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# PV–BES sizing and other storage solutions

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## Outline

PV-BES coupled sizing

PHES in decentralized storage applications

CAES (nearly-isothermal)

Seasonal storage with GH2 in households

# BES - Services from storage

Output smoothing of variable energy sources

Voltage control

Frequency control

Black start

Commodity storage/ arbitrage

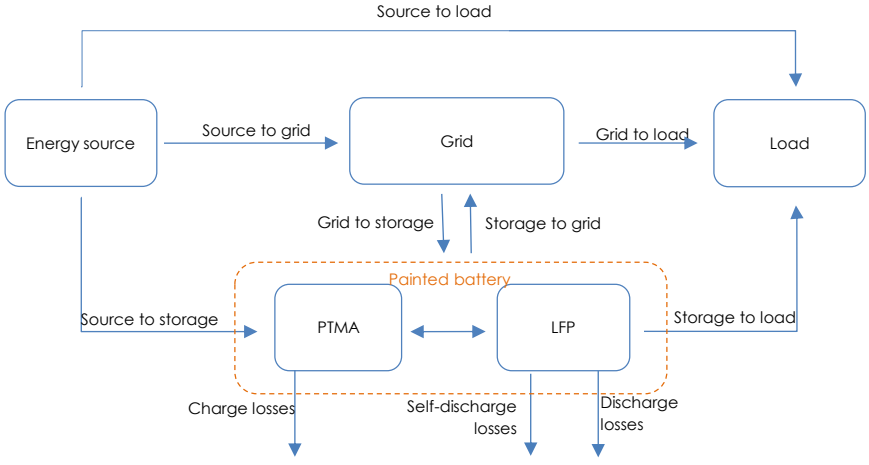
Self-sufficiency

Investment deferral

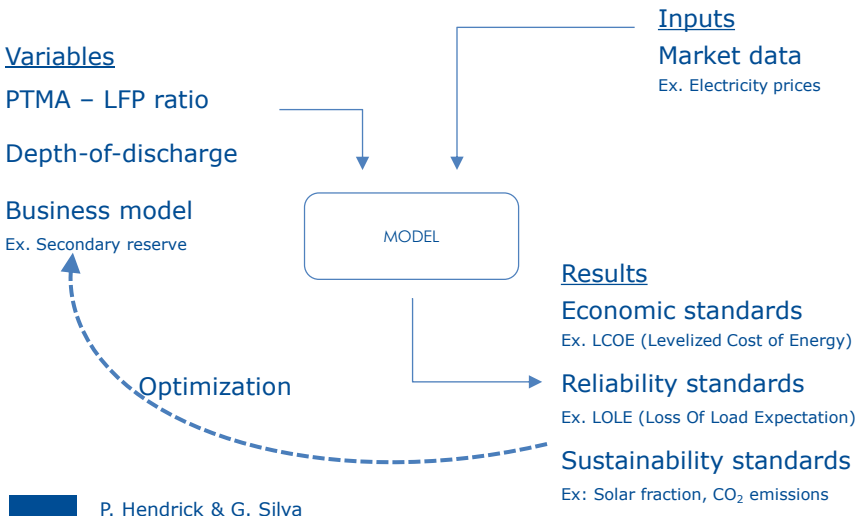
Energy efficiency



# Storage valorization model – Hybrid BES



# Model used



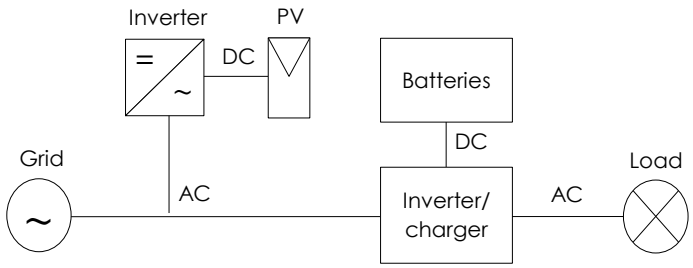



# Home self-sufficiency

Several configurations available

Not much experience from installers in Belgium

Many components unknown to installers/ unavailable in Belgium

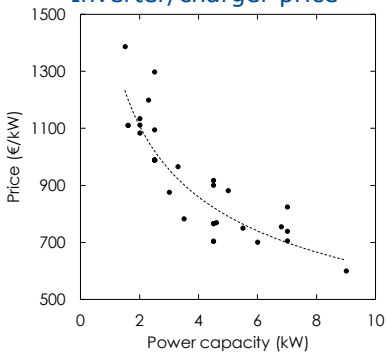



*Source: G. Silva & P. Hendrick. Lead-acid batteries coupled with photovoltaics for increased electricity self-sufficiency in households. Applied Energy 178 (2016) 856-867.

