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DEMAND RESPONSE MODELS AND MARKETS

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P.PORTO

LASI Intelligent Systems Associate Laboratory

CONTENTS

- GECAD introduction
- Portugal initiatives and legislation
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GECAD

Artificial Intelligence & Intelligent systems

Optimization and Computational Intelligence

Machine learning

Knowledge discovery

Big data

Intelligent Interfaces

Affective computing

Power & Energy Systems

Expert Systems

User modeling

Cyber-physical systems

Multi-agent systems

Context Awareness

Semantics

Ambient intelligence

Ontologies

GECAD

Artificial Intelligence & Intelligent systems

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GECAD

60+ Projects In the past 5 years

International:

TIOCPS – Trustworthy and Smart Communities of Cyber-Phisical Systems

IoTalentum

TradeRES – New Markets Design & Models for 100% Renewable Power Systems

Eco Rural IoT

SPEAR – Smart Prognosis of Energy with Allocation of Resources

dominoes – market driven distribution grid

DREAM-GO

M2M Grids

FUeL

SEAS – Smart Energy Aware Systems

National:

MASCOTIE

COMMUNITY·S

CENERGETIC

CONTEST

COLORS

BeNeFICE

União Europeia – Fundo Europeu de Desenvolvimento Regional

HORIZON 2020

EUREKA

ITEA 3

MARIE CURIE ACTIONS

Erasmus+

COMPETE

FCT Fundação para a Ciência e a Tecnologia

PORTUGAL 2020

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Project Partners:

100+ Companies

12+ Countries

- Airbus, Cassidian CyberSec, ENGIE, ITRON, Thales (FR)
- Volvo (SE)
- Nokia Bell Labs (BE)
- Empower (FI)
- EDP Dist, NEW-EDP R&D, Evoleo, Hospital S.João, IPBrick, PH Energia, PortoDigital, SISTRADE, VPS (PT)
- Eletrosul, ENEVA (BR)
- …

Tech transfer institutions

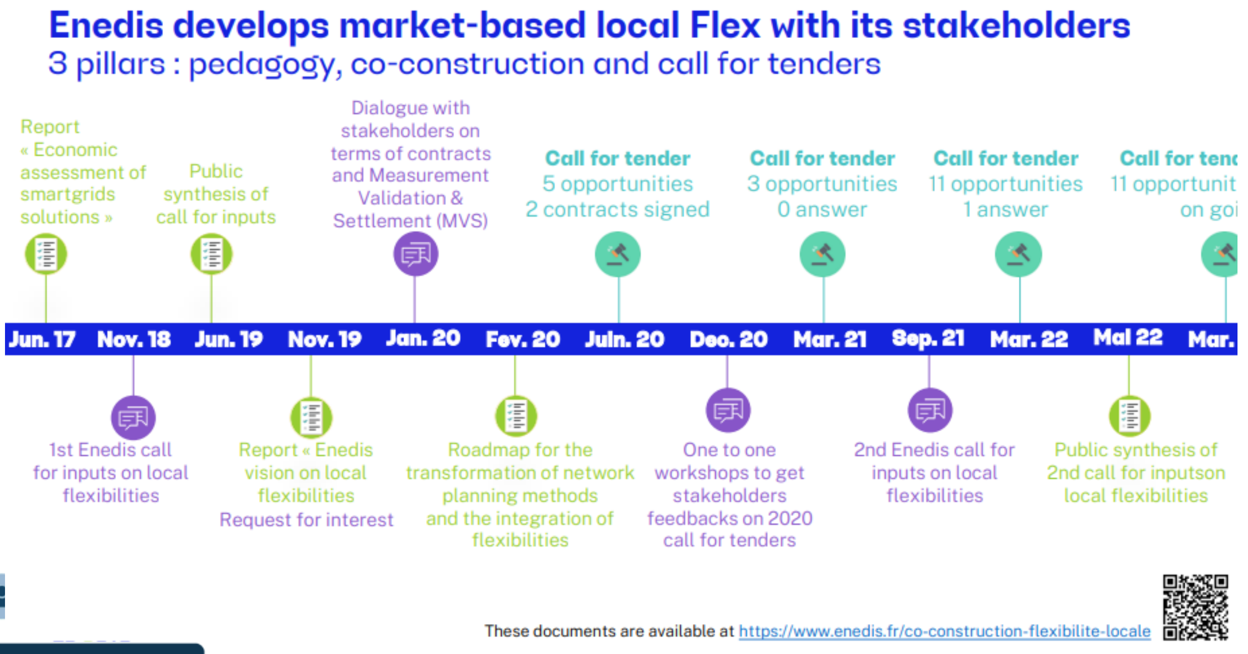
Vale, Zita; Faria, Pedro; Abrishambaf, Omid; Gomes, Luis; Pinto, Tiago. 2021. "MARTINE—A Platform for Real-Time Energy Management in Smart Grids" Energies 14, no. 7: 1820. https://doi.org/10.3390/en14071820

Gomes, Luis; Sousa, Filipe; Vale, Zita. 2018. "An Intelligent Smart Plug with Shared Knowledge Capabilities" Sensors18, no. 11: 3961. https://doi.org/10.3390/s18113961

Abrishambaf, Omid; Faria, Pedro; Gomes, Luis; Spínola, João; Vale, Zita; Corchado, Juan M. 2017. "Implementation of a Real-Time Microgrid Simulation Platform Based on Centralized and Distributed Management" Energies 10, no. 6: 806. https://doi.org/10.3390/en10060806

PORTUGAL INITIATIVES AND LEGISLATION

- DL 162/2019 (25 Oct):
- (a) autoconsumo de energia renovável
- (b) comunidades de energia renovável (CER) - consumidores numa relação de vizinhança próxima:
  - regulamento interno definindo direitos e obrigações
  - entidade jurídica do tipo cooperativa ou sociedade participada tanto por autoconsumidores como por outras entidades envolvidas no projeto de autoconsumo



