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Energy transition - Project

LIÈGE université
School of Engineering

Outline

- Technologies used
- Electrical mix, first idea
- Improvement idea
- Weather and topography analysis
- Mathematical model for a dam
- Final electrical mix
- Conclusion

Technologies

Photovoltaic panels

Wind turbine

Battery

But also :

Import

Export

Implementing in a model of expansion planning

Model formulation

Market clearing: $g + ens + (sd - sc) + import - export = DEMAND$

Import : $import \leq IMPORT\ MAX\ CAP$

Export : $\text{export} \leq EXPORT\ MAX\ CAP$

Technologies : $cap_{tech} \leq TECH\ MAX\ CAP$

Power : $g \leq AF * cap_{tech}$

Energy not served : $ens \leq DEMAND$

Fuel cost : $fcd \leq g * MARGINAL\ FUEL\ COST$

Storage equation :

$$cap_{sto} \leq STO\ MAX\ CAP$$

$$e_{t+1} - e_t = \tau\, \eta^c sc_t - \tau \frac{sd_t}{\eta^d}$$

$$\mathrm{e}_{\mathrm{t=0}} - \mathrm{e}_{\mathrm{t=T}} = -\tau\, sd_T - \tau sc_T$$

$$sc \leq \frac{cap_{sto}}{STO_{dt}} \qquad sd \leq \frac{cap_{sto}}{STO_{dt}}$$

$$SOC\ MIN\ * cap_{sto} \leq se \leq SOC\ MAX\ * cap_{sto}$$

CO2 emissions :

$$co2_{emmision} = CO2\ INTENSITY * g + CO2\ IMPORT * import$$

CO2 maximum:

$$co2_{emmision} = CO2\ BOUND$$

Curtailment:

$$curt = (AF * cap_{tech} - g) * RE\ MASK$$

Total cost (objective function):

$$total\ cost = TECH\ IC * cap_{tech} + STO\ IC * cap_{sto} + \Delta t * fcd + \Delta t * VOLL * ens + IMPORT\ PRICE * import + EXPORT\ PRICE * export$$

PV panels

→unlimited capacity

Efficiency of 20.5%

Lifetime of 35 years

Investment cost = 870 k€/MW

O&M fixed = 10.6 k€/MW/y

O&M variable = 10 €/MWh/y

Source: Danish Energy Agency (Technology Data for Generation of Electricity and District Heating)

Wind turbine

→ unlimited capacity

Efficiency of 47%

Lifetime of 27 years

Investment cost = 1.11 M€/MW

O&M fixed = 16.4 k€/MW/y

O&M variable = 2 €/MWh/y

Source: Danish Energy Agency (Technology Data for Generation of Electricity and District Heating)

Battery

Battery of 3 MW

During 4h

→ Maximal capacity of 12 MWh

Efficiency of 85 %

Lifetime = 25 years

State of charge ∈ $[0.2; 0.8]$

Investment cost = 500 k€/MWh

Source : Invinity data sheet (https://invinity.com/wp-content/uploads/2024/12/Invinity-ENDURIUM-Data-Sheet-MAR000020-2024-12.pdf?_gl=1*lzgj6v*_up*MQ..*_gs*MQ..&gclid=CjwKCAiA65m7BhAwEiwAAgu4JFqYz_U4PtidA2i2jJlRaFiS13FNLzbv9fz0VtaHFF2xsj7x1VRSZBoCTVQQAvD_BwE)

