Investments in Hybrid Renewable Energy Systems in mountain communities

Anna Carozzani[1], Chiara D’Alpaos [1,2], Michele Moretto [3,2]

8th AIEE Energy Symposium

11. Energy communities: some cases

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[1] Department of Civil, Environmental and Architectural Engineering - University of Padova

[2] Interdepartmental Centre “Giorgio Levi Cases” for Energy Economics and Technology

[3] Department of Economics and Management - University of Padova

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Background

Hybrid Renewable Energy System (HRES)

(Bajpai & Dash, 2012)

- Small Hydropower Plant (SHP)
- Photovoltaic Plants with battery-storage system (PVB)

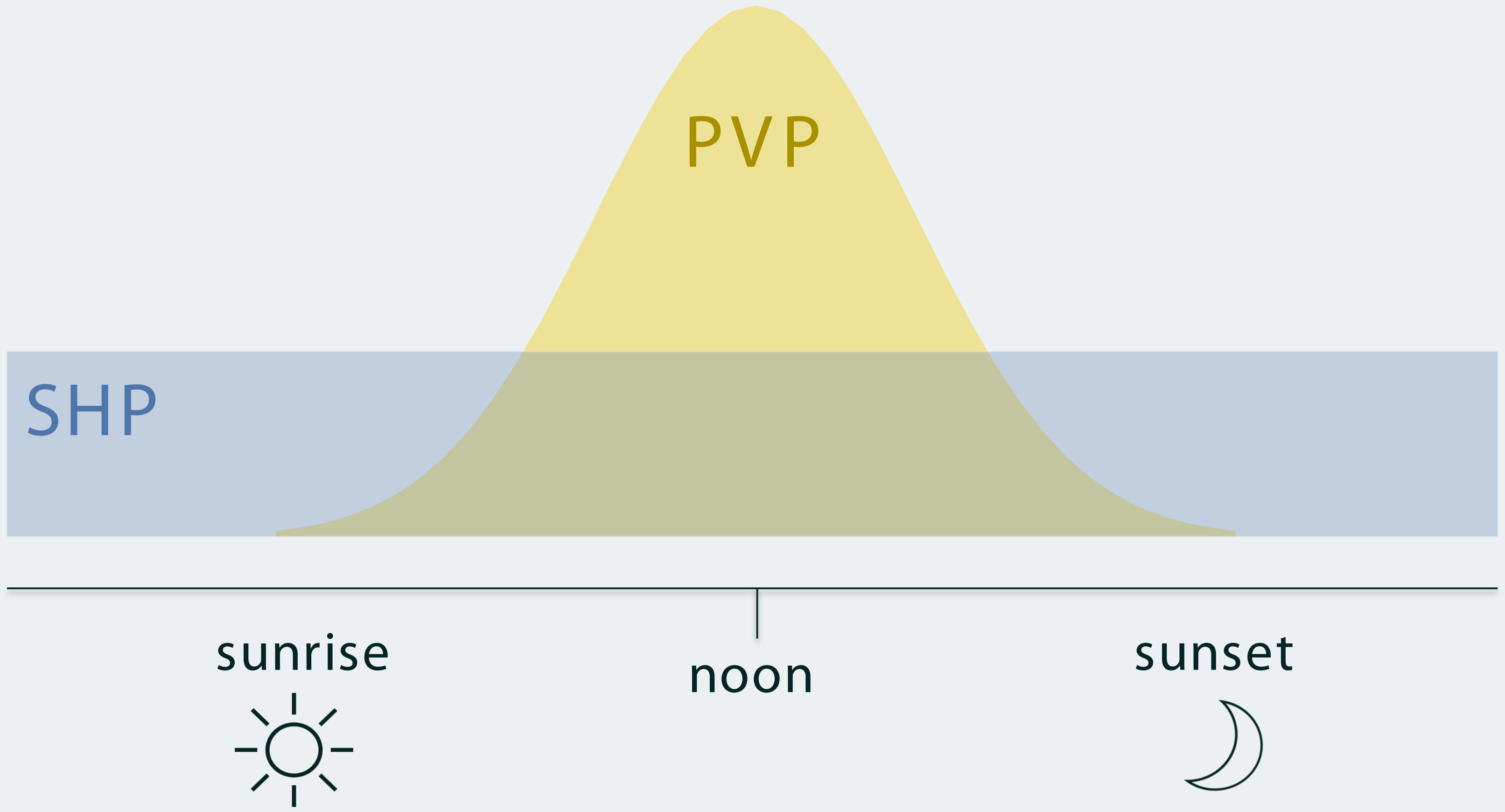
Mountain community

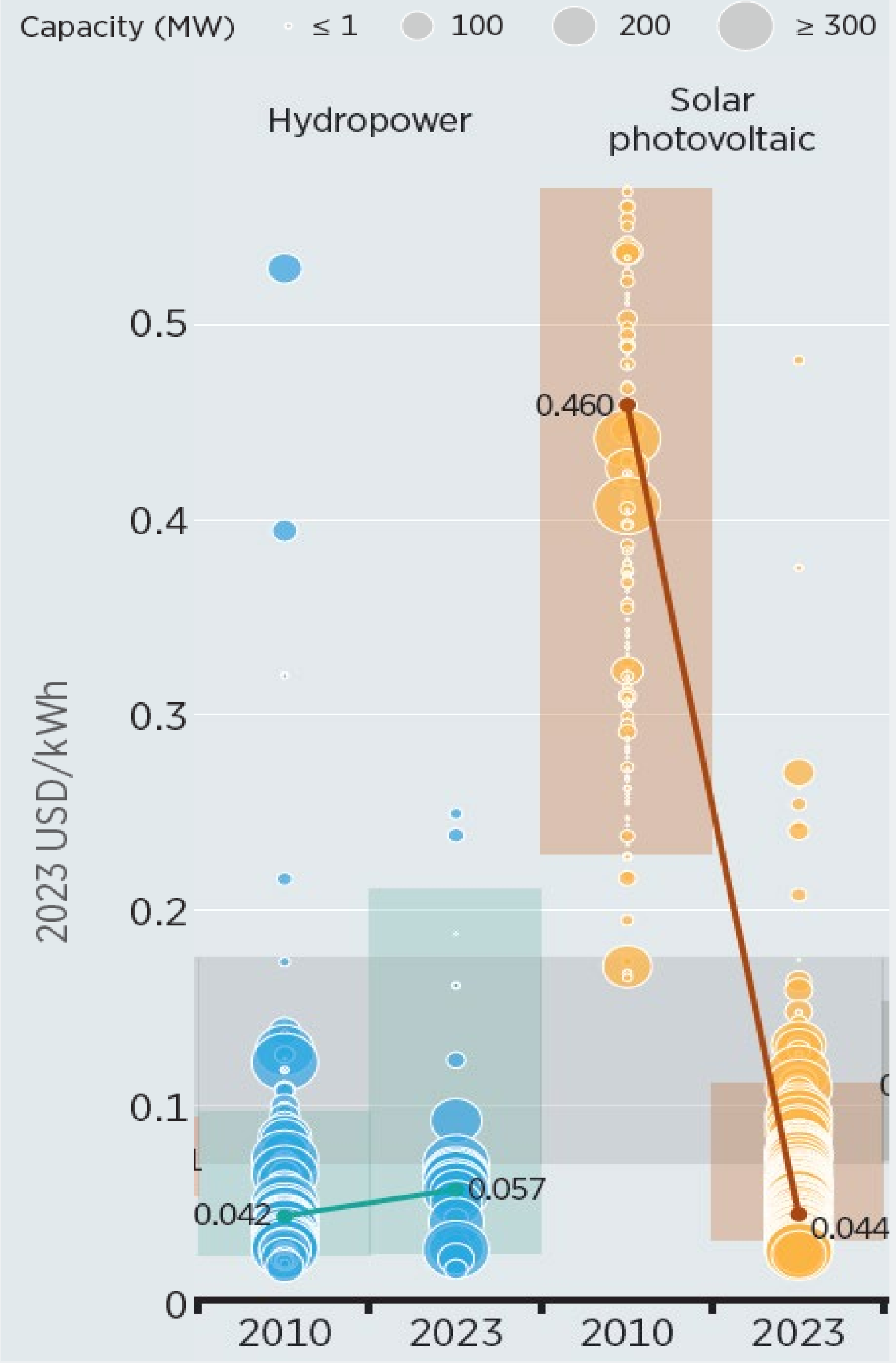
- Natural resource’s availability
- From Community Cooperatives to Renewable Energy Communities *(Robert et al., 2020)*

The Alpine villages producing their own power
Article on BBC site bySophieHardach.

Motivations

- Though the size of PVP is **potentially unlimited**, production is **intermittent,** but energy can be stored
- The size of SHP is **constrained** by the amount of water resources available, and it's typically **quite profitable** even if LCOE is highly variable *(Klein & Fox, 2022)*
- **Complementarity** between the 2 sources at daily scale *(Borkowski et al., 2021)*





LCOE (Irena, 2024)

Research Questions

What is the economic value and the optimal investment size of an HRES combining SHP and PVB to meet a constant energy demand in a mountain community?

Is there a flexibility value in managing the production mix of SHP and PVB and what is the investment strategy in such an HRES? (work in progress...)

