

# Matching Intermittent Electricity Supply And Load With Energy Storage

An optimization based on a time scale analysis

A French case study

5<sup>th</sup> international Conference On Smart Energy Systems, 10-11 Sept 2019

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# Agenda

Topic and goals

Characterizing flexibility

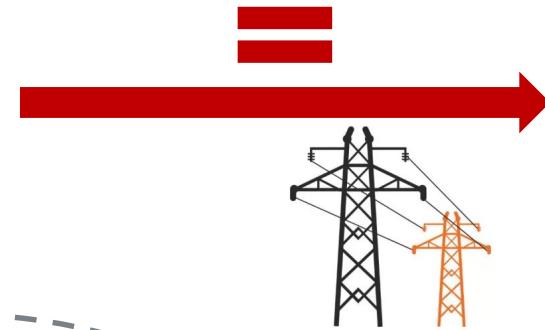
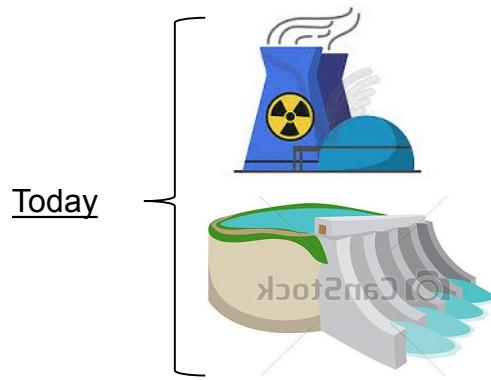
Which storage for which need ?

Conclusion

## Context

**Increasing electricity supply variability with Renewable Energy Sources**  
→ Need in flexibility and storage

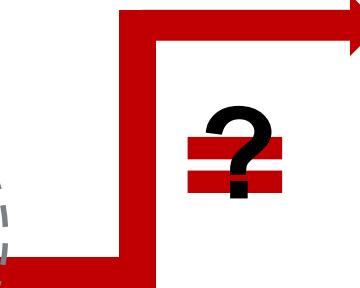
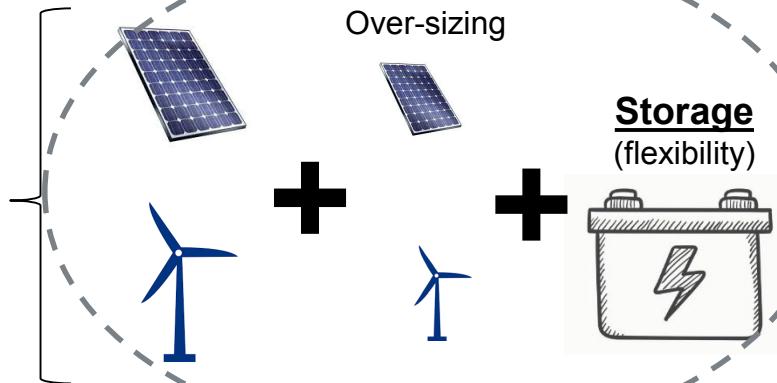
### Dispatchable Supply



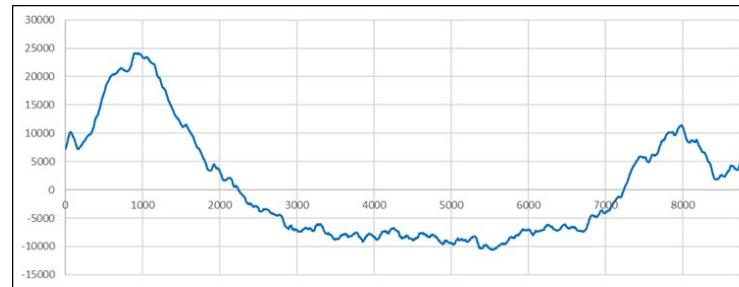
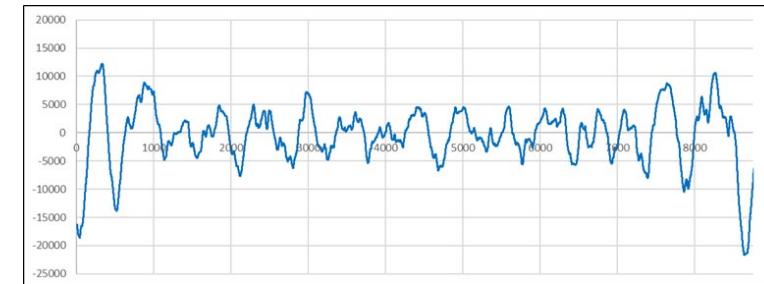
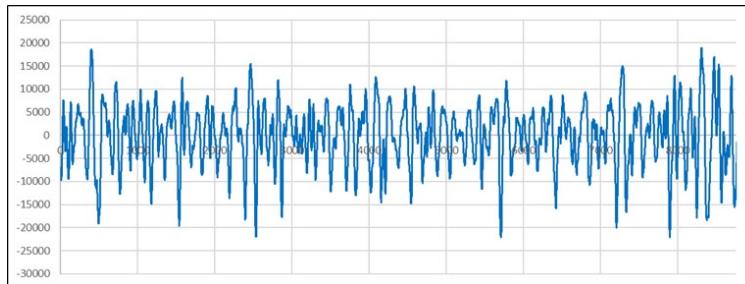
### Electricity Load



### Variable Supply



## We need to quantify the variability of RES



- Variability has different time scales:
  - Human rhythms
  - Climatic cycles (Day, Seasons)
  - Weather fluctuation



### Presentation's goals:

1. Assess and quantify the flexibility need for each time scale
2. Which electricity storage for which need?

# Framework and assumptions

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## A simple model at the French scale

1. No grid losses
2. Current technology performances considered (no prospective technologies)
3. Using French time series for electricity load and supply

# Agenda

Topic and goals

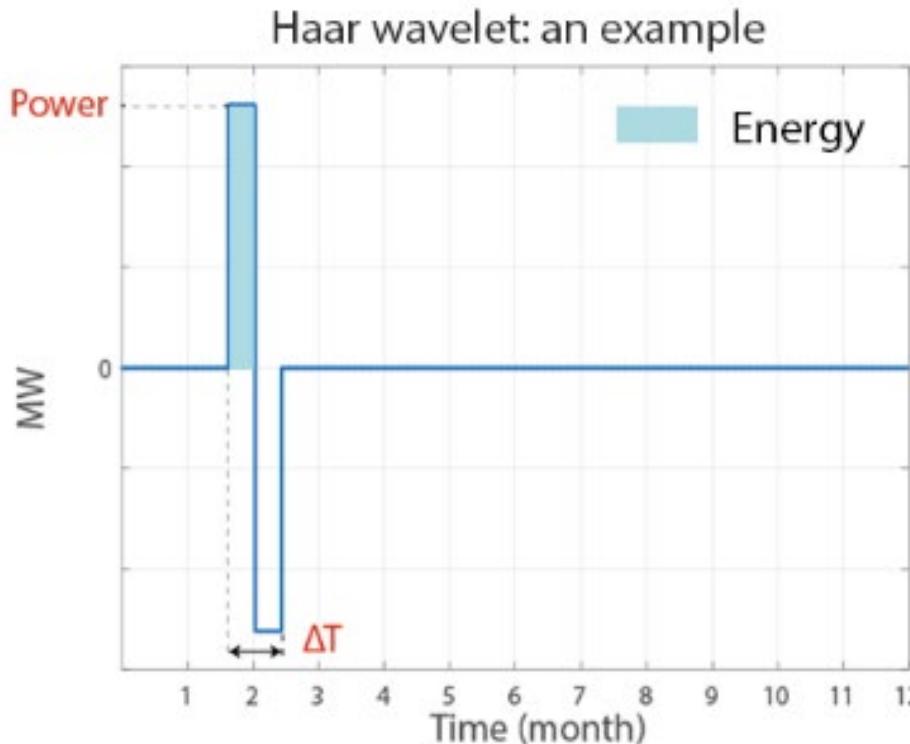
Characterizing flexibility

Which storage for which need ?

Conclusion

## I/ A time scale analysis

### Wavelet decomposition of power time series

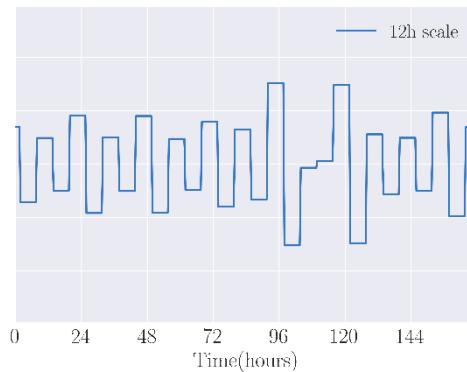


**Each wavelet represent:**

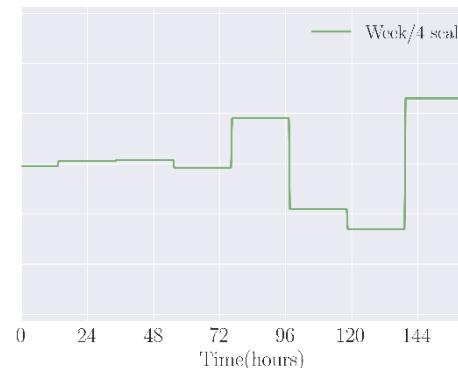
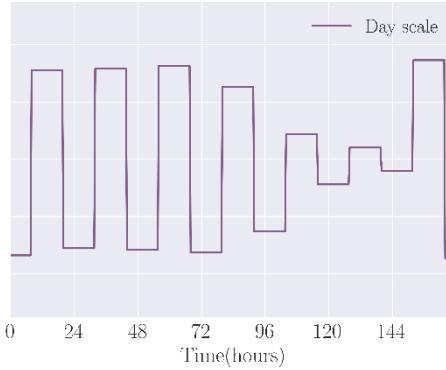
- An amount of energy to be shifted
- Over a given length of lime ( $\Delta T$ )
- At a given time

## II A time scale analysis

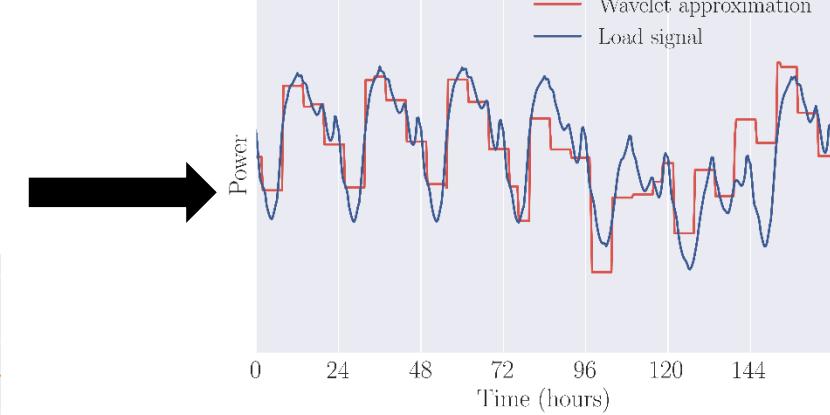
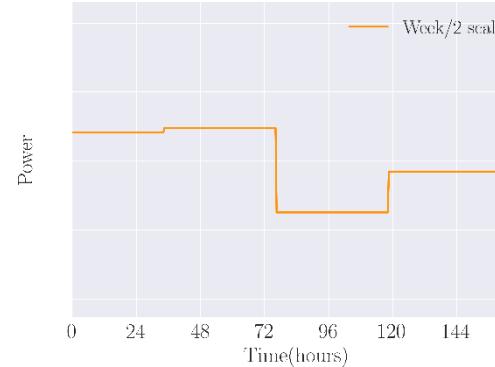
Signals are reconstructed on a set of wavelets with 15 characteristic time scales: 45 minutes → 1 year



+



+ ...



Residual demand decomposition

## II/ Characterizing the flexibility need

### Wavelet decomposition of the residual demand

Flexibility is generated by what is not handled:

**Load – non-dispatchable Supply**

**Load:**

*Unchanged data from RTE\**

**Non dispatchable Supply (PV & Wind):**  
*RTE\* normalised to a future generation mix:*

0% variability

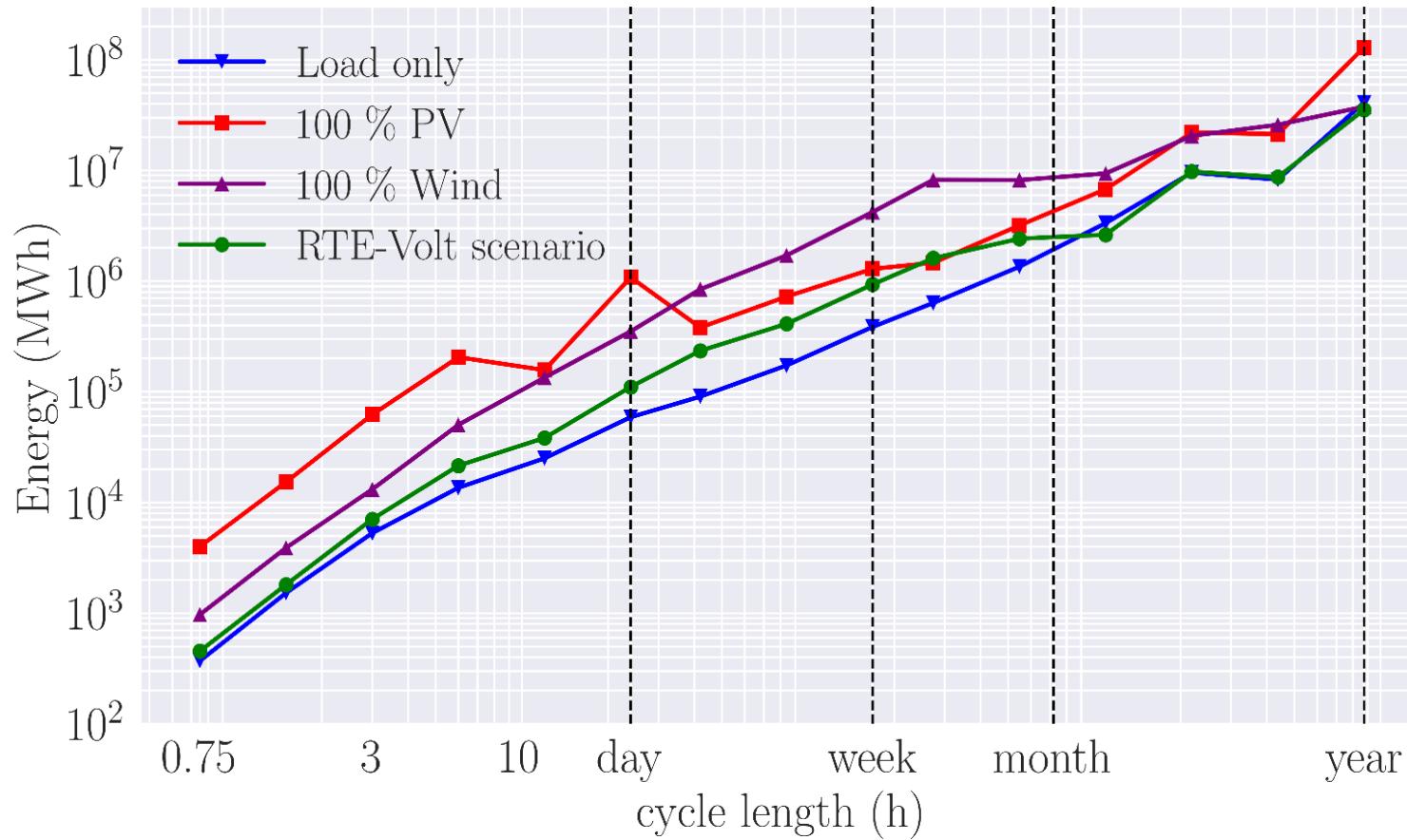
100% PV

100% éolien

10% PV + 26% éolien (~scénario Volt)

