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Load management in multi- energy buildings: a simulation case study



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Summary

- 1 Context and objectives**
- 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

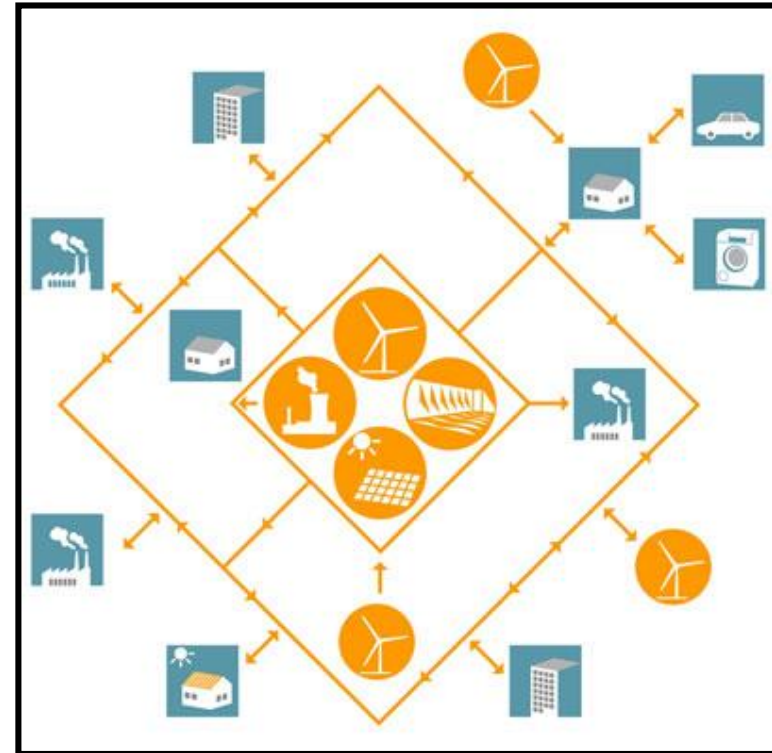
Context of the study

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 optimize its use
 - Adjust supply and demand in energy

Energy criteria

- Use of renewable energy: $J_{EnR} = \frac{\%_{EnR_c} \times \%_{SC}}{100}$
- Self-consumption of energy produced: $\%_{SC} = 100 \times \frac{EnR_c}{EnR_p}$
- 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)

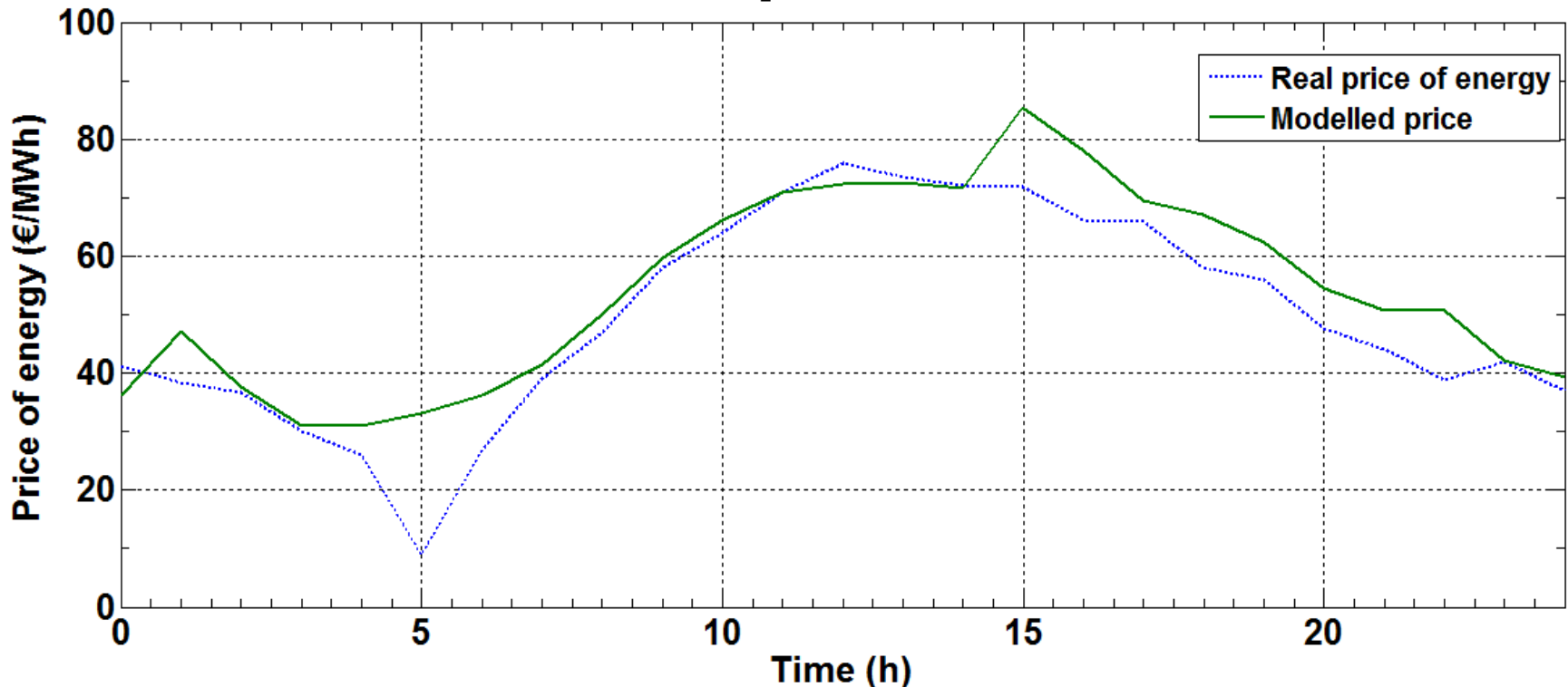
P_{En} : Electricity price (€.kWh⁻¹)