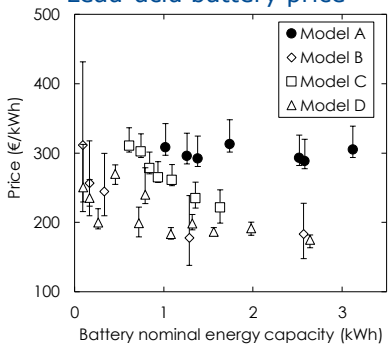
# Home self-sufficiency (PV + lead-acid)

## Characteristics of components

### Inverter/charger price




### Lead-acid battery price




Source: G. Silva & P. Hendrick. Lead-acid batteries coupled with photovoltaics for increased electricity self-sufficiency in households. Applied Energy 178 (2016) 856-867.

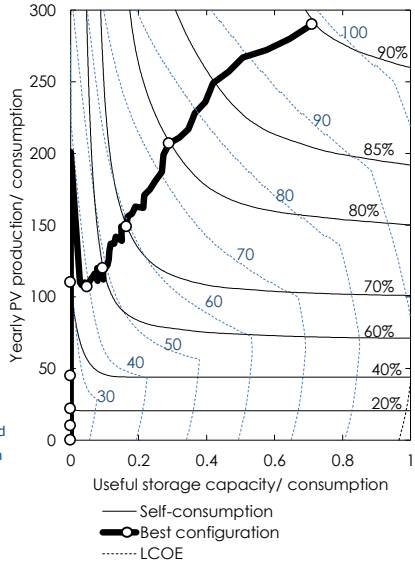


# Home self-sufficiency (PV + lead-acid)

## Optimization

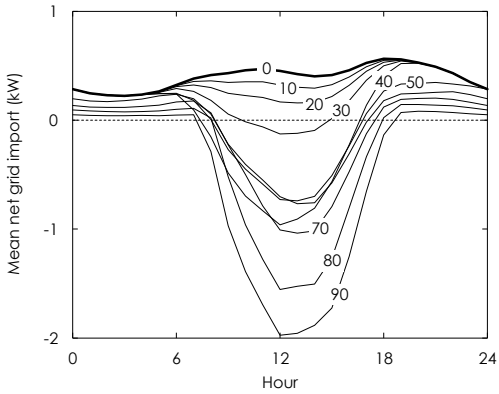
| Parameter | Value |
|---|---|
| Annual real interest rate | 5% |
| PV capital cost | 2000€/$kW_{peak}$ |
| PV lifetime | 30 years |
| Battery installation | 3000€ |
| Battery capital cost | 250€/$kWh_{nominal}$ |
| Battery DoD | 50% |
| Battery throughoutput | 600kWh |
| Battery max lifetime | 12 years |
| Battery charging eff. | 90% |
| Battery discharging eff. | 90% |
| Battery self-discharge | 0,1%/h |
| Grid to load elec. price | 20c€/kWh |
| PV to grid elec. price | 3c€/kWh |

*Source: G. Silva & P. Hendrick. Lead-acid batteries coupled with photovoltaics for increased electricity self-sufficiency in households. Applied Energy 178 (2016) 856-867.



# Home self-sufficiency (PV + lead-acid)

## Impact on the grid




Strong impact on the grid for auto-consumption over 20%.

Probable limits to injection on the Belgian grid in the future to avoid grid problems (these limits already exist in Germany).