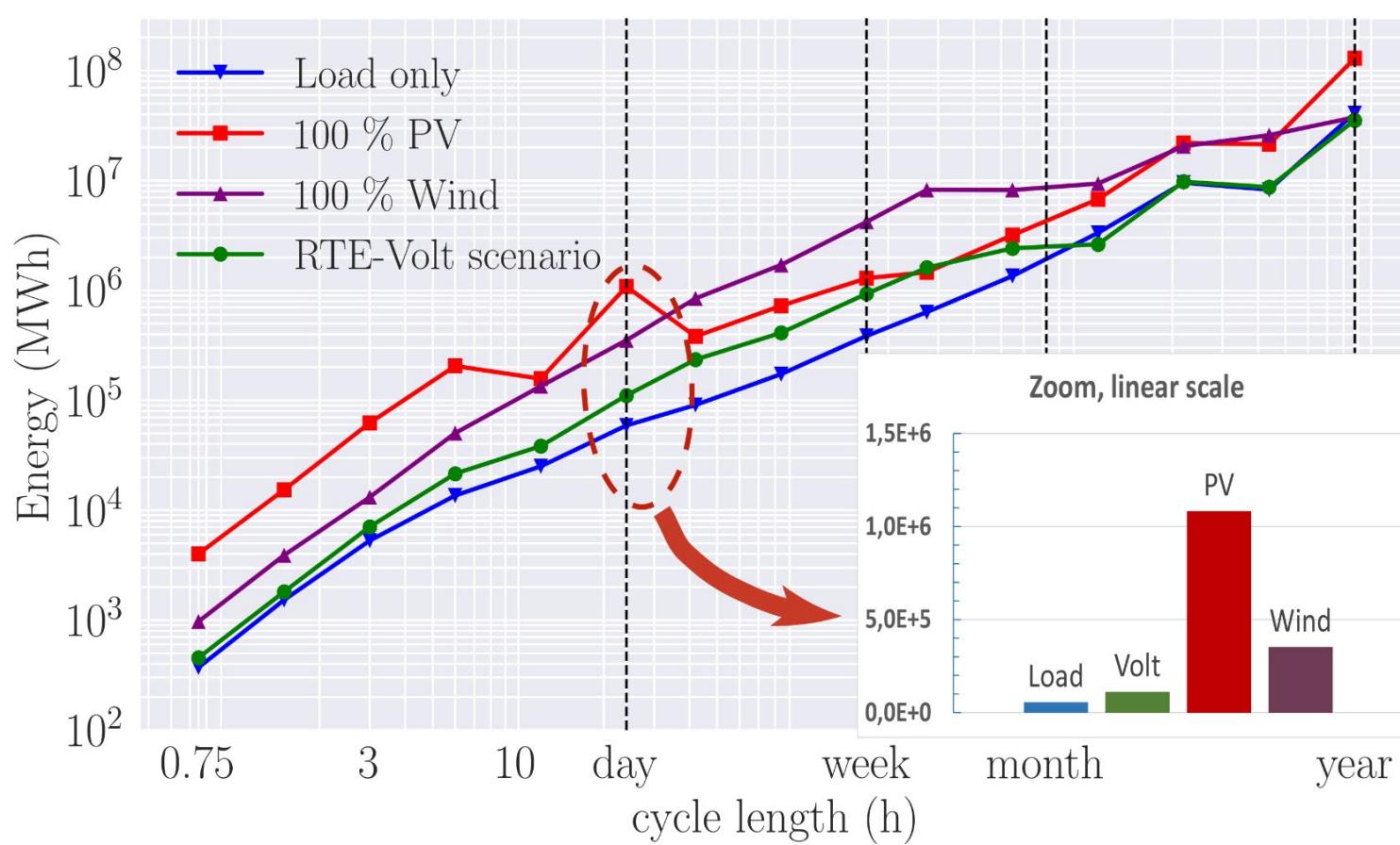
\* RTE is the French TSO

## II/ Characterizing the flexibility need



Size of the required electricity storage stock to fill the electricity shortage

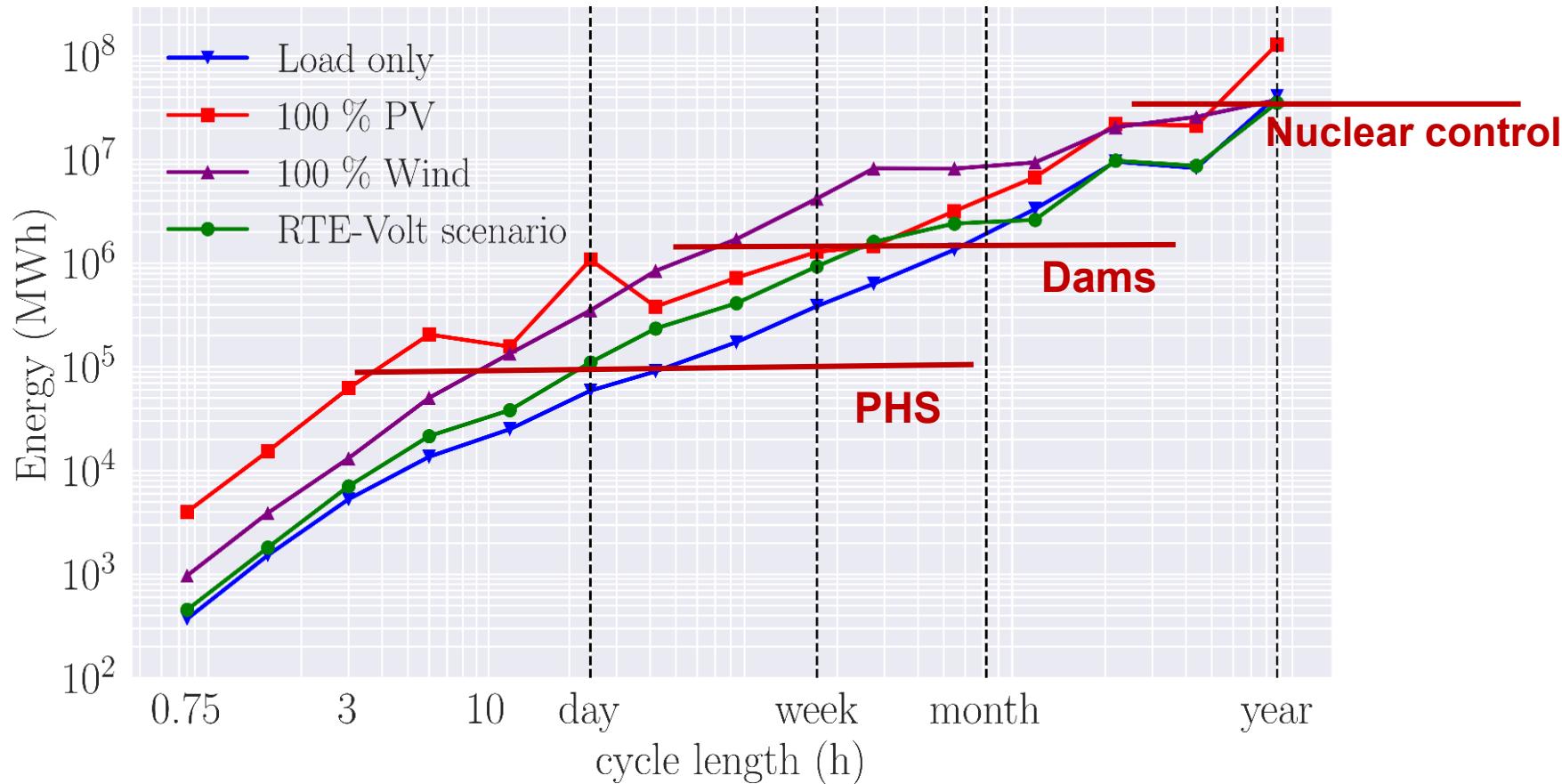
## II/ Characterizing the flexibility need



Size of the required electricity storage stock to fill the electricity shortage

## II/ Characterizing the flexibility need

### Parallel with French current flexibility means



Demand side management in 2017	66 GWh/an
PHS stock	100 GWh
Energy in hydro dams	2 TWh
Nuclear shut down 10% of the time	55 TWh/an

Sources: [http://clients.rte-france.com/lang/fr/visiteurs/vie/prod/stock\\_hydraulique.jsp](http://clients.rte-france.com/lang/fr/visiteurs/vie/prod/stock_hydraulique.jsp)  
<http://bilan-electrique-2017.rte-france.com/flexibilite/53-effacements/#>  
[Cactéristiques générales des STEPS EDF en France, X. URSAT et al, 2011](#)

## Reminder

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- Longer time scales → Large stock → Big dispatchable means
- The more variability, the bigger the storage need
- Except at the year scale: wind power decreased the flexibility need

# Agenda

Topic and goals

Characterizing flexibility

Which storage for which need ?

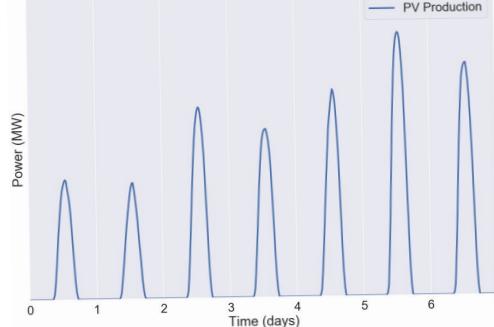
Conclusion

## III/ Which storage to face up to which need ?

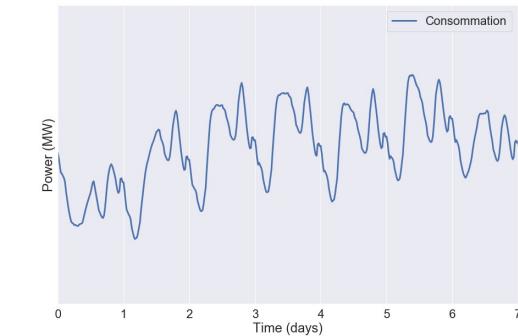
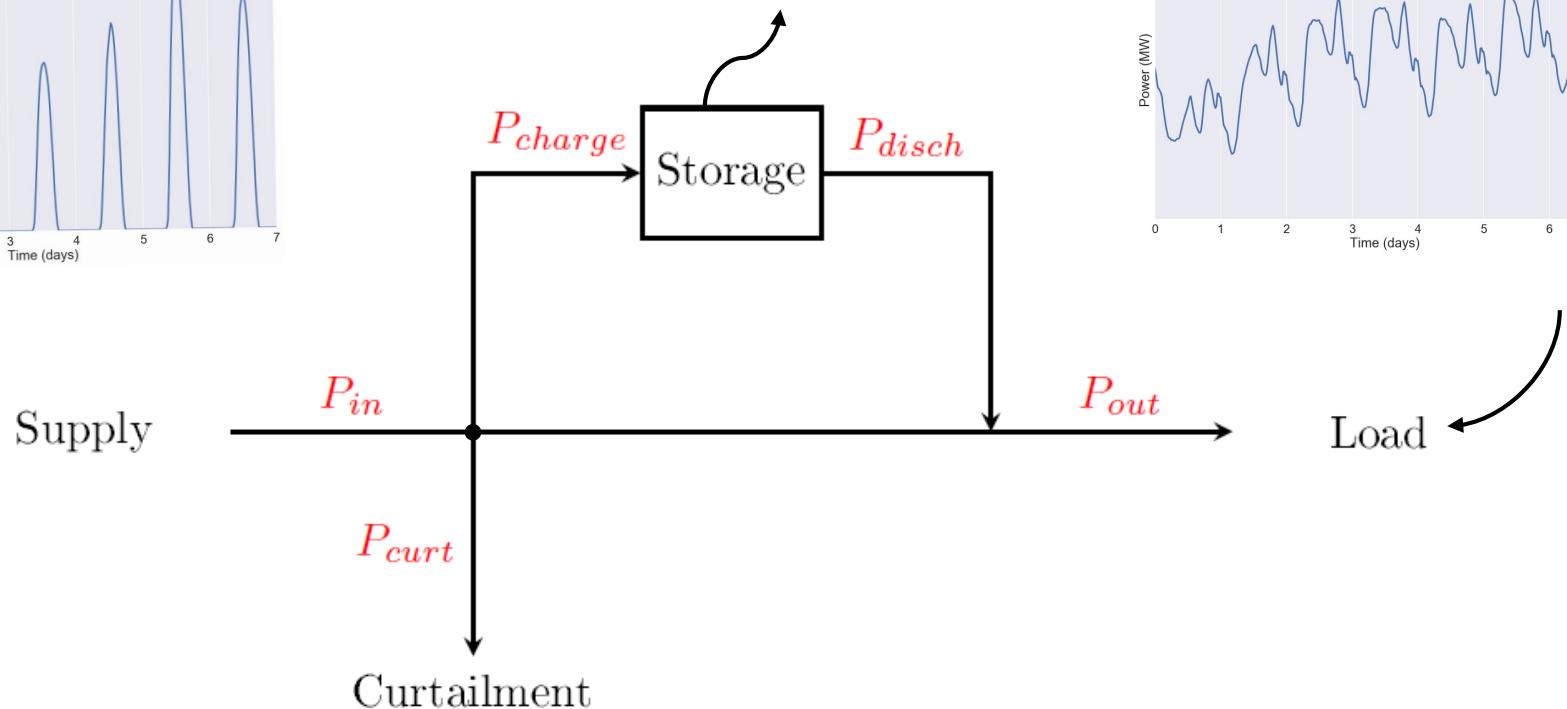
Implementation of the optimisation problem in GAMS

**Objective function:** maximizing Energy Return On Investment (EROI) of the energy system

At each time step: **Consumption is satisfied**



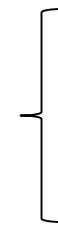
**Sizing**  
Storage Energy, Power  
Power generation capacity



## III/ Which storage to face up to which need ?

**Systems included in the study:**

Scenario 100% PV

- 
- Li-ion battery
  - Hydro storage (PHS)
  - Compressed Air Energy Storage (CAES)
  - Hydrogen (Power to Gas)

**Two questions:**

- 1) Which storage for the short time scales (day) ? For the long ones seasonal ?
- 2) Better investing in big storage devices?  
Or to oversize the power generation and curtailing the excess electricity ?