Dynamic pricing

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

Root mean square: 16.78%

- P_{En} : Electricity price (€·MWh⁻¹)
- L_g : Grid load (MWh)
- T_{out} : Outdoor temperature (°C)
- a : Polynomial model coefficient

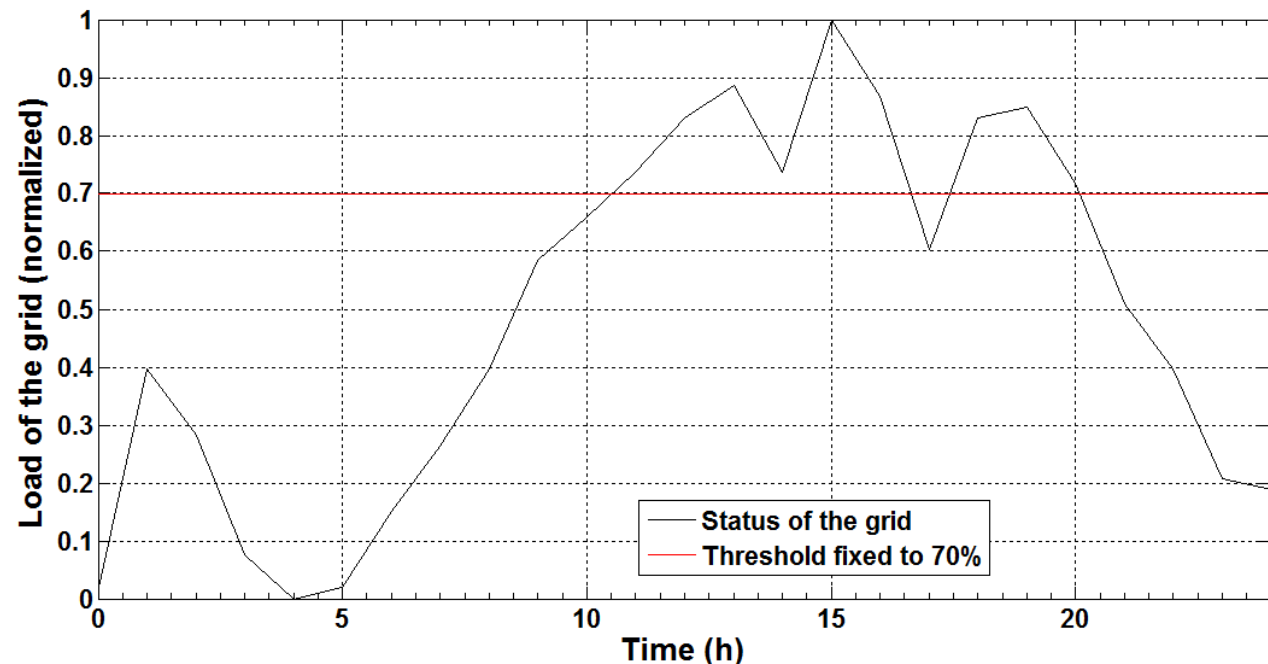


Impact on the grid

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

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

ΔE_{thres} : Normalized deviation between the fixed threshold and the status of the grid