Methodology

1 **MODEL SET-UP FORMULATION**

Technological and economic variables, uncertainty, parameters, assumptions

2 **THE MODEL**

OPTIMIZATION
Decision variables
Constraints
Objective function

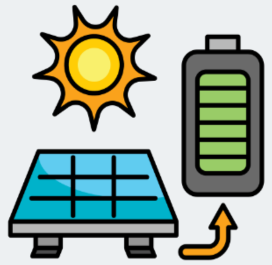
Dynamic Programming (DP) →

Optimal plants' sizes (a*, h*)
Trigger price (p*)

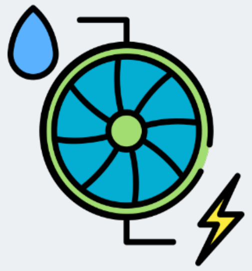
3 **MODEL CALIBRATION**

Available datasets and literature

1 Model set-up: Basic functions



a = PVP production



h = SHP production

Community Energy Demand

$$\underbrace{D = 1\,MWh}_{\text{energy demand}} = \underbrace{\alpha[\xi(a) + \eta_s\,(a - \xi(a))]}_{\text{energy from PVB}} + \underbrace{(1 - \alpha)h}_{\text{energy from SHP}} + \underbrace{\gamma}_{\text{purchased energy}}$$

Investment Cost Function → *f(LCOE)*

$$I^{HRES} = I^{PVB} + I^{SHP}$$

$$= [\,k_0 + k_1(a)] + [k_2\left(a - \xi(a)\right)] + [\,k_c + k_{sh}\,(h)^{\,b/d}\,]$$

