SCUOLA ALTI STUDI LUCCA

IMPACT OF INCENTIVE REGULATION FOR BATTERY SIZING AND MANAGEMENT

6th AIEE Energy Symposium,

Angelo Facchini, A. Rubino, A. Damiano
angelo.facchini@imtlucca.it

Overview

- Deployment of RES is expected to increase in the next years
- Energy storage is a promising strategy, but technological and economic sustainability are still debated
- Reduce fluctuation from renewable intermittent sources is a key topic.

- Energy communities and self-consumers are a promising paradigm to improve the resilience of the energy system in view of a high share of RES.

- Current regulation show different roles for storage systems in microgrids

- Degradation costs are currently not considered

EU Framework

Collective self-consumption and renewable energy communities

- ➢ Citizens can adopt to respond collectively to certain energy, social and environmental needs.
- ➢ Consistent with the decarbonisation objectives adopted at European level.
- ➢ Two directives: Clean Energy for All Europeans Package - the Renewable Energy Directive (RED II) and the Electricity Market Directive (EMI) - are formally recognised and promoted at institutional level.

The directives call on Member States to regulate and promote **solutions of increasing complexity**:

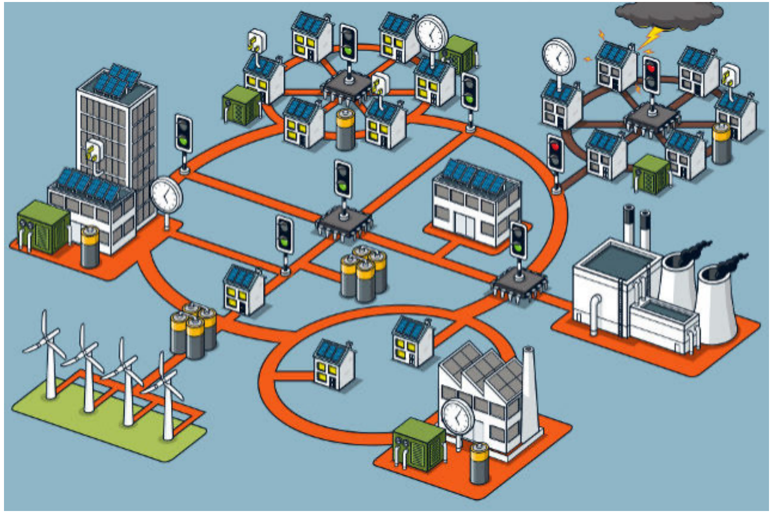
- ✓ **Individual self-consumption**,
- ✓ **Collective self-consumption** (the energy produced by an installation on the roof of a block of flats can also be made available to individual tenants and no longer just to common services, as is currently the case)
- ✓ **Renewable Energy Communities**: Not individuals but legal entities (e.g. cooperatives and purchasing groups)

Renewable Energy Communities

- Operational definition of REC:

communities operate in the energy market without having a predominantly profit-making purpose, with the objective of meeting environmental, economic and social needs and, only as a last resort, profit

- Peculiar characteristics that are difficult to find within the current energy market.
- Based on a democratic model, in which choices are shared among community members in an independent and autonomous way.



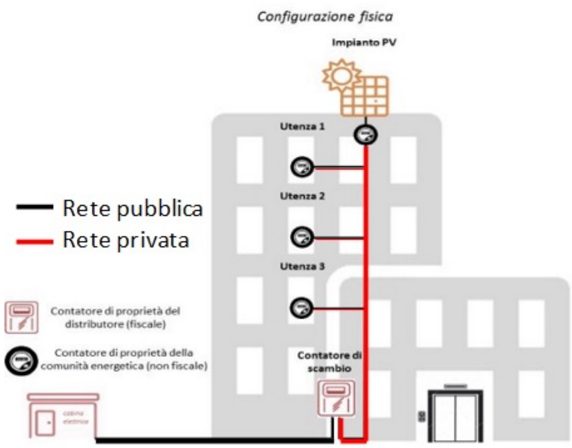
More formally: renewable energy community' means a legal entity:

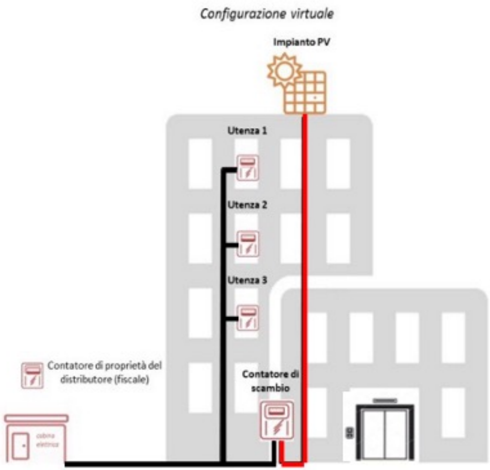
(a) which, in accordance with the applicable national law, is based on open and voluntary participation, is autonomous, and is effectively controlled by shareholders or members that are located in the proximity of the renewable energy projects that are owned and developed by that legal entity;
(b) the shareholders or members of which are natural persons, SMEs or local authorities, including municipalities;
(c) the primary purpose of which is to provide environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits;

Possible configurations: virtual and real

Member States may grant CERs the right to operate the local distribution network.

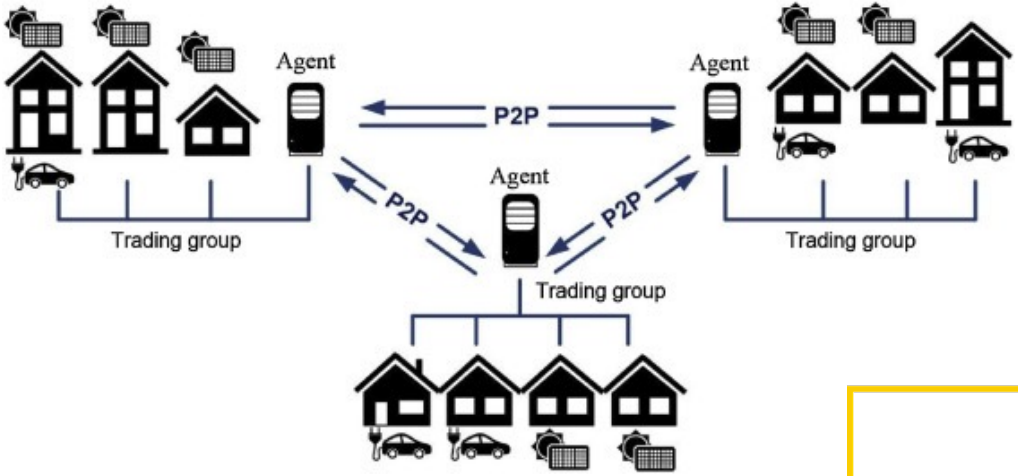
- physical model: involves the use of the community's own grid to exchange energy between members;
- virtual model: involves the use of the public grid and the need to define what energy is actually shared;