National grid

Import and Export

→ Unlimited capacity

Composed of 80 % of hydropower

→ import not expensive

Import price of 74 €/MWh

Export price of 20 €/MWh

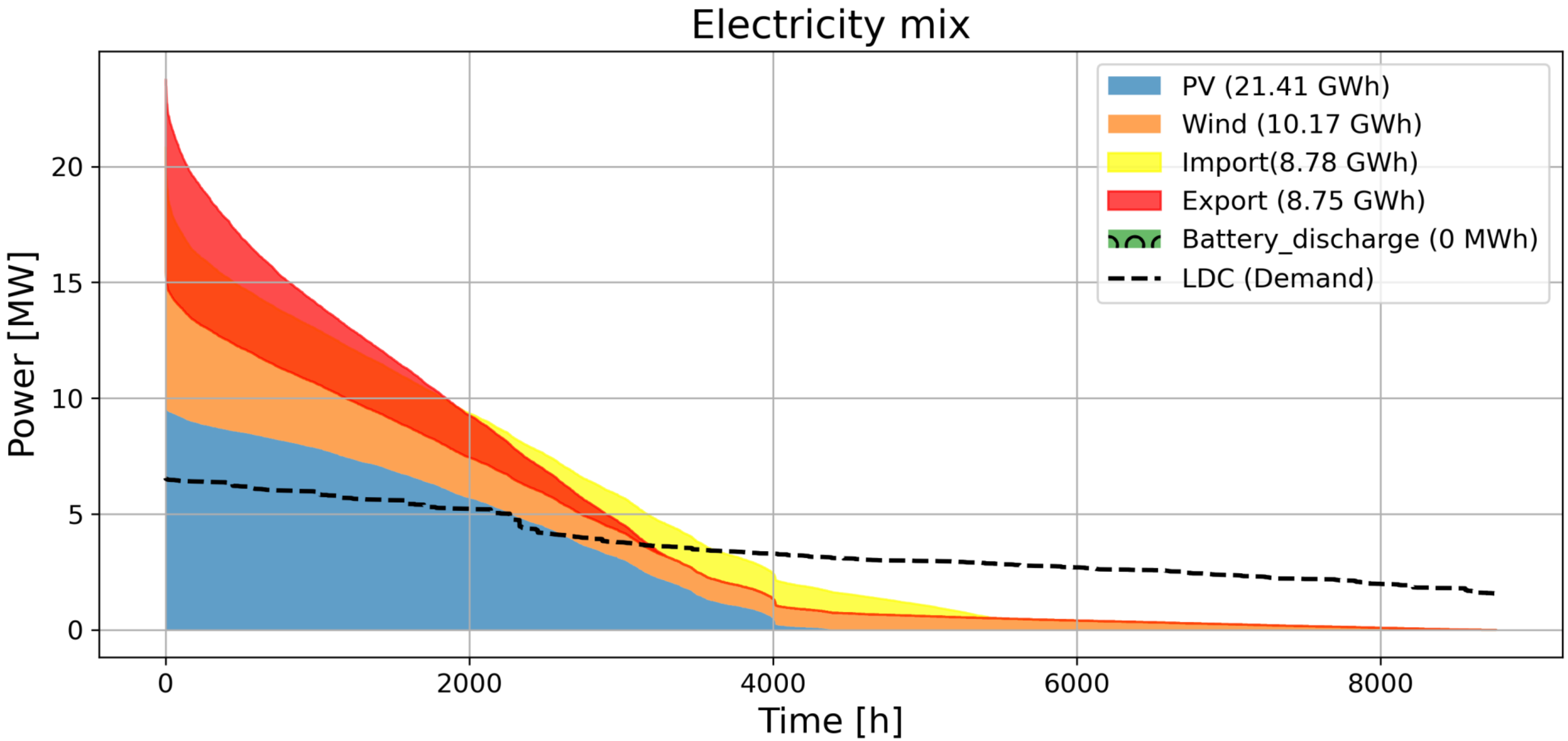
Demand

Electrical consumption of 31.6 GWh

Colling produce with absorption chiller → solar pannel and biomass, so no electrical consumption.

→ total demand of 31.6 GWh

Electrical mix – First version



7.1 MW of wind turbine

12.9 MW of PV

1.562 M€

LCOE = 49.40 €/MWh

Comparaison with results of last semester

Last semester	This semester
LCOE = 60 €/MWh	LCOE = 49 €/MWh
PV = 4.4 MW	PV = 12.9 MW
Wind turbine = 4.9 MW	Wind turbine = 7.1 MW
Energy stored = 3.5 GWh	Energy stored = 0 GWh

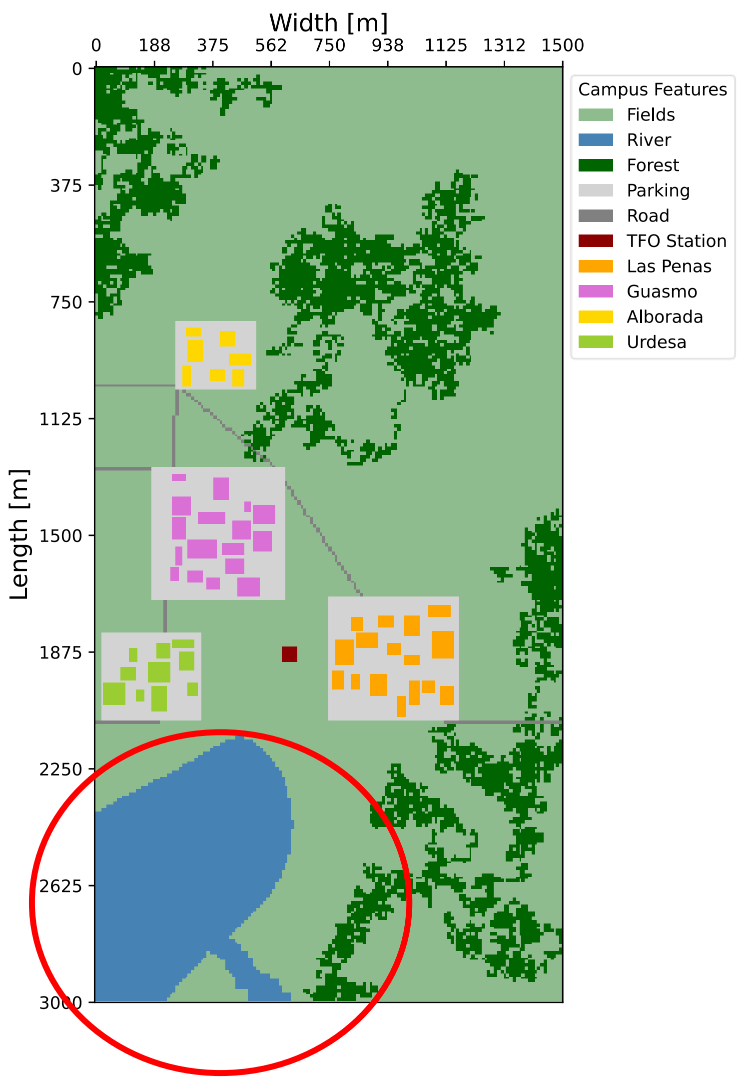
Same import and export price, but enhance of renewable energy and battery prices which were not accurate (particullary information about PV).