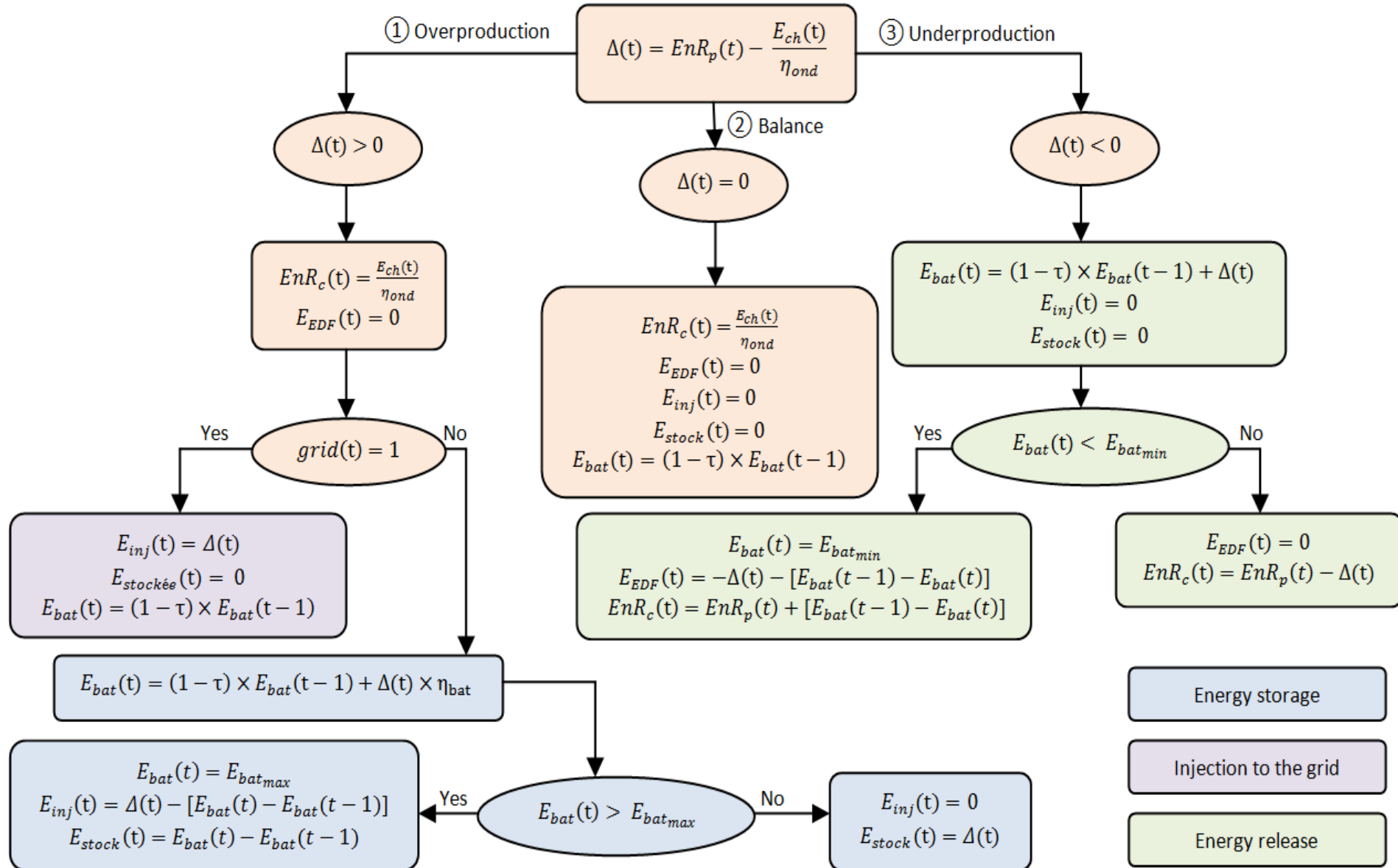


Impact on the grid

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

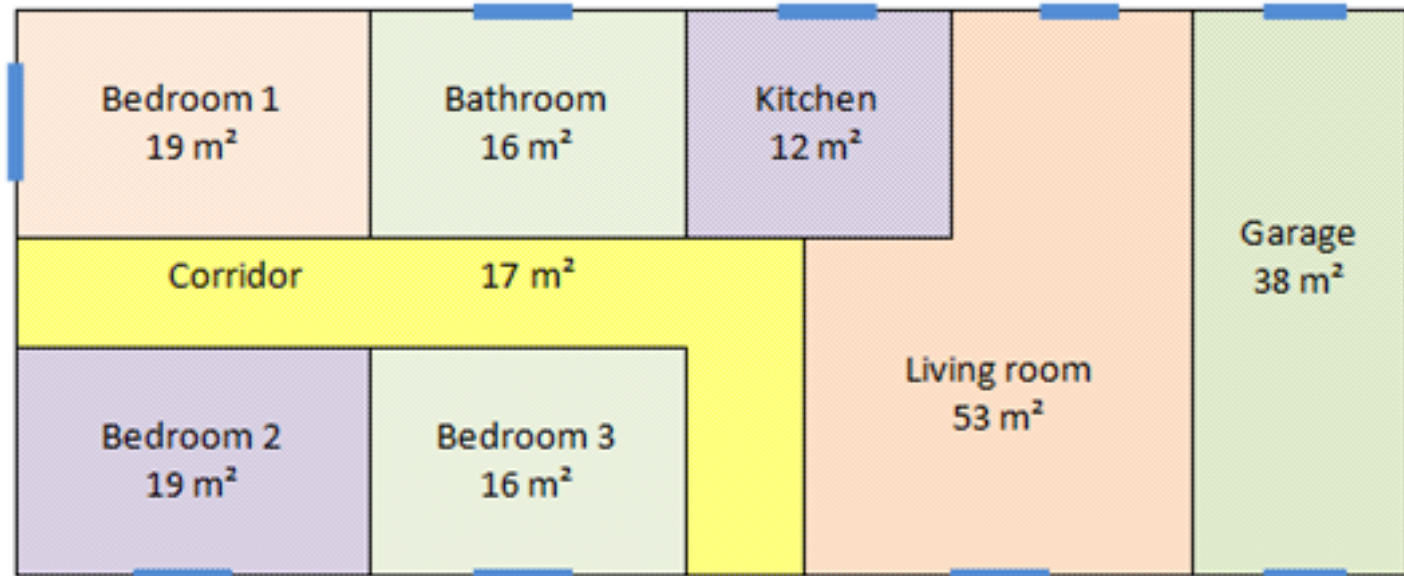
E_{EDF} : Energy extracted from the electricity grid (kWh)