DEMAND RESPONSE PROGRAMS AND MODELS

- Market
- Consumers
- Industry

BI-LEVEL OPTIMIZATION

- i) Upper-level (multi-leader):
  - Minimization of consumers' costs
  - Maximization of producers' profits
- ii) Lower-level (single-follower):
  - Maximization of energy transacted in the LEM
  - Clearing price calculated by a symmetric pool-based market
- iii) Network constraints:
  - Power flow analysis after LEM response to determine DN current and voltages.
  - DSO aims at the minimization of voltage violations and network losses.
  - MATPOWER for DSO validation
- EV requirements:
  - SoC
  - Minimum consumption for the trips

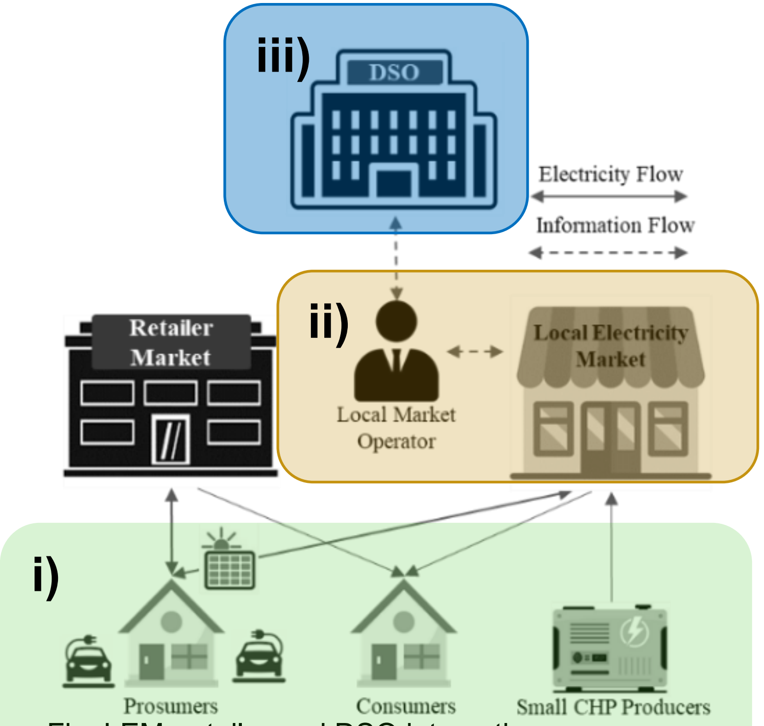
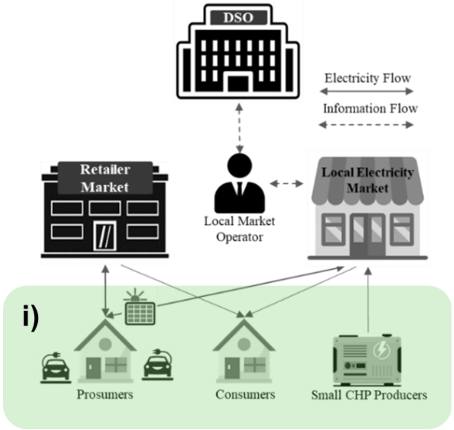


Fig. LEM, retailer and DSO interactions

i) UPPER-LEVEL (MULTI-LEADER)



The cp (clearing price) is determined at the **lower-level** and is the same for consumers and producers.

Maximization of producers' profits

$$\max_{s_{j,t},g_{j,t}} In_j = \sum_{t=1}^{T}\left(\sum_{i} cp_t \cdot x_{j,i,t} + c_t^{\mathrm{F}} \cdot E_{j,t,s}^{\mathrm{sell}} - \mathbf{C}_{j,t}^{\mathrm{total}}\right)$$

LEM energy | Grid energy | Production cost

st.

$$g_{i,j}^{\mathrm{PV}} - d_{i,t}^{\mathrm{Total}} - \sum_{v} E_{i,t}^{\mathrm{EV}-} = \sum_{i,j\neq i} x_{j,i,t} + E_{j,t}^{\mathrm{sell}} \text{ for PV } \forall t \in T$$

$$g_{j,t}^{\mathrm{CHP}} = \sum_{i,j\neq i} x_{j,i,t} \text{ for CHP } \forall t \in T$$

$$0 \le c_t^{\mathrm{F}} \le s_{j,t} \le cp_t \le c_t^{\mathrm{grid}} \quad \forall t \in T$$

Minimization of consumers' costs

$$\min_{s_{i,t},d_{i,t}} C_i = \sum_{t=1}^{T}\left(\sum_{j} cp_t \cdot x_{j,i,t} + c_t^{\mathrm{grid}} \cdot E_{i,t}^{\mathrm{buy}}\right)$$

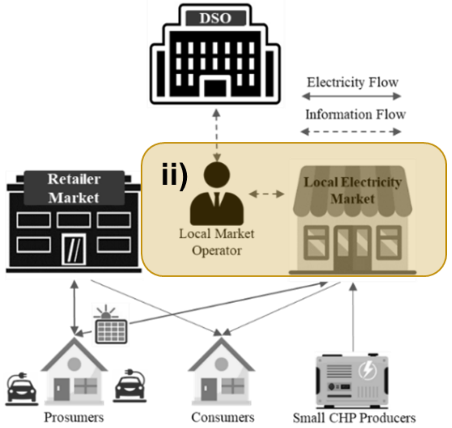
LEM energy | Aggregator energy

st.