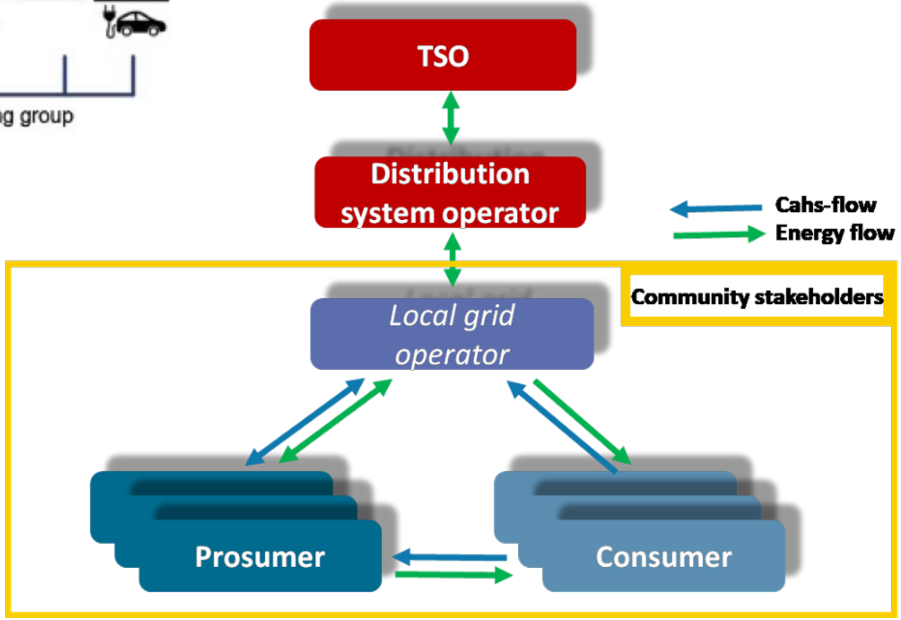




NOTE: If a REC decides to manage the distribution network, it will be subject to the same conditions as other concessionaires, and will be subject to the regulation, guaranteeing, for example, a service provision with a certain level of quality.

Peer to Peer Energy & local markets





Full deployment of EC challenges and opportunities

- Actual models encourage the development of REC and self-consumption schemes at local level.

- A full development requires a wide adoption of REC at building level, meaning a large diffusion of distributed generation and storage systems

In addition:

- Full involvement of consumers in the energy market

- Implementation of the electric city (but…is it net-negative?)

Current incentives in Italy

AUTOCONSUMATORI DI ENERGIA RINNOVABILE CHE AGISCONO COLLETTIVAMENTE	
Restituzione componenti tariffarie (C_{AC})	$C_{AC} = CU_{Af,m} * E_{AC} + \Sigma_{i,h} (E_{AC,i} * c_{PR,i} * Pz)_h$
Incentivazione dell'energia condivisa (I_{AC})	$I_{AC} = TP_{AC} * E_{AC}$
Ritiro dell'energia (R_{AC})	$R_{AC} = P_R{}^4 * E_{immessa}$
COMUNITÀ DI ENERGIA RINNOVABILE	
Restituzione componenti tariffarie (C_{CE})	$C_{CE} = CU_{Af,m} * E_{AC}$
Incentivazione dell'energia condivisa (I_{CE})	$I_{CE} = TP_{CE} * E_{AC}$
Ritiro dell'energia (R_{CE})	$R_{CE} = P_R{}^3 * E_{immessa}$

Battery degradation

BATTERY LIFE

$$L = 1 - D$$

REMAINING CAPACITY

$$L = 1 - \alpha_{sei} e^{-\beta_{sei} f_d} - (1 - \alpha_{sei}) e^{-f_d}$$

BATTERY DEGRADATION FUNCTION

SEI FILM FORMATION

CALENDAR AGING

CYCLE AGING

$$f_d (t, \delta, \sigma, T_C) = f_t (t_{use}, \bar{\sigma}, \bar{T}_c) + \sum_{n}^{N} f_c (\delta, \sigma, T_c)$$

DOD OF ITS CYCLES

BESS USAGE TIME

AVERAGE SOC

AVERAGE TEMPERATURE

$$S_\sigma (\sigma) = e^{k_\sigma (\sigma - \sigma_{ref})}$$

$$f_t (t, \sigma, T_C) = S_t (t) \cdot S_\sigma (\sigma) \cdot S_{T_C} (T_C)$$

$$S_t (t) = k_t t$$

$$S_{T_C} (T_C) = e^{-k_T (T_C - T_{ref}) \frac{T_C}{T_{ref}}}$$

$$S_\delta (\delta) = (k_{\delta 1} \delta^{k_{\delta 2}} + k_{\delta 3})^{-1}$$

$$f_c (\delta, \sigma, T_C) = S_\delta (\delta) \cdot S_\sigma (\sigma) \cdot S_{T_C} (T_C)$$