ΔE_{thres} : Normalized deviation between the fixed threshold and the status of the grid



TRNSYS thermal model of an individual house

Case study: 150 m² 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 [W.m ⁻² .K ⁻¹]	U _{RT2005} [W.m ⁻² .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		
	BA13	0.013		
Floor	Tiles	0.022	0.415	0.4
	Mortar	0.05		
	Heavy concrete	0.16		
	Expanded polystyrene	0.08		
Ceiling	BA13	0.013	0.196	0.34
	Glass wool	0.1		
	Air knife	0.5		
	Terracotta	0.01		
Garage ceiling	BA13	0.013	2.37	0.34
	Terracotta	0.2		
Window	Double glazed	0.2	1.43	2.6

Modeling of lifestyle and habits

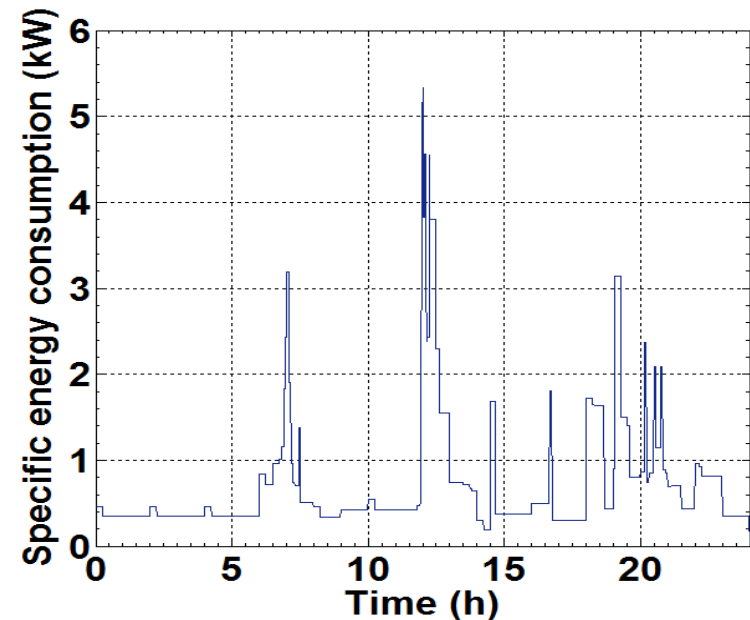
Conventional occupation scenario set by RT 2005

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

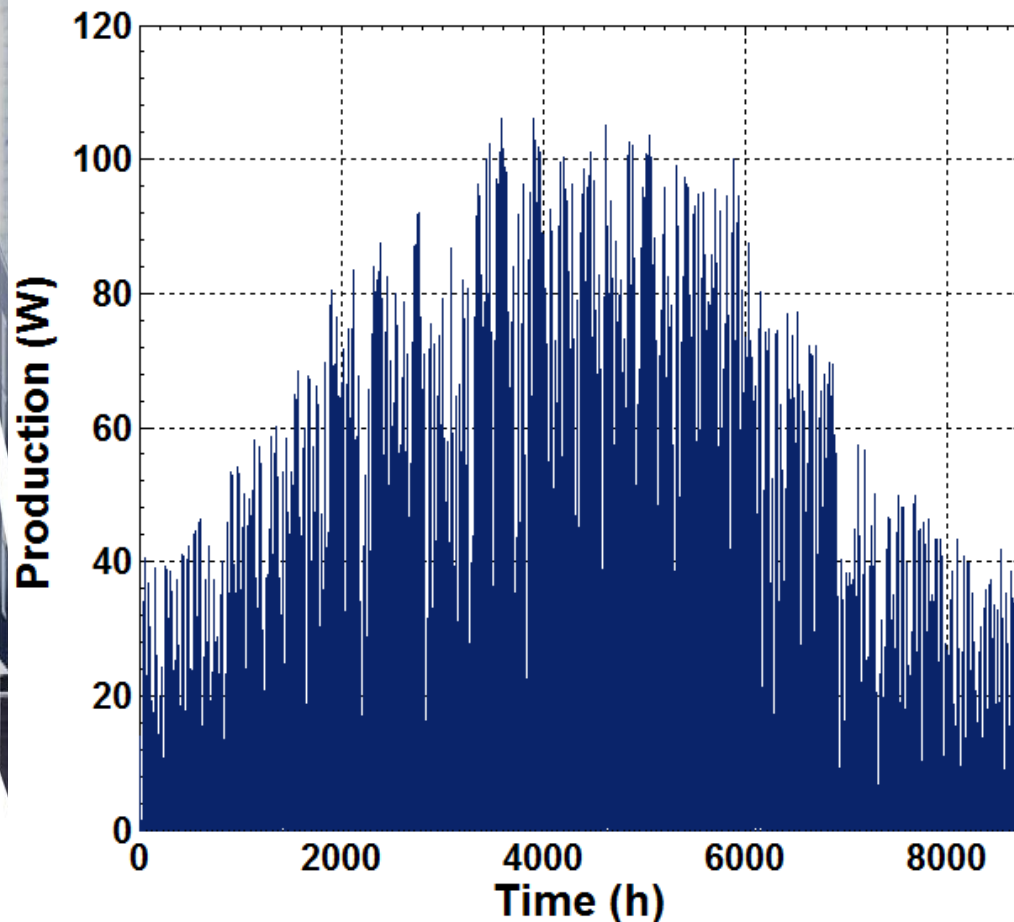
Conventional French RT 2005 temperature set-point