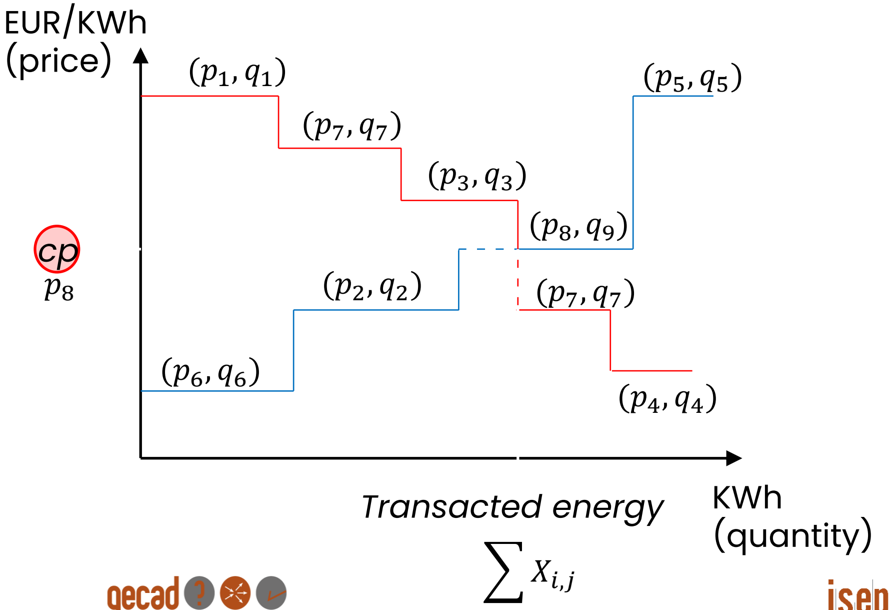
$$d_{i,t}^{\mathrm{Total}} + E_{i,t}^{\mathrm{EV}+} = \sum_{j,j\neq i} x_{j,i,t} + E_{i,t}^{\mathrm{buy}} \quad \forall t \in T$$

$$0 \le c_t^{\mathrm{F}} \le cp_t \le s_{i,t} \le c_t^{\mathrm{grid}} \quad \forall t \in T$$

ii) LOWER-LEVEL (SINGLE-FOLLOWER)



Maximization of energy transacted in the LEM



Clearing price calculated by a symmetric pool-based market

- Symmetric pool model
- Bids/offers allocation using merit order based on price
- Supply curve, from highest to lowest price (red line)
- Demand curve, from lowest to highest price (blue line)
- The *cp* is the interception of both curves

Social-welfare optimization problem

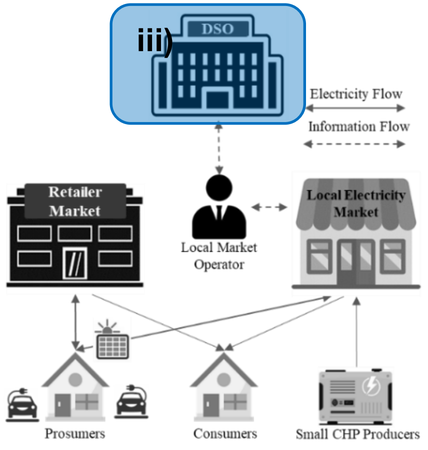
$$\max_{d_i^*, g_j^*} \underbrace{\sum_{i=1}^{N_c} \lambda_i^{d} \cdot d_i^*}_{\text{Demand curve}} - \underbrace{\sum_{j=1}^{N_p} \lambda_j^{g} \cdot g_j^*}_{\text{Supply curve}}$$

$$\underbrace{\sum_{i=1}^{N_c} d_i^* - \sum_{j=1}^{N_p} g_j^* = 0}_{\text{Balance constraint (demand equal to supply)}} \qquad : cp_t$$

Balance constraint (demand equal to supply)

$: cp_t$ Dual variable (Clearing price)

iii) NETWORK CONSTRAINTS



Power flow analysis after LEM response to determine DN current and voltages.
DSO aims at the minimization of voltage violations and network losses.
MATPOWER for DSO validation

$$\min_{g_j^{CHP}} DN^{\text{impact}} = \sum_{t=1}^{T} \Bigg(\underbrace{\sum_{b\in\Omega_b} B_{t,b}}_{\text{Voltage violation}} + \underbrace{\sum_{b\in\Omega_b} \theta_{t,b}}_{\text{Angle violation}} + \underbrace{\sum_{l\in\Omega_l} L_{t,l}}_{\text{Line limit violation}} + \underbrace{\sum_{l\in\Omega_l} P_{t,l}^{\text{loss}}}_{\text{Active power loss}} + \underbrace{\sum_{l\in\Omega_l} Q_{t,l}^{\text{loss}}}_{\text{Reactive power loss}} \Bigg)$$

- Power flow after players' bids/offers are set and the LEM has been cleared.
- MATPOWER at each iteration varying the CHP generation depending on LEM results.
- Consumers are inelastic loads, and PV generation is injected to the LEM or grid.
- DN validation is a fast procedure since market clearing results can be easily implemented.

EV CHARGING OPTIMIZATION

- Standard EV charging formulation without V2G:

$E^{EV+}_{i/j,t} \cdot \mathbf{X}^{EV+}_{i/j,t} \leq \alpha \quad \forall t \in T$ → limits energy to charge up to charging rate α.
binary variables $\mathbf{X}^{EV+}_{i/j,t}$ indicates when the EV is connected or on trip

$SoC^{min}_{i/j,t} \leq SoC_{i/j,t} \leq SoC^{max}_{i/j,t}$ → limits SoC to the minimum preference $S^{min}_{i/j,t}$ and maximum battery capacity $S^{max}_{i/j,t}$

$SoC_{i/j,t} = SoC_{(i/j,t-1)} + \eta^{+}_{i/j} \cdot E^{EV+}_{i/j,t}$ → models the SoC considering charging values and battery efficiency

$SoC_{i/j,t_0} \leq SoC_{i/j,T}$ → final SoC be greater or equal to the initial SoC
(to guarantee that EVs charge the energy they spend during day trips)

CASE STUDY

- 61 players in a DN
  - 13 consumers
  - 6 CHP producers (max capacity of 10 kW)
  - 42 prosumers (with PV)

  - Peak power consumption ≈140.49 kW
  - Peak power PV generation ≈193.69 kW

- Experiments for the 24 hours (T=24)
  - flat feed-in tariff $c_t^{\mathrm{F}} = 0.045$ EUR/kWh $\forall\ t \in T$,
  - Two retail tariffs:
    - plain of 0.158 €/kWh
    - bi-hourly of 0.1023 €/kWh off-peak, and 0.1924 €/kWh in peak periods (i.e., from 9 to 22).