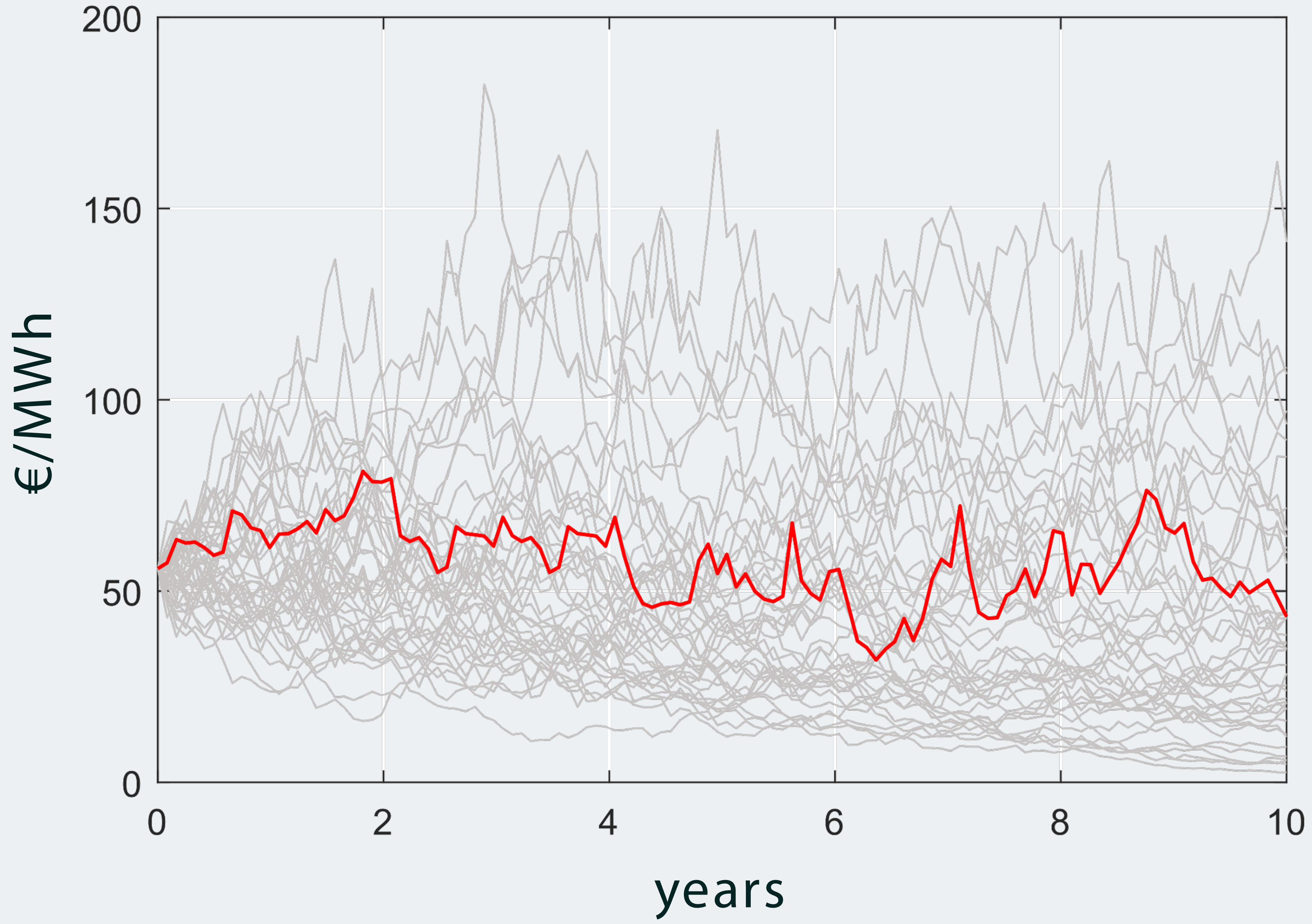
1 Model set-up: Purchased Energy Price

Geometric Brownian Motion (GBM) process for buying price of energy

$$dp_t = \delta p_t dt + \sigma p_t dz_t$$

Parameter	Annual	Monthly
Drift, δ	0.02	0.002
Volatility, σ	32.35%	9.34%

Monthly PUN prices (€/MWh), 120 data from 2010-2019 and GBM realizations



2 The model: Optimization & DP

HRES investment value

$$V\left(p_\tau, a, h, \alpha\right) = \mathbb{E}_\tau\left[\int_\tau^\infty e^{-r(t-\tau)} \underbrace{p_t\,(\overbrace{D-\gamma}^{\text{purchased energy savings}})}_{\text{cost savings}}\,dt - \underbrace{I_{HRES}(a,h)}_{\text{investment costs}}\right]$$

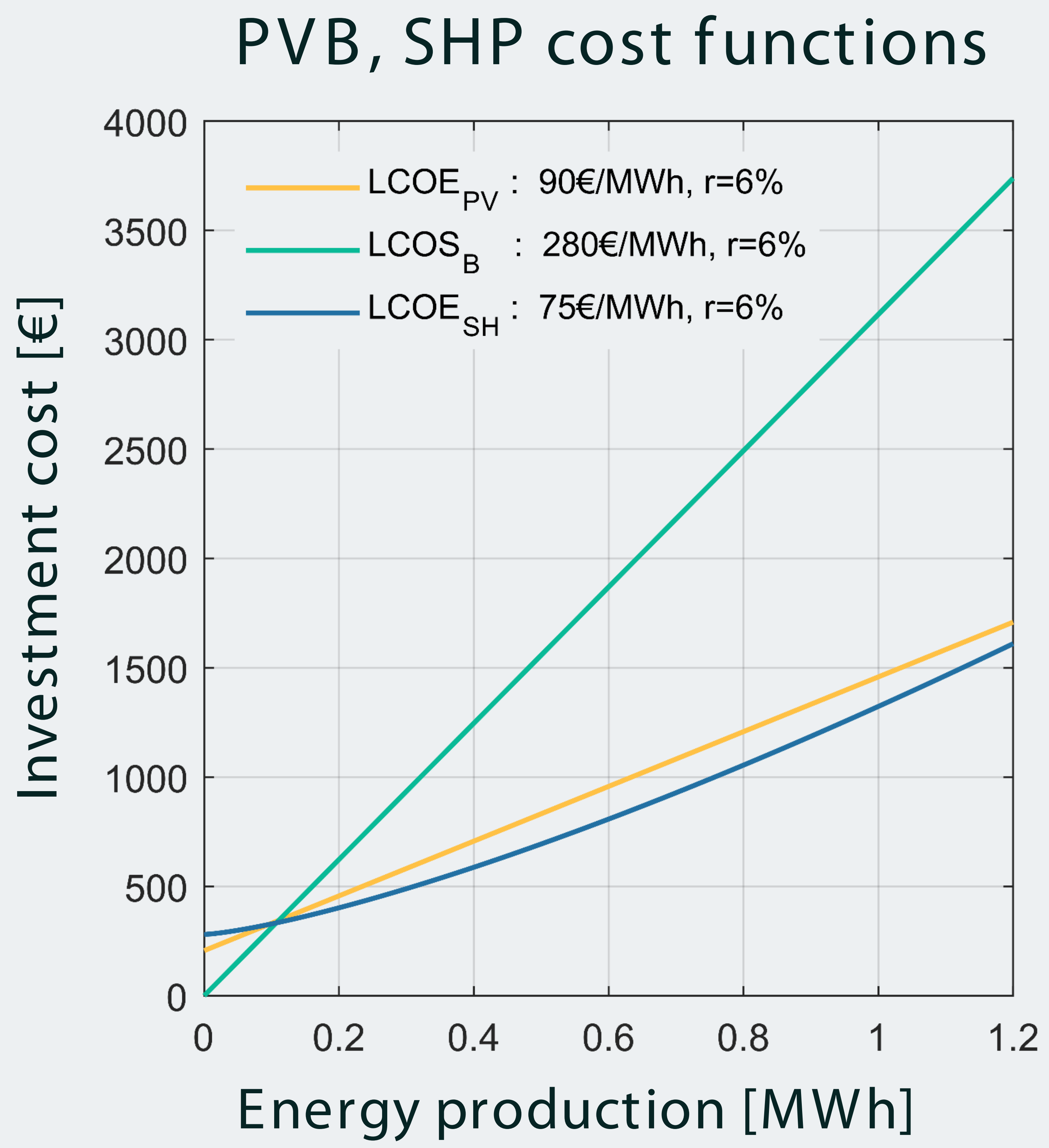
Optimal sizes :