## III/ Which storage to face up to which need ?

An Energy Return on Investment (*ESOI*) based optimisation

By the generation plant over-sizing



By the storage

Service

= Electricity supplied when lacking

ESOI =

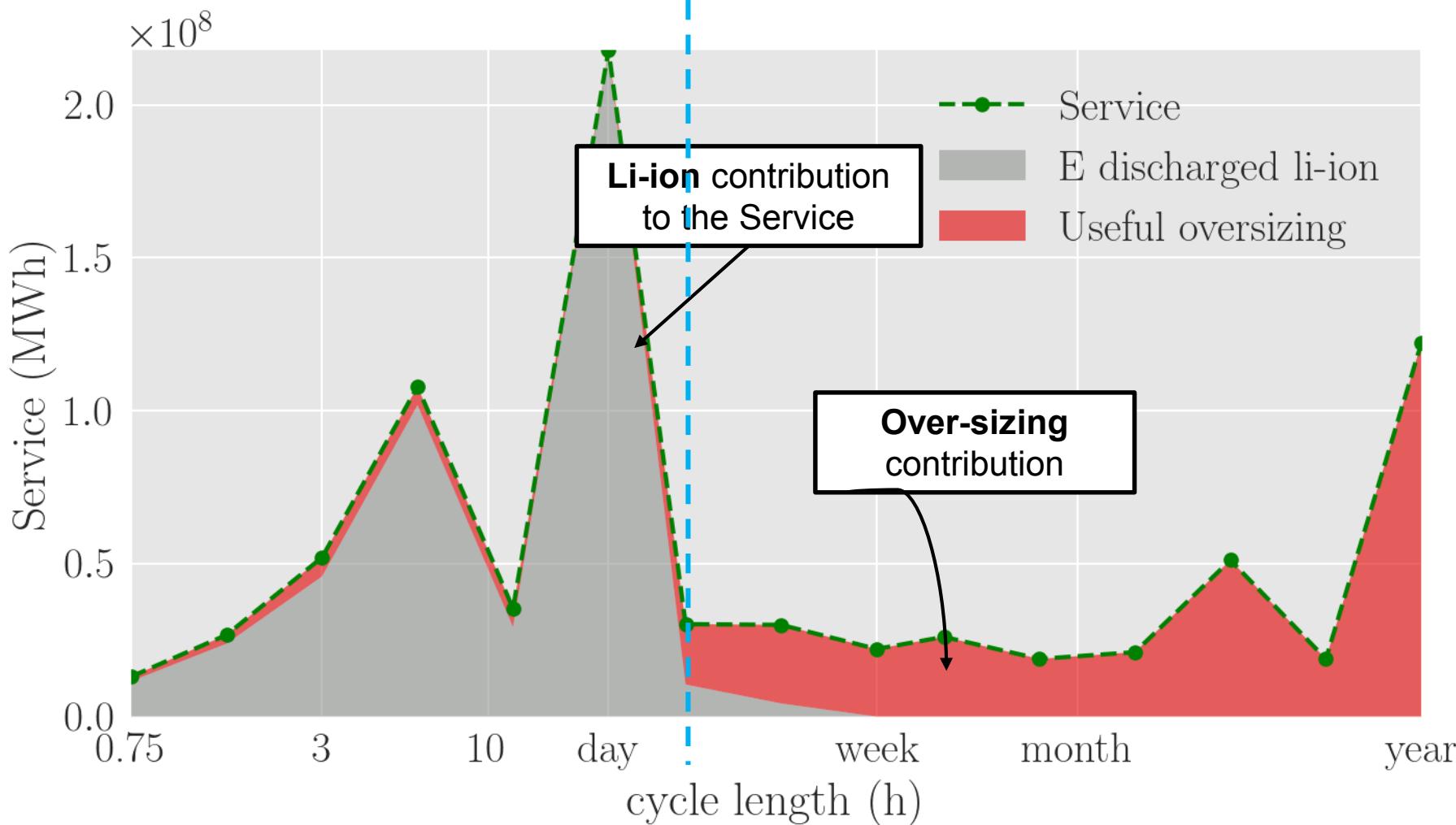
Cost (embodied energy)



Embodied energy to oversize the power generation

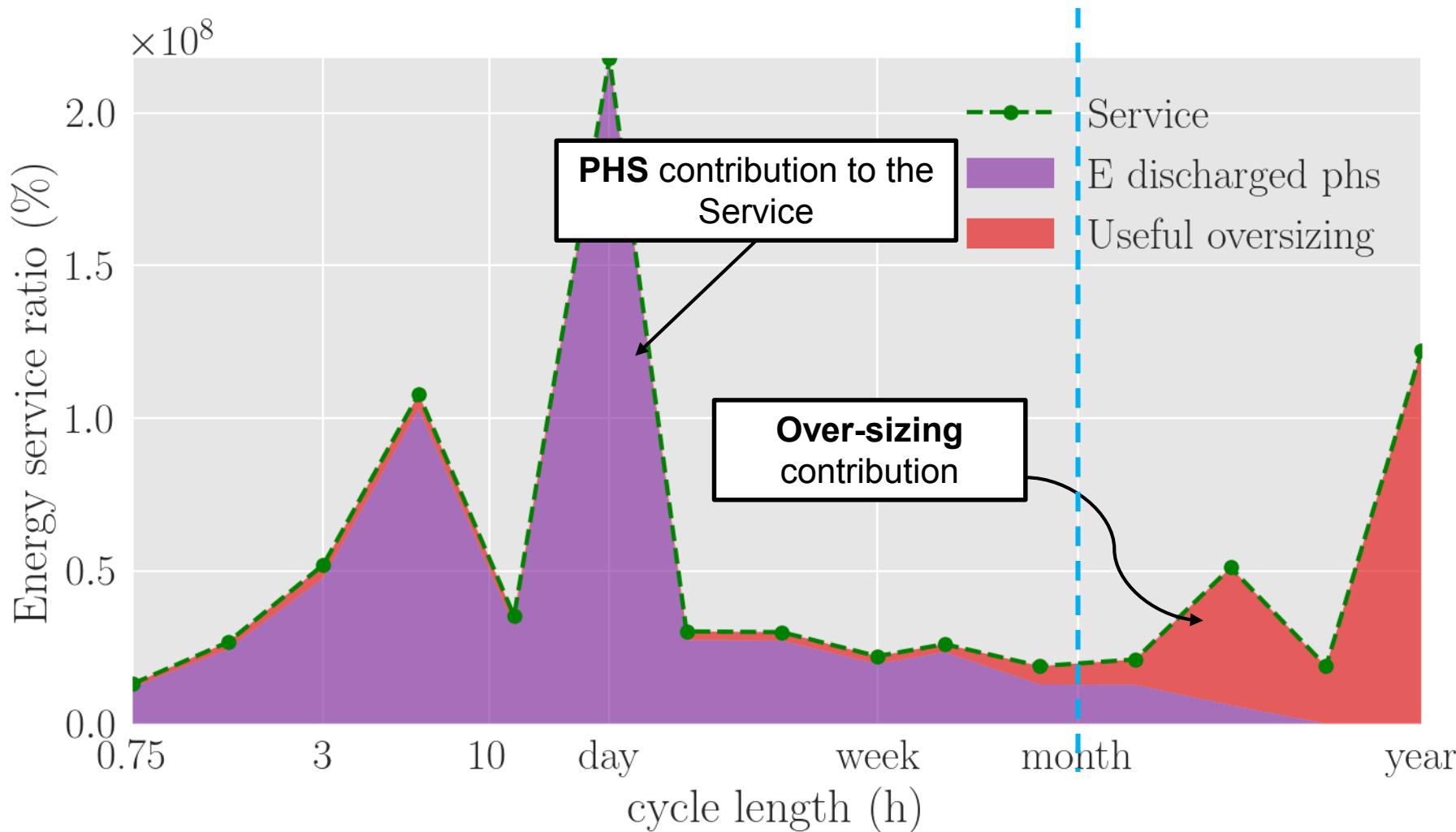
Storage embodied energy

# Oversizing Power generation or storage ? (scenario 100% PV)



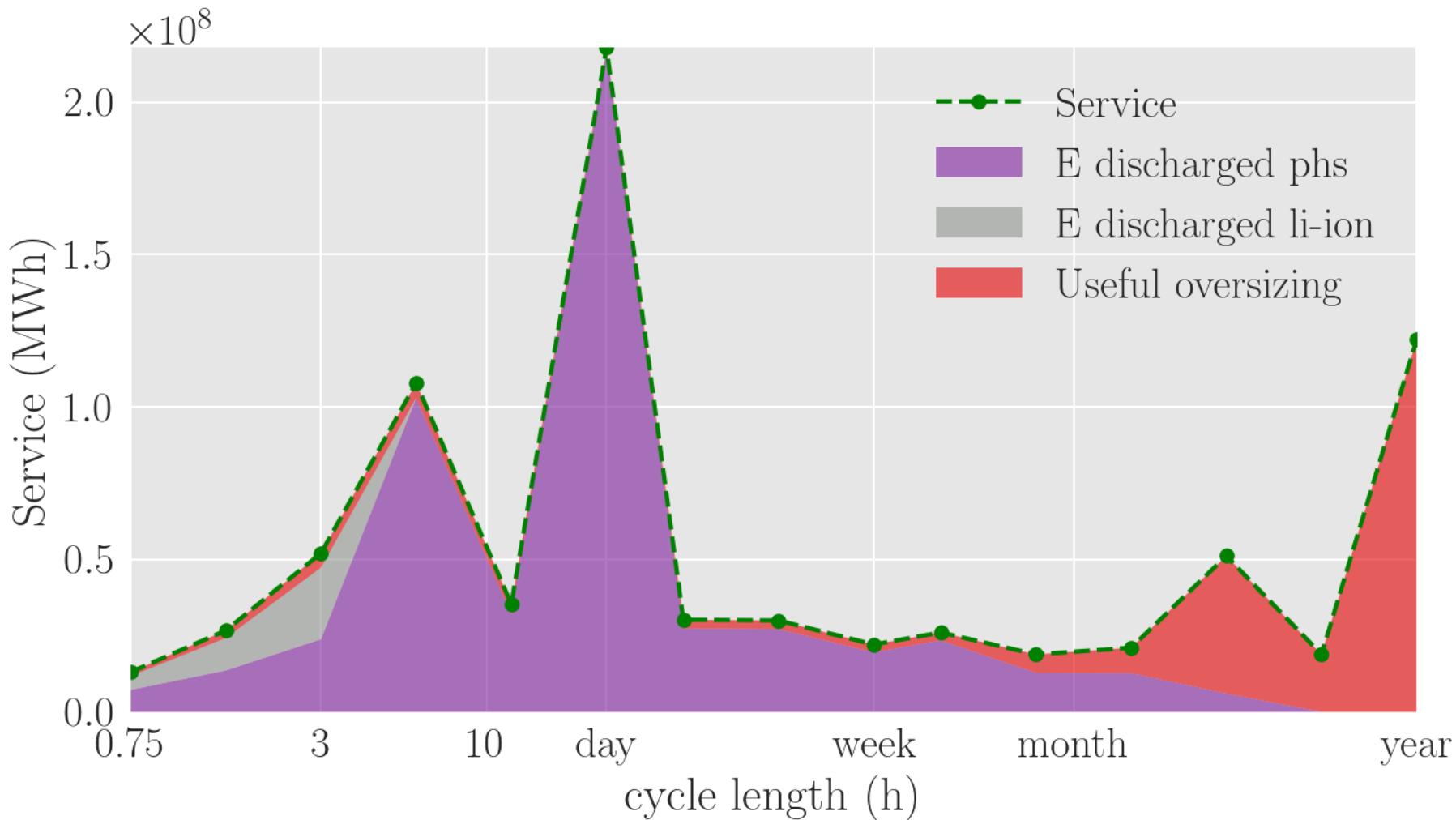
Using Li-ion batteries for short terms (< day)  
Oversize the power generation for long time scales