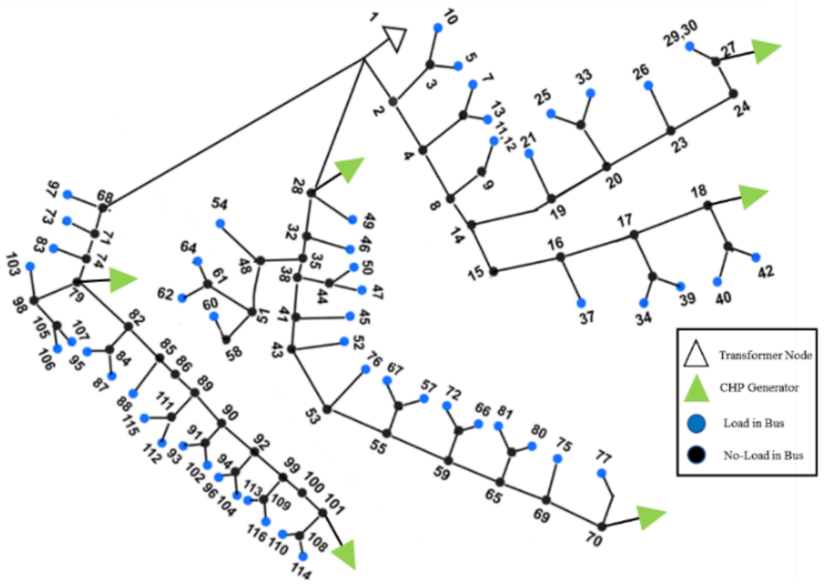


Fig. Equivalent model of the modified IEEE low voltage test feeder.

Adapted from M. A. Khan and H. Barry, "A Reduced Electrically-Equivalent Model of the IEEE European Low Voltage Test Feeder.," 2021. doi: 10.36227/techrxiv.16785832.v1..

EXPERIMENTS

3 scenarios and 2 tariffs (flat and double) were evaluated:

- Worst-case scenario: no local transactions and EVs always connected and charging.
- Business-as-usual (BAU) scenario: no local transactions but smart charging scheduling of EVs.
- Case 1: LEMs with intelligent management of EVs battery charge.

TABLE II. ANALYSED SCENARIOS IN THIS ARTICLE.

Scenario	Tariff	LEM	EV-EMS
Worst-case	Flat	No	No
	Double	No	No
BAU	Flat	No	Yes
	Double	No	Yes
Case 1	Flat	Yes	Yes
	Double	Yes	Yes

- 10 runs for each experiment reporting the best values of different metrics. Vortex Search only requires the number of iterations (set to 2000) and neighbor solutions (set to 20) to provide near-optimal solutions.
- Experiments implemented in MATLAB 2018a in PC with Intel (R) Core (TM) i7-8650U CPU@1.90GHz processor with 16GB of RAM running Windows 10.

OVERALL RESULTS

TABLE III. OVERALL COSTS/INCOMES/PROFITS, FITNESS, AND EXECUTION TIME IN EACH SCENARIO.

Scenario	Tariff	Consumers & prosumers (EUR)			Producers (EUR)			Total (EUR)			Fitness	Time (mins)
		Cost	Income	Profit (loss[a])	Cost	Income	Profit (loss[a])	Cost	Income	Profit (loss[a])		
Worst-case	Flat	885.10	0.00	-885.10	0.00	0.00	0.00	885.10	0.00	-885.10	24630.75	-
	Double	827.82	0.00	-827.82	0.00	0.00	0.00	827.82	0.00	-827.82	24628.91	-
BAU	Flat	413.87	0.00	-413.87	0.00	0.00	0.00	413.87	0.00	-413.87	12214.12	25.11
	Double	412.11	0.00	-412.11	0.00	0.00	0.00	412.11	0.00	-412.11	10813.97	25.05
Case 1	Flat	366.94	15.93	-351.01	50.65	55.38	4.74	366.94	20.67	-346.27	11.47	36.79
	Double	401.98	28.85	-373.14	45.92	55.14	9.23	401.98	38.07	-363.91	13.08	42.77

[a] Profits are calculated as Incomes minus Costs. Thus, a negative value of profits indicates a loss (i.e., costs are higher than incomes).

- The cost of consumers and prosumers decreases in each scenario, achieving the best values in Case 1 (LEM and smart charging). Producers only able to participate in Case 1, and achieve best results with the Double tariff.
- Double tariff gets slightly worst profits for consumers and prosumers. This is also reflected in the fitness value.
- The extremely large fitness value in Worst case and BAU scenarios indicates network violations.