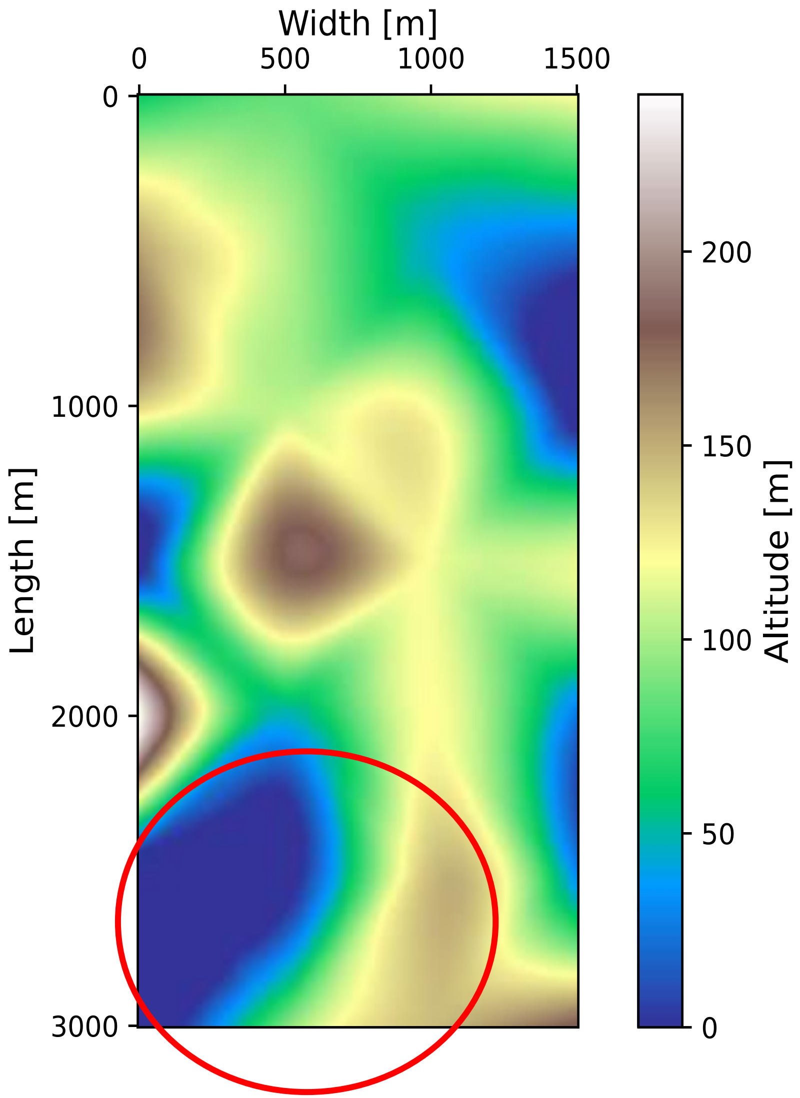
A step further

- The national energy mix contains 80% hydropower. However, hydropower prices vary significantly depending on rainfall.

➔ Design and implementation of a dam on campus, along with analysis over several weather years using uncertainty model.

