

4th Inverse Problems, Design and Optimization  
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# Optimal design of energy production and storage systems in buildings

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# Summary

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- 2 Energy management strategy**
  - Criteria
  - Overview of the strategy
- 3 Modeling**
  - Load modeling in TRNSYS
  - Modeling of production and storage systems
- 4 Design of energy production and storage systems and impact on the grid**
- 5 Conclusion and outlook**

# Context of the study

- Growing environmental concerns
- Decentralized energy production booming
- Intermittent renewable energy resources
- Integration of production systems in individual houses

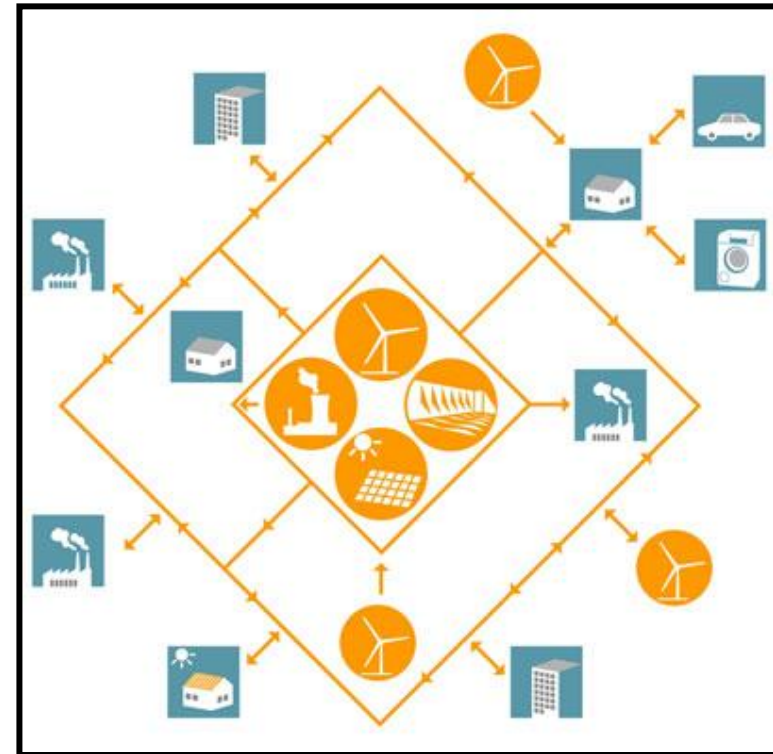
# Context of the study

## Issue:

- A massive penetration of the renewable energy production impacts on the electricity grid operation
- Necessary changes in electricity grid leading to an increase in flexibility and security

## Solution:

- Develop intelligent management systems that minimize the impact induced by the injection of the distributed generation



# Objectives

Develop a comprehensive and multi-criteria approach for energy management in individual multi-energy houses (equipped with production and storage systems)

- Optimize local energy consumption
- Minimize production impact on the local grid
  - Satisfy the peak demand
  - Store energy and thus optimize its use
  - Adjust supply and demand in energy

# Energy criteria

- Use of renewable energy:  $J_{EnR} = \frac{\%_{EnR_c} \times \%_{SC}}{100}$
- Energy self-consumption:  $\%_{SC} = 100 \times \frac{EnR_c}{EnR_p}$
- Renewable energy coverage rate:  $\%_{EnR_c} = 100 \times \frac{EnR_c}{EnR_c + E_{EDF}}$

$\%_{SC}$  : Ratio of the renewable energy consumed in situ to the renewable energy produced (%)

$\%_{EnR_c}$  : Ratio of the renewable energy produced and consumed in situ to the total energy consumed (%)

$J_{EnR}$  : Global criterion (%)

$E_{EDF}$  : Energy extracted from the electricity grid (kWh)

$EnR_c$  : Renewable energy consumed (kWh)

$EnR_p$  : Renewable energy produced (kWh)

# Economic cost criteria

$$J_{cost} = \sum_t \left( E_{inj}(t) P_{En}(t) - E_{EDF}(t) P_{En}(t) \right)$$

$J_{cost}$  : Criterion about economic cost (€)

$E_{EDF}$  : Energy extracted from the electricity grid (kWh)

$E_{inj}$  : Energy injected to the grid (kWh)

$P_{En}$  : Electricity price (€)

# Dynamic pricing

$$P_{En}(t) = \sum_{i,j} a_{ij} \times L_g^i(t) \times T_{out}^j(t)$$

Coefficients of the energy price model

$j \setminus i$	0	1	2	3	4	5
0	$6.58 \times 10^1$	$-0.38 \times 10^1$	$7.67 \times 10^{-2}$	$-5.12 \times 10^{-4}$	$3.48 \times 10^{-7}$	$6.37 \times 10^{-9}$
1	$-1.77 \times 10^1$	$9.27 \times 10^{-1}$	$-1.64 \times 10^{-2}$	$1.30 \times 10^{-4}$	$-4.04 \times 10^{-7}$	-
2	$6.04 \times 10^{-2}$	$-3.12 \times 10^{-3}$	$4.41 \times 10^{-3}$	$2.29 \times 10^{-7}$	-	-
3	$-5.16 \times 10^{-4}$	$-1.96 \times 10^{-4}$	$2.38 \times 10^{-6}$	-	-	-
4	$4.11 \times 10^{-4}$	$1.19 \times 10^{-5}$	-	-	-	-
5	$2.01 \times 10^{-5}$	-	-	-	-	-