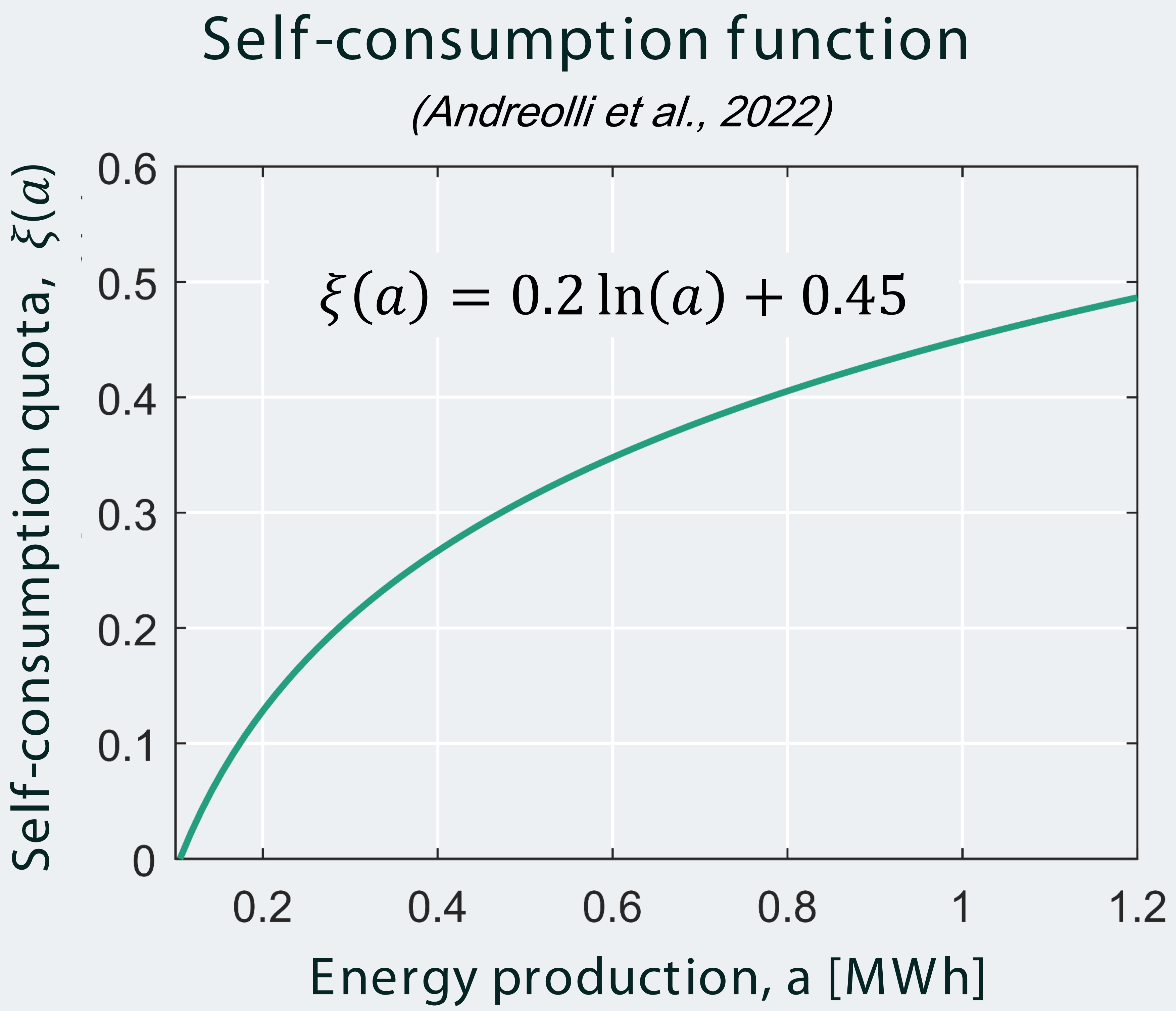
$$a^*, h^* = \underset{p_\tau,\,\alpha}{\arg\max}\left[V\left(p_\tau, a, h, \alpha\right)\right]$$

