Techno-Economical analysis of Energy Storage Applications

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Today, you can learn :

How to evaluate the cost of an energy storage application over its lifetime ?

How to compare the cost for storing with the cost for producing ?

How to apply the economic analysis in a simplistic example of hydropower storage for seasonal storage ?

Diverse costs of energy storage systems

Levelized Cost of Storage $LCOS$ [€/MWh]

$$LCOS = \frac{C_{cap} + \sum_{t=1}^{T} \frac{C_{O\&M} + C_{ch}}{(1+r)^t} + \frac{C_{DR}}{(1+r)^{T+1}}}{\sum_{t=1}^{T} \frac{E_{disch}}{(1+r)^t}}$$

Cost terms

- C_{cap} : investment cost [€]
- $C_{O\&M}$: operation and maintenance cost [€]
- C_{ch} : charging cost [€]
- C_{DR} : disposal and recycling cost [€]

Energy terms

- E_{disch} : Annual discharged energy [MWh]

Financial terms

- r : discount rate [%]
- t : ongoing year
- T : application lifetime [yr]

➡ Accounts for the **lifetime application**

➡ **Reflects the** internal average **price of electricity**

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Schmidt et al., « Projecting the future levelized cost of electricity storage technologies », Joule 3, pp. 81-100, 2019

Diverse costs of energy storage systems

Annual Discharged Energy E_{disch} [MWh]

$$\sum_{t=1}^{T} \frac{E_{disch}}{(1+r)^t} = N_a \, DoD \, E_u \, \eta_{RT} \left(1-\eta_{self}\right) \sum_{t=1}^{T} \frac{\left(1-N_d\right)^{(t-1)N_a} \left(1-T_d\right)^{t-1}}{\left(1+r\right)^{T_c+t}}$$

Energy discharged to the consumer

Degradation factor

Application terms

- N_a : number of cycles per year
- DoD : depth of discharge [%]
- E_u : energy capacity [MWh]
- η_{RT} : round trip efficiency [%]
- η_{RT} : self-discharge portion [%]
- T_c : construction period [yr]

Degradation parameters

- N_d : rate of energetic degradation per cycles [%]
- T_d : rate of temporal degradation relative to shelf time [%]

Schmidt et al., « Projecting the future levelized cost of electricity storage technologies », Joule 3, pp. 81-100, 2019

Diverse costs of energy storage systems

Investment costs C_{cap} [€]

$$C_{cap} = C_P \, P_n + C_E E_u + \sum_{k=1}^{R} \frac{C_{PR} \, P_n}{(1+r)^{T_c + k\, T_r}}$$

Electrical Components	Storage Device	Replacements

Cost terms

- C_E : energetic cost [€/MWh]
- C_P : power cost [€/MW]
- C_{PR} : replacement cost [€/MW]

Application terms

- E_u : energy capacity [MWh]
- P_n : installed power [MW]
- T_c : construction period [yr]
- T_r : replacement period [yr]
- R : number of replacements

⚠️ Do not count an element twice ⚠️

Diverse costs of energy storage systems

Operation and maintenance costs $C_{O\&M}$ [€]

$$\sum_{t=1}^{T} \frac{C_{O\&M}}{(1+r)^{t}} = \sum_{t=1}^{T} C_{P,OM} P_n + C_{E,OM} \; N_a \; DoD \; E_u \frac{(1-N_d)^{(t-1)N_a} (1-T_d)^{t-1}}{(1+r)^{T_c+t}}$$

Electrical Components

Discharged energy by the storage

Degradation factor

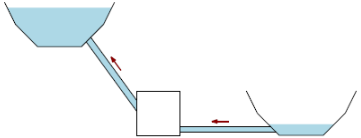
Cost terms
- $C_{P,OM}$: power O&M cost [€/MW]
- $C_{E,OM}$: energetic O&M cost [€/MWh]

Application terms
- N_a : number of cycles per year
- DoD : depth of discharge [0;1]

⚠ Do not count an element twice ⚠

Diverse costs of energy storage systems

Levelized cost due to Charging [€/MWh]



$$\frac{\sum_{t=1}^{T}\frac{C_{ch}}{(1+r)^{t}}}{\sum_{t=1}^{T}\frac{E_{disch}}{(1+r)^{t}}}=\frac{C_{el}}{\eta_{RT}}$$

Disposal and Recycling cost C_{DR} [€]

$$C_{DR}=F_{DR}C_{cap}$$

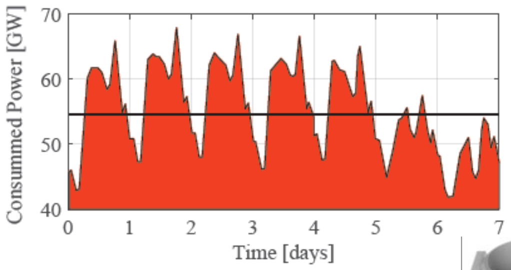
Cost terms

- C_{el} : electricity price[€/MW]
- C_{ch} : charging cost [€]
- C_{cap} : investment cost [€]