$P_{En}$  : Electricity price (€)

$L_g$  : Grid load (MWh)

$T_{out}$  : Outdoor temperature (°C)

$a_{ij}$  : Polynomial model coefficient

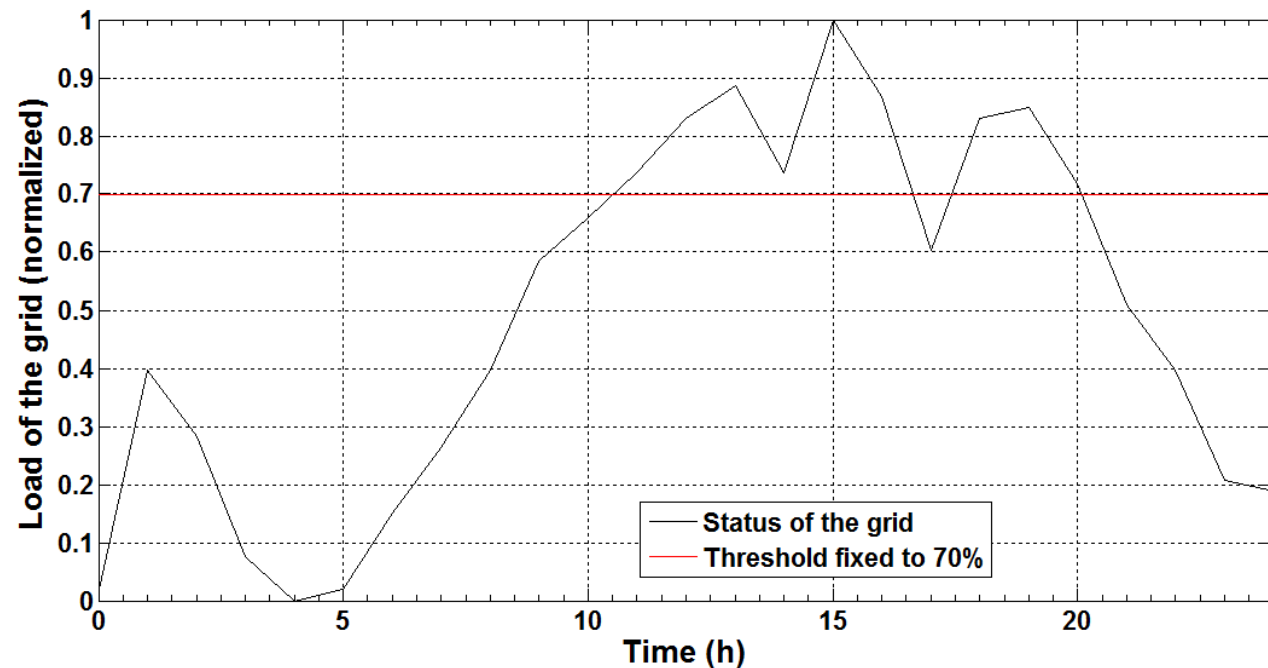


# Impact on the grid

- Injection impact: 
$$I_{inj} = \frac{1}{1000} \times \sum_t \left( E_{inj}(t) \times \Delta E_{thres}(t) \right)$$

$E_{inj}$  : Energy injected to the grid (kWh)

$\Delta E_{thres}$  : Normalized deviation between the fixed threshold and the status of the grid