RATING AND REMUNERATING THE LOAD SHIFTING BY CONSUMERS PARTICIPATING IN DEMAND RESPONSE PROGRAMS

- Deal with the rebound effect when using DR programs, such as load shifting
- Sensitivity test regarding the period range where the load should be shifted
- Select the proper participants for a DR event considering a Trustworthy Rate (TR)
- TR provides contextual information to the community manager
- Use contextual features to predict the participation through TR, resorting to the period and the weather

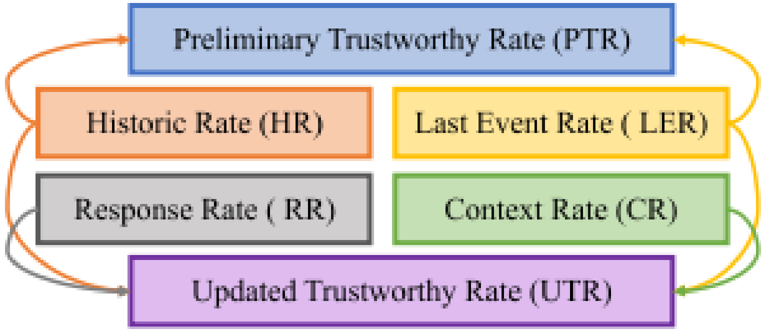


Fig. 1. DR trustworthy rate: Independent rates used for formulation.

C. Silva, P. Faria and Z. Vale, "Rating and Remunerating the Load Shifting by Consumers Participating in Demand Response Programs," in IEEE Transactions on Industry Applications, vol. 59, no. 2, pp. 2288-2295, March-April 2023, doi: 10.1109/TIA.2022.3224414.

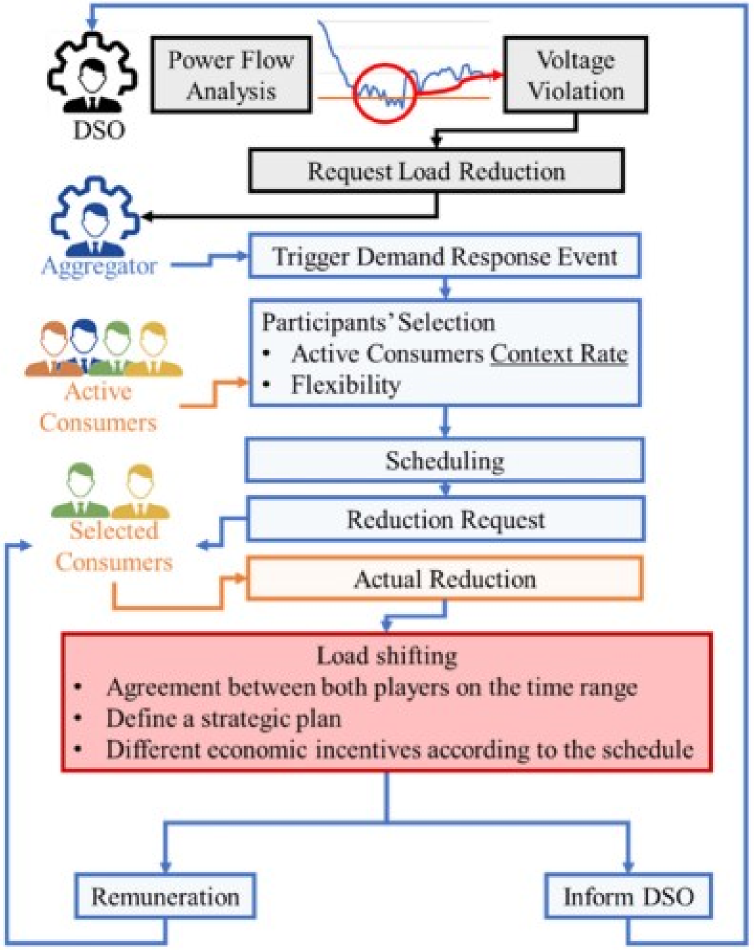


Fig. 2. The proposed DR trustworthy rate methodology is adapted from [1] but focuses on the load shifting step.

4 DR events declared in a week according to the voltages in the network

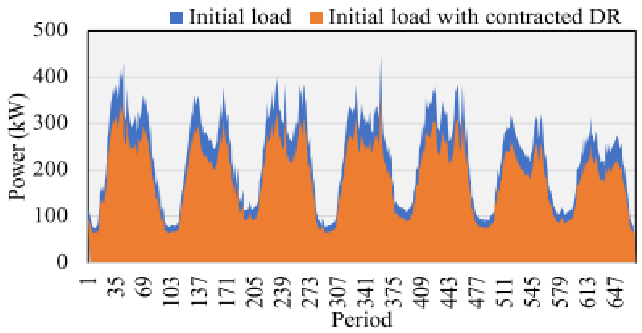


Fig. 3. Prediction of the load consumption before the DR event.

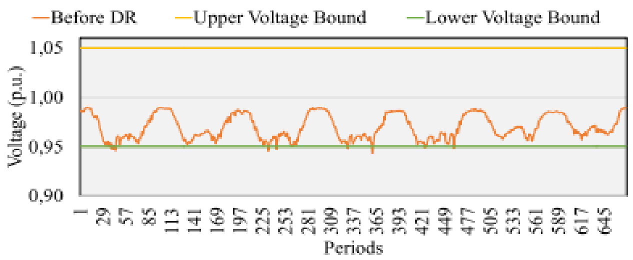


Fig. 4. Limit violation detection throughout the week.