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)

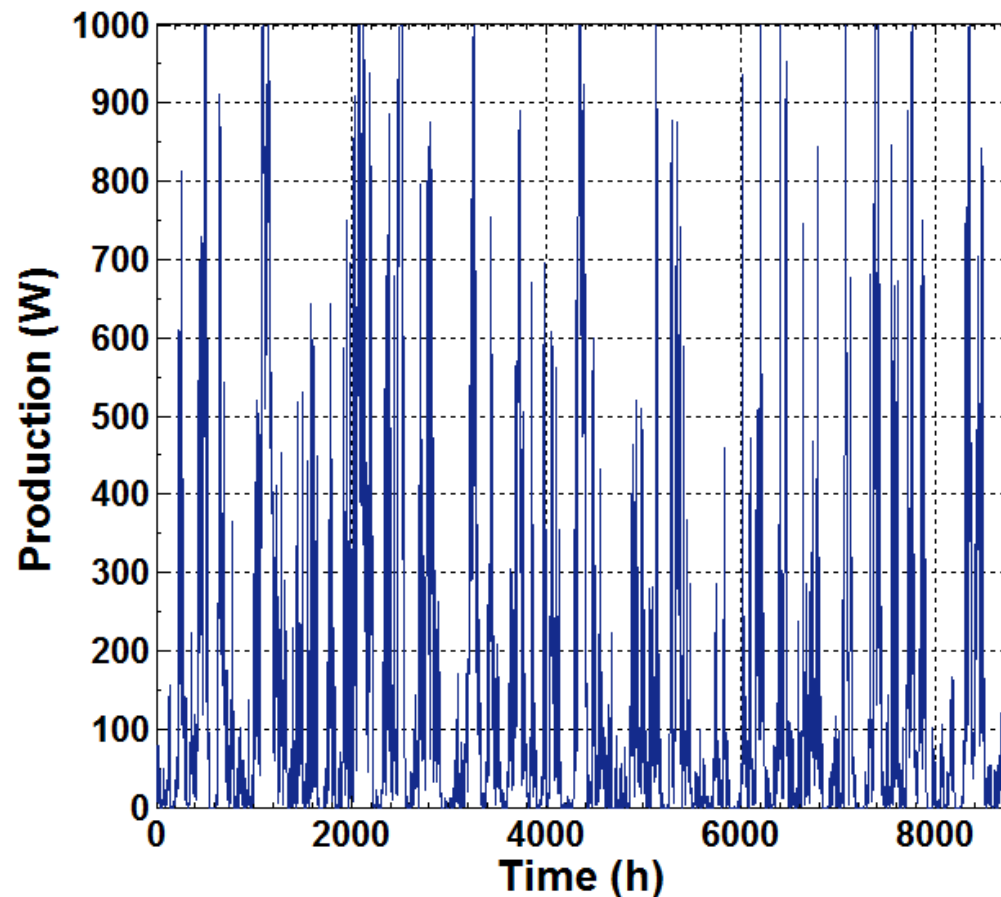


Photovoltaic array
TRNSYS model 194

- Based on the calculation method presented by DeSoto¹ and used various semi-empirical equations
- Determines the current and power of a photovoltaic array at a specific voltage

¹ DeSoto W., Klein S.A., Beckman W.A., 2006. Improvement and validation of a model for photovoltaic array performance, Solar Energy, vol. 80, pp. 78-88.