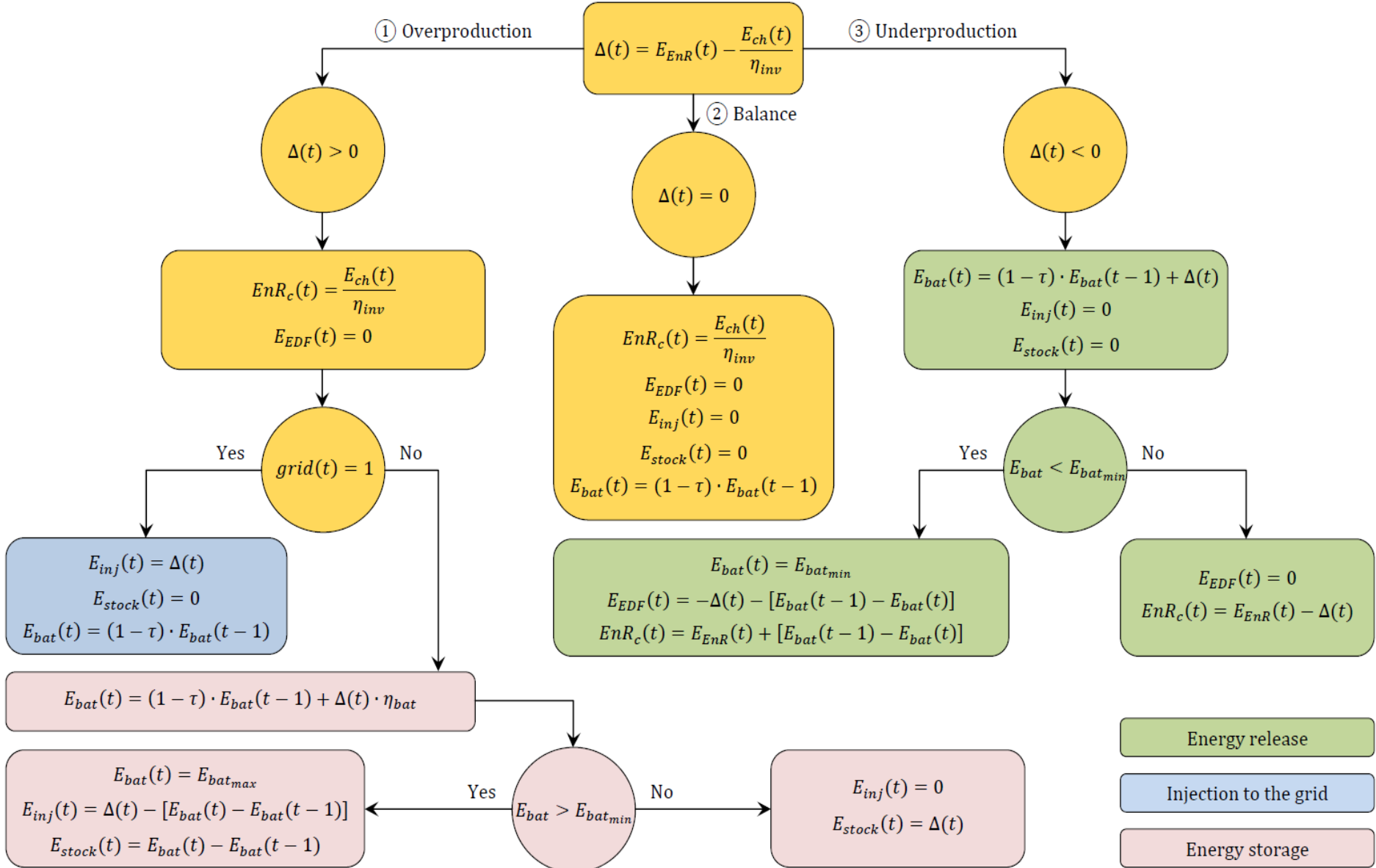


# Impact on the grid

- Extracted impact:  $I_{ext} = -\frac{1}{1000} \times \sum_t (E_{EDF}(t) \times \Delta E_{thres}(t))$
- Global impact:  $I_{over} = I_{inj} + I_{ext}$

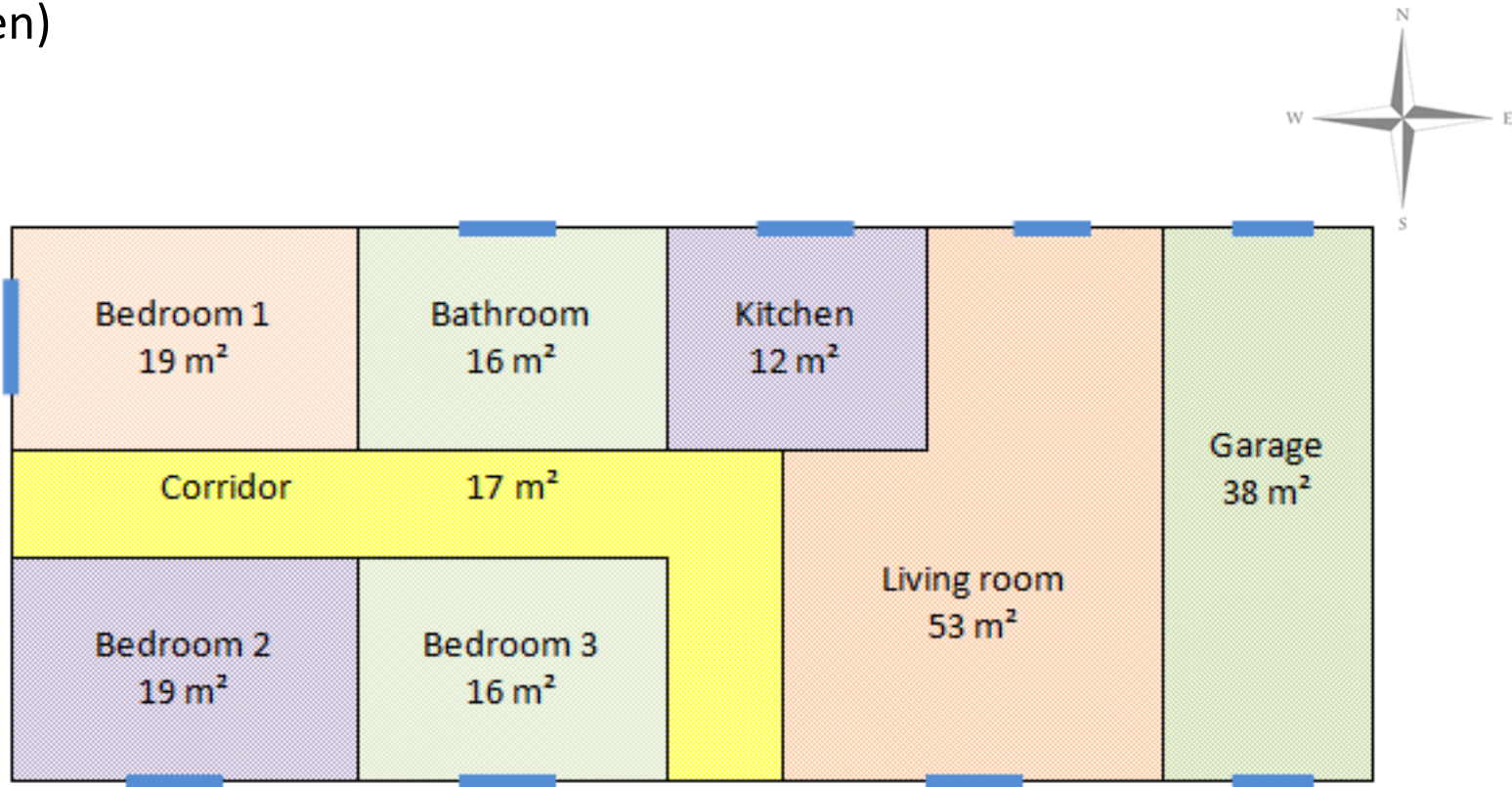
$E_{EDF}$  : Energy extracted from the electricity grid (kWh)