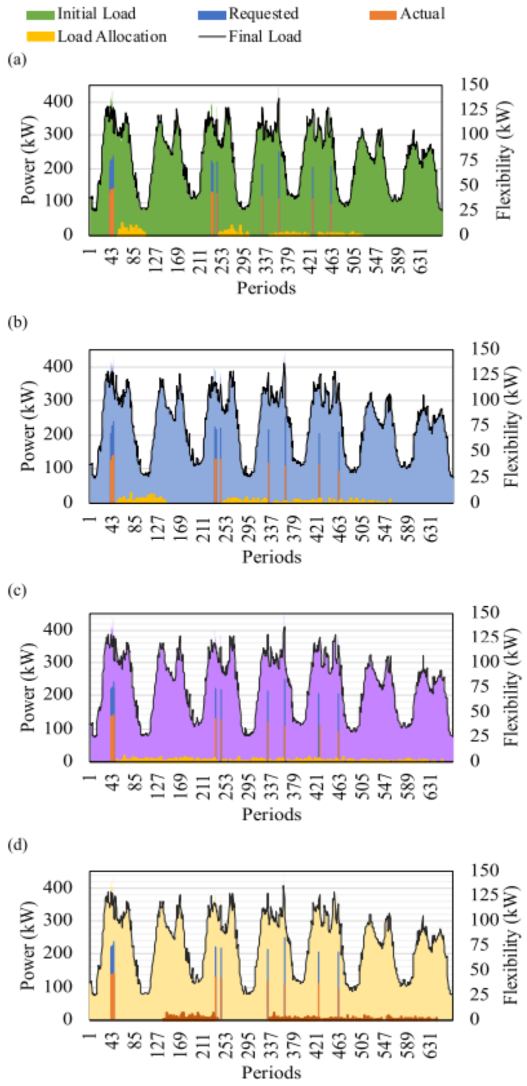


Fig. 5. Scheduling results and load allocation from (a) DR1, (b) DR2, (c) DR3, and (d) DR4 perspective.

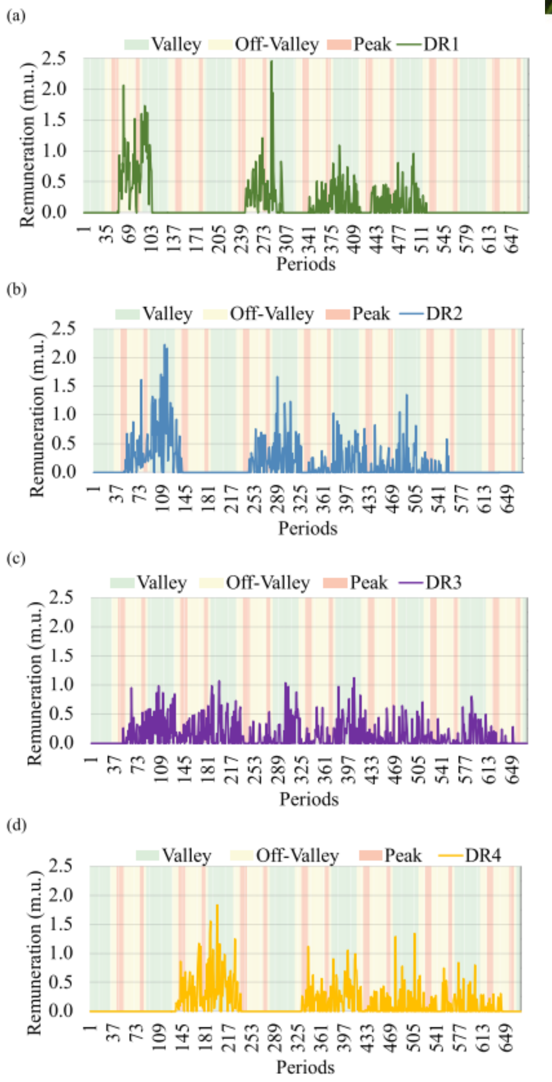
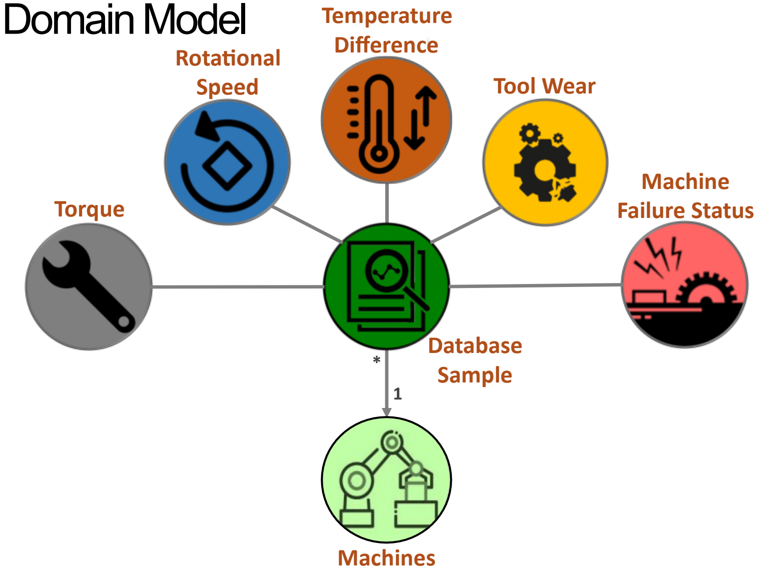


Fig. 6. Remuneration per period for (a) DR1, (b) DR2, (c) DR3, and (d) DR4 perspective.