Production and storage systems modeling (Energy mix)



Vertical-axis-windmill TRNSYS model 90

- Based on the work of Quilan¹
- Calculates the power output of energy conversion systems based on a power versus wind speed characteristics

¹ Quilan P.J., 2000. A time-series wind turbine array simulator. In Proceeding of ASES Conference SOLAR 2000, Madiso, USA.

Production and storage systems modeling (Energy mix)

Description of the functioning of the batteries:

➤ charging mode:
$$E_{bat}(t) = (1 - \tau) \cdot E_{bat}(t - 1) + \left(E_{EnR}(t) - \frac{E_{ch}(t)}{\eta_{inv}} \right) \cdot \eta_{bat}$$

➤ discharging mode:
$$E_{bat}(t) = (1 - \tau) \cdot E_{bat}(t - 1) + \left(\frac{E_{ch}(t)}{\eta_{inv}} - E_{EnR}(t) \right)$$

Constraints: $E_{bat_{min}} = (1 - DOD) \times E_{bat_{max}}$ and $E_{bat_{max}} = C_n$

η_{inv} : Inverter performance

η_{bat} : Charge performance

E_{bat} : Energy stored (kWh)

E_{ch} : Energy required by the load (kWh)

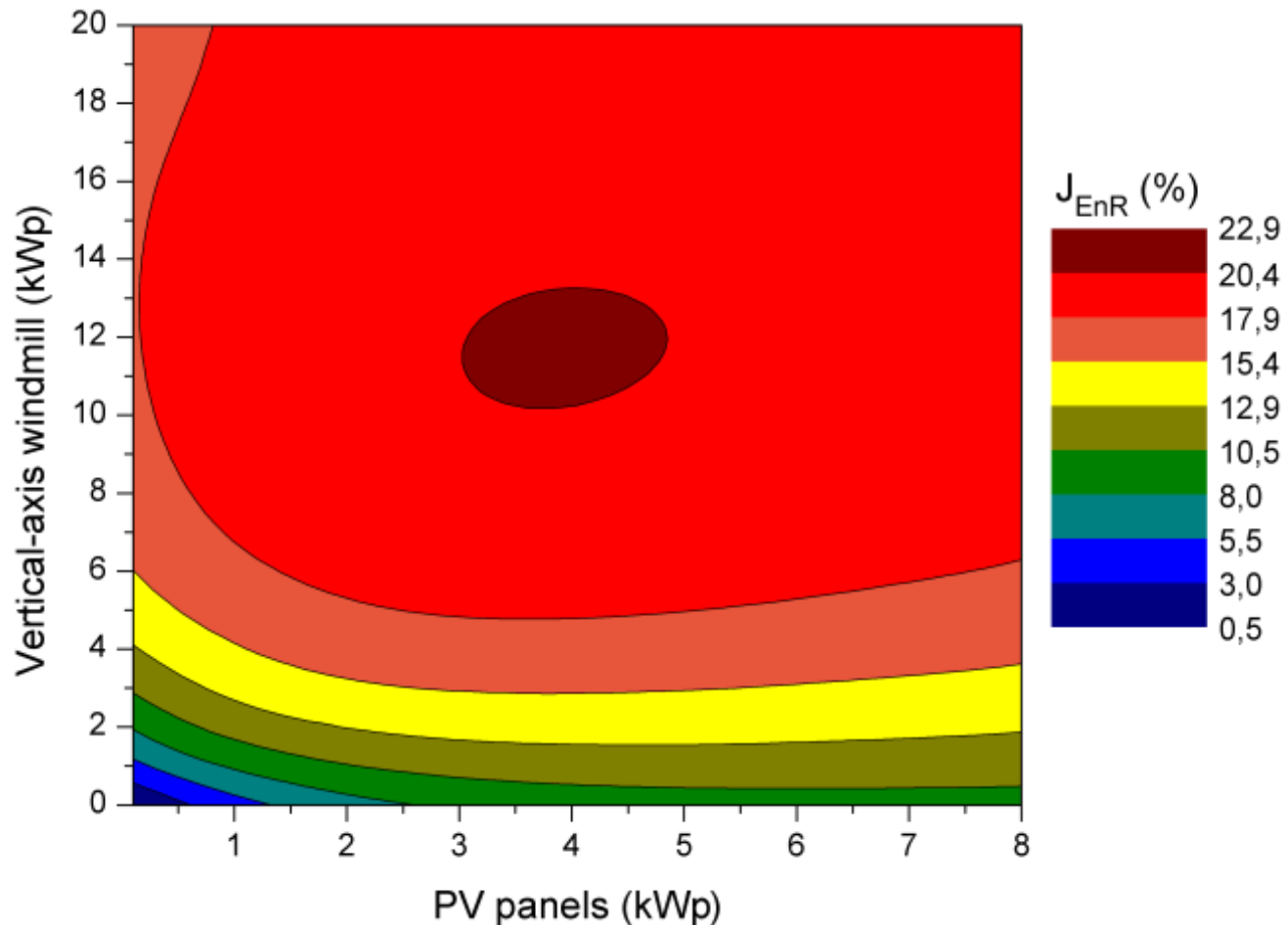
E_{EnR} : Energy produced by the local production systems (kWh)

