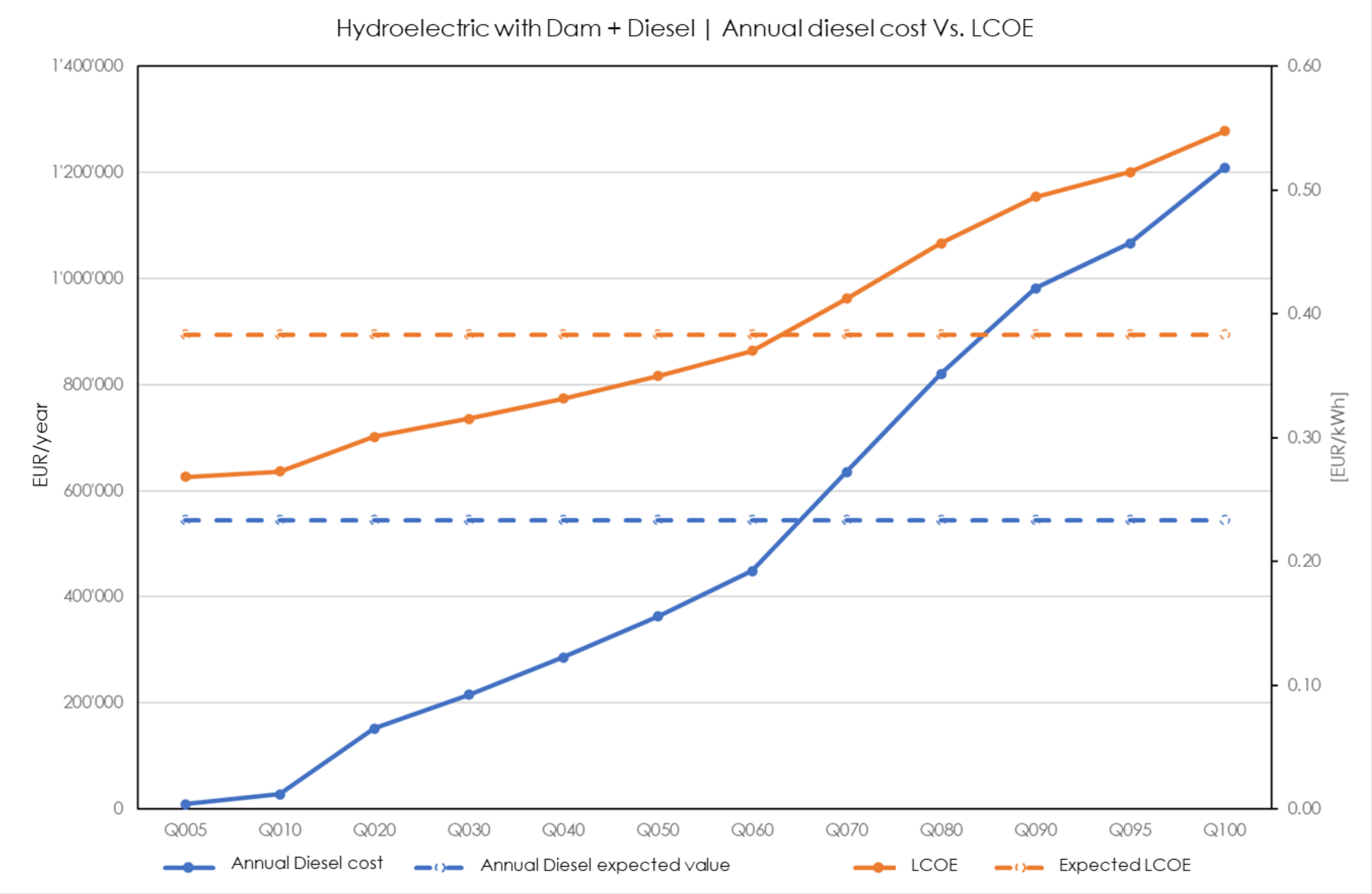
Results

- Diesel only
  - Yearly cost
    - **Actual** ~ 1.6 M EUR /year
    - **P75** ~ 2.9 M EUR/year
    - **Max** ~ 3.4 M EUR/year