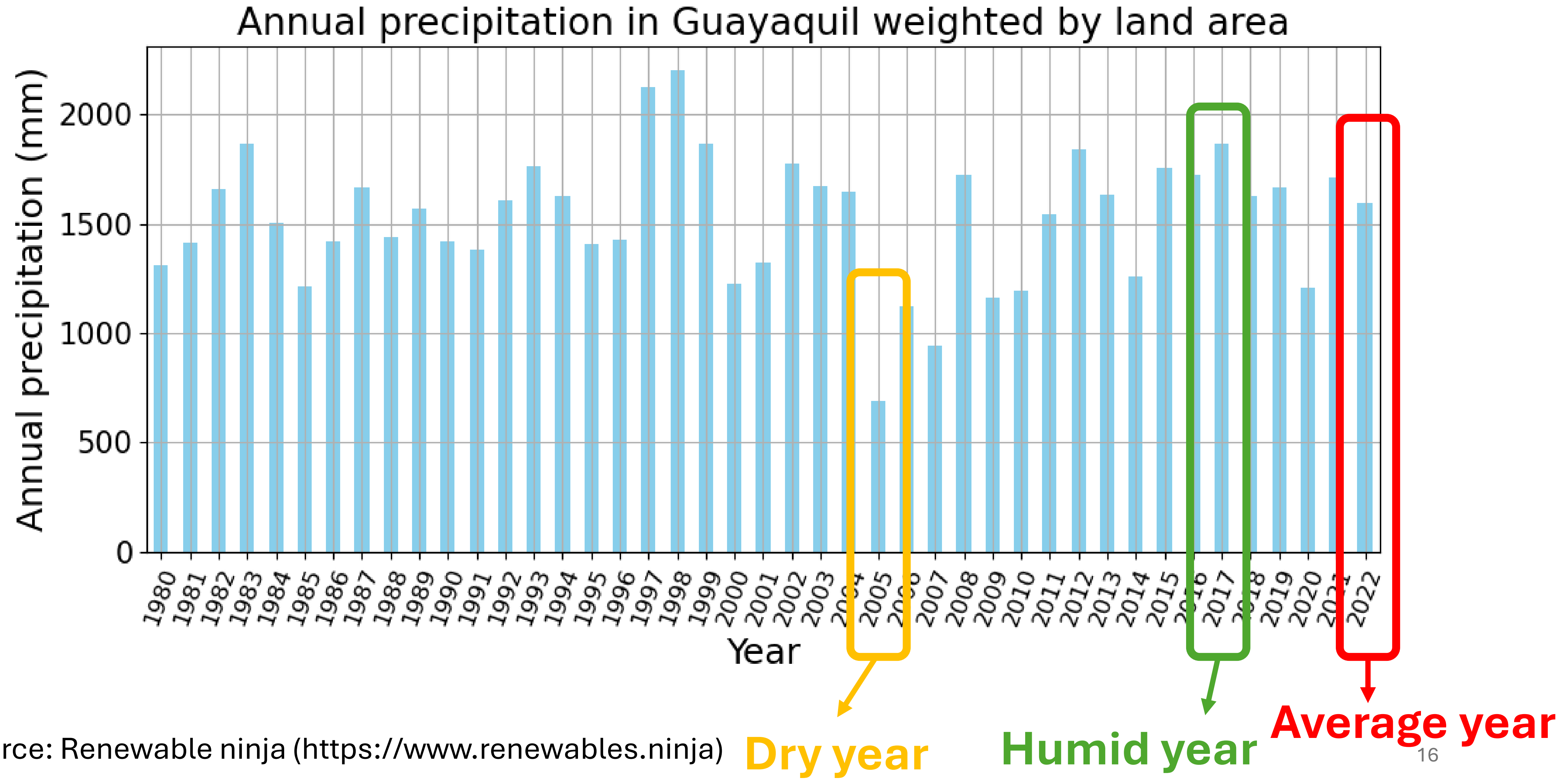
Topography analysis





- ➔ River available on the campus
- ➔ Head of 150m
- ➔ Installation of the dam there

Weather analysis



Source: Renewable ninja (https://www.renewables.ninja)

Precipitation translation

[MWh]

Dimensionalised using an average year (2022) as reference.

$$\text{CF} = \frac{\sum P_{inflow}\,\tau}{D_{max}\,\tau\,8760} = 70\%$$

$$= \frac{\frac{\sum P_{inflow}}{D_{max}}\,\tau}{\frac{D_{max}}{D_{max}}\,\tau\,8760}$$

$$\Leftrightarrow \frac{\sum P_{inflow}}{D_{max}} = 0.7 \ * 8760 = 6132\ h$$

Precipitation translation

$$\frac{\sum P_{inflow}}{D_{max}} = 0.7 \ * 8760 = 6132 \text{ [h]}$$

$$\alpha = \frac{\sum P_{inflow}[MW](2022)}{\sum P_{inflow}\left[\frac{mm}{h}\right](2022)} \frac{1}{D_{max}}$$

$$= \frac{6132}{701.881} = 8.74$$

Constant converting all the precipitation in power

$$\Rightarrow \sum P_{inflow}[MW](t) = \sum P_{inflow}\left[\frac{mm}{h}\right](t) \times \frac{\alpha}{D_{max}}$$

➔ D_{max} is the variable representing the installed power of the power plant. The value of P_{inflow} is adimensionalised with D_{max} . It will be multiplied later by cap_{dam}, a variable representing the installed capacity.