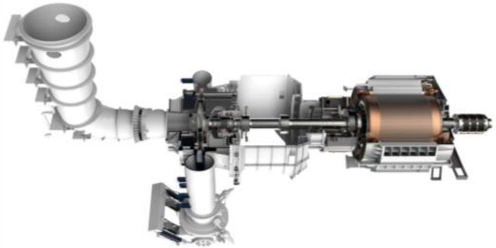
Application terms

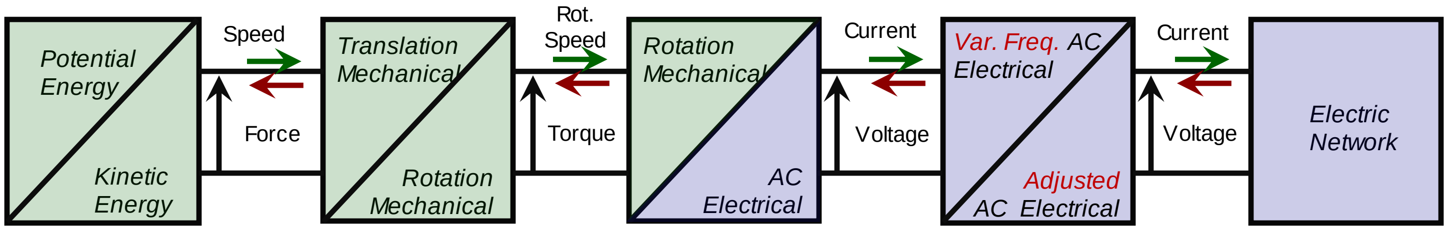
- η_{RT} : round trip efficiency
- E_{dish} : discharged energy to the consumer [MWh]
- F_{DR} : factor for recycling and disposal

Hydropower Seasonal Storage System



Sustaining consumption when average consumed power is ensured with nuclear plants





E_u = 169 GWh
P_n = 15.4 GW
DoD = 65 %

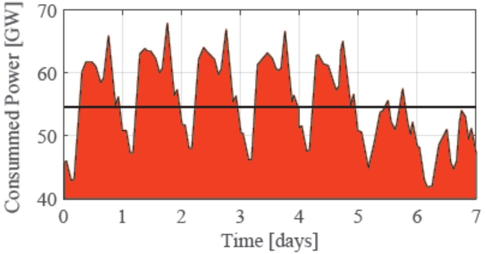
P_n = 17.7 GW
η_{pump} = 87 %

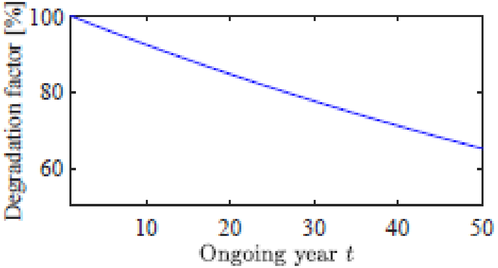
P_n = 17.9 GW
η_{mot} = 98,5 %

P_n = 18.5 GW
η_{turb} = 97 %

η_{RT} = 69 %

Hydropower Storage System





Annual Discharged Energy

Number of cycle per week : 6,5 → N_a = 338 cycles/yr

Self discharge/ idle ratio : $\eta_{self} = 0$ %

Application lifetime : $T = 50$ yr

Construction time : $T_c = 3$ yr

Cycle degradation ratio: $N_d = 0{,}0007$ %

Time degradation ratio: $T_d = 0{,}4$ %

Discount rate : $r = 8$ %

$$\sum_{t=1}^{T} \frac{E_{disch}}{(1+r)^t} = 232 \text{ TWh}$$

Hydropower Storage System

Investment costs C_{cap}

Energetic cost (above ground) : $C_E = 66{,}4$ €/kWh

→ Reservoir cost : $C_E E_u = 7\ 769$ M€

Power cost : $C_P = 937$ €/kW

→ Cost for Pump/turbine & Motor & Frequency Converter: $C_P P_n = 17\ 336$ M€

Replacement cost : $C_R = 95{,}45$ €/kW
Replacement interval: 7300 cycles or 21 years
Number of replacement along 50 years lifetime : $R = 3$

→ $$\sum_{k=1}^{R} \frac{C_{PR}\, P_n}{(1+r)^{T_c + k\, T_r}} = 331 \text{ M€}$$

$C_{cap} = 25\ 341$ M€

Hydropower Storage System

Operation and maintenance costs $C_{O\&M}$


Energy conversion components: $C_{P,OM} = 8$ €/kW per year

→ Turbine & Motor & Power Electronic: $C_{P,OM} P_n T = 6\ 108$ M€

Energetic operation cost: $C_{E,OM} = 1$ €/MW

→ $$C_{E,OM}\ N_a\ DoD\ E_u \sum_{t=1}^{T} \frac{\left(1-N_d\right)^{(t-1)N_a}\left(1-T_d\right)^{t-1}}{\left(1+r\right)^{T_c+t}} = 280{,}6\ \text{M€}$$

$$\sum_{t=1}^{T} \frac{C_{O\&M}}{\left(1+r\right)^{t}} = 6\ 389\ \text{M€}$$

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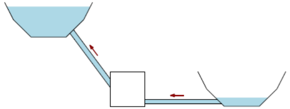
Hydropower Storage System