Trigger price :

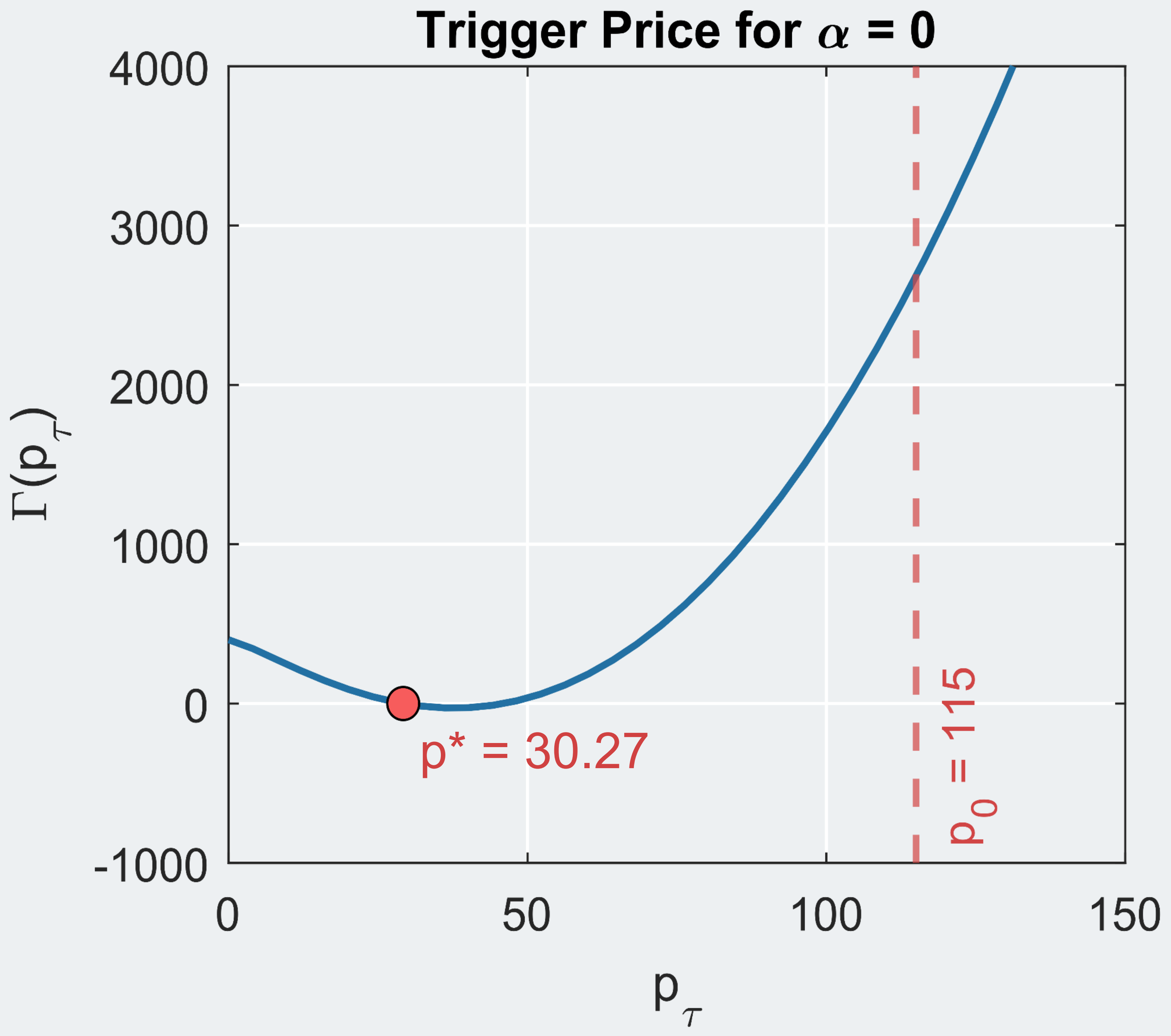
$$p^* \rightarrow F(p_\tau) = \max_\tau \mathbb{E}\left[V\left(p_\tau, a^*, h^*, \alpha\right)e^{-r\tau}\right]$$