$\Delta E_{thres}$  : Normalized deviation between the fixed threshold and the status of the grid



## TRNSYS thermal model of an individual house

Case study: 150 m<sup>2</sup> single-storey house located in Perpignan (south of France), facing south and inhabited by four persons (two adults and two children)



# TRNSYS thermal model of an individual house

Characteristics of the materials used in the considered single-storey house:

Element	Material	Thickness [m]	U [ $\text{W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$ ]	$U_{\text{RT2005}}$ [ $\text{W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$ ]
External wall	BA13	0.013	0.602	0.45
	Rockwool	0.06		
	Cinderblock	0.2		
	Surface coating	0.02		
Internal wall	BA13	0.013	0.845	/
	Glass wool	0.04		
Floor	BA13	0.013	0.415	0.4
	Tiles	0.022		
	Mortar	0.05		
	Heavy concrete	0.16		
Ceiling	Expanded polystyrene	0.08	0.196	0.34
	BA13	0.013		
	Glass wool	0.1		
	Air knife	0.5		
Garage ceiling	Terracotta	0.01	2.37	0.34
	BA13	0.013		
	Terracotta	0.2		
Window	Double glazed	0.2	1.43	2.6

# Modeling of lifestyle and habits

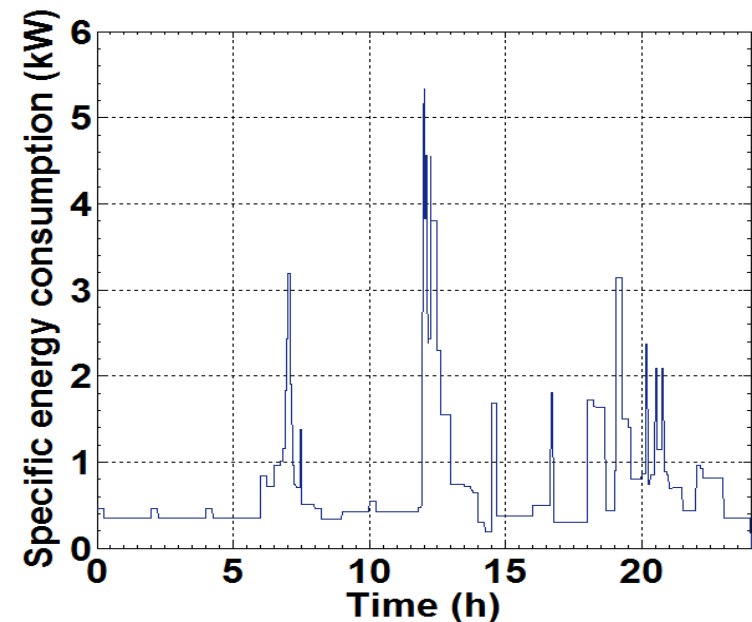
## Conventional occupation scenario set by RT 2005

Week occupancy	Weekend occupancy
0h-10h ; 18h-24h	0h-24h

## Conventional RT 2005 temperature set-point

Set point	Occupancy periods	Non occupancy periods
Heating	19°C	16°C
Air conditioning	28°C	30°C