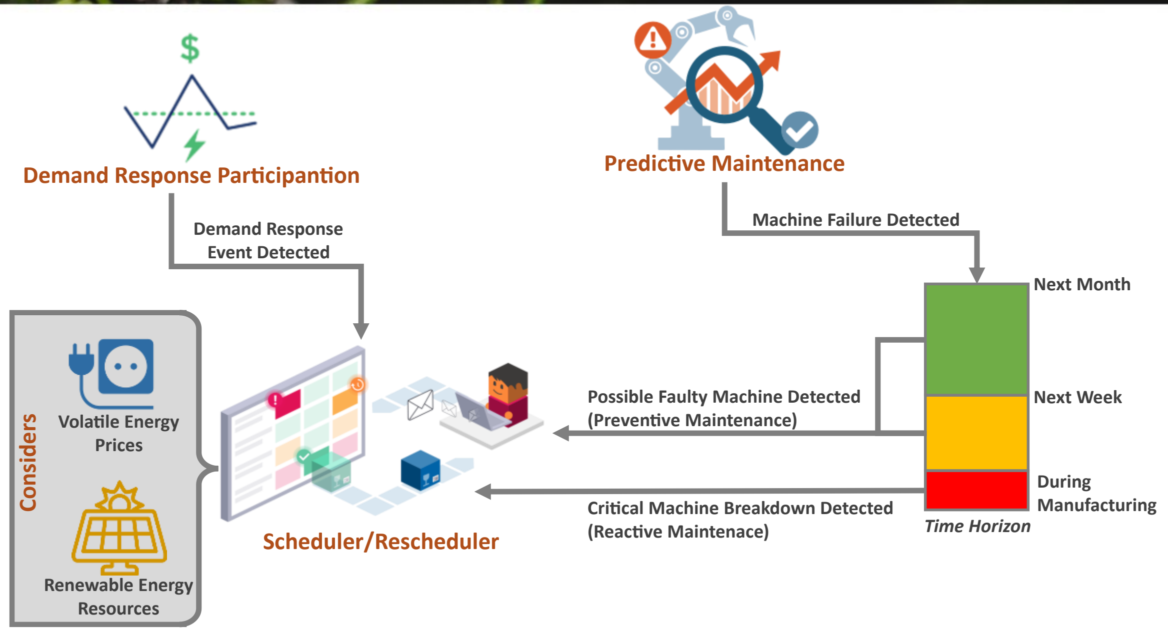
C. Silva, P. Faria and Z. Vale, "Rating and Remunerating the Load Shifting by Consumers Participating in Demand Response Programs," in IEEE Transactions on Industry Applications, vol. 59, no. 2, pp. 2288-2295, March-April 2023, doi: 10.1109/TIA.2022.3224414.

JOINT OPTIMIZATION OF PRODUCTION AND MAINTENANCE CONSIDERING DEMAND RESPONSE PARTICIPATION AND MACHINE BREAKDOWN EVENTS FOR EFFECTIVE MANUFACTURING