3 Calibration





Preliminary Results : SHP only

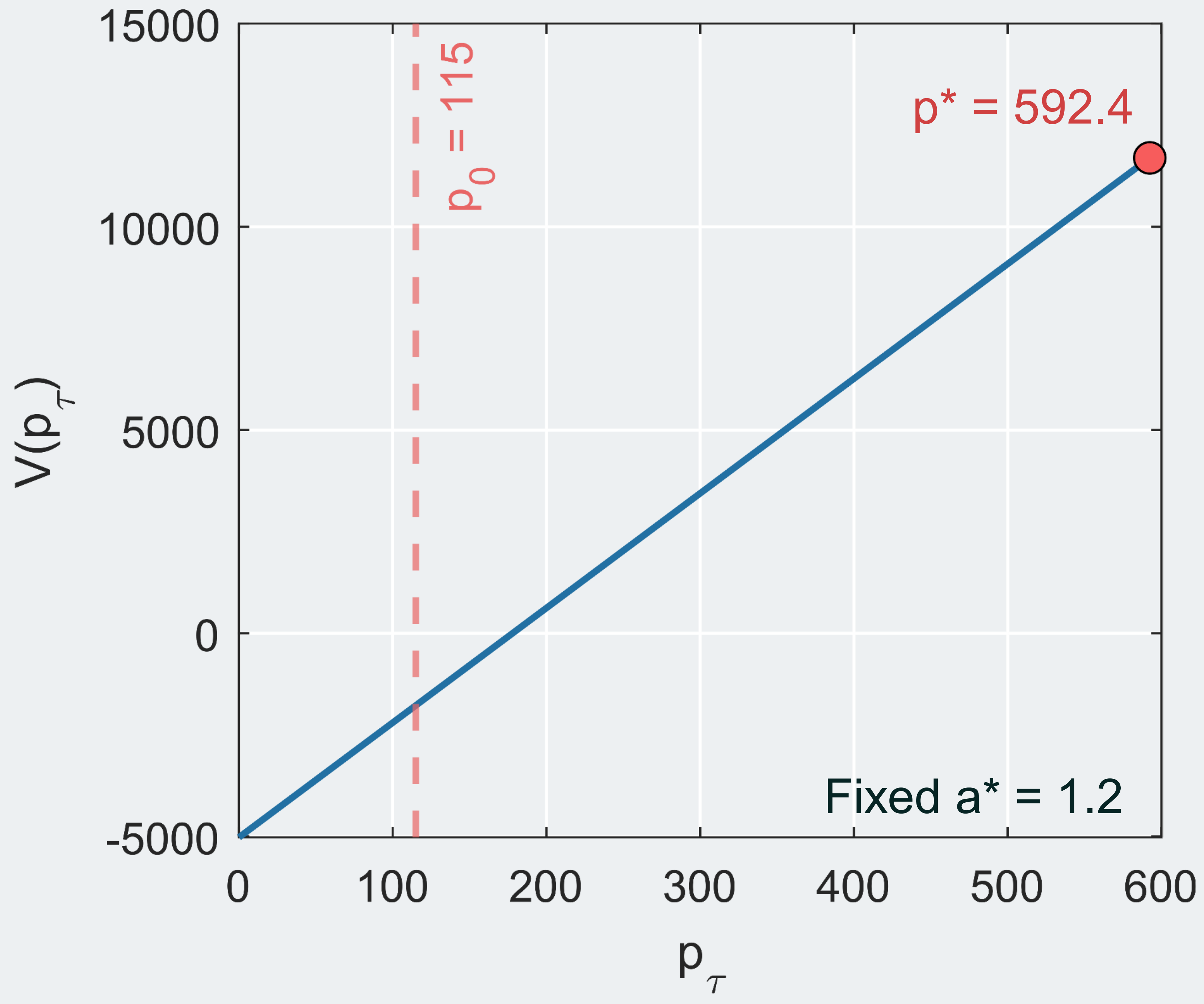


Invest now at p_0 or wait until p* is reached?

p* < or > p_0	p^*	p_0	h^*	V^*
LCOE = 75 €/MWh *(Trinomics, 2020)*				
r = 0.04	166.26	115	1.1	7376.6
r = 0.06	177.29	115	1.1	3411.1
LCOE = 140 €/MWh *(IRENA, 2024)*				
r = 0.04	10.15	115	1.8	4647.9
r = 0.06	30.27	115	1.1	674.4