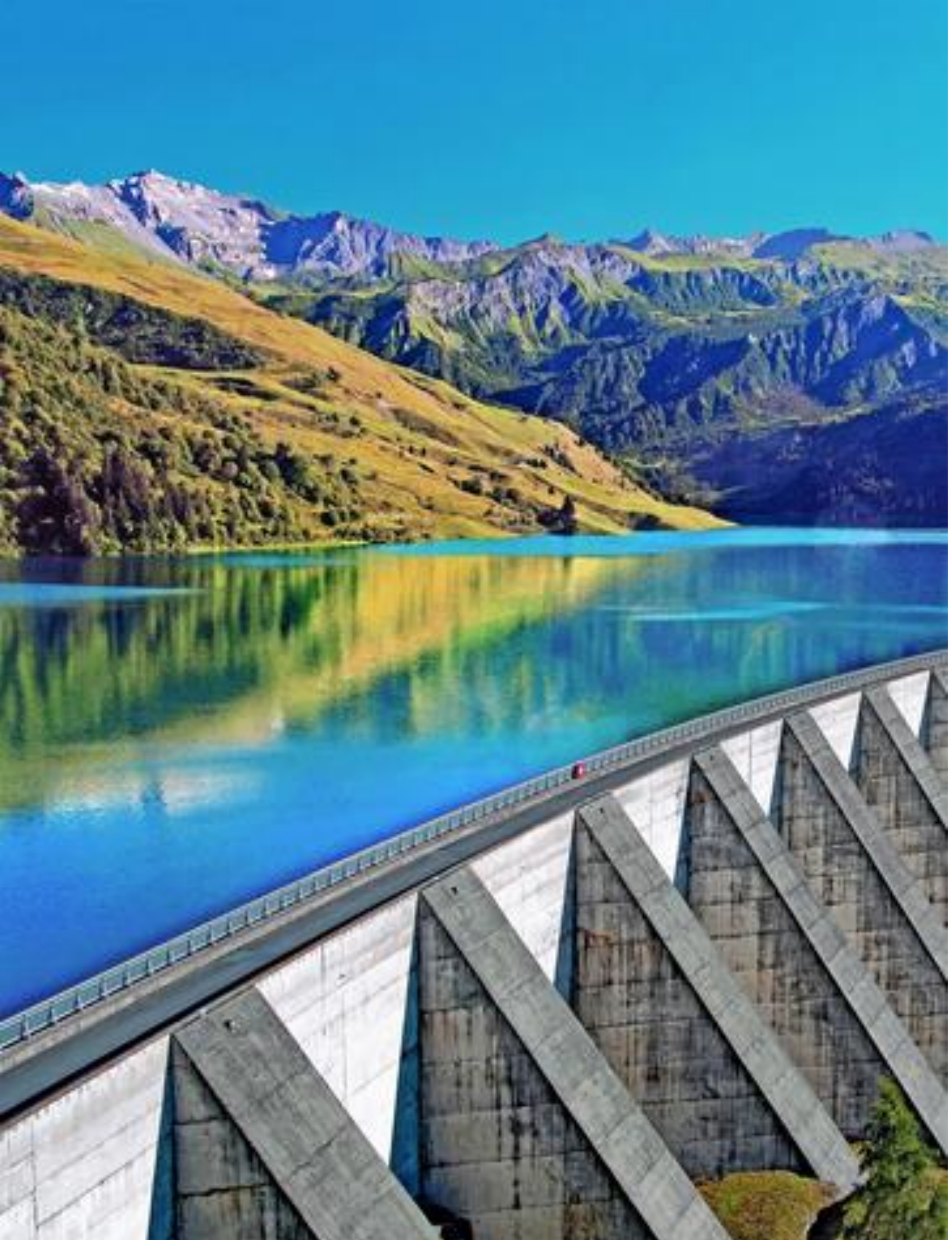
Assumptions

Uncertainty is applied on the model

Propability of 60% of an average year, based on precipitation.

Probablility of 20% for a dry year

Probability of 20% for a humid year.



Dam

Capacity stored : 100 MWh

Empty in 20h

Efficiency of 75%

Lifetime = 75 years

Assume already constructed

→ Investment price of 0 €/MWh

Dam storage equations

No environmental flow is considered

$\in [0; \infty]$

<u>Balance</u> :

$$e_{t+1} - e_t = \cancel{\tau\, \eta^c sc_t} - \tau \frac{sd_t}{\eta^d} + \tau\left(p_{inflow,t} - \cancel{P_{outflow,t}} - P_{spill,t}\right)$$

$$= P_{inflow,t} \times \frac{cap_{dam}}{DAM_{dT}}$$

Only power generation, no pumping.

<u>Initial state</u> :

$$\mathrm{e}_{\mathrm{t=0}} - \mathrm{e}_{\mathrm{t=T}} = -\tau\, sd_T - \tau P_{spill,T} + \tau P_{inflow,T}$$

Where T is the last time step

Capacity max :

$$cap_{dam} \leq 100\ MWh$$

This maximum capacity corresponds to a reservoir holding 326 200 m^3 of water.

Discharge max :

