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Optimal Supply and Demand Bidding Strategy for Aggregators of Small Prosumers

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ERA-NET SMART GRIDS PLUS | FROM LOCAL TRIALS TOWARDS A EUROPEAN KNOWLEDGE COMMUNITY

This project has received funding in the framework of the joint programming initiative ERA-Net Smart Grids Plus, with support from the European Union's Horizon 2020 research and innovation programme.

Smart Grids Plus ERA-Net

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Motivation

<u>EU targets for 2030:</u>

- 40% cut in greenhouse gas emissions
- 27% share of renewable energy consumption
- 27% energy savings

One of the solutions consists of

exploiting building automation solutions to:

- **increase** the integration of renewable generation
- **increase** energy efficiency
- **decrease** energy costs

Sensors

Smart appliances

PV systems

Electric vehicles

Challenge

Automation functionalities, flexibility, data…

Smart appliances

Electric vehicles

PV systems

Sensors

Transform to

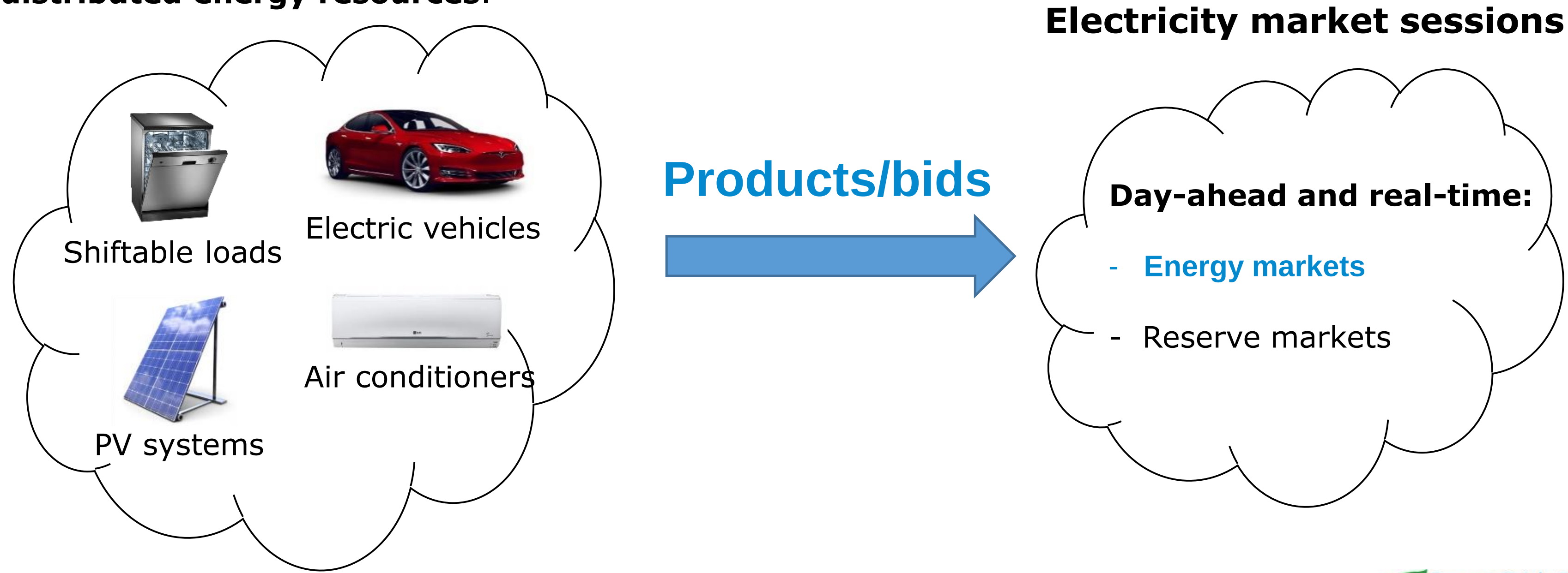
Electricity market services/products

Objectives:

- reduce electricity costs
- promote the increase integration of RES

Approach

The **aggregator** represents the small prosumers in the electricity markets and exploits their **distributed energy resources**.