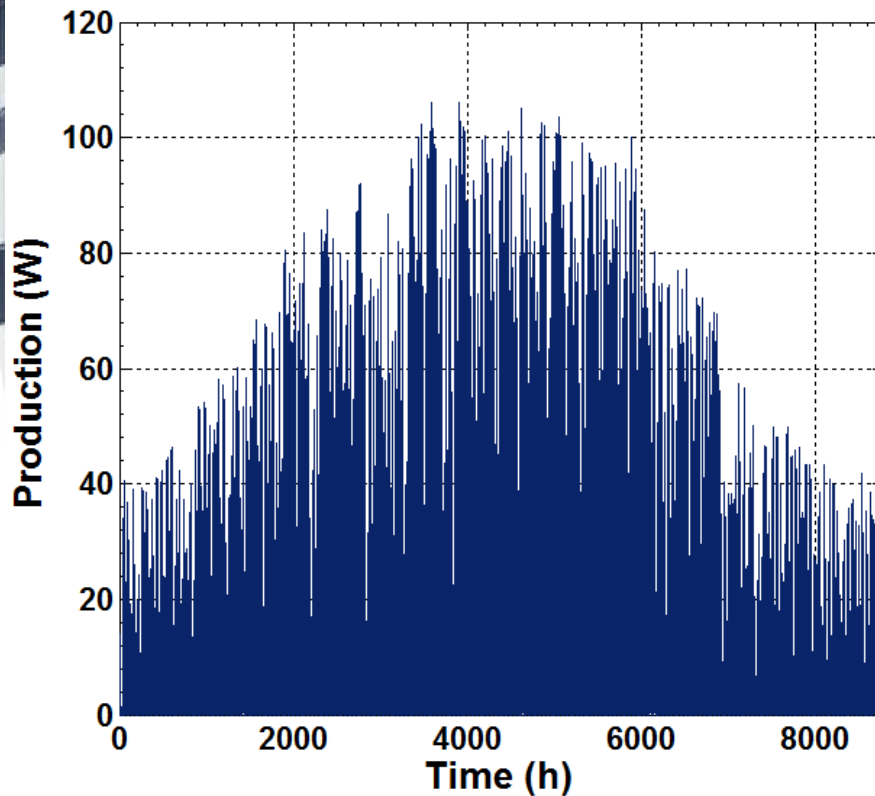
## Behavior scenario



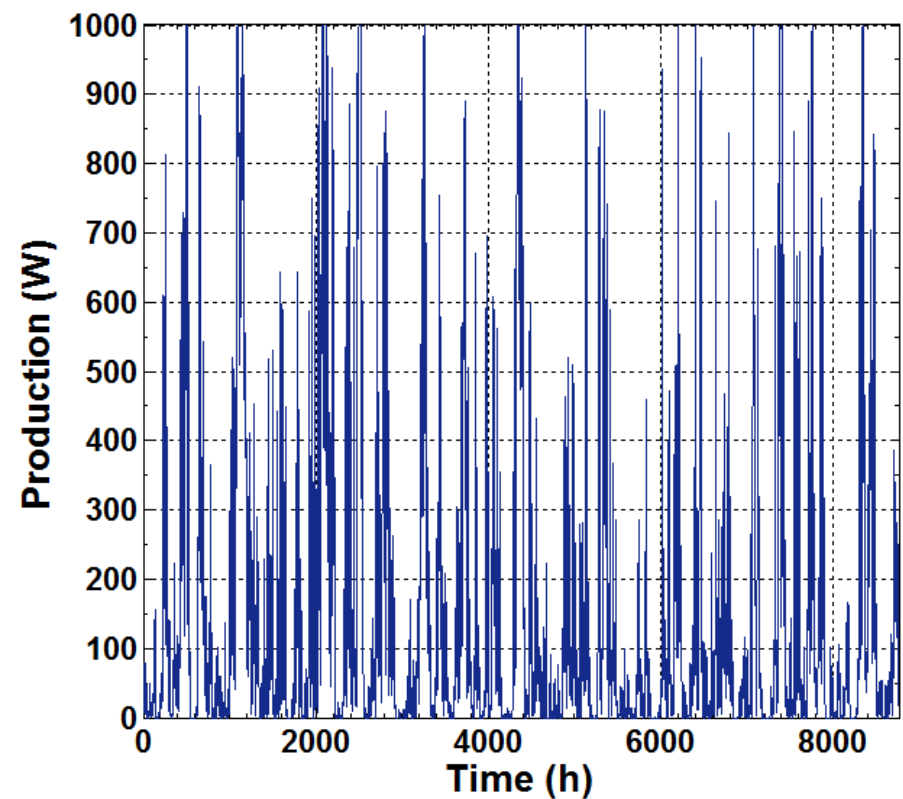
# Production and storage systems modeling