# Oversizing Power generation or storage ? (scenario 100% PV)



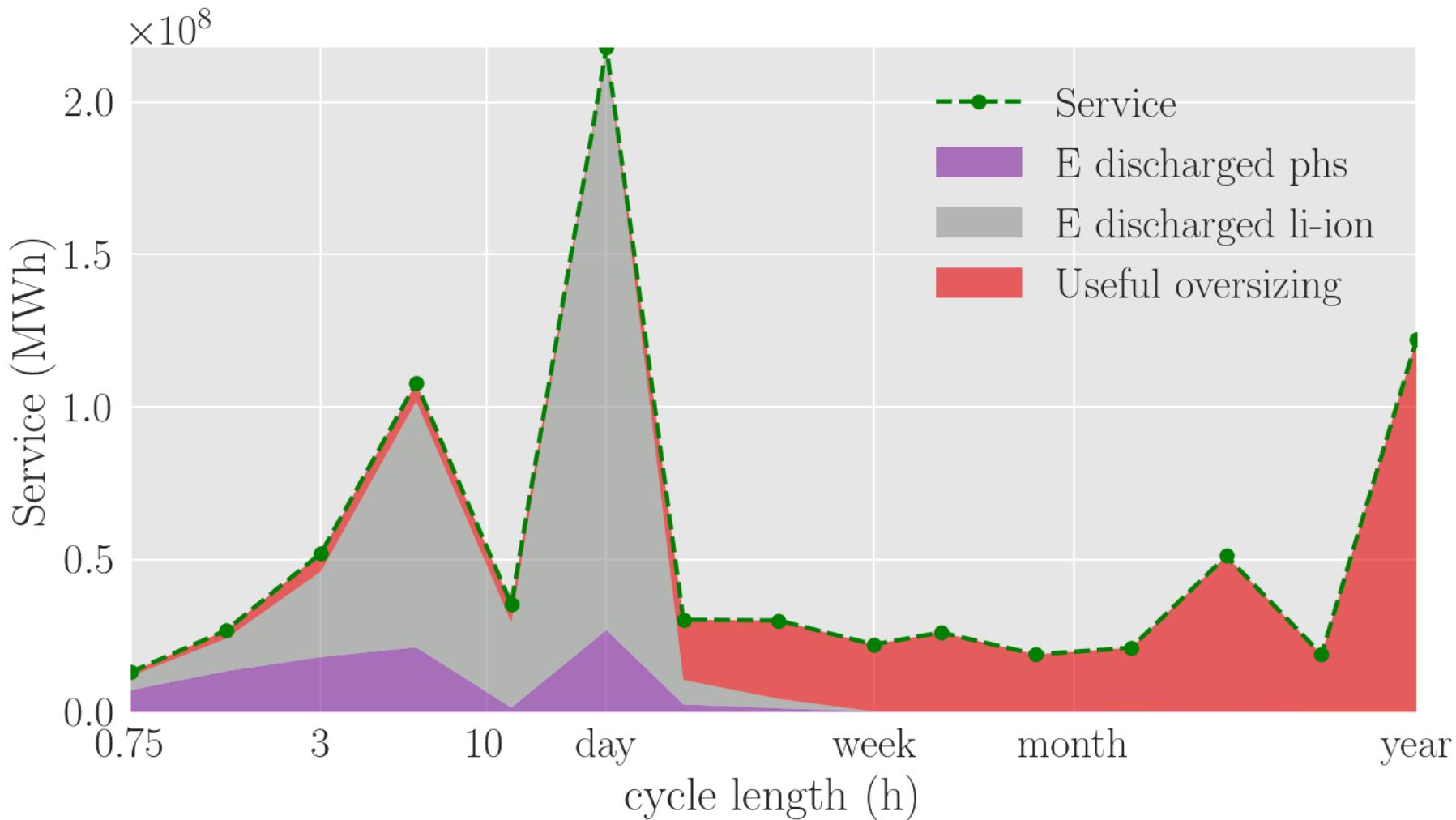
**Using PHS for storage up to a few month remains relevant**

# Oversizing Power generation or storage ? (scenario 100% PV)



**However PHS stocks are not infinite**

# Oversizing Power generation or storage ? (scenario 100% PV)



**With a PHS limitation (100GWh, current French development)**

# Agenda

Topic and goals

Characterizing flexibility

Which storage for which need ?

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# Results – Sum up



## Oversizing storage for short time scales

Batteries and PHS are relevant for short time scales



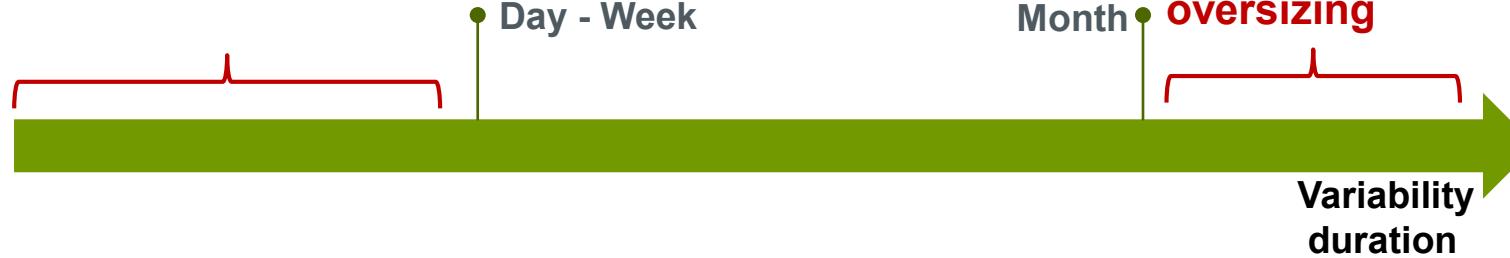
## Oversizing power generation for long time scales

Difficulties to store electricity for long time scales ( $> 1$  month)

Today solution = Dispatchable production (nuclear)

Tomorrow solution ? = Complementarity with heat storage ?

### Storage oversizing



A high penetration rate of Variable RES strongly decreases the Energy Return On Investment of the energy system

Especially for low efficiency storage ( $H_2$ , CAES)

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THANK YOU FOR LISTNING  
ANY QUESTIONS ?

Let's keep in touch !  
[arthur.clerjon@cea.fr](mailto:arthur.clerjon@cea.fr)

[More details here :](#)

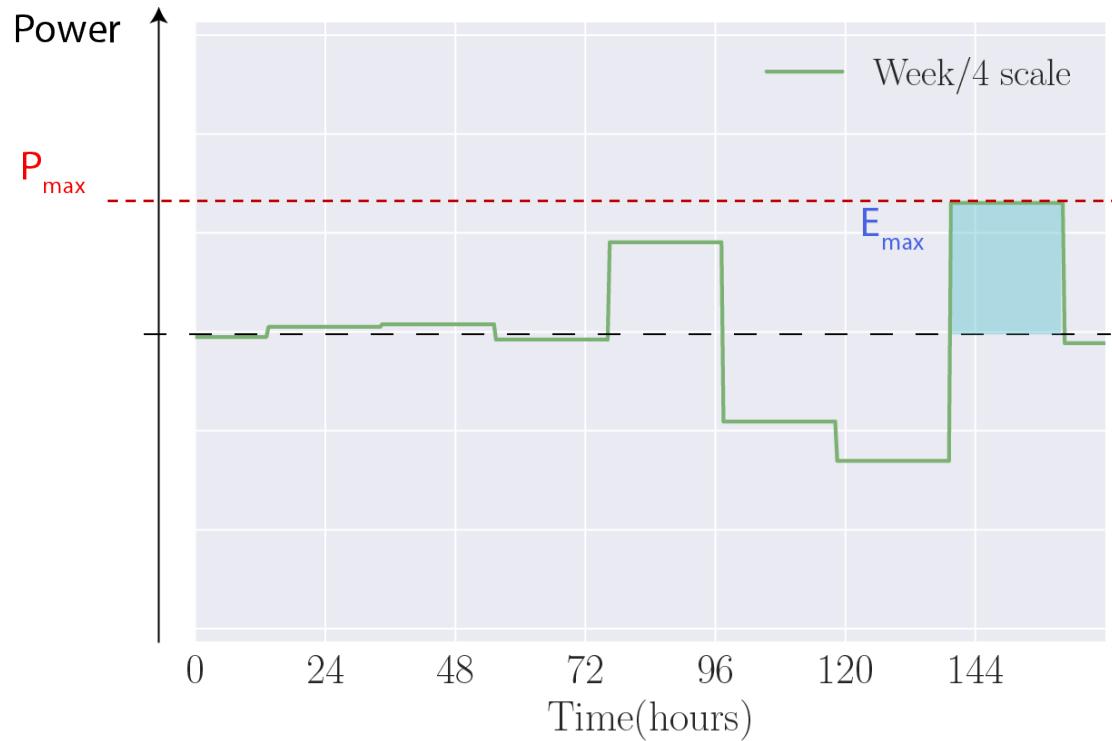
Clerjon, A., & Perdu, F. (2019). Matching intermittency and electricity storage characteristics through time scale analysis: an energy return on investment comparison. *Energy & Environmental Science*, 12(2), 693-705. doi: 10.1039/c8ee01940a

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## ANNEXES

## I/ A time scale analysis

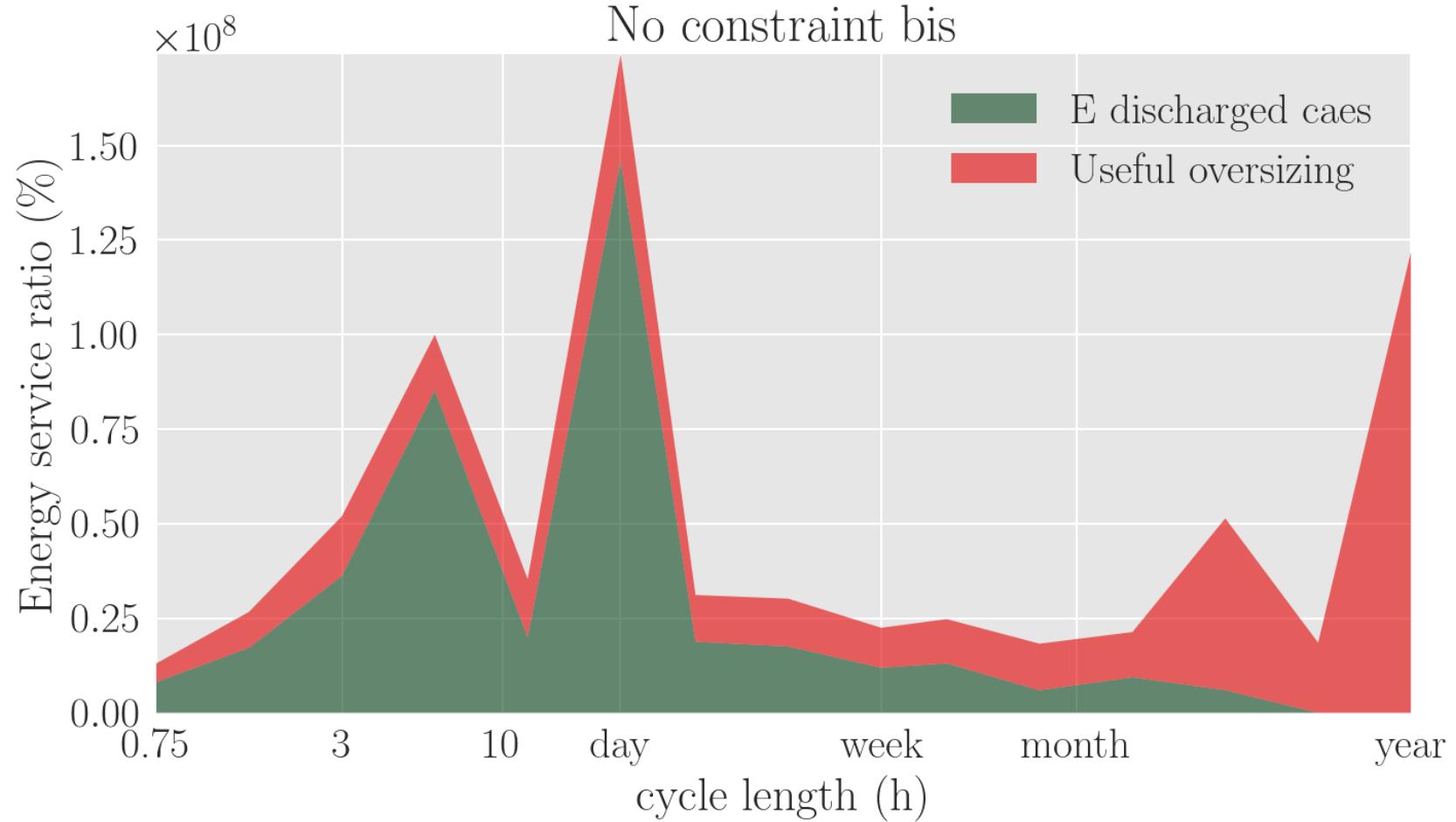
From wavelets decomposition → Storage need sizing