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Tool

Two-stage stochastic optimization model to support the participation of aggregators of small prosumers in the **energy market**.

Exploits

Flexibility of **electric vehicles**, **shiftable loads** and **air conditioners**.

Objective

Define optimal and robust **demand** and **supply bids**, in order to:

- Value load flexibility
- Value generation surplus
- Avoid investments of dedicated storage devices

Scenario-based stochastic programming is used to deal with the uncertainty of

- Dwelling occupancy
- Mobility patterns
- Shiftable load patterns
- Renewable generation
- Inflexible load

Two-stage stochastic optimization model

$$Min \sum_{t \in H} \left(\hat{\lambda}_t^{DA,E} E_t^{DA} + \sum_{j \in S} \pi_j \left(\hat{\lambda}_t^{DA,-} I_{j,t}^{-} - \hat{\lambda}_t^{DA,+} I_{j,t}^{+} \right) \right)$$

- DA stage: net cost of buying and selling energy in the DA market
- RT stage: expected net cost of buying and selling energy in the RT market

Subject to:

$$I_{j,t}^{-} - I_{j,t}^{+} = E_{j,t}^{RT} - E_t^{DA}, \qquad \forall\, j \in S, \qquad t \in H$$

$$-\bar{E}^{\wedge} \leq E_t^{DA} \leq \bar{E}^{\underline{\vee}}, \qquad \forall\, t \in H$$

$$0 \leq I_{j,t}^{+}, I_{j,t}^{-} \leq \max\left(\bar{E}^{\underline{\vee}}, \bar{E}^{\wedge}\right), \qquad \forall\, j \in S, t \in H$$

$$E_{j,t}^{RT} = \sum_{v} \left(\sum_{i \in L^v} P_{j,i,t}^{v} \Delta t \right), \qquad \forall\, j \in S, t \in H,\; v \in \{EV, TCL, SL, INL\}$$

→ Market trading constraints

Scenario-based inputs

$\{Pr_{j,i}^{INL}, \forall\, j, i\}$ → Inflexible net load

Two-stage stochastic optimization model

$$0 \leq E_{j,i,t}^{EV,\vee} \leq \emptyset_{j,i,t}\overline{P}_i^{EV}\Delta t, \quad \forall\, j \in S, i \in L^{EV}, t \in H_{j,i}^{EV}$$

$$0 \leq E_{j,i,t}^{EV,\overline{\wedge}} \leq (1-\emptyset_{j,i,t})\overline{P}_i^{EV}\Delta t, \quad \forall\, j \in S, i \in L^{EV}, t \in H_{j,i}^{EV}$$

$$SOC_{j,i,t+1} = SOC_{j,i,t} + \eta_i^{\vee}E_{j,i,t}^{EV,\vee} - E_{j,i,t}^{EV,\overline{\wedge}}/\eta_i^{\overline{\wedge}}, \quad \forall\, j \in S, i \in L^{EV}, t \in H_{j,i}^{EV}$$

$$\underline{SOC_i} \leq SOC_{j,i,t+1} \leq \overline{SOC}_i, \quad \forall\, j \in S, i \in L^{EV}, t \in H_{j,i}^{EV}$$

$$SOC_{j,i,t_{j,i}^{DE}} = SOC_{j,i}^{DE}, \quad \forall\, j \in S, i \in L^{EV}$$

→ Electric vehicle constraints

Scenario-based inputs

$$\{t_{j,i}^{DE}, t_{j,i}^{AR}, SOC_{j,i}^{DE}, SOC_{j,i}^{AR}, H_{j,i}^{EV}, \forall\, j, i\}$$

→ Departure and arrival times
→ State-of-charge at departure and arrival times
→ Availability to charge and discharge

