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# Intelligent Participation of Electric Vehicles in Demand Response Programs

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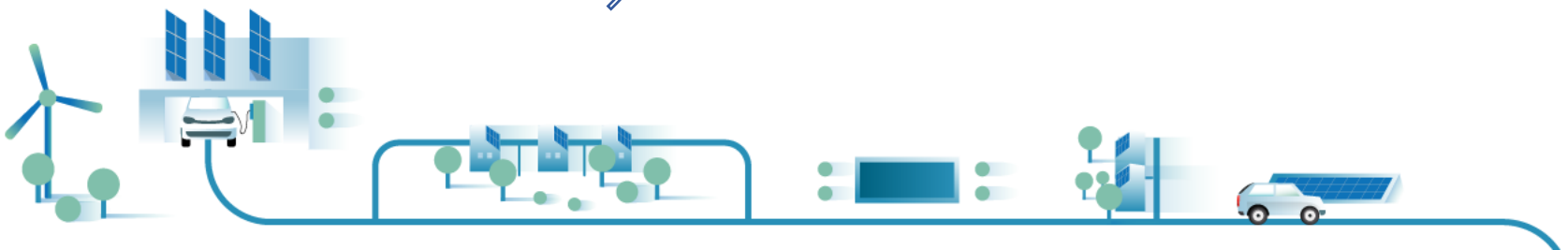
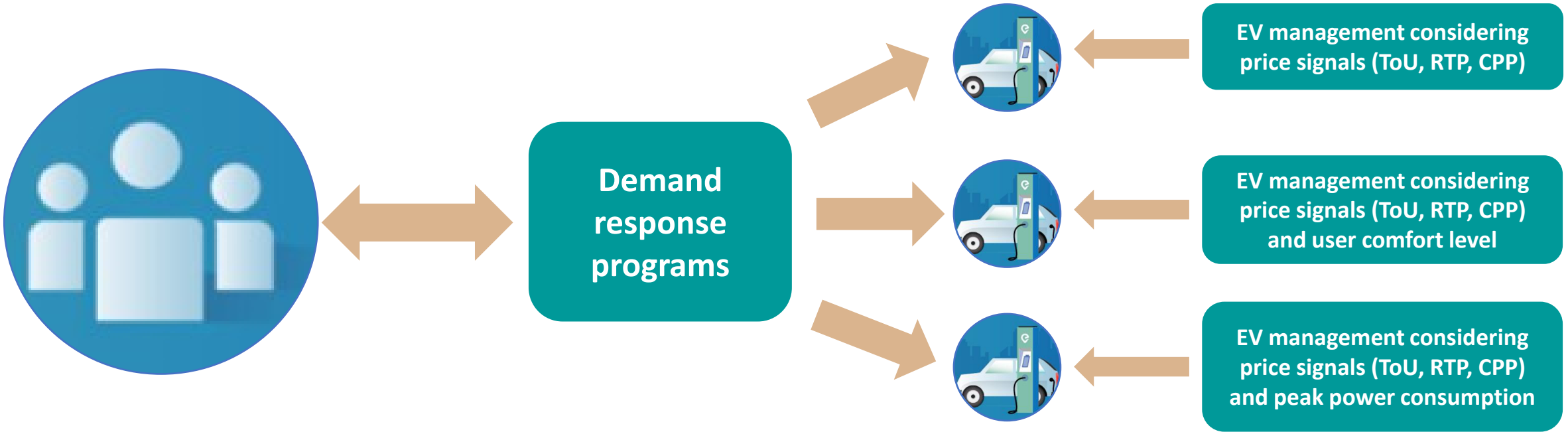
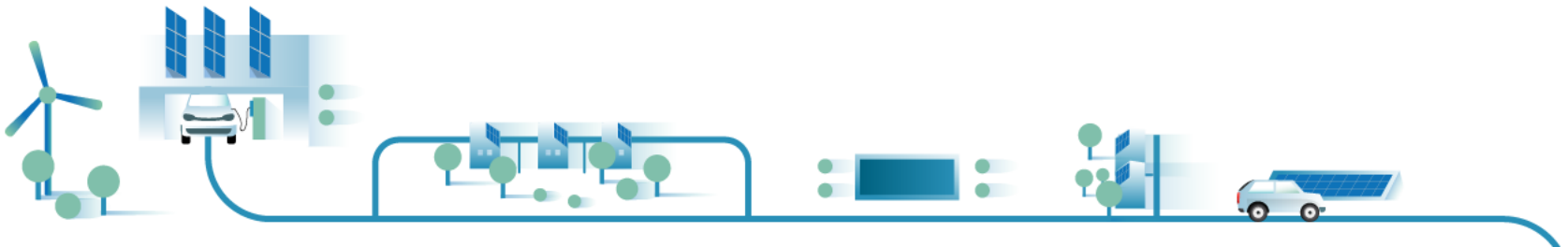