Charging and recycling costs



$$\frac{C_{el}}{\eta_{RT}} = 21 \text{ €/MWh}$$

Electricity cost : $C_{el} = 17{,}4$ c/kWh

$$C_{DR} = 1\,072 \text{ M€}$$

Environmental cost factor: $F_{DR} = 4{,}23$ %

Levelized cost of storage

LCOS = 161,6 €/MWh

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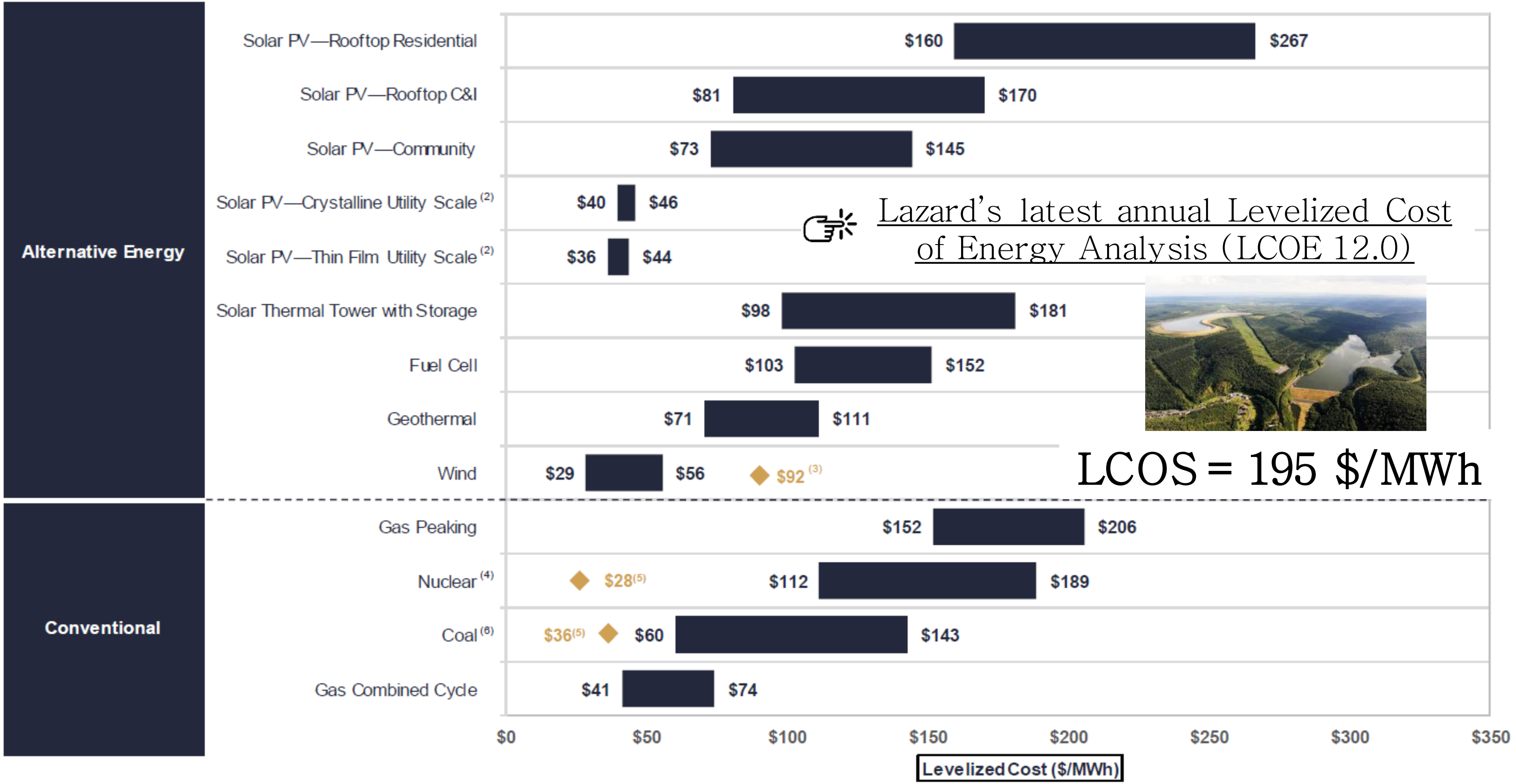
Vougioukli et al., « Financial Appraisal of Small Hydro-Power Considering the Cradle-to-Grave Environmental Cost: A Case from Greece», Energies, 10, 430, 2017

Some levelized cost of energy production



Lazard's latest annual Levelized Cost of Energy Analysis (LCOE 12.0)

LCOS = 195 $/MWh

A?

Towards design improvements

Should we oversize our storage solution in order to fulfil the capacity near the end of the application lifetime ?

Would our cost analysis be more sensitive to the number of replacements or the round-trip efficiency?

Should we oversize our application to anticipate higher consumption in the future?

Would we get a lower levelized cost with Compressed Air Energy Storage system ?

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