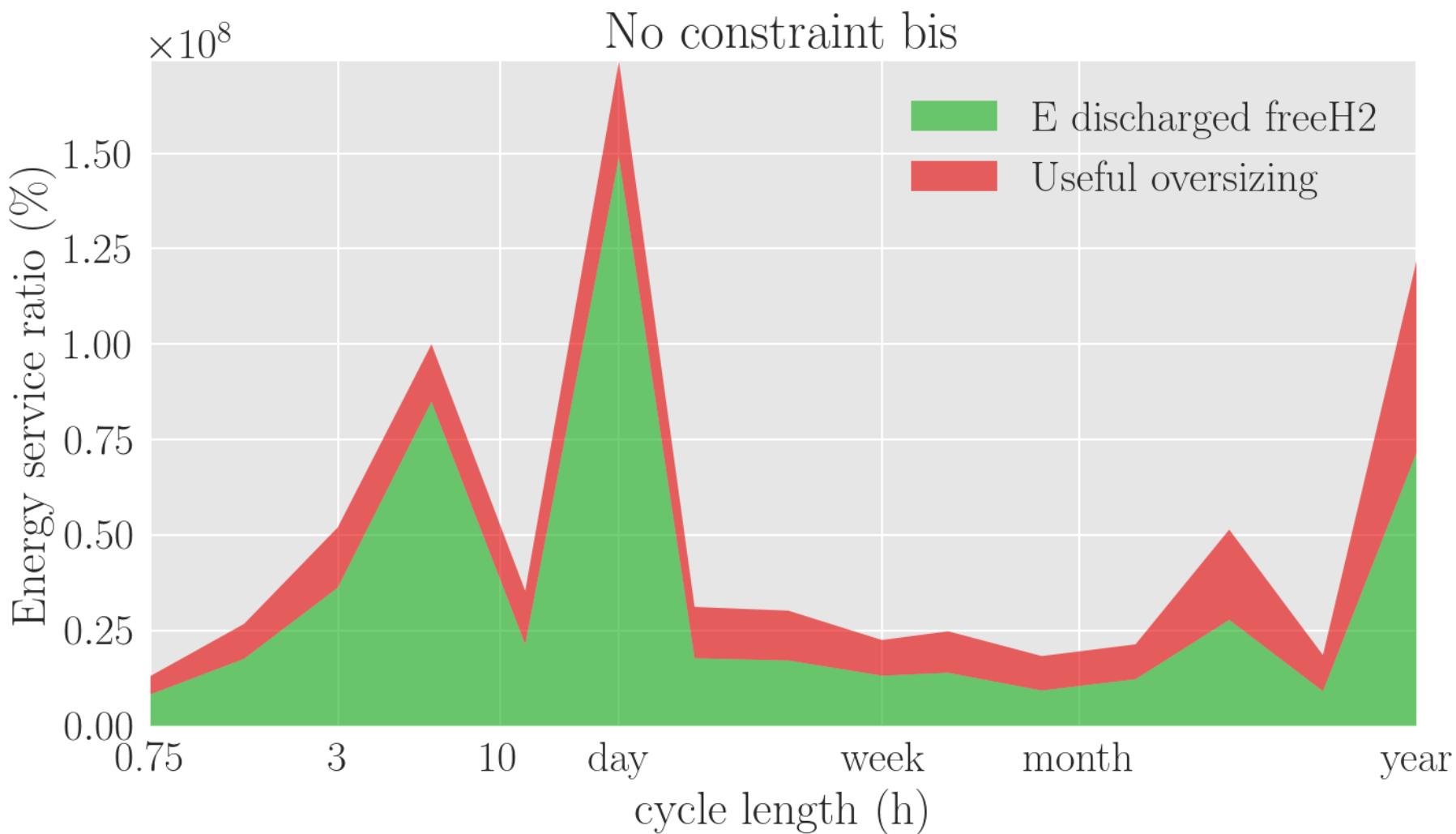


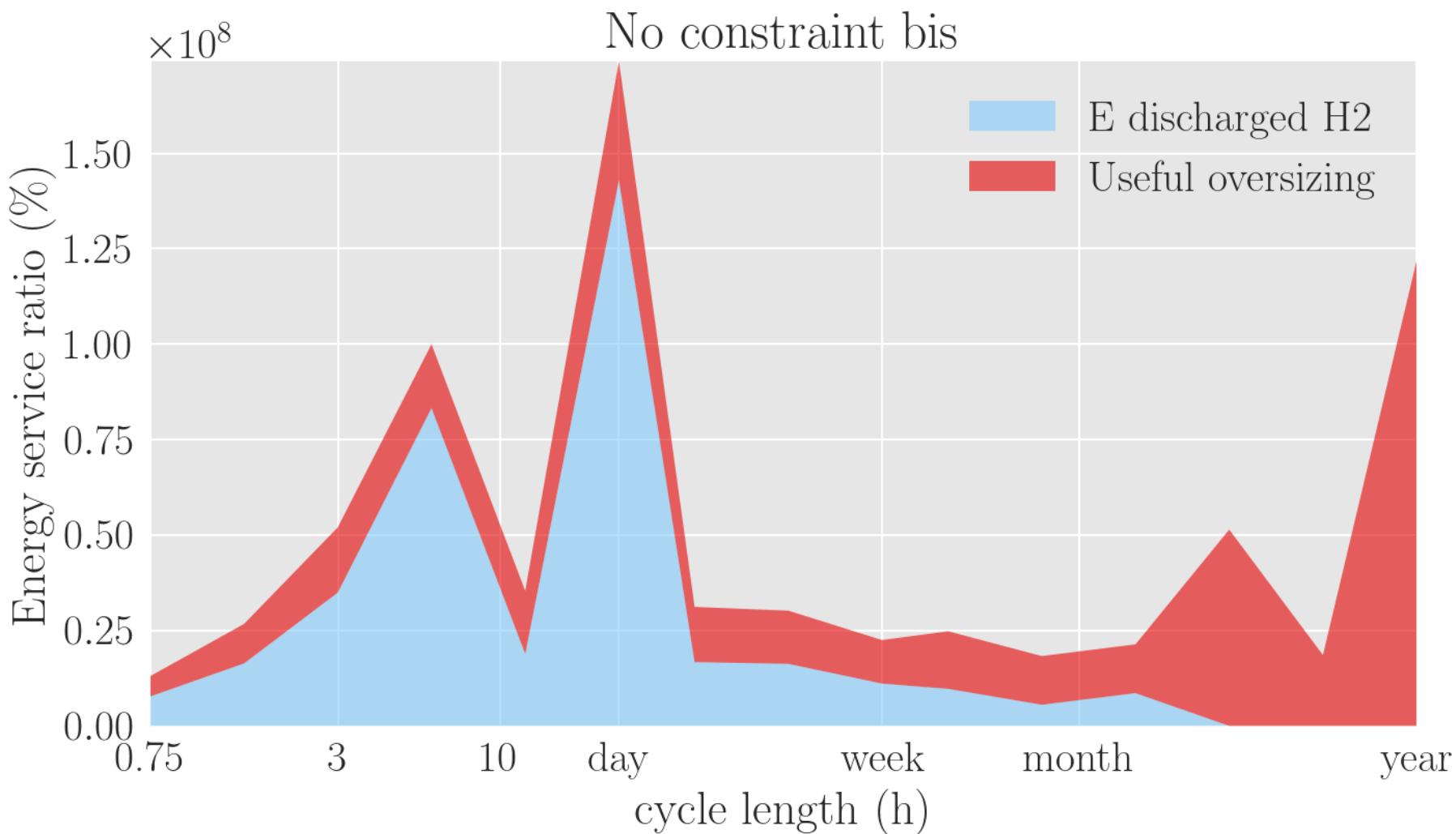
$$\text{Energie} = \max_i(E_i)$$

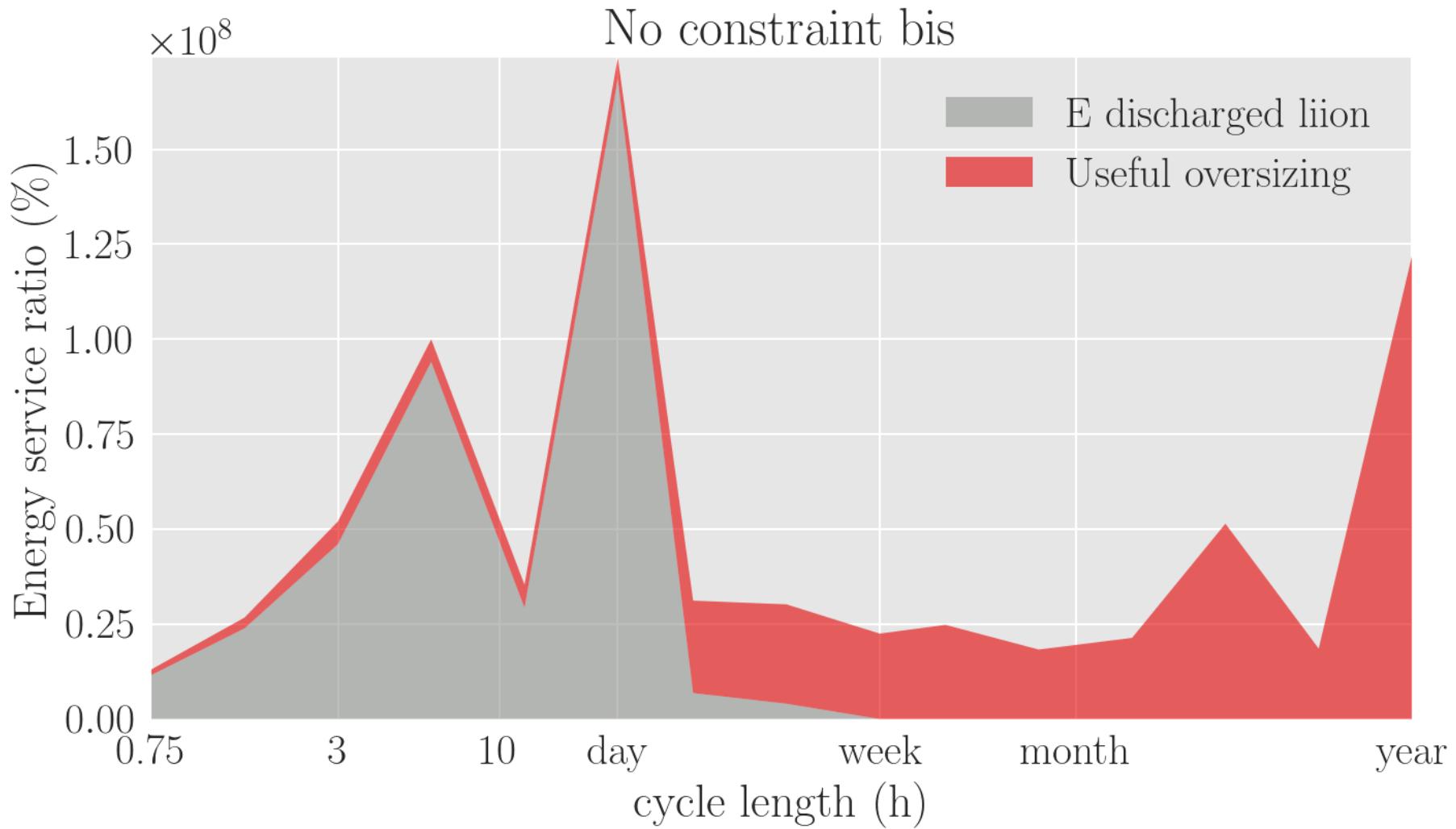
$$\text{Puissance} = \max_i(P_i)$$

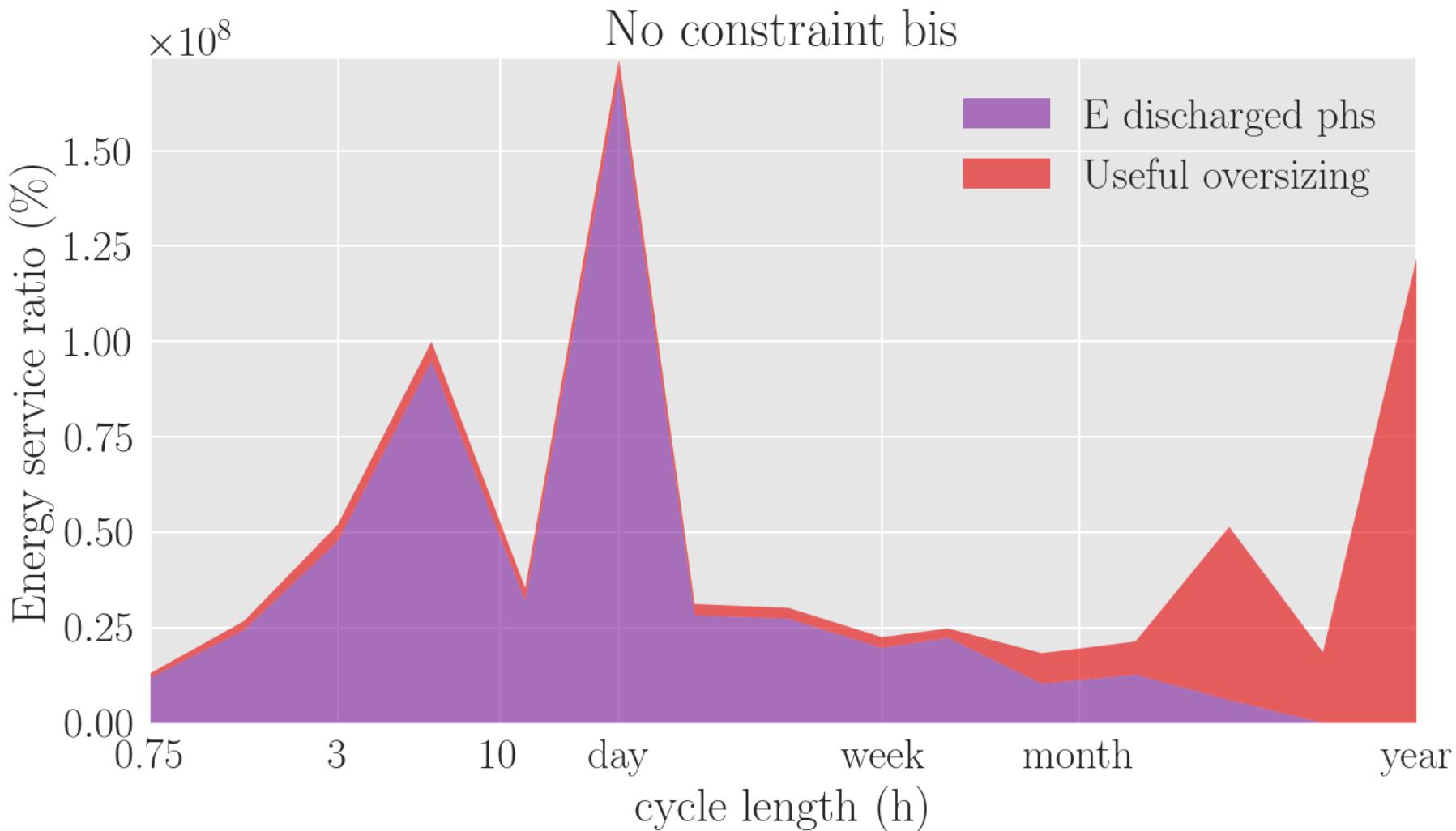
with  $i \in [1, \text{Wavelets/an}]$

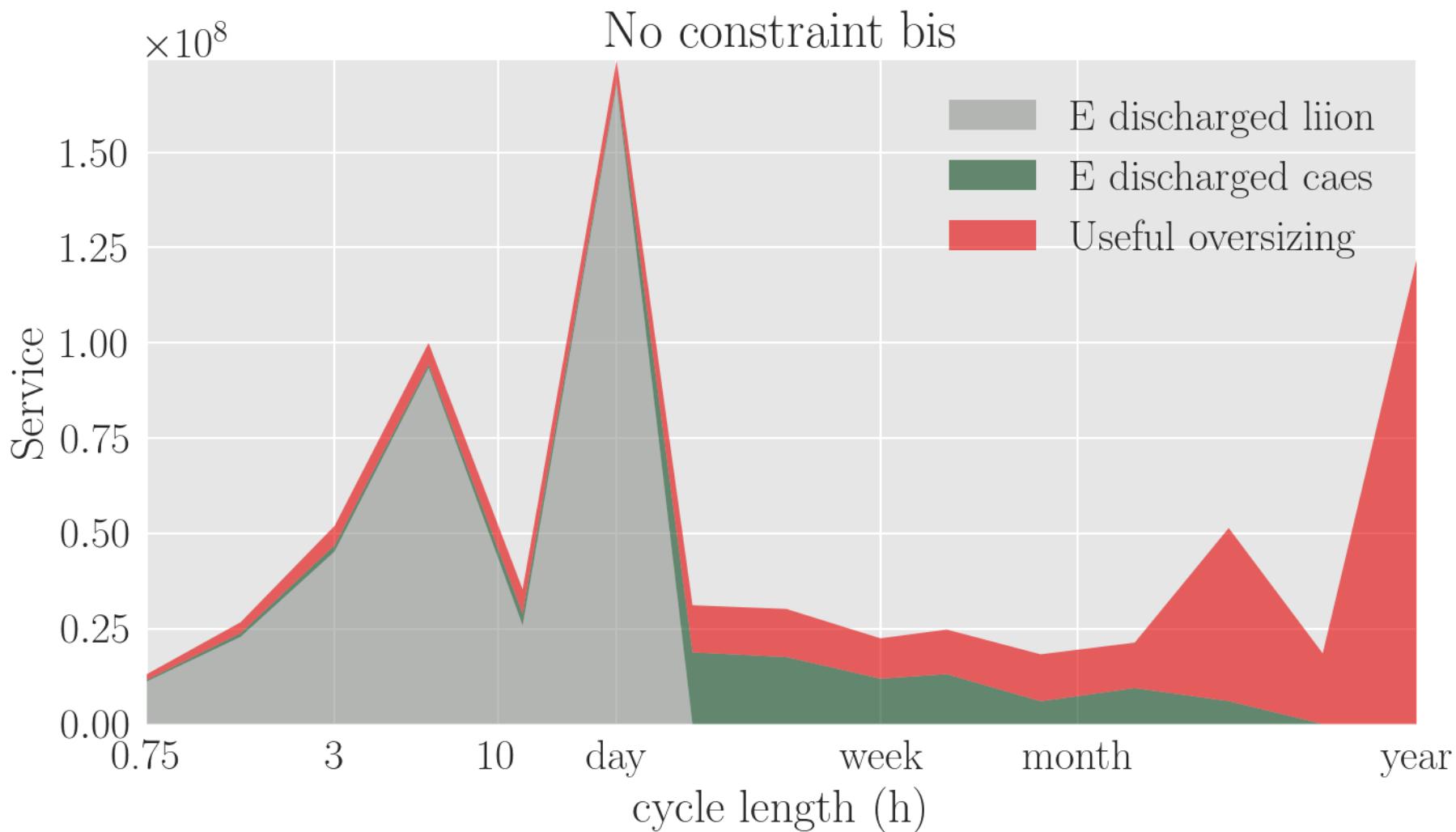


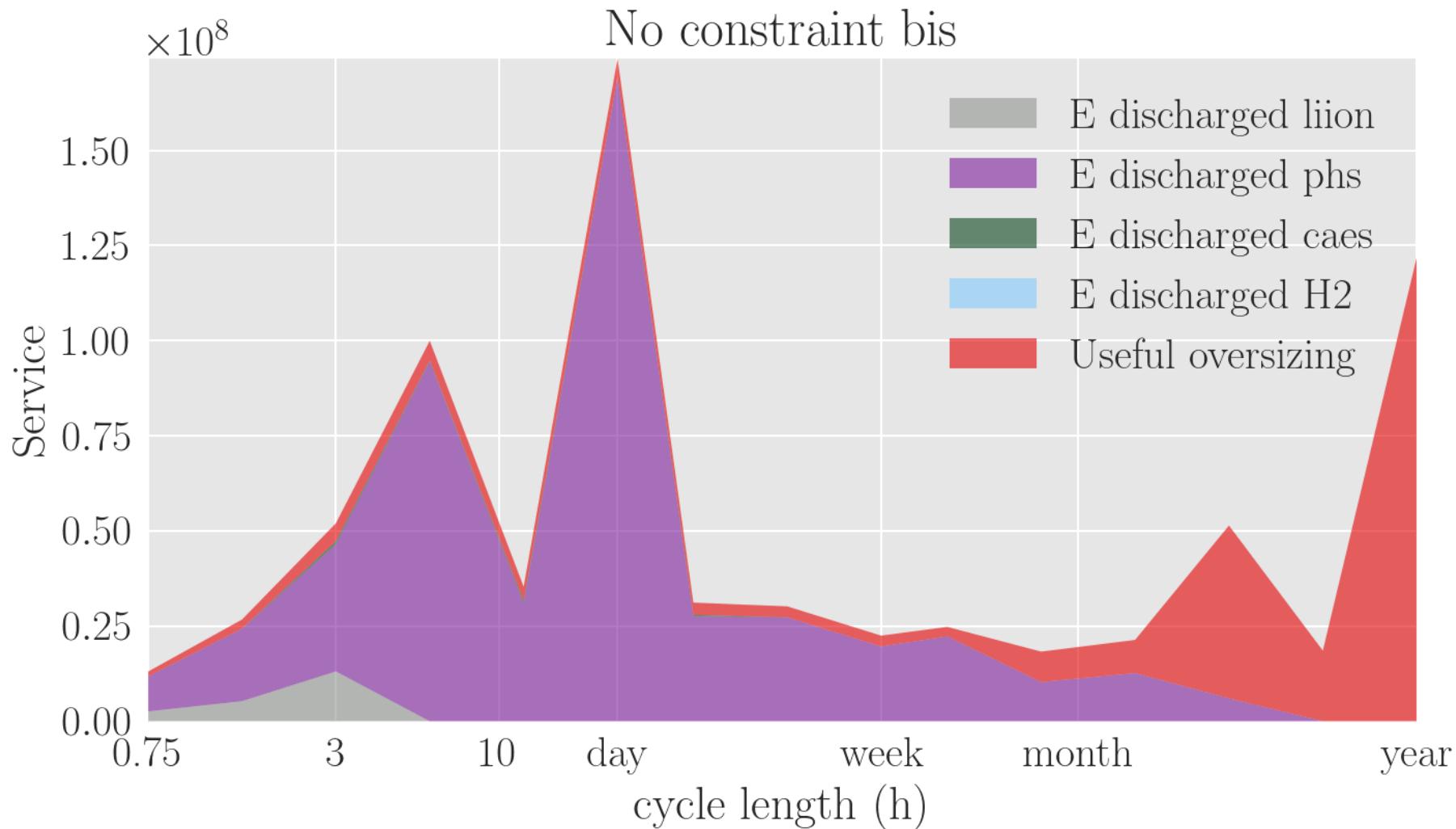


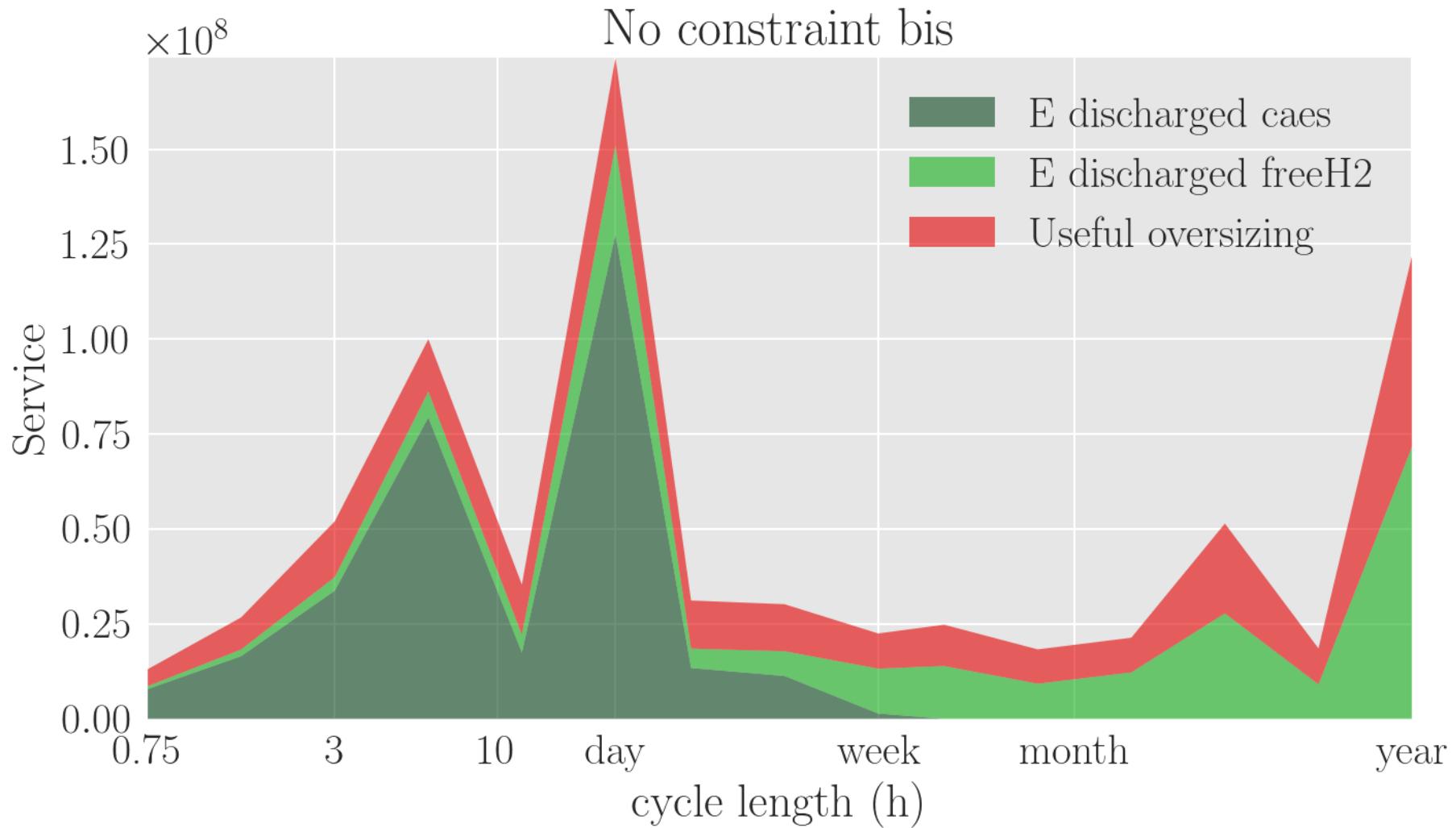


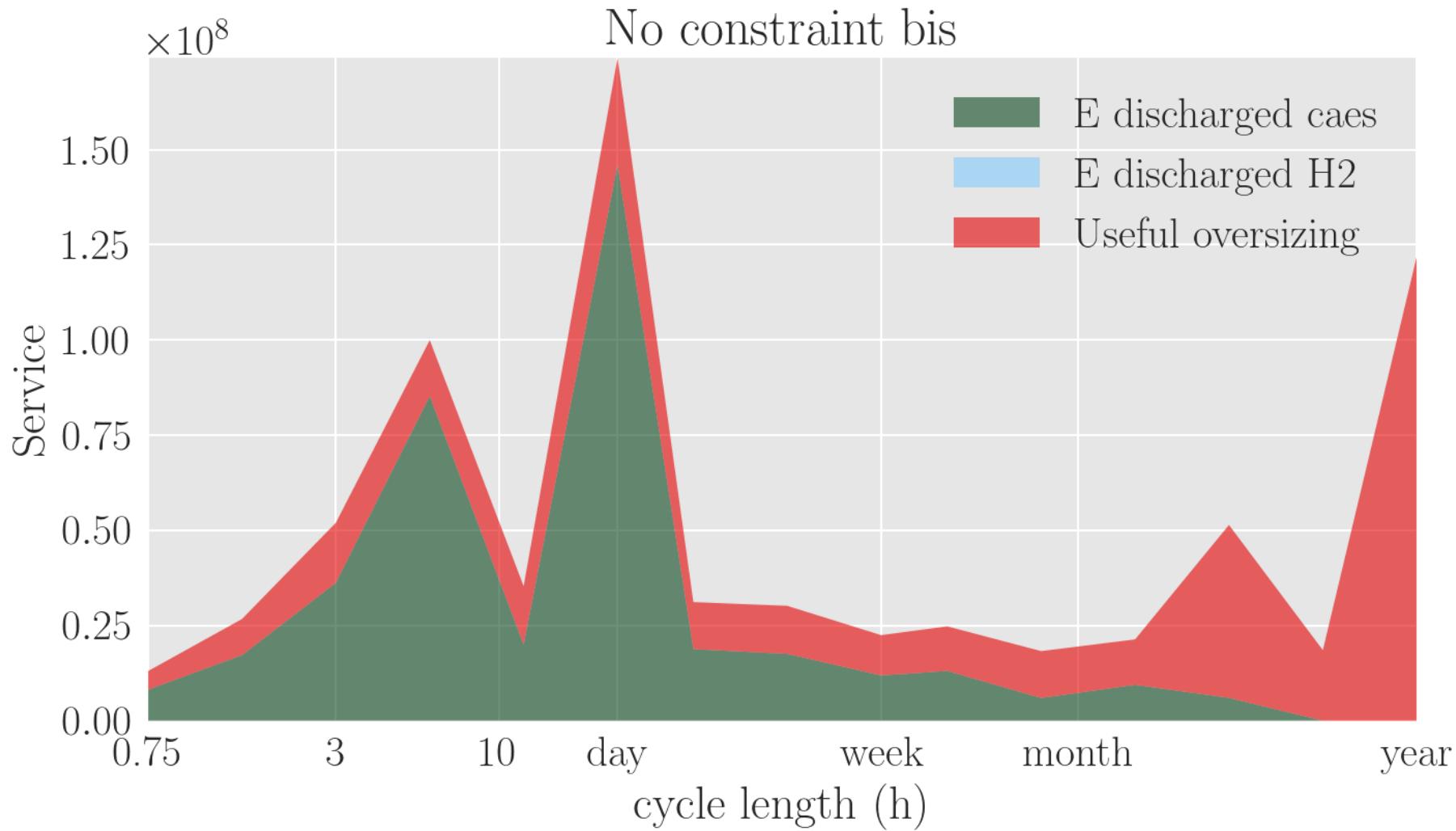