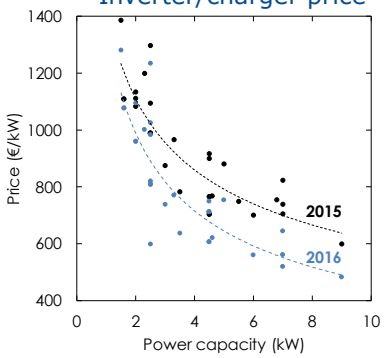
*Source: G. Silva & P. Hendrick. Lead-acid batteries coupled with photovoltaics for increased electricity self-sufficiency in households. Applied Energy 178 (2016) 856-867.



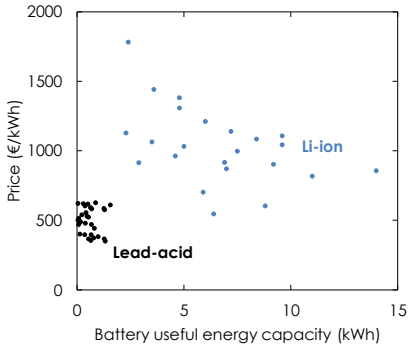
# Home self-sufficiency (PV + Li-ion)

## Characteristics of components

### Inverter/charger price




### Battery price




Source: G. Silva & P. Hendrick. Photovoltaic self-sufficiency in households using lithium-ion batteries, and its impact on the grid. Applied Energy 195 (2017) 786-799.

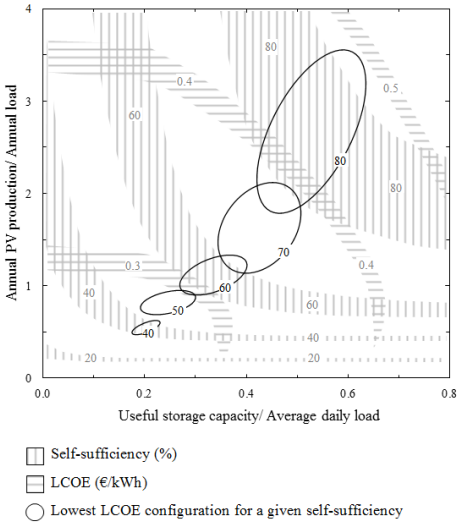
# Home self-sufficiency (PV + Li-ion)

## Optimization

| Parameter | Value |
|---|---|
| Annual real interest rate | 5% |
| PV capital cost | 2164 $P^{0.81}$€ |
| PV lifetime | 30 years |
| Battery installation | 2000€ |
| Battery capital cost | 600€/$kWh_{useful}$ |
| Inverter/ charger cost | 500€/kW |
| Battery lifetime | 5000 cycles/ 20 years |
| Battery power capacity | 0.5 kW/$kWh_{useful}$ |
| Battery round-trip efficiency | 90% |
| Battery self-discharge | 3%/month |
| Grid connection cost | 70€/ year |
| Grid to load elec. price | 0.18€/kWh |
| PV to grid elec. price | 0.03€/kWh |

*Source: G. Silva & P. Hendrick. Photovoltaic self-sufficiency in households using lithium-ion batteries, and its impact on the grid. Applied Energy 195 (2017) 786-799.

## Results






# PHES in decentralized way

1 MW to 10 MW units (identical in MWh)

Use existing lower / upper water reservoirs

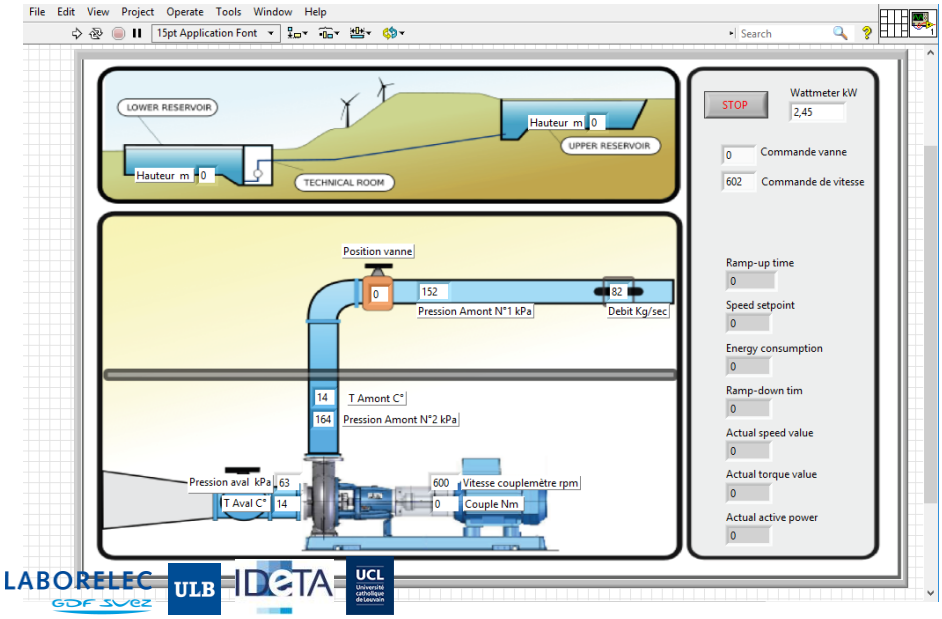
Use low cost turbomachinery (PaTs)