Introducing degradation in the agent’s decision 1/2

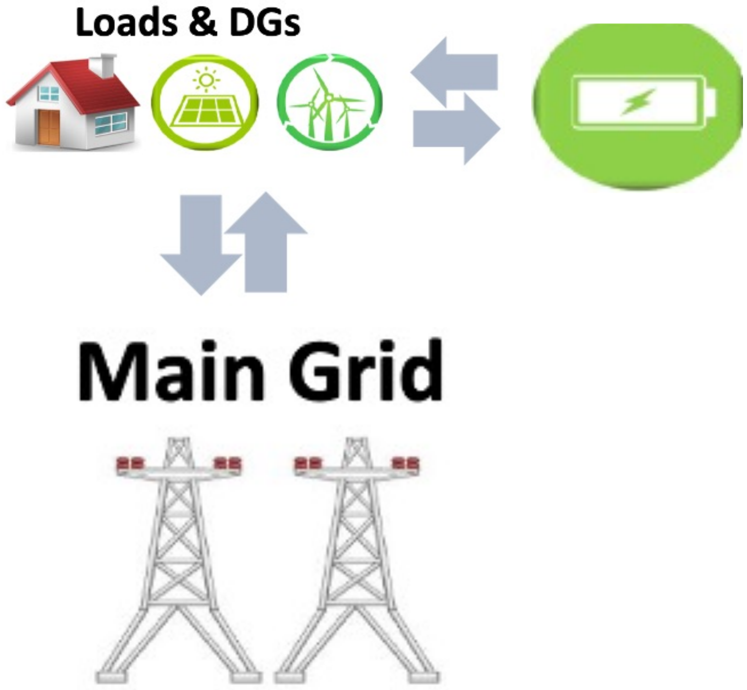
Problem setup:

- Open system
- The agent self consumes energy from a RES
- Store o drain energy has a cost

- The agent is called to take a decision when an amount of energy E does not match its demand profile:

E > 0: Store in the storage system or sell energy in case of surplus in supply.

E < 0: Buy or drain the storage system in case of deficit in supply.



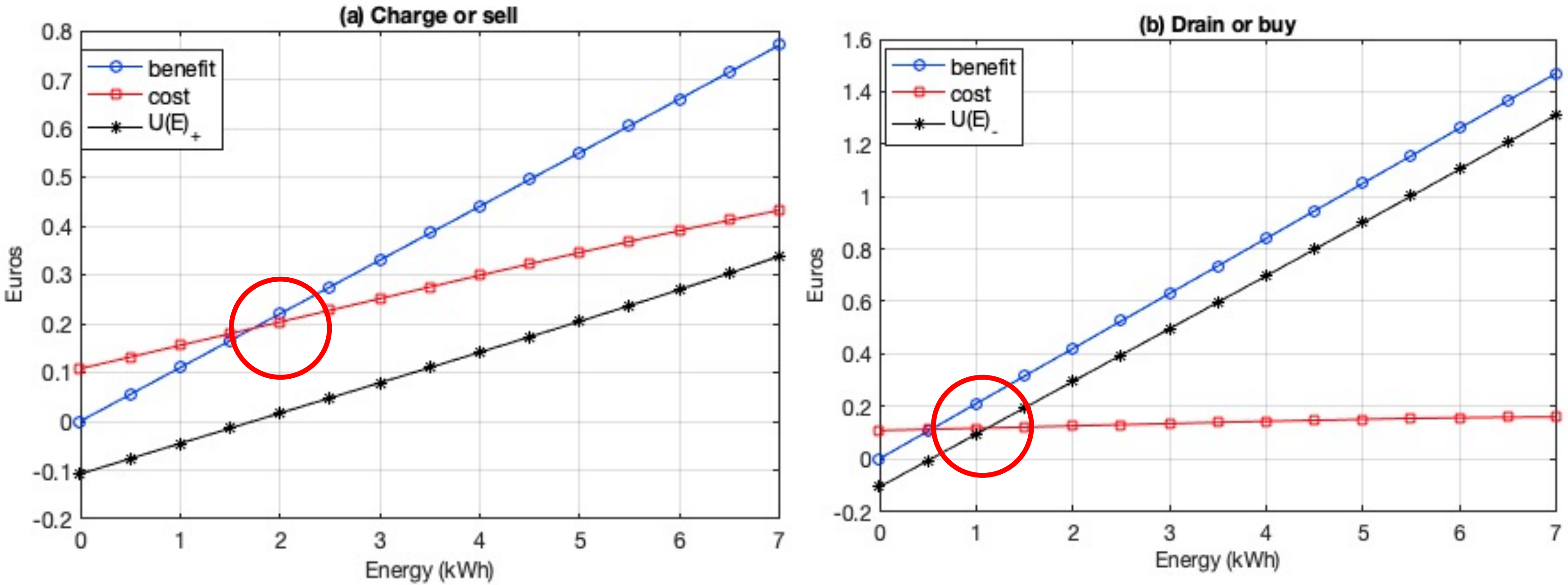
Introducing degradation in the agent’s decision 2/2

- The decision is therefore between using or not the storage system according to the market conditions:

  - ✓ A linear incentive I_R = 0.039 Eur/kWh is in force when selling electricity.
  - ✓ A linear incentive I_{SC} = 0.110 Eur/kWh is in force when self consuming energy.
  - ✓ The gross price of energy is set to PE = 140Eur/MWh
  - ✓ Charging or draining an amount of Energy E from the battery has a cost CS (E).