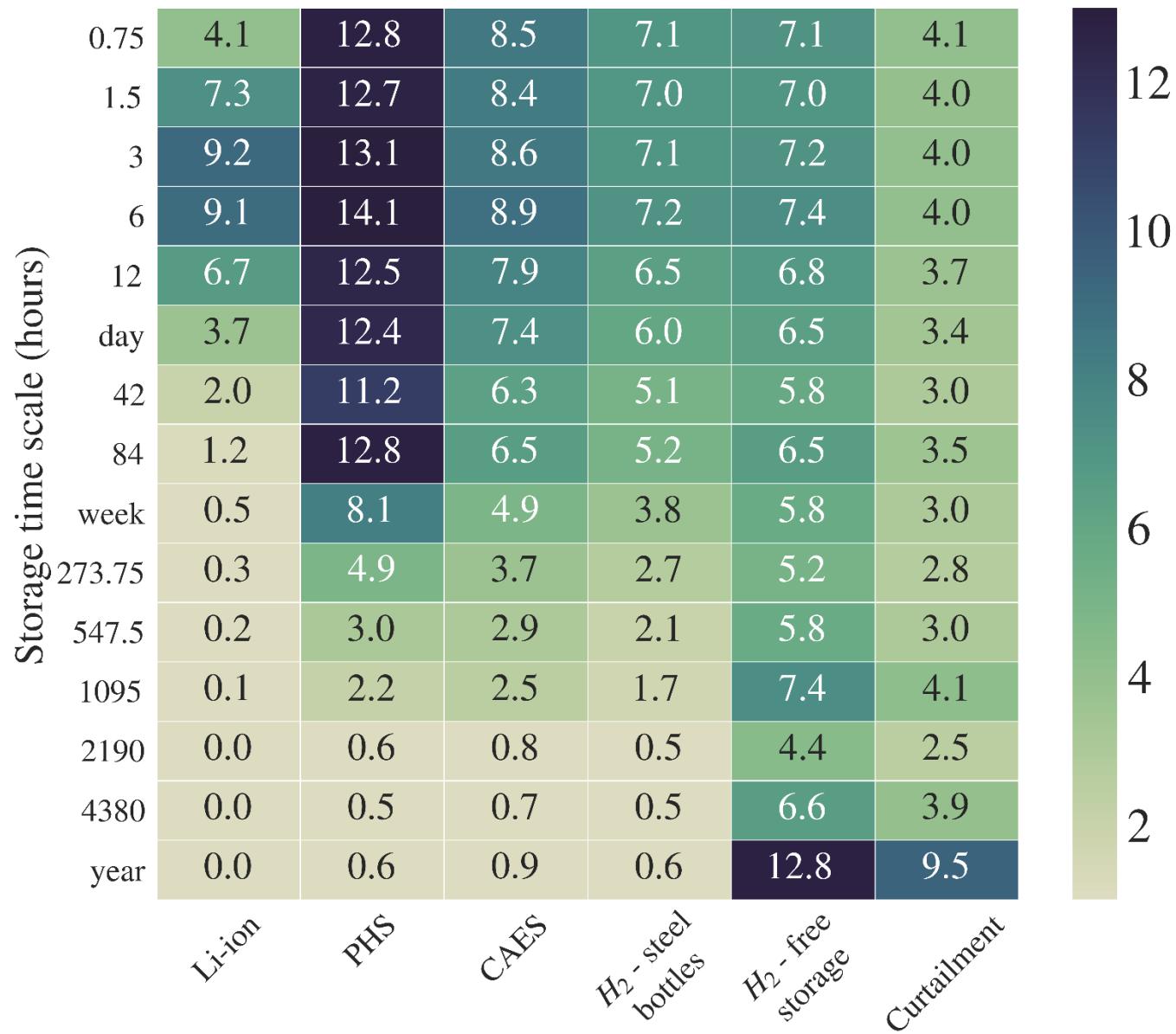












Storage time scale (hours)	Li-ion	PHS	CAES	H <sub>2</sub> -steel bottles	H <sub>2</sub> -free storage	Curtailment
0.75	4.0	9.9	5.5	4.7	4.7	2.6
1.5	6.7	9.2	4.9	4.2	4.3	2.3
3	8.1	9.3	4.9	4.1	4.2	2.1
6	7.9	8.7	4.3	3.6	3.7	1.7
12	5.2	9.0	4.2	3.5	3.6	1.5
day	3.3	10.1	4.3	3.5	3.7	1.4
42	1.8	8.9	3.2	2.5	2.7	0.6
84	1.0	9.8	3.5	2.7	3.3	0.9
week	0.5	7.1	2.9	2.2	3.1	0.8
273.75	0.3	4.3	2.1	1.5	2.6	0.8