τ : Hourly self-discharge rate

DOD : Depth of discharge

C_n : Nominal capacity (kWh)

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

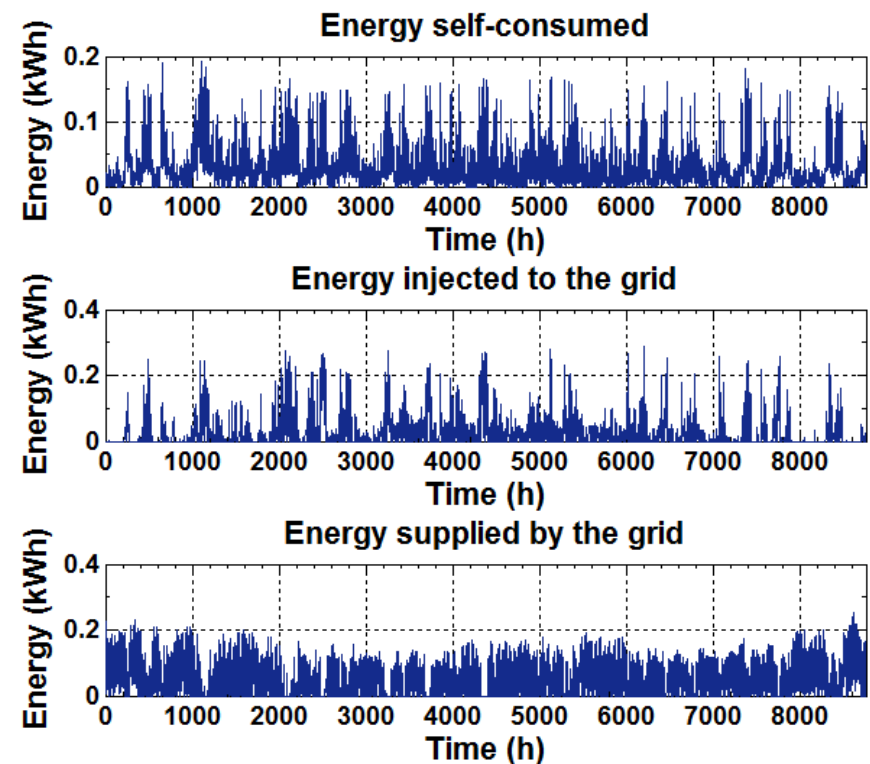
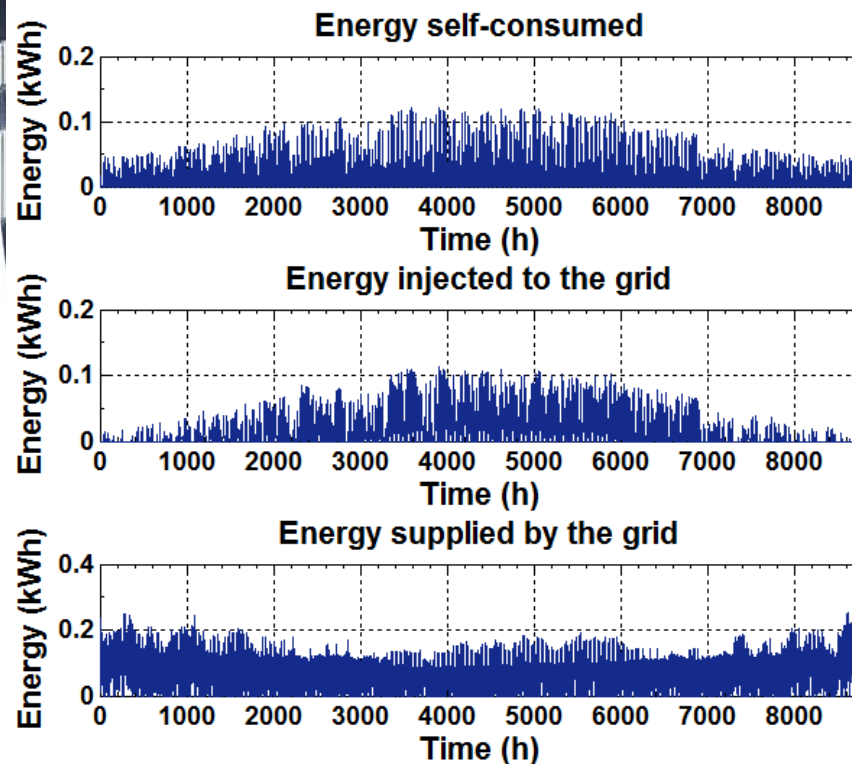
	Optimized PV (6.9 kWp) vs. standard PV (3 kWp)	Optimized PV and vertical-axis windmill vs. optimized PV
$\%_{sc}$ (%)	↗ 61.7%	↗ 50%
E_{EDF}	↘ 7.8%	↘ 11%
J_{cost} (€)	↘ 25%	↘ 52%