Average PUN in October 2024 = 115 €/MWh

Preliminary Results : PVB only

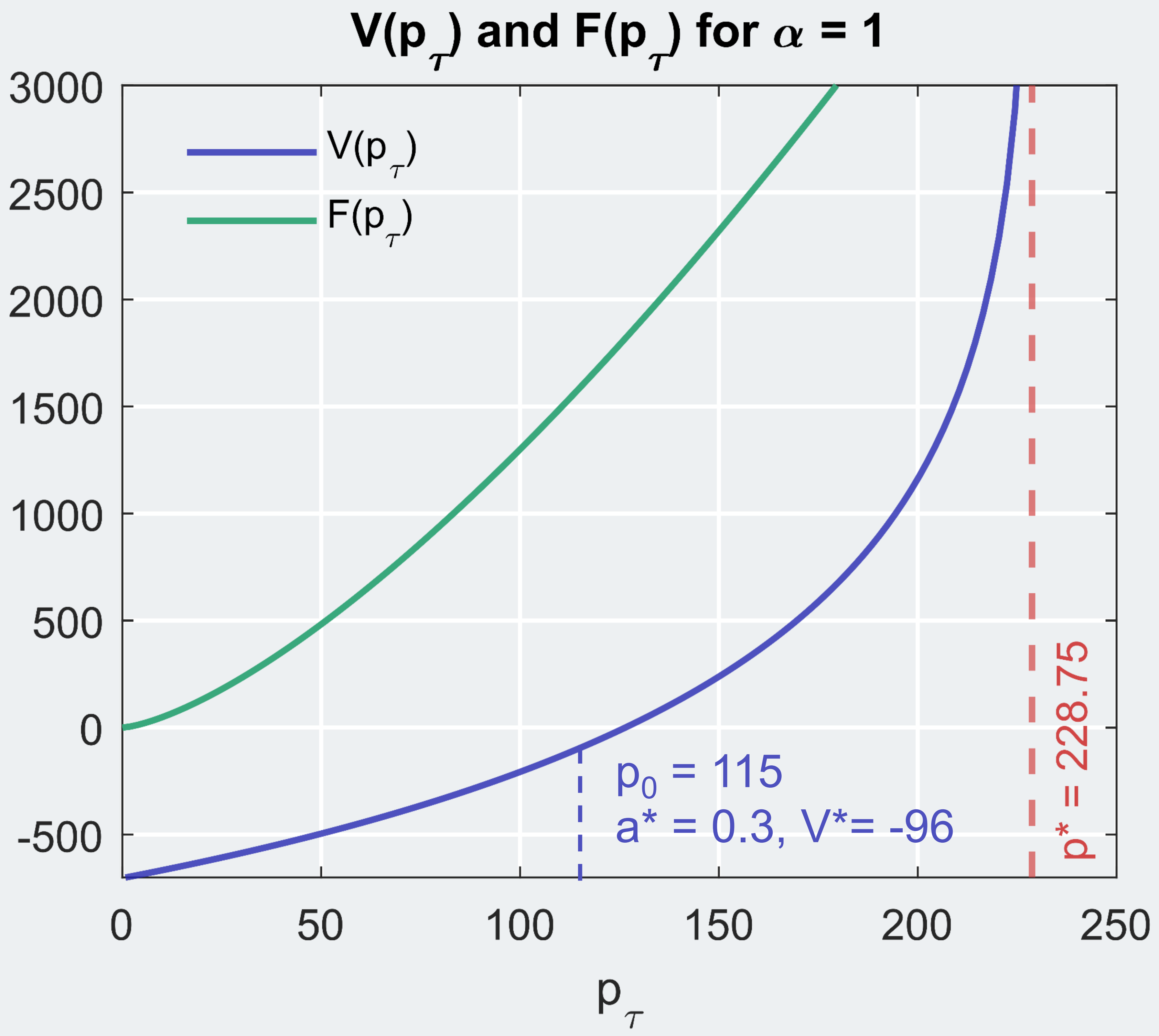


Invest now at p_0 or wait until p* is reached?

$p^* <$ or $> p_0$	p^*	p_0	a^*	V^*
LCOE = 90 €/MWh, LCOS = 280 €/MWh *(Andreolli et al., 2022; Poli et al., 2024)*				
r = 0.04	511.8	115	1.2	23300.7
r = 0.06	529.6	115	1.2	10454.1
LCOE = 110 €/MWh, LCOS = 300 €/MWh *(Andreolli et al., 2022; Poli et al., 2024)*				
r = 0.04	573.2	115	1.2	26092.8
r = 0.06	592.4	115	1.2	11694.9

Average PUN in October 2024 = 115 €/MWh

Discussion



Empirical Check on PVB result

Case: r = 0.06, LCOE = 90 MWh, LCOS = 280 MWh
When a* varies with p_τ

The option F(p_τ) and investment value V(p_τ) match asymptotically in p*…

At p*=229 the size a* goes to infinite as the value of the investment…

Unrealistic case: the demand of energy is finite (i.e., D = 1 MWh/year in our model), we would never invest in a huge plant to satisfy a "normal" demand.

Conclusions

- For the **extreme cases**: invest now in half of SHP results and wait to invest in all PVB results
- The **choice of $\boldsymbol{p_0}$** is a fundamental step to decide the investment timing especially in a volatile energy market
- The **long-term mean price** could be a better proxy of p_0 as compared to the current price
- **Incentives** not included in the model
- The **mix scenario** is a work in progress
- Future developments: using share coefficient (α) to include **variability of climatic conditions**

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Any questions?

anna.carozzani@phd.unipd.it

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