547.5	0.1	2.7	1.9	1.3	3.1	1.1
1095	0.1	1.6	1.6	1.1	3.8	1.7
2190	0.1	1.1	1.2	0.8	4.7	2.0
4380	0.0	0.4	0.5	0.3	3.9	1.9
year	0.0	0.3	0.5	0.3	6.0	3.1

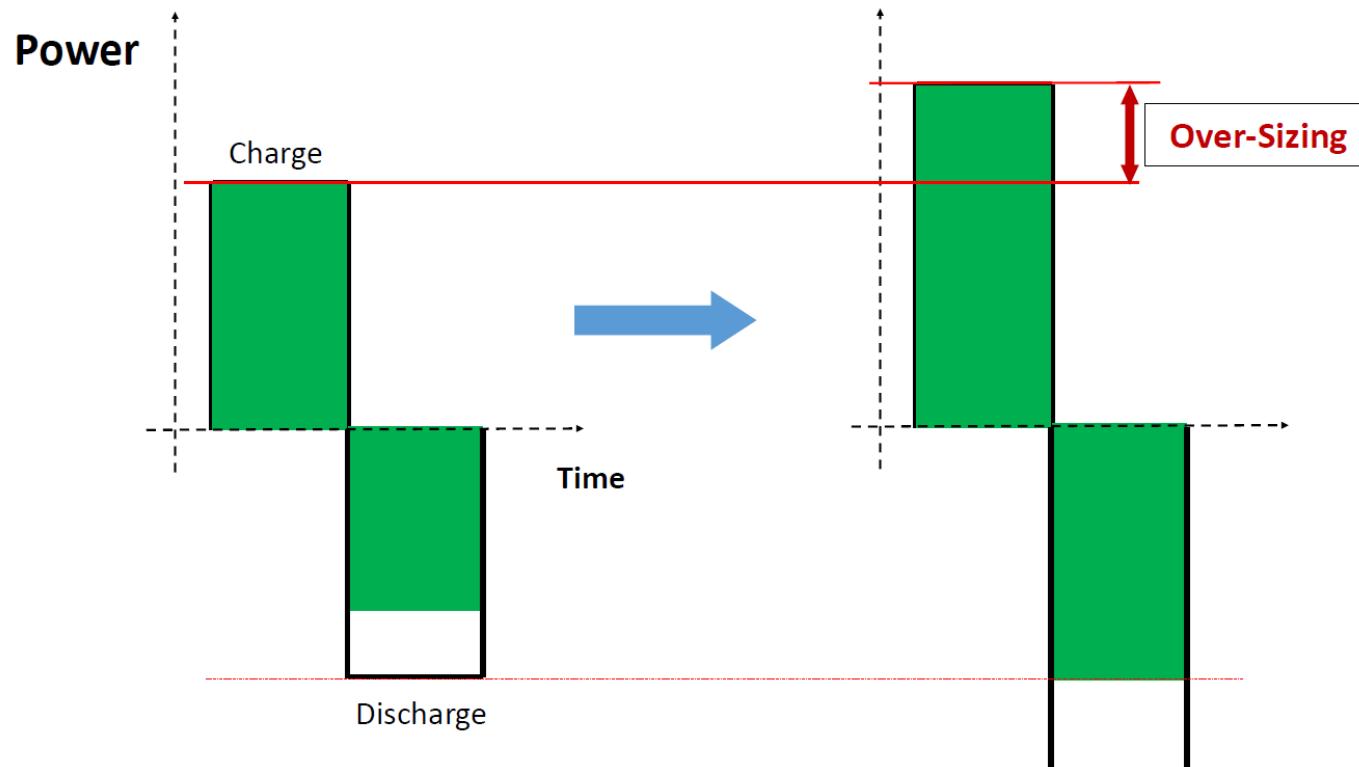
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# POTENTIEL DES STOCKAGES

Problème : le rendement d'un stockage n'est jamais 100%

⇒ Il faut surdimensionner le parc de production

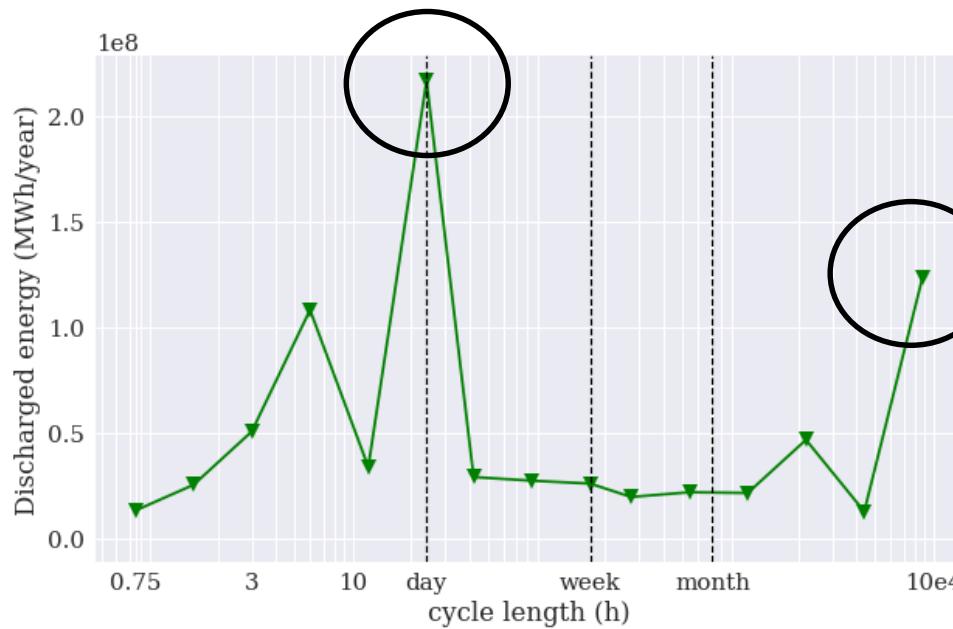
⇒ Cela induit une énergie grise supplémentaire