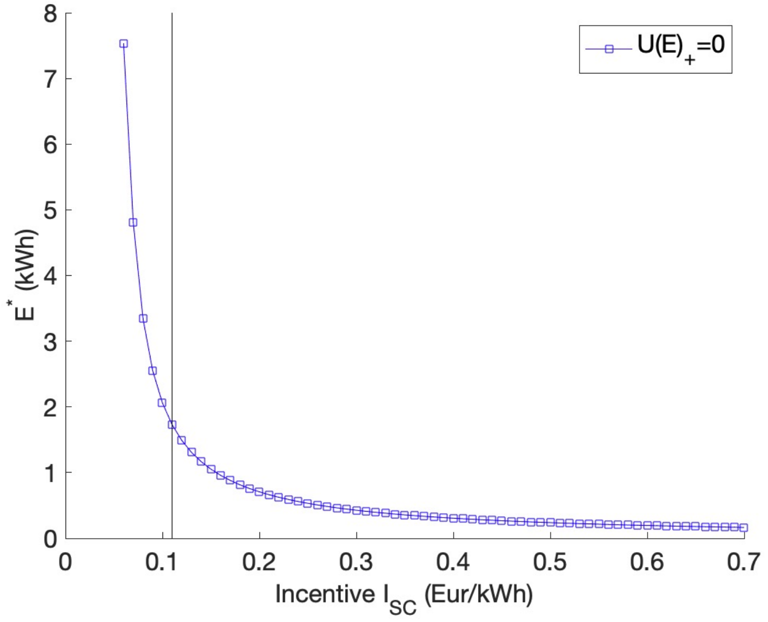
$$
\begin{aligned}
\mathcal{U}(E)_+ &= I_{SC}E - I_R E - C_S(E)), \quad \text{if } E > 0 \\
\mathcal{U}(E)_- &= I_{SC}E + P_E E - C_S(E), \quad \text{if } E < 0
\end{aligned}
$$

Results 1

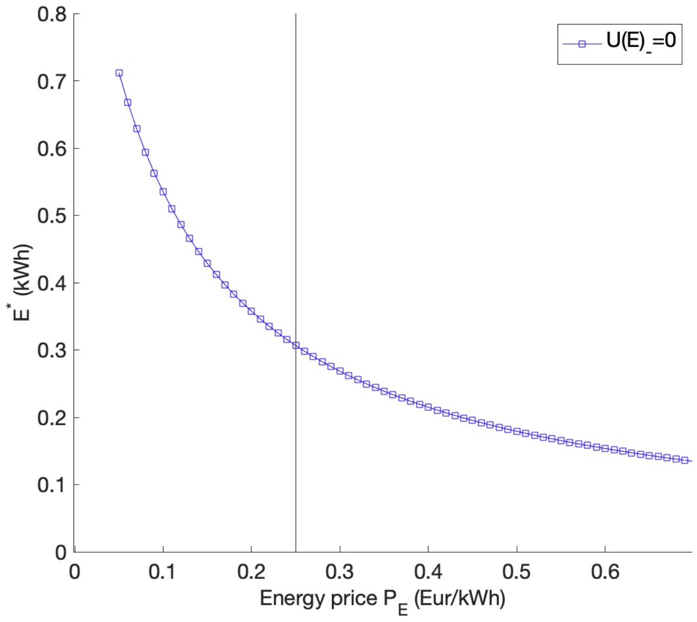


- Solve a transcendental equation to find the equilibrium E* for both utility functions