Results

- Hydroelectric with Dam + Diesel
  - Annual Diesel cost for different water inflows probabilities
  - LCOE for different water inflows probabilities



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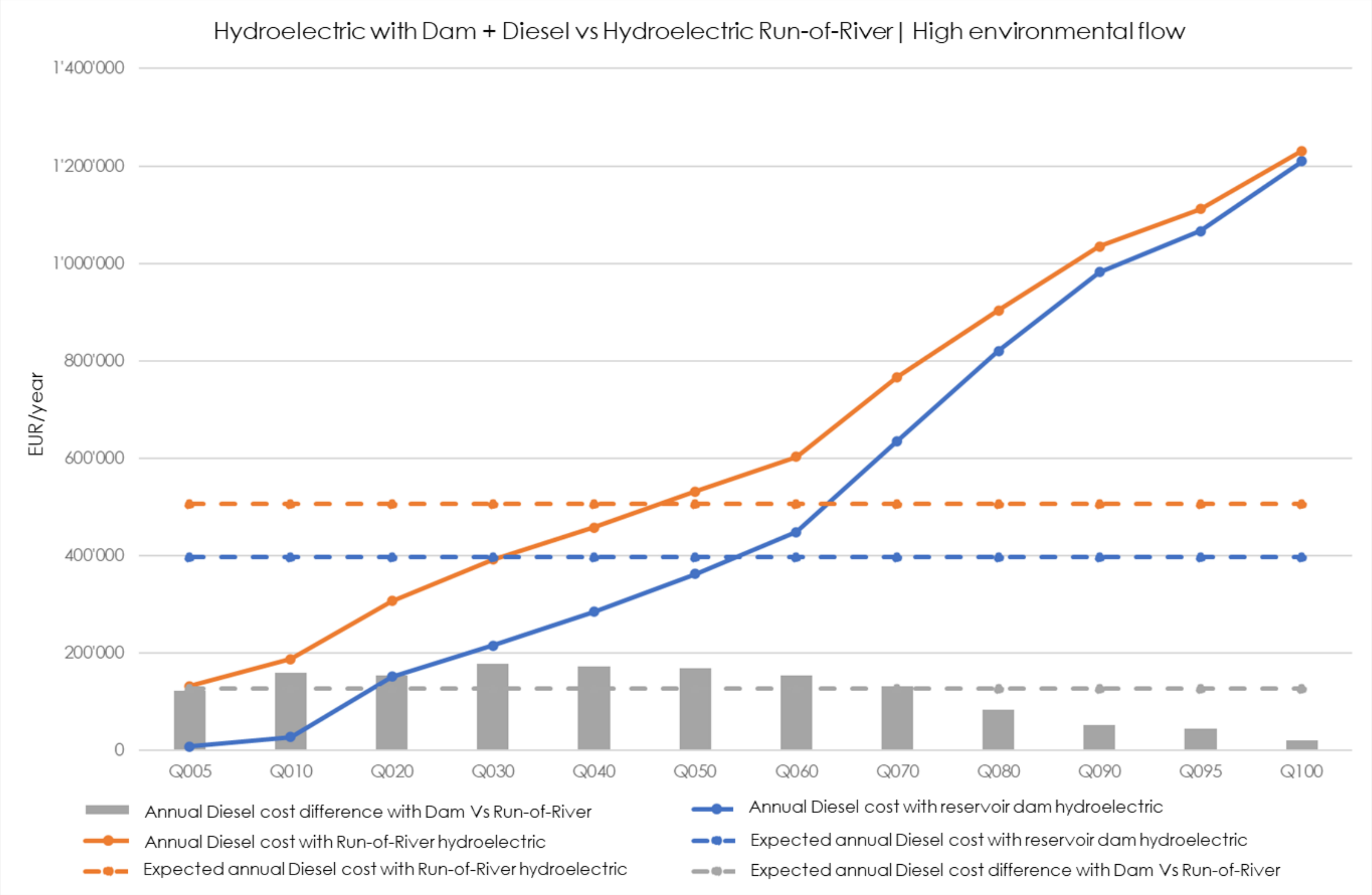
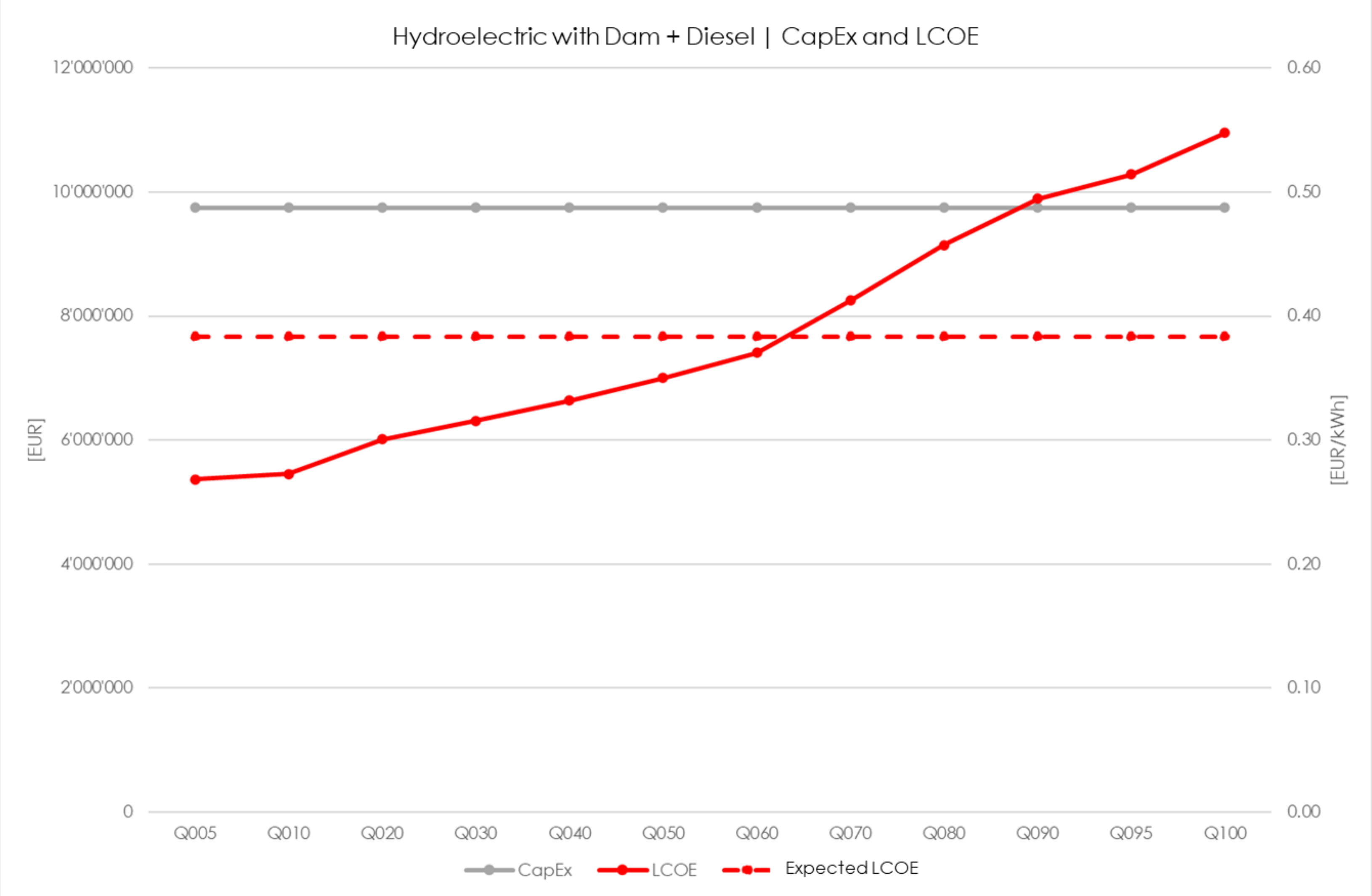
Results

- Hydroelectric with **Dam** + Diesel vs **Run-of River** + Diesel
  - Comparison between Hydroelectric with Dam and Run of River for different water inflows probabilities
  - Comparison based on Diesel consumption for different water inflows probabilities
  - Annual cost difference: ~ 180 k EUR/year (Q50)