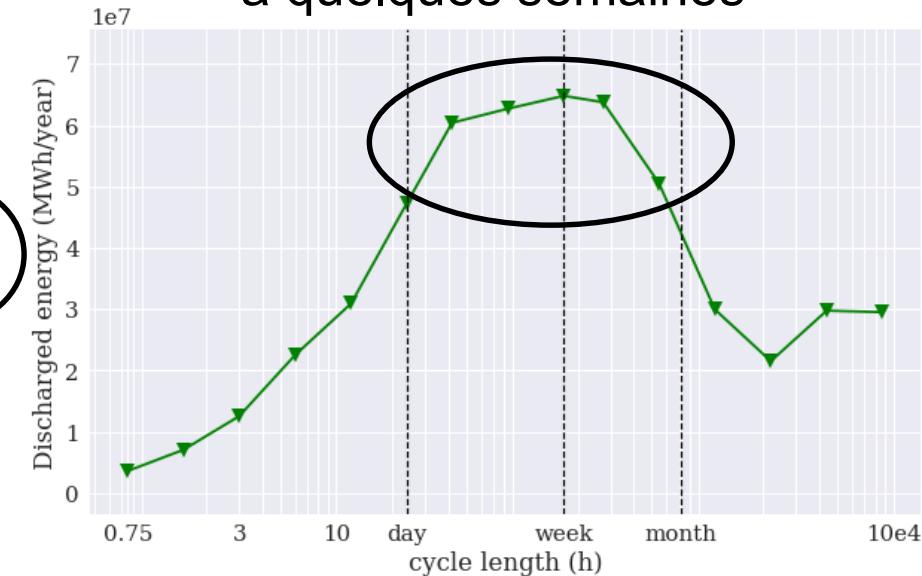
# Besoin de flexibilité

**Energie totale à déplacer pendant l'année**  
(=service rendu par la flexibilité)

PV : concentré sur 1 jour et un an

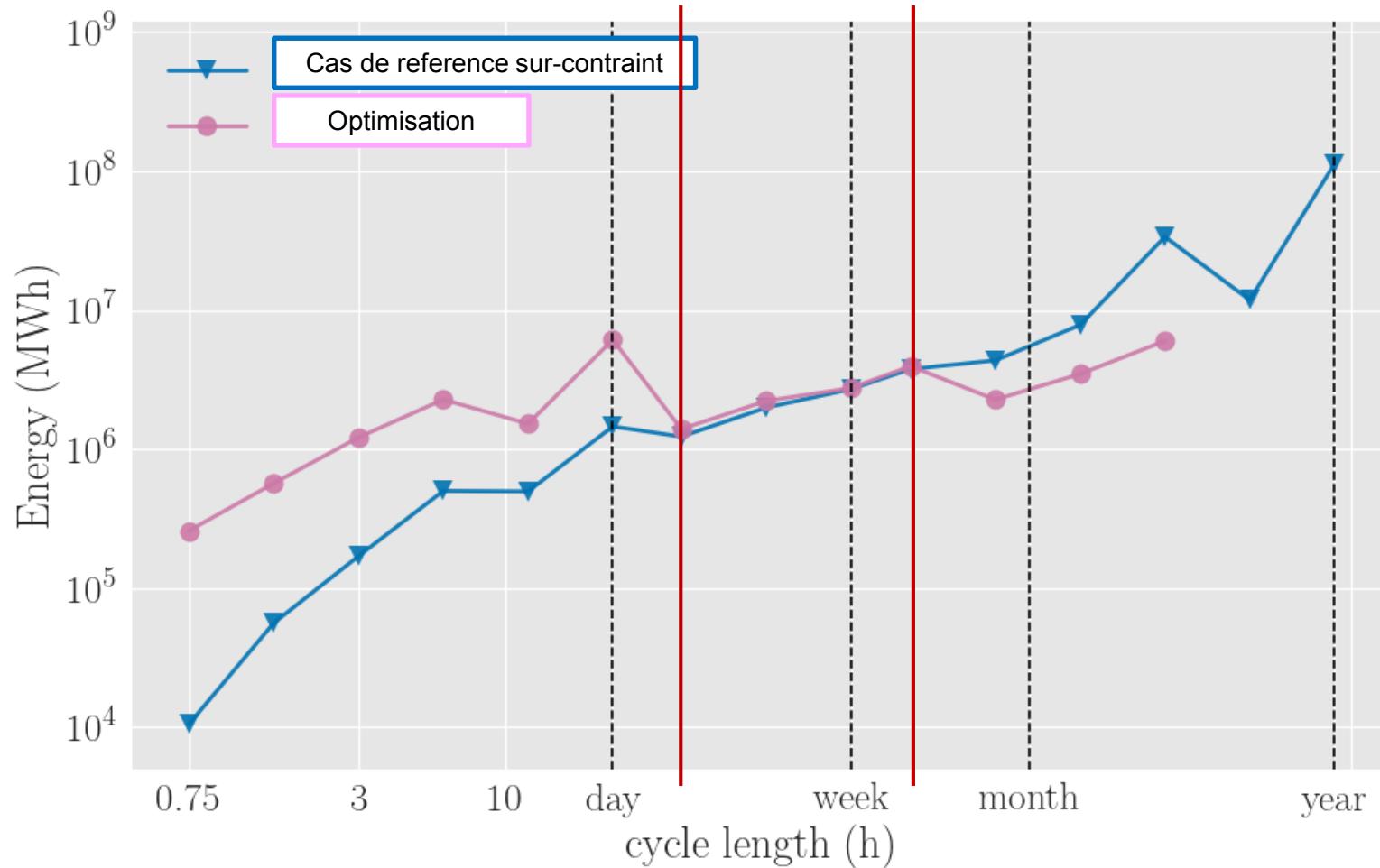


Eolien : de quelques jours à quelques semaines



# Surdimensionner le stockage ou la production ?

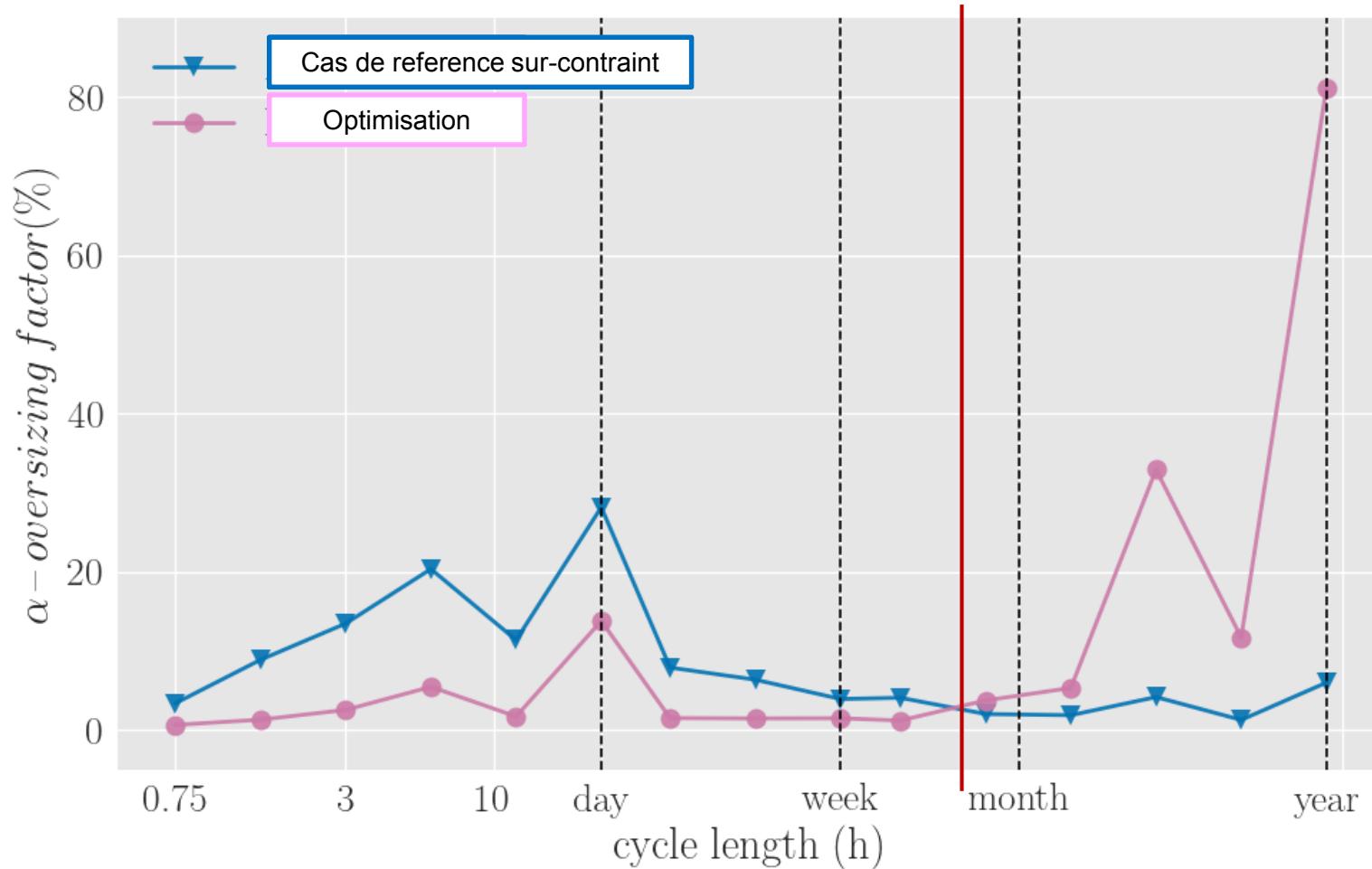
L'exemple du stockage type STEP dans un mix 100% PV



Capacité du stockage en énergie à installer  
(MWh)

# Surdimensionner le stockage ou la production ?

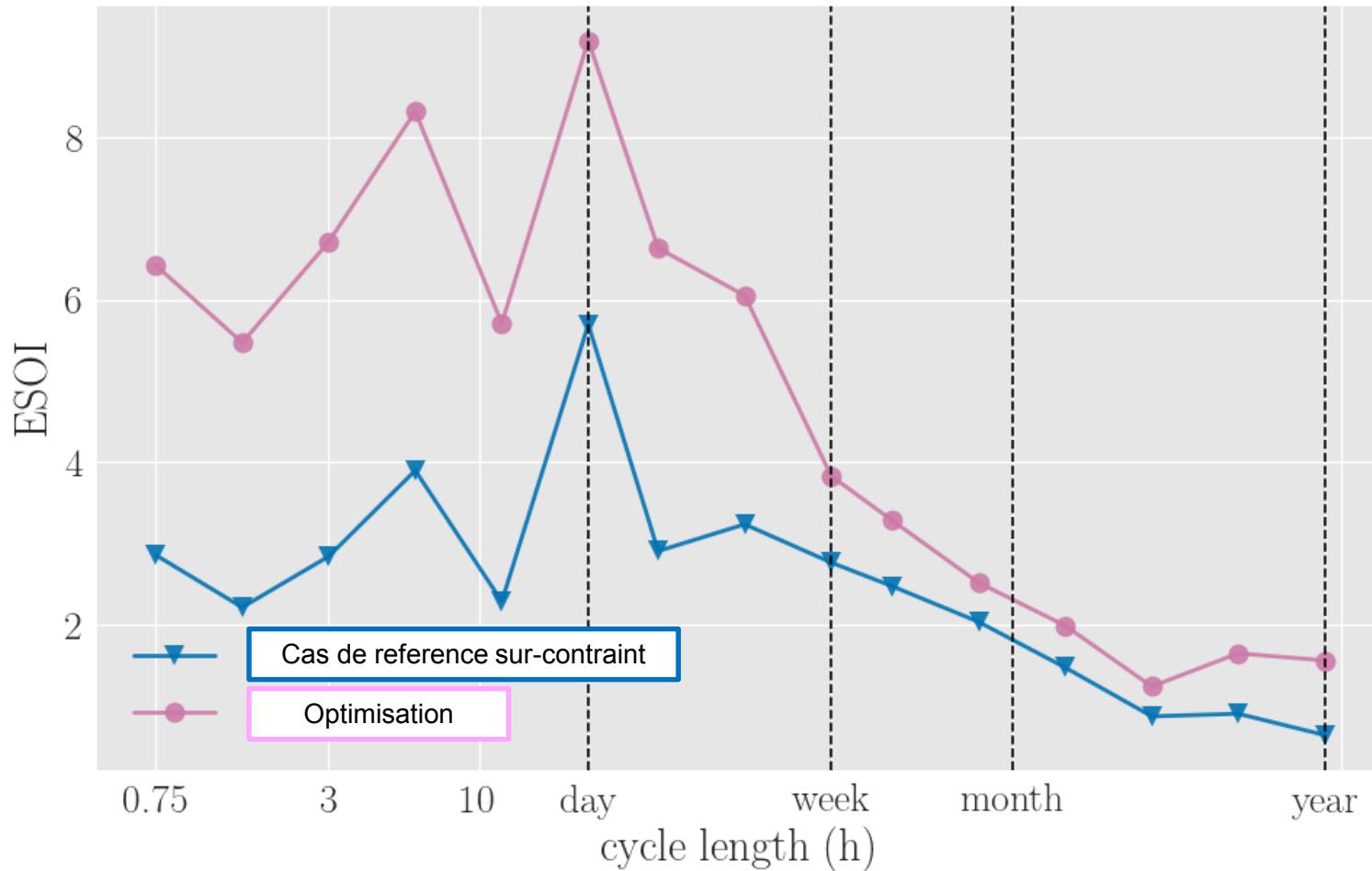
L'exemple du stockage type STEP dans un mix 100% PV



Facteur de surdimensionnement su parc de production  
(%)

# Surdimensionner le stockage ou la production ?

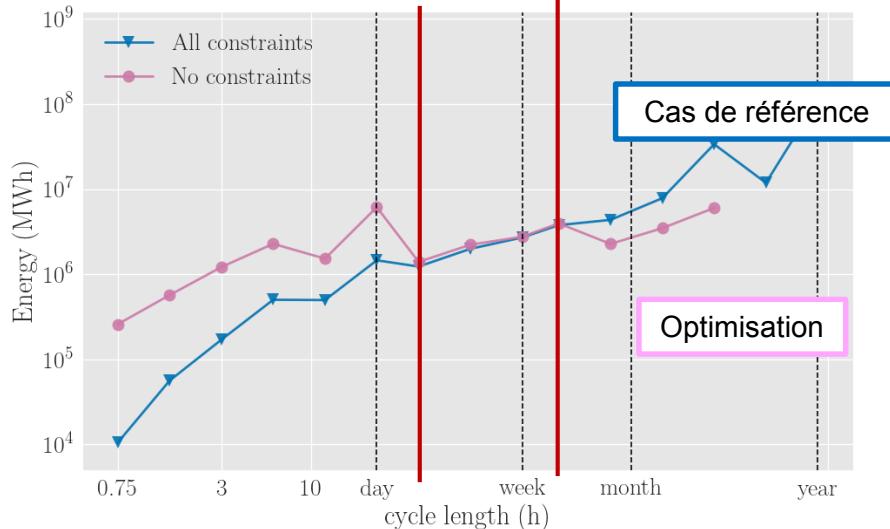
L'exemple du stockage type STEP dans un mix 100% PV



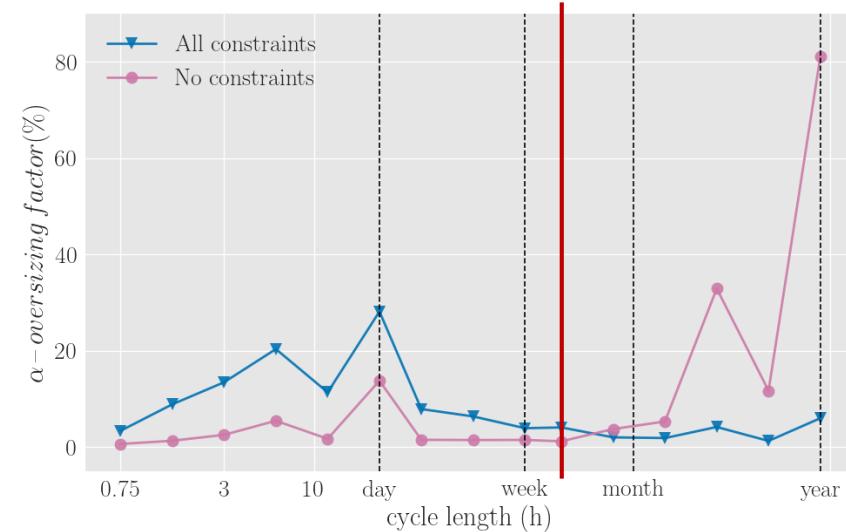
**Retour sur investissement énergétique (ESOI)**

# Sur-dimensionner le stockage ou la production ?

## Capacité énergétique du stockage (MWh)



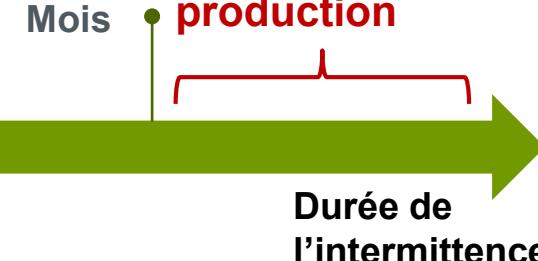
## Surdimensionnement de la production (%)



## Sur-dimensionner le stockage



## Sur-dimensionner la production



Cas d'un scénario de production 100% PV. En rose, résultat de l'optimisation