Use high flexibility of the facility

Large number of starts & stops per day

PaTs of small size in parallel (100 to 250 kW)

# Decentralized PHES – Test facility @ Negundo

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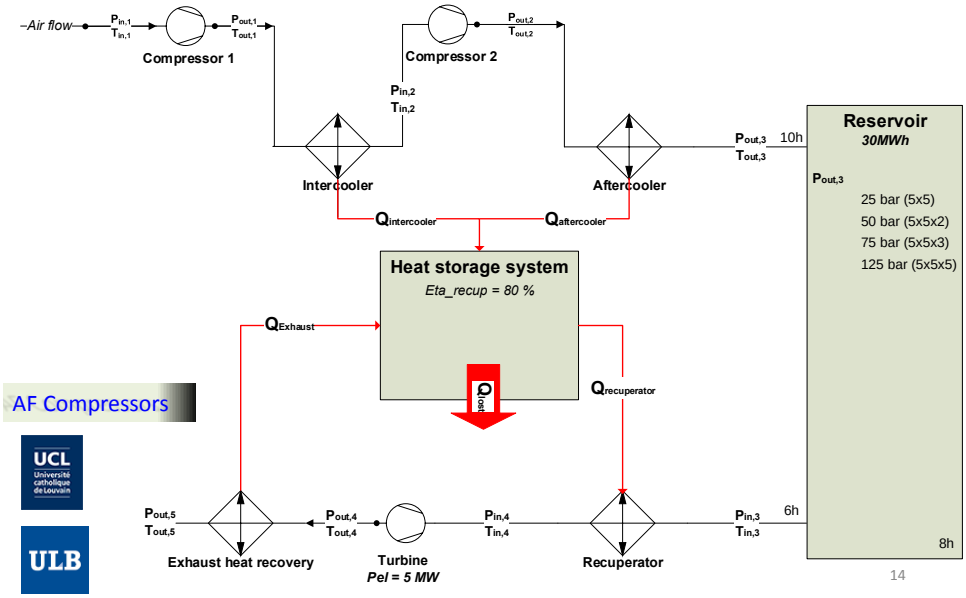
# CAES – Nearly isothermal

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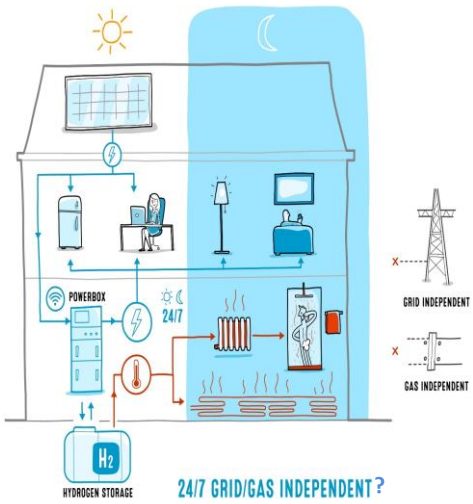
# Seasonal energy storage using GH2




- Reversible PEMFC used as FC and electrolyser
- Delivery of electricity and heat (global efficiency of 20-25%)
- Extra heater to be flexible in E/H ratio
- Extra compression to store 1.500-1.800 kWh/family for winter season
- Storage tank (in composites)
- Safety aspects and certification
- Coupling with car with H2 ?