## Energy mix

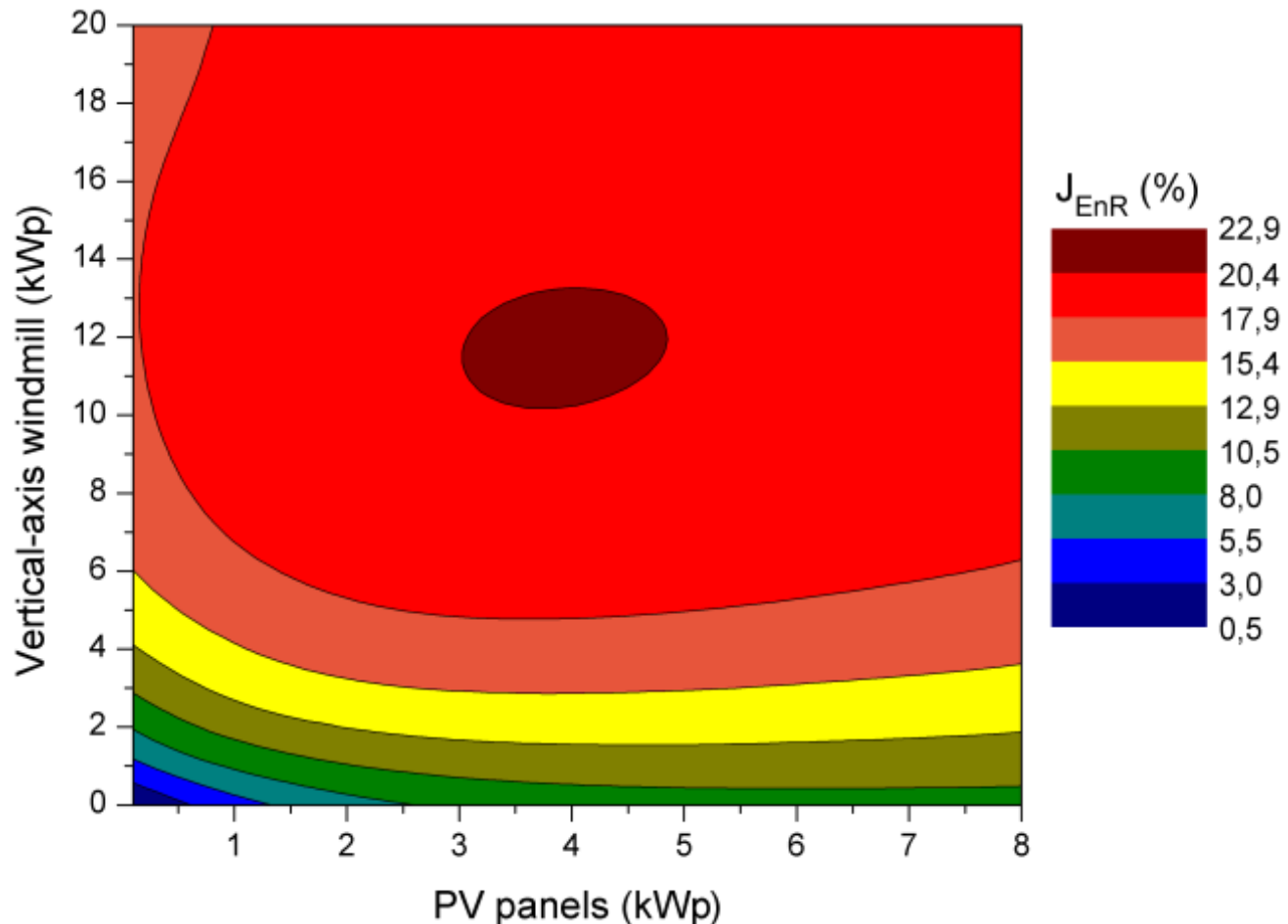
PV panels



Vertical-axis windmill



# Design of PV panels and vertical-axis windmill (no energy storage)





# Design of PV panels and vertical-axis windmill (no energy storage)

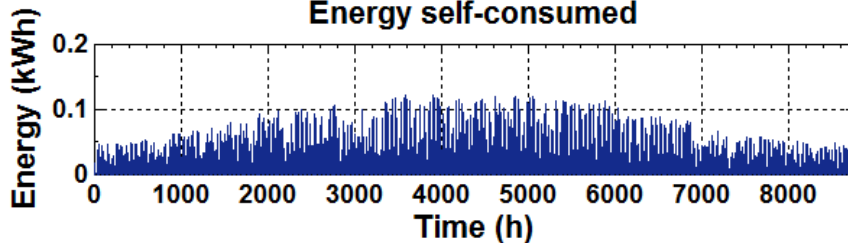
PV panels (kWp) Vertical axis windmill (kWp)	3 -	6.9 -	3.8 11
$EnR_c$ (kWh)	3305	5345	10994
$EnR_{inj}$ (kWh)	1132	4860	9124
$E_{EDF}$ (kWh)	26078	24038	18390
$\%_{SC}$ (%)	74.49	52.38	54.65
$\%_{EnR_c}$ (%)	11.25	18.19	37.41
$J_{ENR}$ (%)	8.38	9.53	20.45
$J_{cost}$ (€)	-1281.30	-977.20	-468.52

	Optimized PV (6.9 kWp) vs. standard PV (3 kWp)	Optimized PV and vertical-axis windmill vs. optimized PV
$\%_{SC}$ (%)	↗ 61.7%	↗ 50%
$E_{EDF}$	↘ 7.8%	↘ 11%
$J_{cost}$ (€)	↘ 25%	↘ 52%

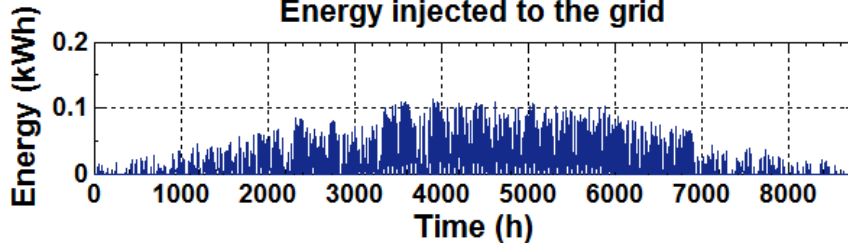
# Design of PV panels and vertical-axis windmill (no energy storage)