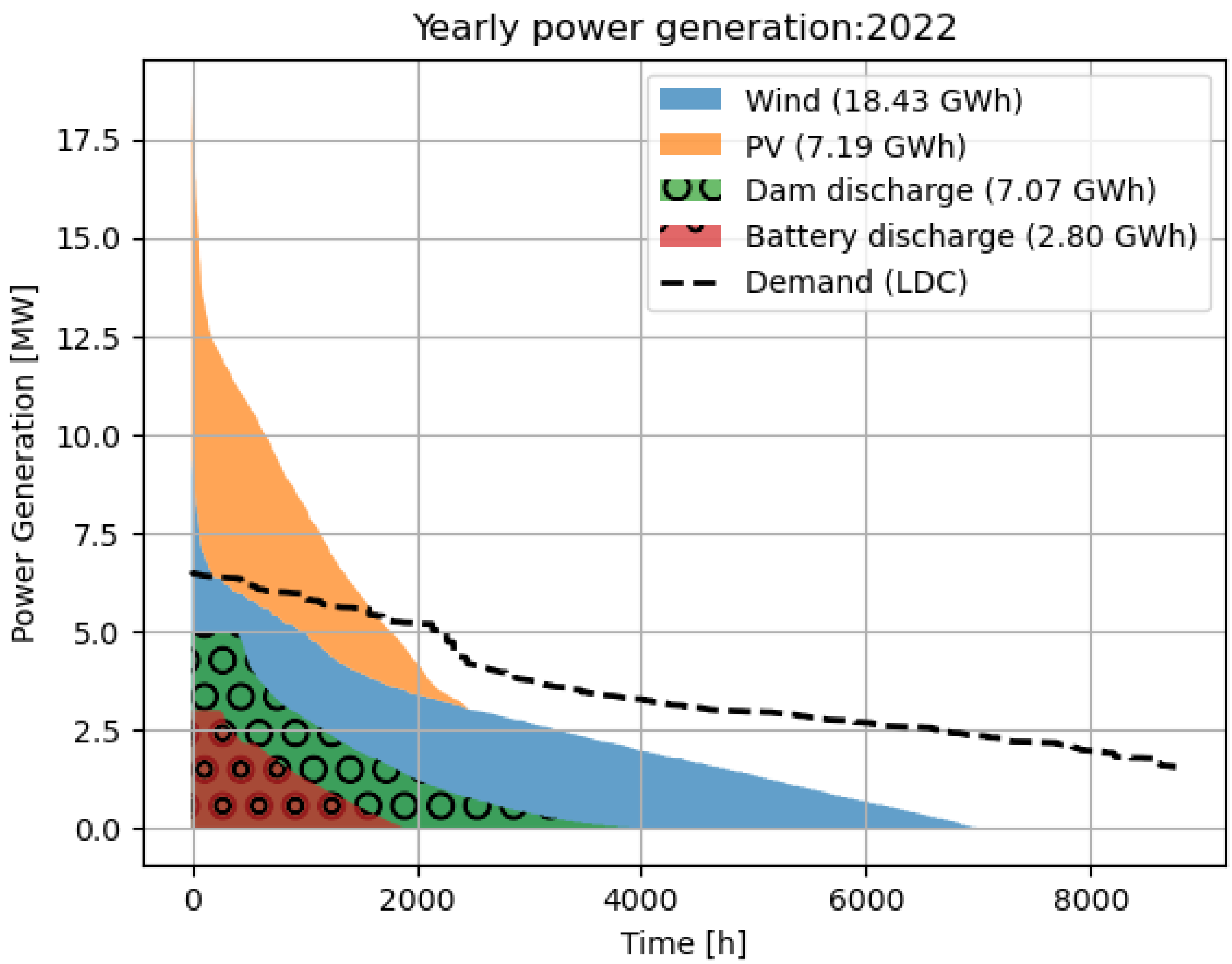
$$sd \leq \frac{cap_{dam}}{Dam_{dt}} = \frac{100\ MWh}{20\ h}$$

Energy stored range:

$$0 \leq se \leq \ cap_{dam}$$

There is no minimum water required in the reservoir

Final electrical mix



Power installed

PV panels : 17.4 MW

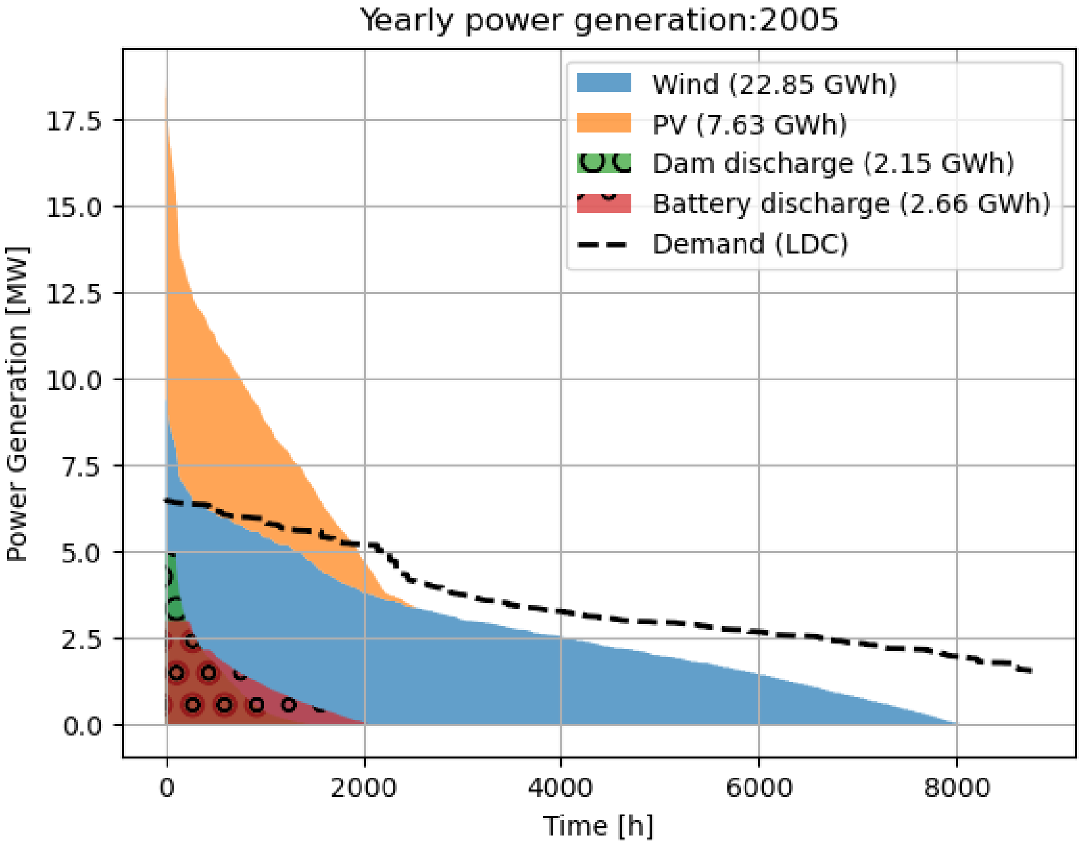
Wind turbine : 32 MW

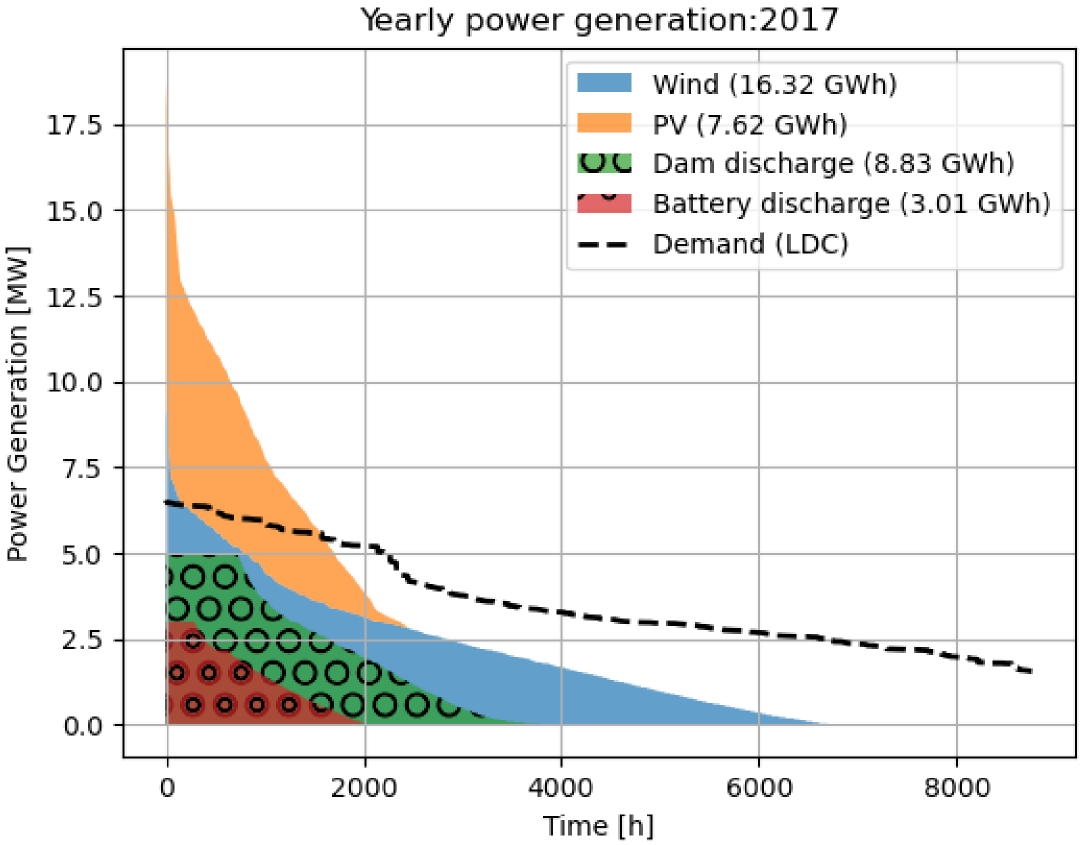
Dam : 5 MW (20h)

Battery : 3 MW (4h)