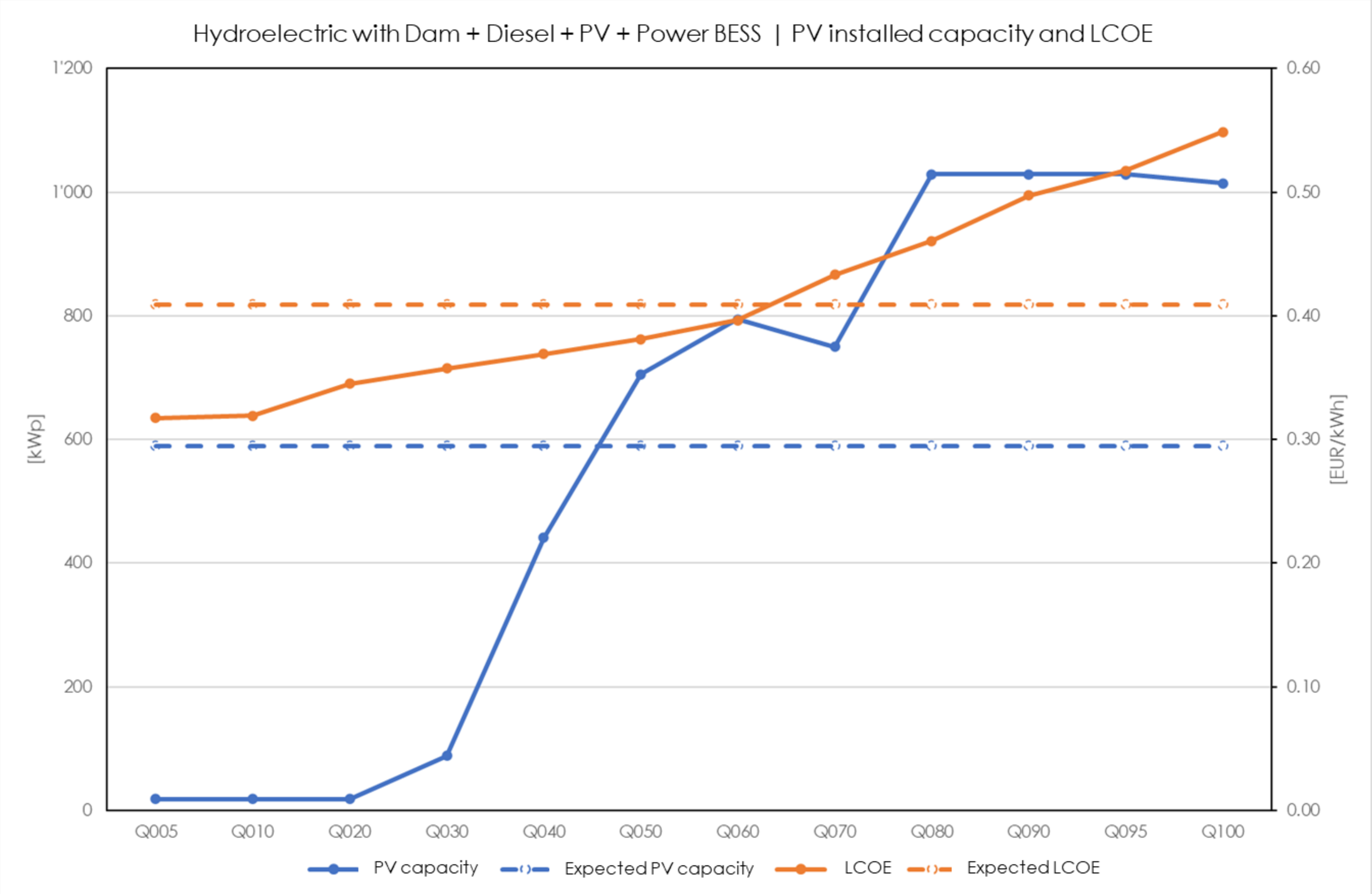
Results

- Hydroelectric with **Dam + Diesel**
  - LCOE variation for different water inflows probabilities