Two-stage stochastic optimization model

$$0 \leq P_{j,i,t}^{TCL} \leq \overline{P}_i^{TCL}, \quad \forall j \in S, i \in L^{TCL}, t \in H_i^{TCL}$$

$$\theta_{j,i,t+1} = \beta_i \theta_{j,i,t} + (1-\beta_i)\left(\theta_{j,t}^{o} + COP_i \cdot R_i \cdot P_{j,i,t}^{TCL}\right), \quad \beta_i = e^{-\frac{\Delta t}{C_i R_i}}, \quad \forall j \in S, i \in L^{TCL}, t \in H_i^{TCL}$$

$$\underline{\theta}_i \leq \theta_{j,i,t+1} \leq \overline{\theta}_i, \quad \forall j \in S, i \in L^{TCL}, t \in O_{j,i}$$

→ Heat pump constraints

$$P_{j,i,t}^{SL} = \sum_{w=0}^{D_{j,i}-1} Pr_{j,i,w}^{SL} \psi_{j,i,t-w}, \quad \forall j \in S, i \in L^{SL}, t \in \overline{H}_{j,i}^{SL}$$

$$\sum_{t \in \underline{H}_{j,i}^{SL}} \psi_{j,i,t} = 1, \quad \forall j \in S, \forall i \in L^{SL}$$

→ Shiftable load constraints

Scenario-based inputs

$\{O_{j,i}, \theta_j^0 \ \forall j, i\}$

→ Dwelling occupancy
→ Outdoor temperature

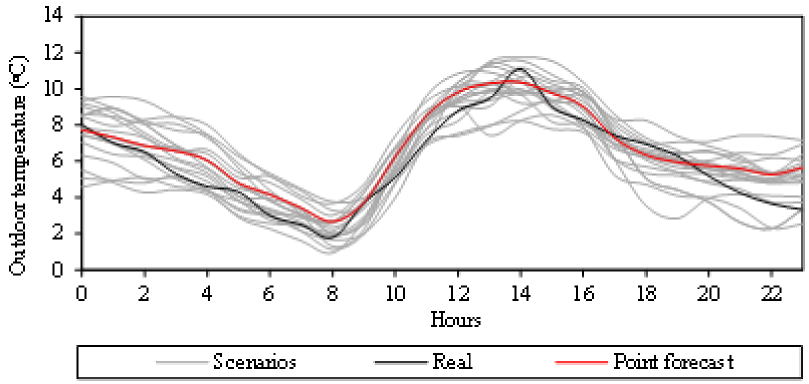
$\{\overline{H}_{j,i}^{SL}, Pr_{j,i}^{SL}, \underline{H}_{j,i}^{SL}, D_{j,i}, \forall j, i\}$

→ Availability to complete a working cycle
→ Power profile
→ Availability to start a working cycle
→ Duration of a working cycle

Case study

- The aggregator manages **1000 prosumers** from the Iberian market.
- Each prosumer has one **PV system** and three flexible loads: one **electric vehicle,** one **heat pump** and one shiftable load.
- Scenarios of outdoor temperature and inflexible net load were generated using **Gaussian copula** method.
- Scenarios of **dwelling active occupancy**, **shiftable loads** and **electric vehicles** requirements were generated using a naive forecasting method (based on historical data).
- Electricity prices were forecasted using **Gradient boosting** algorithm.