PV: 6.9 kWp

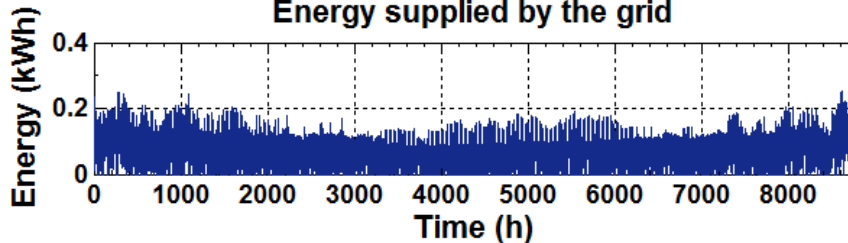
**Energy self-consumed**



**Energy injected to the grid**



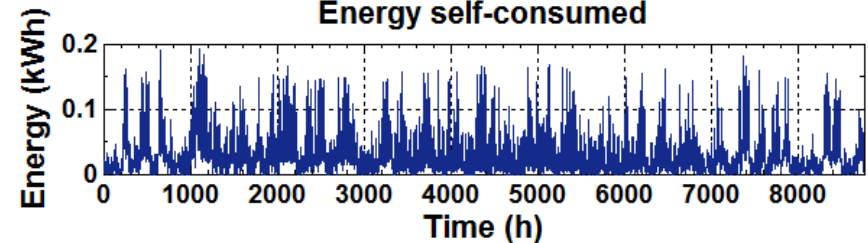
**Energy supplied by the grid**



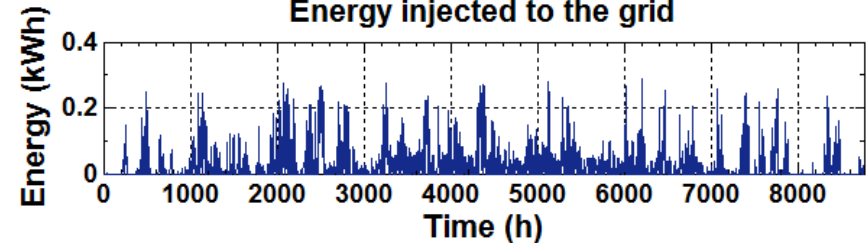
PV: 3.8 kWp

Vertical-axis windmill: 11 kWp

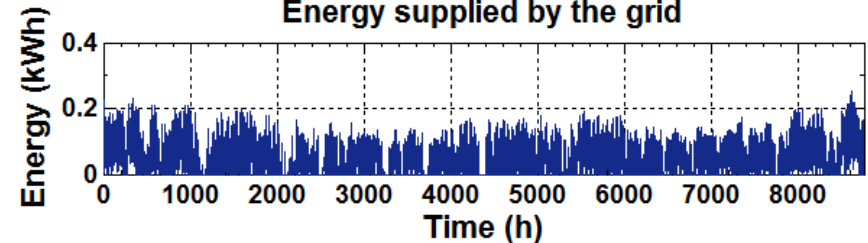
**Energy self-consumed**



**Energy injected to the grid**



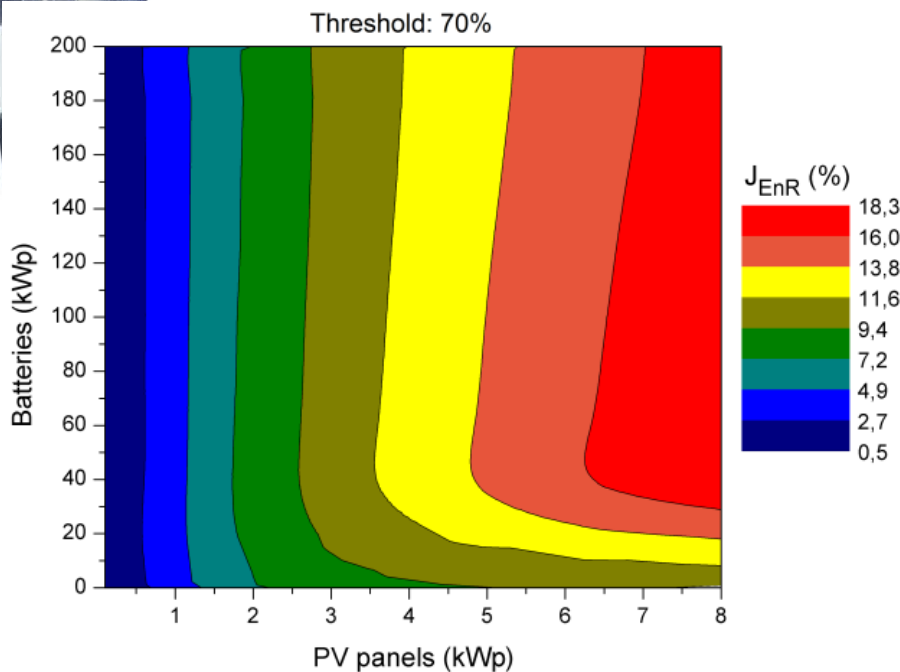
**Energy supplied by the grid**



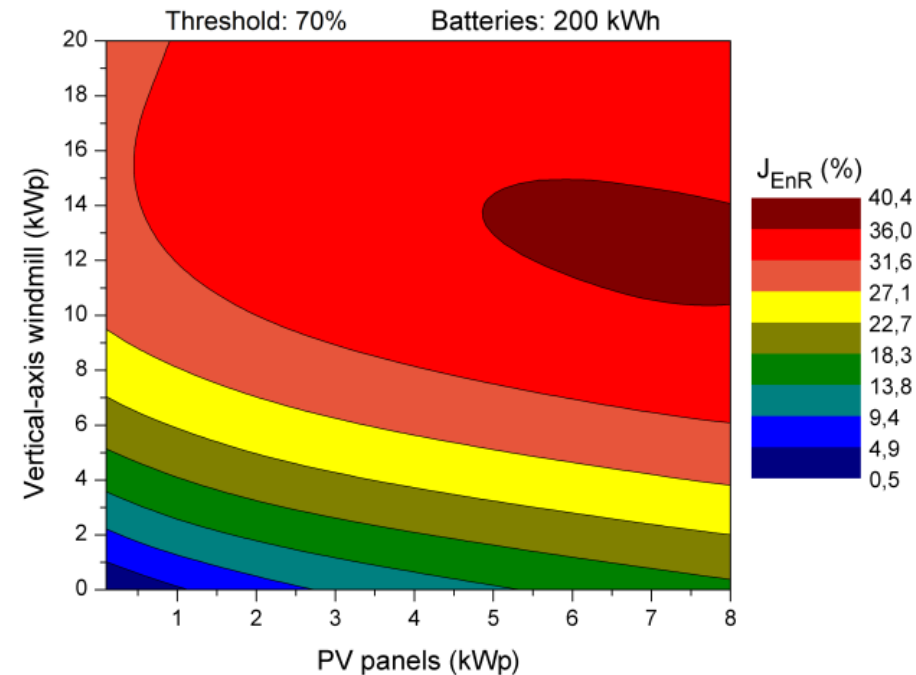
# Design of energy production and storage systems

## Grid thresholds is 70%

With PV panels and batteries



With PV panels, a vertical-axis  
windmill and batteries



# Design of energy production and storage systems

## Grid thresholds is 70%

<b>PV panels (kWp)</b>	<b>6.9</b>	<b>8</b>	<b>3.8</b>	<b>5.8</b>
<b>V.-a. windmill (kWp)</b>	-	-	<b>11</b>	<b>15</b>
<b>Batteries (kWh)</b>	<b>40 (-)</b>	<b>50 (-)</b>	<b>200 (-)</b>	<b>200 (-)</b>
$EnR_c$ (kWh)	7117 (5345)	7959 (5746)	14251 (10994)	17313 (12917)
$EnR_{inj}$ (kWh)	2695 (4860)	3370 (6087)	4621 (9124)	9373 (15431)
$E_{EDF}$ (kWh)	22266 (24038)	21425 (23638)	15132 (18390)	12070 (16466)
$E_{stock}$ (kWh)	2166 (-)	2717 (-)	4504 (-)	6058 (-)