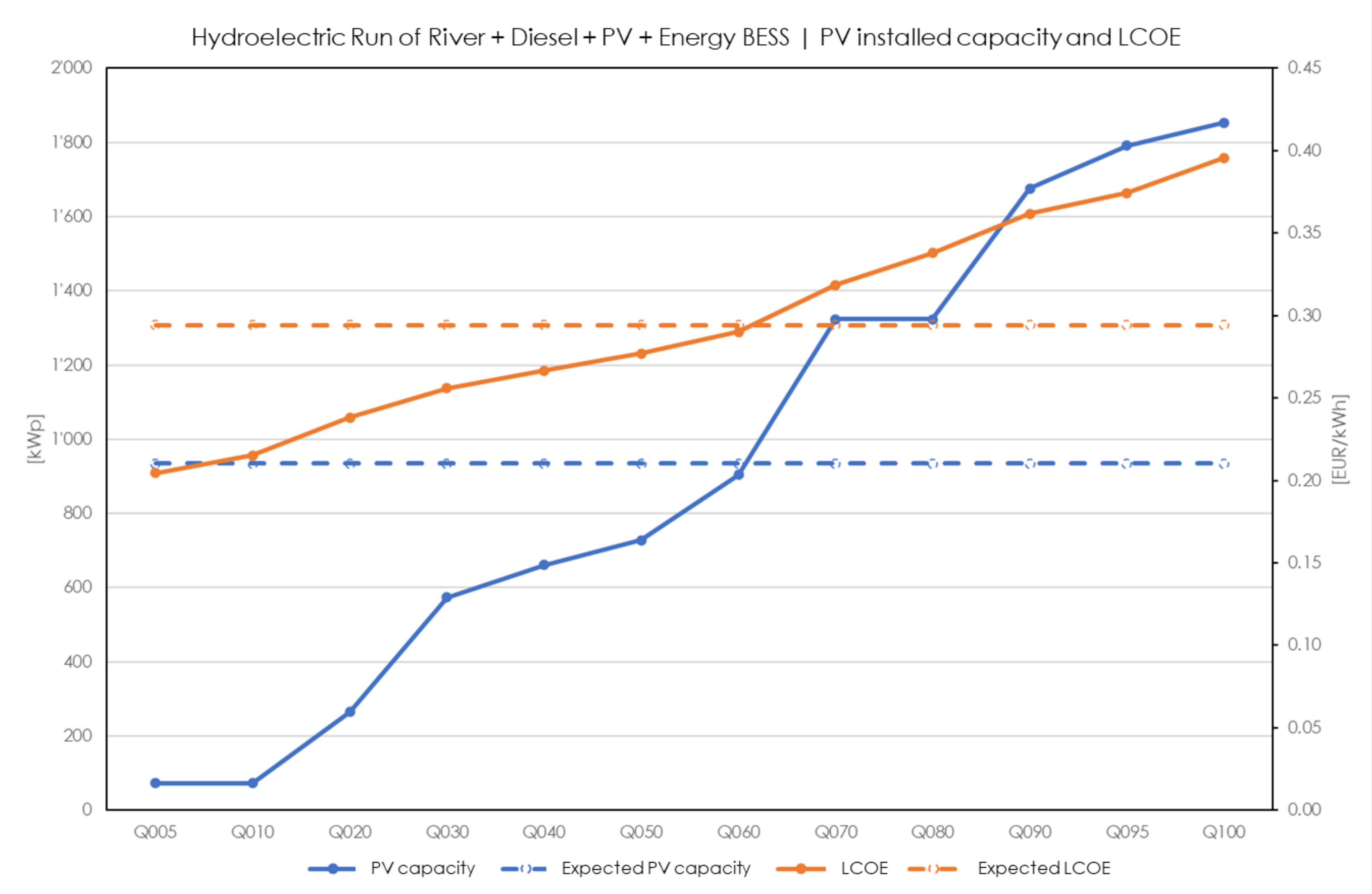
Results

- Hydroelectric with **Dam + Diesel + PV + Power BESS**
  - PV capacity and LCOE variation for different water inflows probabilities