# PROPOSAL


Demand response programs
EV management considering price signals (ToU, RTP, CPP)
EV management considering price signals (ToU, RTP, CPP) and user comfort level
EV management considering price signals (ToU, RTP, CPP) and peak power consumption

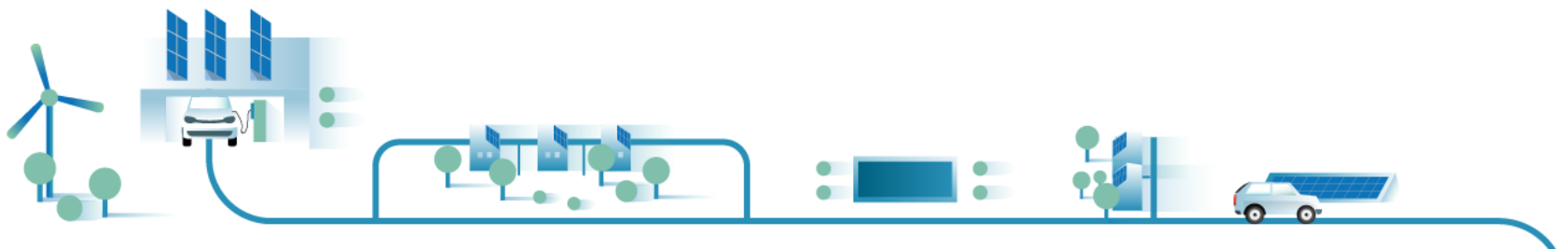


# OBJECTIVE FUNCTIONS

$$\boldsymbol{OF1} = minF_{BaU} = \sum_{v=1}^{nV}\sum_{t=1}^{T}\left(1 - SOC_{\%(v,t)}\right)$$

$$\boldsymbol{OF2} = minF_{cost} = \sum_{v=1}^{nV}\sum_{t=1}^{T}\left(P_{v,t}^{ch}.\Delta_t.C_t^{ch}\right) + \boldsymbol{M.AuxSOC_{tlast}^{EV}}$$

$$\boldsymbol{OF3} = minF_{cost+comf} = \sum_{v=1}^{nV}\sum_{t=1}^{T}\left(P_{v,t}^{ch}.\Delta_t.C_t^{ch}\right) + m.\left(1 - SOC_{\%(v,t)}\right) + \boldsymbol{M.AuxSOC_{tlast}^{EV}}$$



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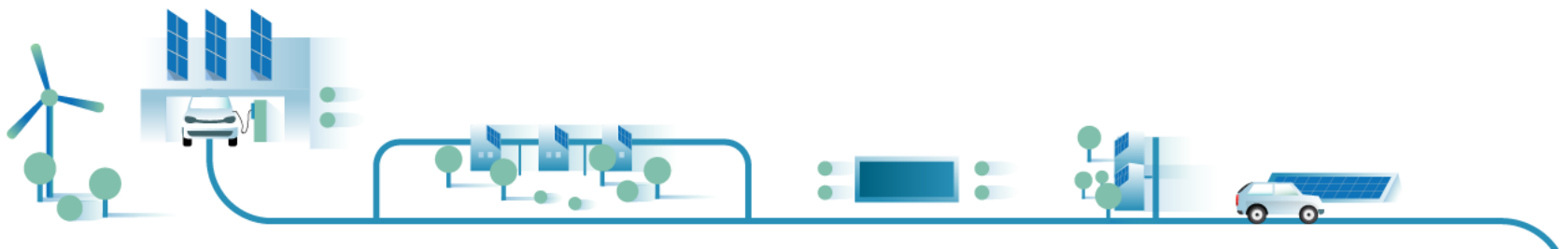
# OBJECTIVE FUNCTIONS