Dry year

Humid year



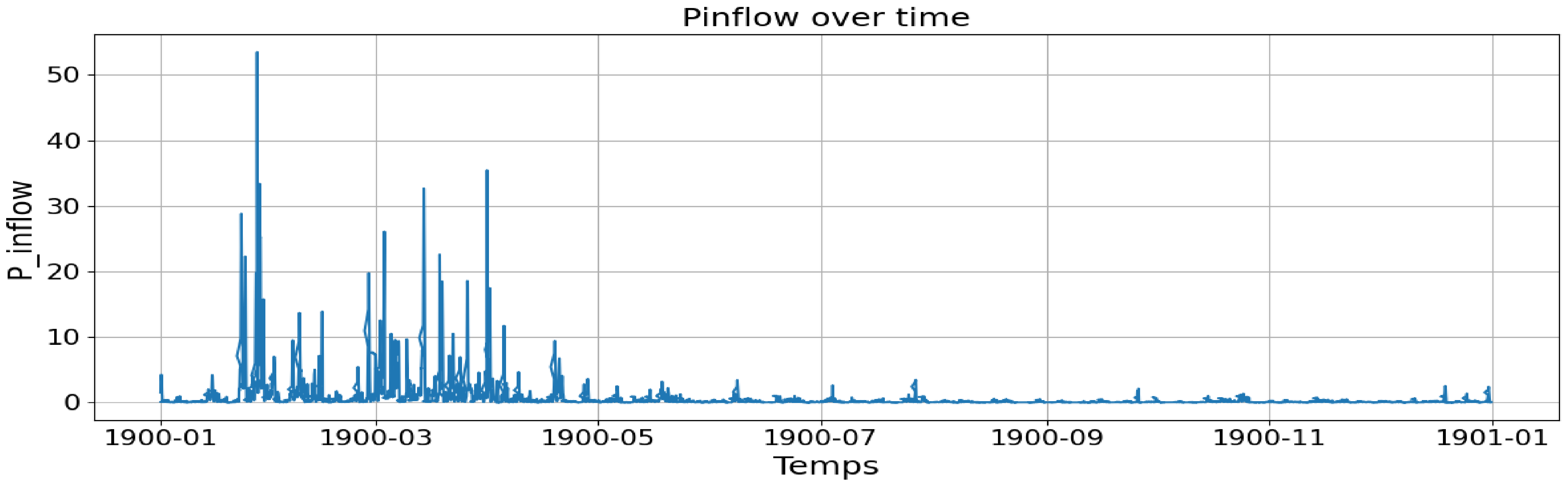


Total cost : 3.4 M€ → LCOE = 106.60 €/MWh

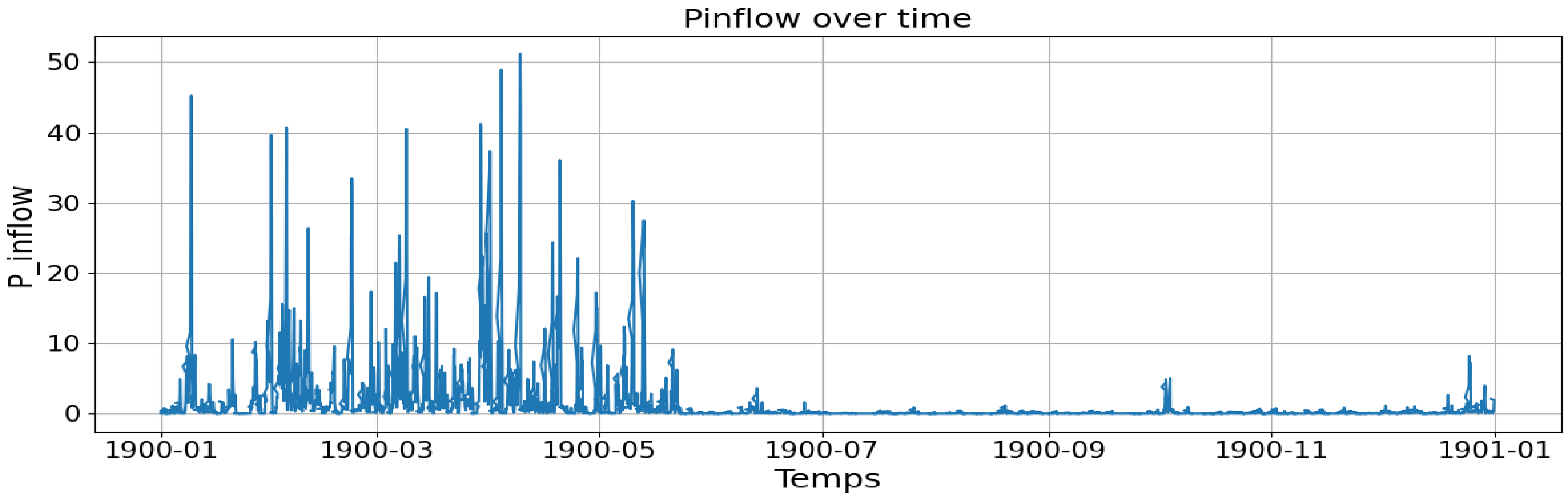
Why doesn’t the dam store more ?

- There is a strong seasonal contrast between the humid and dry periods in Ecuador.
- There was more water in 2017 due to extrem rainfall.
- When extrem rainfall occurs, the reservoir is quicly full, so the excess water is splilled rather than stored. In 2017, 80 % of water was spilled from the dam.

2022


Pinflow over time
P_inflow
0
10
20
30
40
50
1900-01
1900-03
1900-05
1900-07
1900-09
1900-11
1901-01
Temps

2017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1900-11
1901-01
Temps

Conclusion

- Integrating the dam on the campus allows to observe the variability of hydropower in Ecuador.
- These fluctiations cause variations in the cost of importing electricity from the national grid.
- The final Levelized cost of Electricity (LCOE) is much higher, since more renewable energy sources must be available to meet electricity demand, even when water suffly is insufficient.
- Link to the online repositery : https://github.com/Zazhein/Energy_transition

Thank you!