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

PV: 6.9 kWp

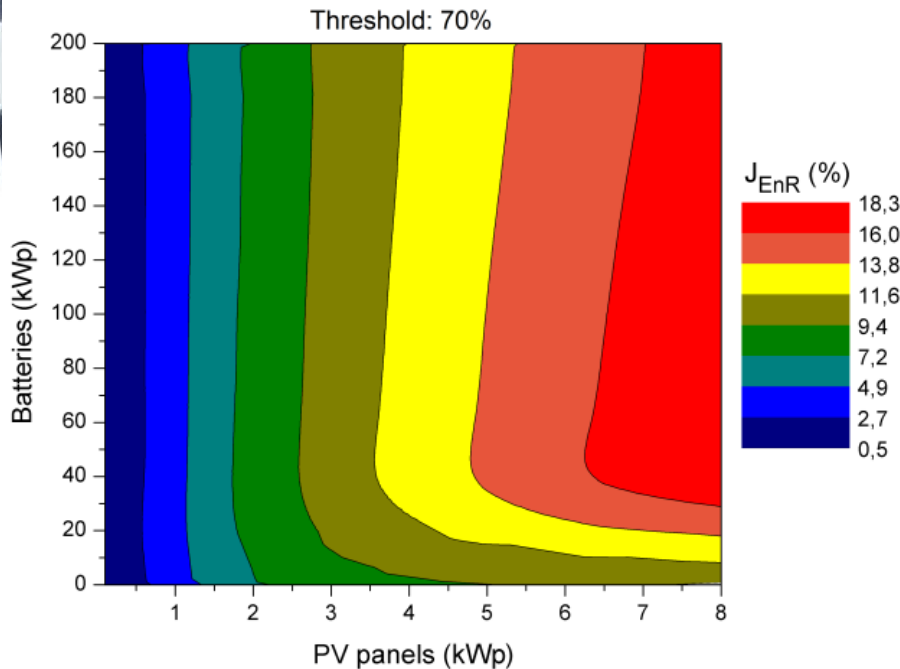
PV: 3.8 kWp

Vertical-axis windmill: 11 kWp

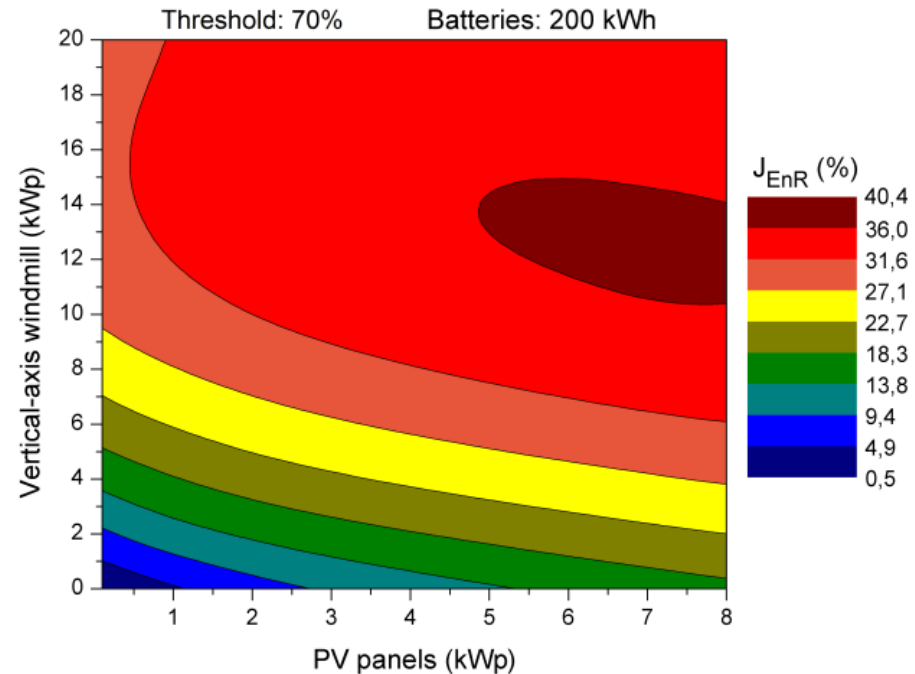


Design of energy production and storage systems (Grid thresholds is 70%)

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%)

PV panels (kWp)	6.9	8	3.8	5.8
V.-a. windmill (kWp)	-	-	11	15
Batteries (kWh)	40 (-)	50 (-)	200 (-)	200 (-)
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		% SC	\nearrow 33 - 39 %
EnR_c	\nearrow 33 - 39 %	J_{EnR}	\nearrow 68 - 92 %
EnR_{inj}	\searrow 44 - 49 %	J_{cost}	\nearrow 20 - 100 €
E_{EDF}	\searrow 7 - 27%	Grid impact	$\nearrow I_{inj}$, $\searrow I_{ext}$, $\nearrow I_{over}$

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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