20 scenarios



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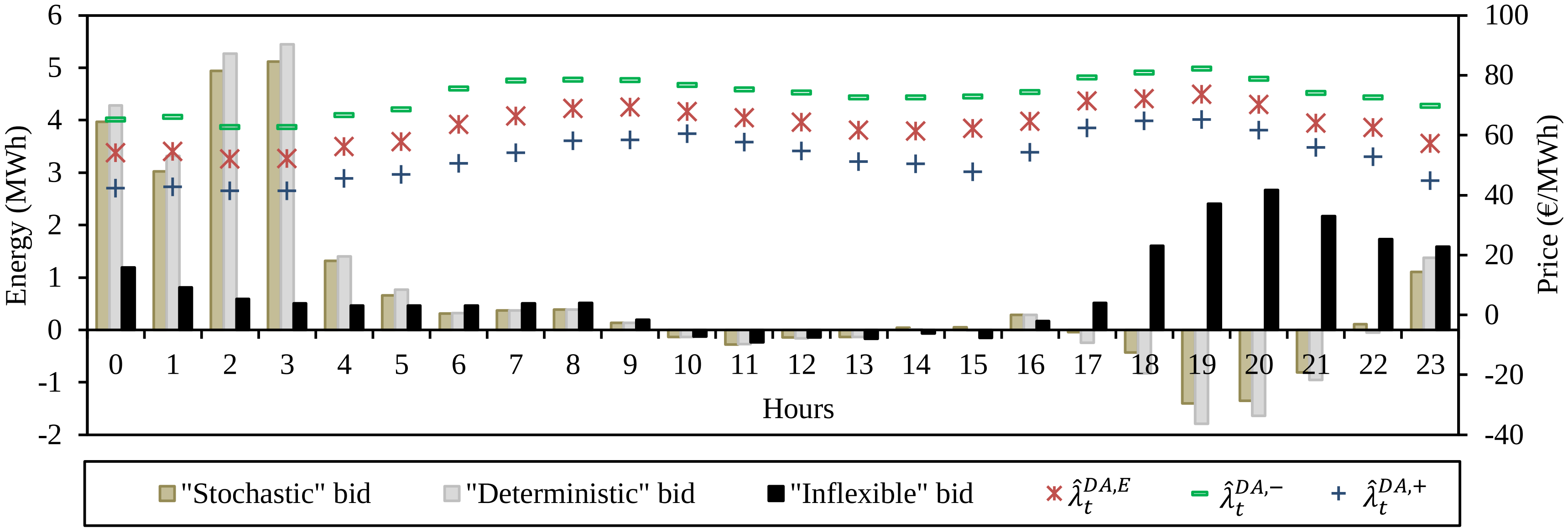
Bidding results



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Cumulative bidding results

24%   26%

	Stochastic	Deterministic	Inflexible
Net cost (k€)	0.87	0.84	1.14
Energy cost (k€)	1.19	1.27	1.20
Energy revenue (k€)	0.33	0.43	0.06
Expected imbalance cost (k€)	0.005	-	-
Demand bids (MWh)	21.84	23.36	18.54
Supply bids (MWh)	4.74	6.20	0.89
Expected net load (MWh)	17.12	-	-

→ **Stochastic strategy** presents a conservative behavior, since the difference between net bids and expected net consumption is negative ($I^{-} = 0.02\ \mathrm{MWh}$).

Stochastic strategy computes robust bids. **Deterministic strategy** presents the lowest DA net costs.

Cumulative RT results

- **RT control** consists of a centralized dispatch of flexible loads.

5%

16%

	Stochastic	Deterministic	Inflexible
Net cost (k€)	0.99	1.04	1.18
Energy cost (k€)	1.22	1.24	1.21
Energy revenue (k€)	0.26	0.28	0.05
Regulation cost (k€)	0.04	0.08	0.02

- **Stochastic strategy** outperforms deterministic and inflexible strategies in RT, since it computes more robust bids than the other strategies in the DA stage.

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Conclusions

- Exploiting the **flexibility** of the distributed energy resources enables aggregators and small prosumers to reduce their **electricity costs**.
- The proposed methodology allows the aggregator to value the **load flexibility** of the prosumers, as well as the their **generation surplus**
- The deployment of building automation systems **empower** prosumers and may contribute for the increase of **RES** at local level.
- The proposed methodology may be used to avoid **investments** on dedicated **storage devices**.

José Iria, Filipe Soares, Manuel Matos, Optimal supply and demand bidding strategy for an aggregator of small prosumers, Applied Energy, 2017, , ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2017.09.002

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