Results 2

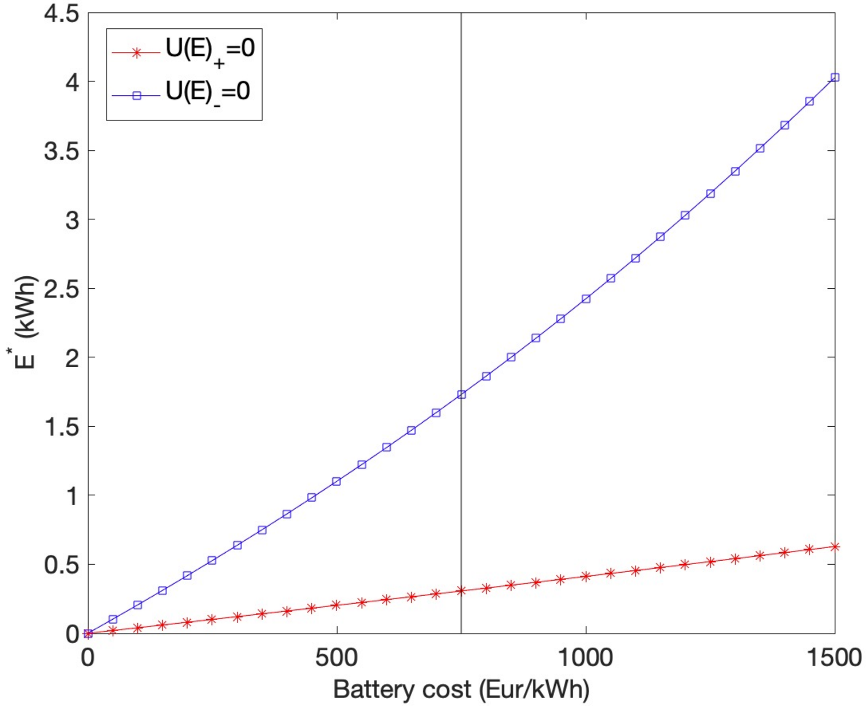


8
7
6
5
4
3
2
1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
E^* (kWh)
Incentive I_{SC} (Eur/kWh)
$U(E)_+=0$

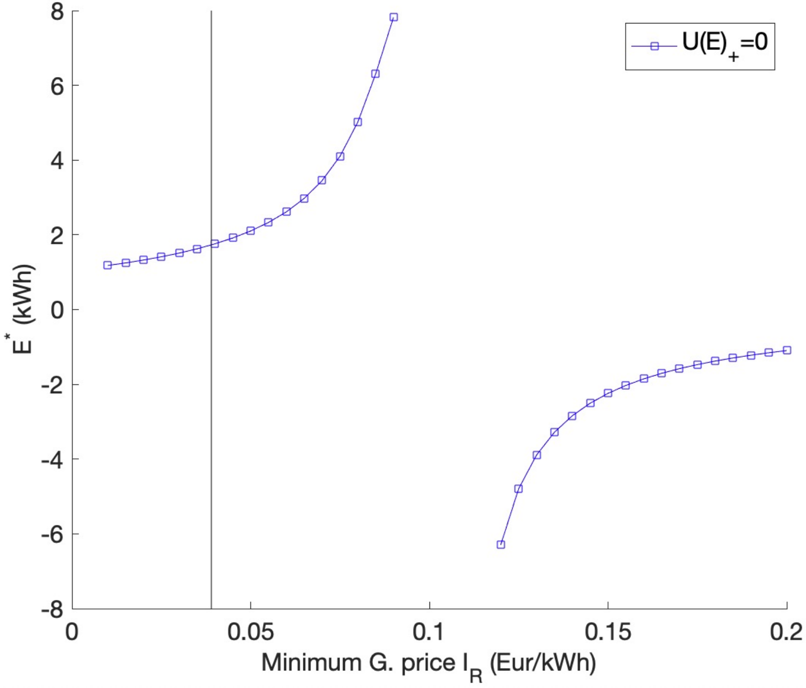


0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
E^* (kWh)
Energy price P_E (Eur/kWh)
$U(E)_-=0$

Results 3



U(E)+=0
U(E)-=0
E* (kWh)
Battery cost (Eur/kWh)
0
500
1000
1500
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5



U(E)+=0
E* (kWh)
Minimum G. price lR (Eur/kWh)
0
0.05
0.1
0.15
0.2
-8
-6
-4
-2
0
2
4
6
8

Conclusions