Results

- Hydroelectric **Run of River + Diesel + PV + Energy BESS**
  - PV capacity and LCOE variation for different water inflows probabilities
  - **Higher amount of PV capacity** than in the case of reservoir dam



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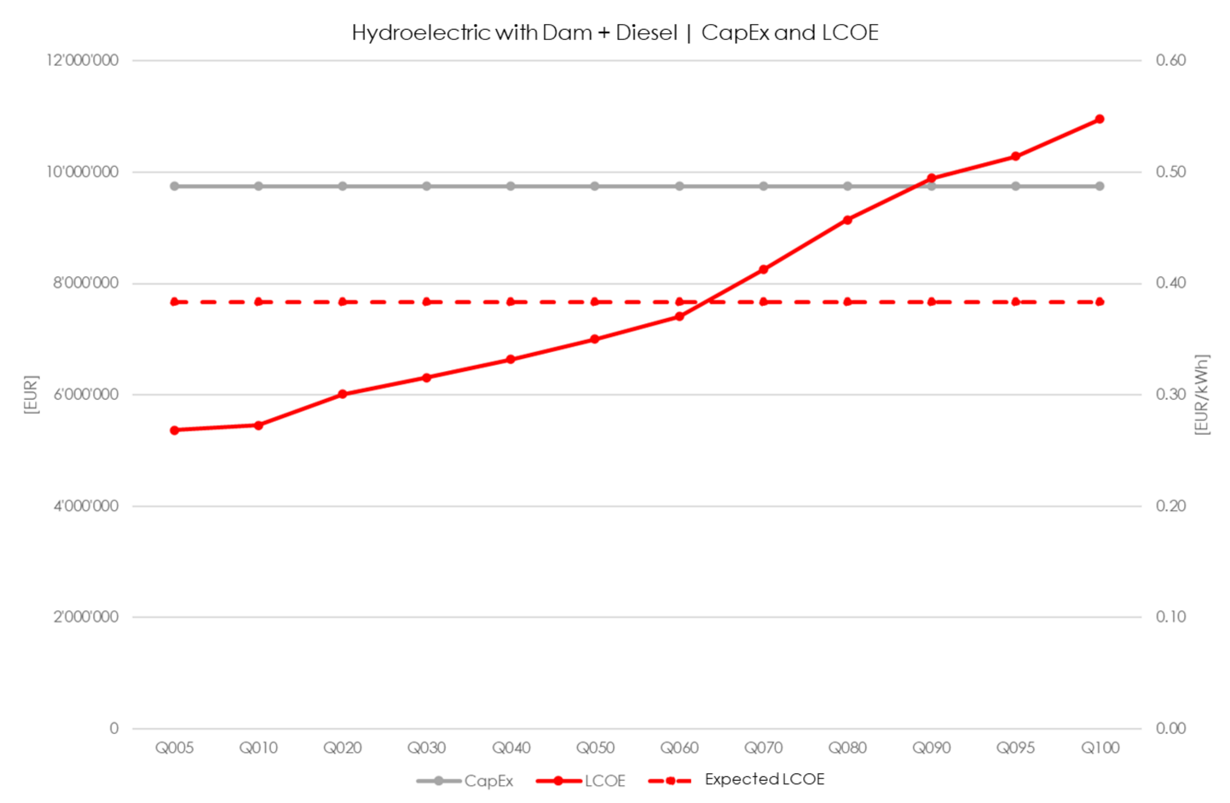
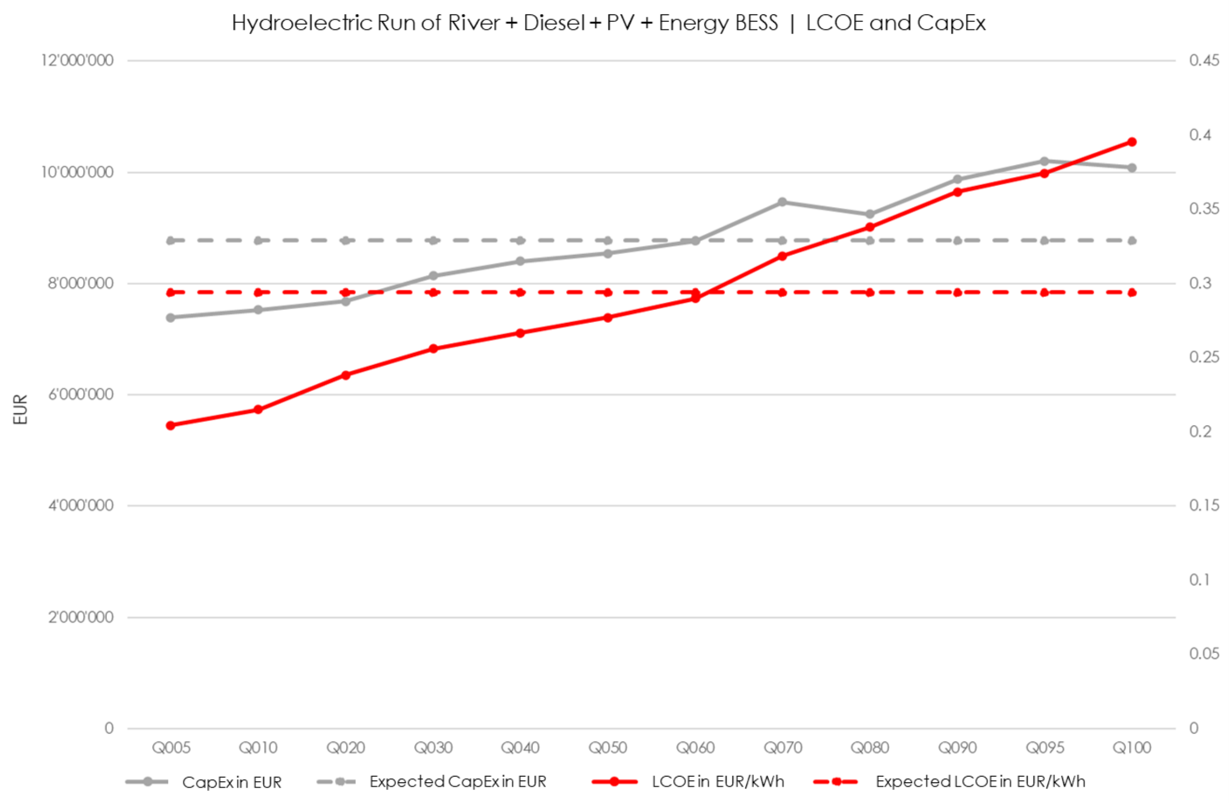
Results