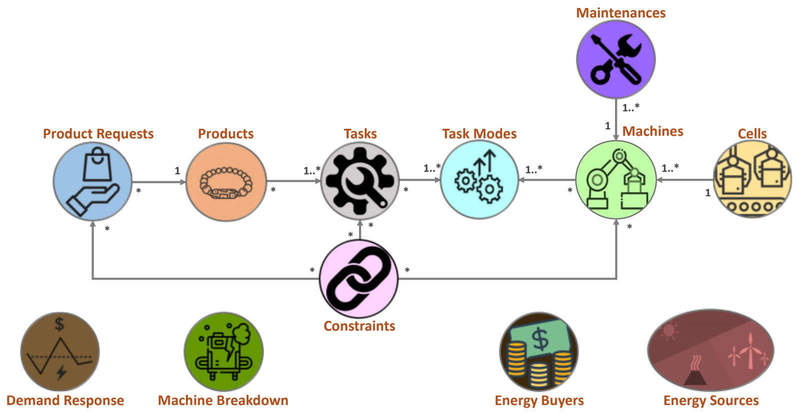
Predictive Maintenance Domain Model



Overview of the Proposed System



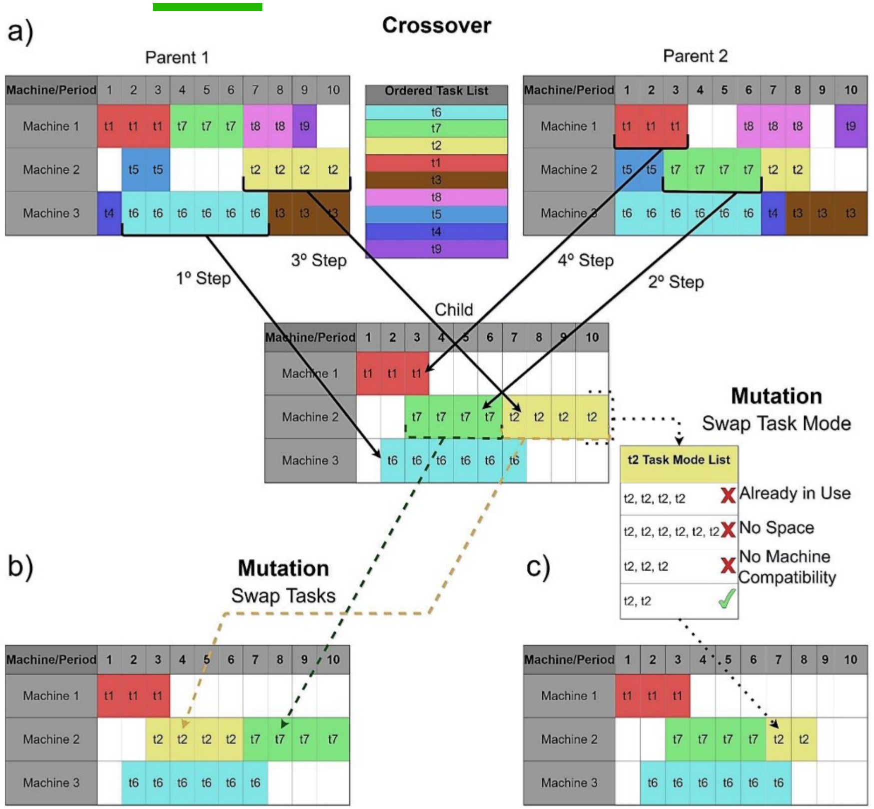
Scheduler/Rescheduler Domain Model



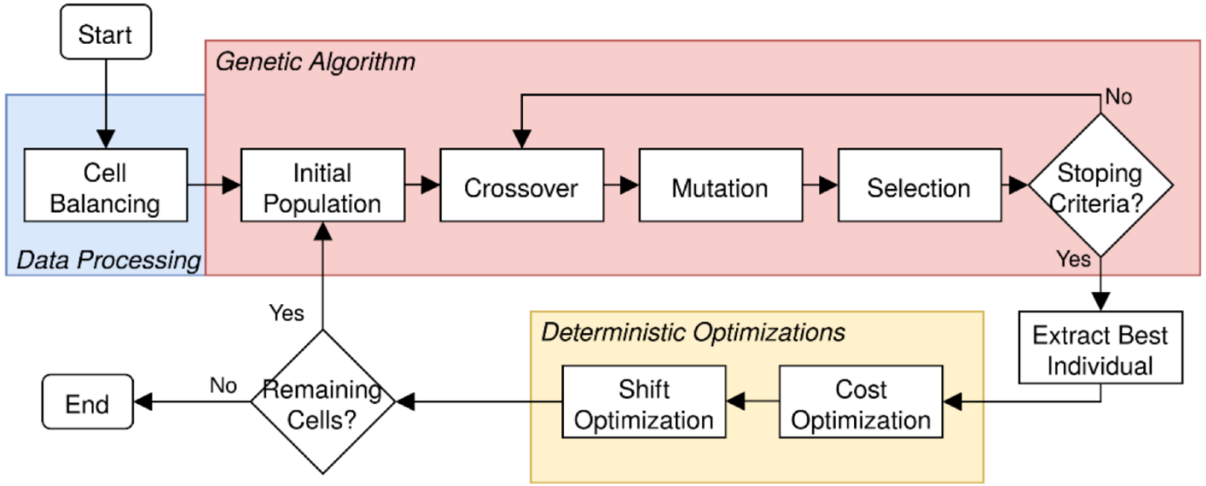
Bruno Mota, Pedro Faria, Zita Vale, Residential load shifting in demand response events for bill reduction using a genetic algorithm, Energy, Volume 260, 2022, https://doi.org/10.1016/j.energy.2022.124978.

Genetic Algorithm

Production Line Optimization to Minimize Total Cost and Maximize Machine Longevity



Bruno Mota, Pedro Faria, Zita Vale, Residential load shifting in demand response events for bill reduction using a genetic algorithm, Energy, Volume 260, 2022, https://doi.org/10.1016/j.energy.2022.124978.



Genetic Algorithm

- A novel crossover approach, which combines deterministic and non-deterministic elements;
- A mutation phase focusing on switching two tasks and/or changing the task mode;
- A hybrid selection technique, consisting of an elite selection and non-elite tournaments, is employed for a joint optimization that minimizes total costs (energy and maintenance) and machine degradation (standard deviation of machine occupancy rate).

Rescheduler (Genetic Algorithm) – Demand Response

After the participation in a Demand Response program, there was a significant **decrease in energy usage during the Demand Response** periods and the spread of tasks to other periods, indicating an intelligent shift of tasks.

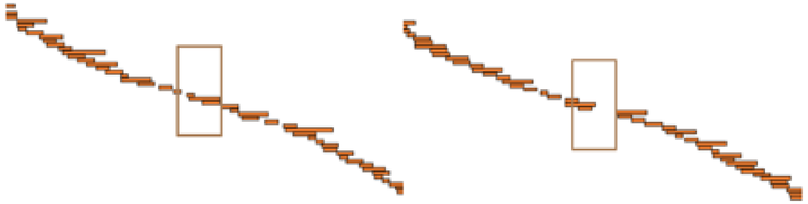
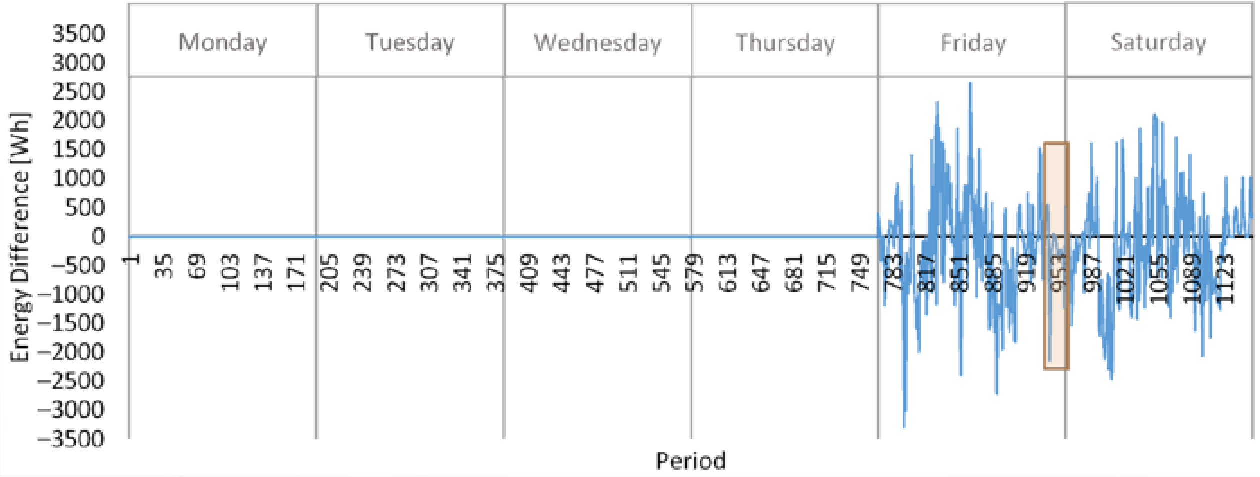


Figure 17 — Before and after Gantt diagrams of the demand response event, respectively, from period 848 to period 1058



Energy consumption difference (after – before) of the demand response event

Demand Response

Energy Consumption Limit of 2.5 kWh between periods 937 and 960

Bruno Mota, Pedro Faria, Zita Vale, Residential load shifting in demand response events for bill reduction using a genetic algorithm, Energy, Volume 260, 2022,https://doi.org/10.1016/j.energy.2022.124978.

WRAP-UP

- Market models with DR
- Prosumer in the center
- Energy storage
- Energy communities

THANK YOU!

Questions?

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