$\%SC$ (%)	69.74 (52.38)	67.26 (48.56)	70.84 (54.65)	61.07 (45.57)
$\%EnR_c$ (%)	24.22 (18.19)	27.09 (19.55)	48.50 (37.41)	58.92 (43.96)
$J_{EnR}$ (%)	16.89 (9.53)	18.22 (9.49)	34.36 (20.45)	35.99 (20.03)
$J_{cost}$ (€)	-997.27 (-977.20)	-927.33 (-901.44)	-531.54 (-468.52)	-136.38 (-52.35)
$I_{inj}$ (-)	1034 (616)	1292 (762)	942 (-662)	911 (-1166)
$I_{ext}$ (-)	6383 (6645)	6238 (6634)	3790 (4634)	3036 (4326)
$I_{over}$ (-)	7417 (7261)	7529 (7396)	4732 (3972)	3947 (3160)

### Optimized batteries

$EnR_c$  ↗ 33 - 39 %

$EnR_{inj}$  ↘ 44 - 49 %

$E_{EDF}$  ↘ 7 - 27%

$\%SC$  ↗ 33 - 39 %

$J_{EnR}$  ↗ 68 - 92 %

$J_{cost}$  ↗ 20 - 100 €

**Grid impact** ↗  $I_{inj}$ , ↘  $I_{ext}$ , ↗  $I_{over}$

# Conclusion

- Configurations promoting energy self-consumption are highlighted
- Impact of local production on the grid is minimized
- Better match between decentralized production, energy needs and injection to the grid

# Outlook

- Energy resources, energy consumption and load of the grid forecasting
- Development of a predictive approach to improve the strategy
- Analysis of the location impact, insulation level and behavior scenarios

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