- Hydroelectric Dam + Diesel vs. Hydroelectric Run of River + Diesel + PV + Energy BESS energy mix
  - CapEx and LCOE variation for different water inflows probabilities





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Results overview

- Scenarios results order from lower to higher LCOE

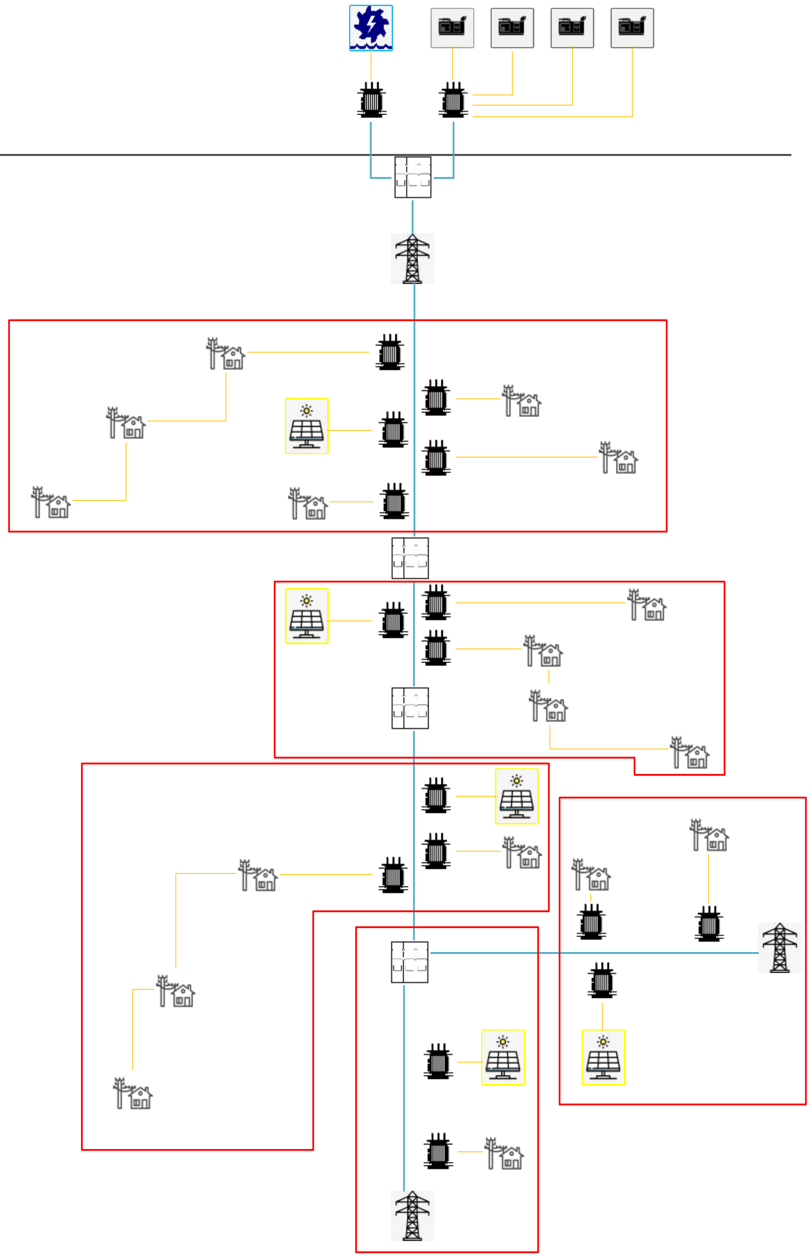
Energy Mix	PV capacity	Battery Capacity	LCOE
– Hydro RoR + Diesel + PV + energy BESS	950 kWp PV	2’900 kWh BESS	0.29 EUR/kWh
– Diesel	0 kWp PV	0 kWh BESS	0.34 EUR/kWh
– Hydro Dam + Diesel	0 kWp PV	0 kWh BESS	0.38 EUR/kWh
– Hydro Dam + Diesel + PV + Power BESS	590 kWp PV	236 kWh BESS + 9’150 kWh Dam	0.41 EUR/kWh

- Scenarios results order from lower to higher CapEx

Energy Mix	CapEx	OpEx	LCOE
– Diesel	1 M EUR	1’600 k EUR/year	0.34 EUR/kWh
– Hydro RoR + Diesel + PV + energy BESS	9 M EUR	600 k EUR/year	0.29 EUR/kWh
– Hydro Dam + Diesel	10 M EUR	900 k EUR/year	0.38 EUR/kWh
– Hydro Dam + Diesel + PV + Power BESS	12 M EUR	800 k EUR/year	0.41 EUR/kWh

System structure & control

- **Central hydroelectric** power generation with **Diesel** generators power plant
- **Distributed** PV and BESS generation
- **Grid forming** capability: Hydroelectric, Diesel, BESS
- **Operation: One source in grid forming** and other sources in grid following in **droop mode** (grid alleviation)
- **MV segments isolation** capability
- **LV load shedding** capability



Conclusion

- The optimal system consists of a **hydroelectric plant without reservoir dam** supplemented by a **PV plant with batteries (Lithium)** and **diesel generators**.
- We present the advantages and disadvantages of the solution of replacing the **dam with diesels** with a **run-of-river with PV and storage in lithium batteries** for this specific project.

Advantages	Disadvantages
Lower CapEx	Lower asset value
Lower OpEx	Loss of efficiecny in batteries
Lower LCOE	Capacity losses in time
Load adaptation capability	Battery recycling
Higher renewable share	Less mature technology
Lower construction time	Repacement and addition needs
Easier maintenance	Cooling needs
Distributed solution that reinforces the grid	Theft proness
Higher quality ancillary services	

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