$$\boldsymbol{OF4} = minF_{cost+PeakEV} = \sum_{v=1}^{nV}\sum_{t=1}^{T}(P_{v,t}^{ch}.\Delta_t.C_t^{ch}) + \boldsymbol{M.AuxSOC_{tlast}^{EV}} + m.P_v^{Peak}$$

$$\boldsymbol{OF5} = minF_{cost+PeakEV} = \sum_{v=1}^{nV}\sum_{t=1}^{T}(P_{v,t}^{ch}.\Delta_t.C_t^{ch}) + \boldsymbol{M.AuxSOC_{tlast}^{EV}} + m.P_{peakTotal}$$

$$\boldsymbol{OF6} = minF_{cost} = \sum_{v=1}^{nV}\sum_{t=1}^{T}(P_{v,t}^{ch}.\Delta_t.C_t^{ch}) - \left(P_{v,t}^{Dch}.\Delta_t.C_t^{Dch}\right) + \boldsymbol{M.AuxSOC_{tlast}^{EV}}$$



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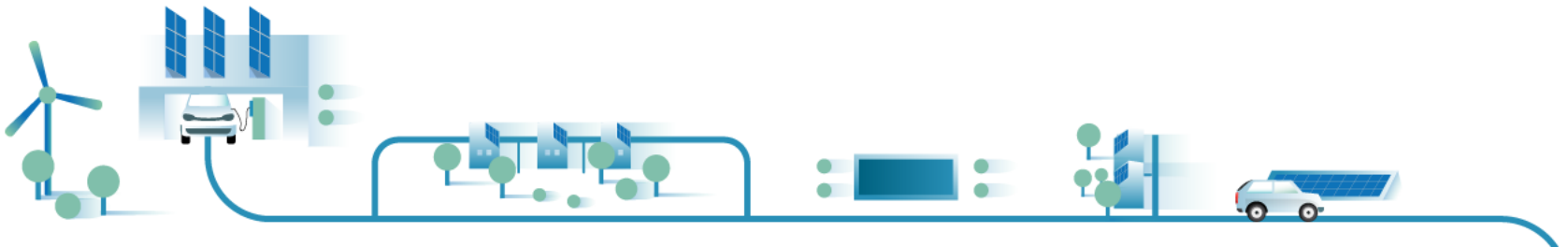
# CONTRAINTS

$$OF1, OF2, OF3, OF4, OF5, OF6$$

Subject to

EV operational constraints considering both charging and discharging

Power system operational constraints



# TEST AND RESULTS

The participants would leave their homes in the morning (6h00-8h00) and return at the end of the day (18h00-20h00).

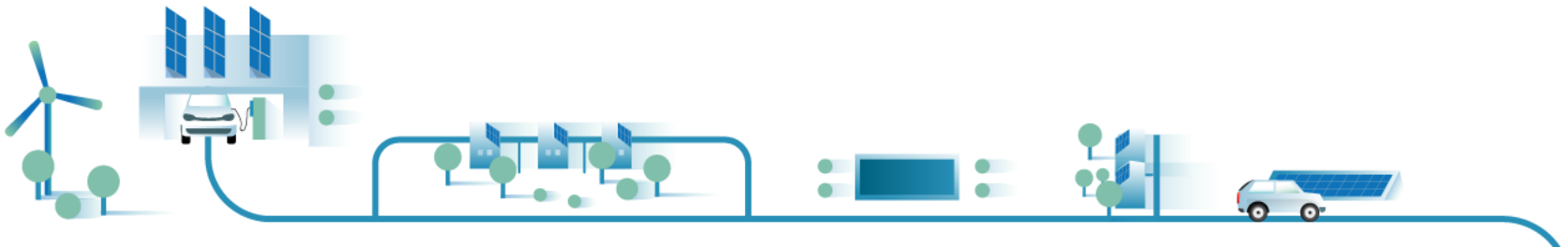
They were considered 200 EVs considering a mix of BEV and PHEV in which each EV user charges on its individual CS, with a maximum charging capacity of 7.2kW.

The data related to EV user profiles were obtained from a simulator.

TABLE I
DESCRIPTION OF ELECTRICITY HOURLY RATE PROGRAMS UTILISED.

| Tariff Type | Periods | Time Intervals | Electricity Price (€/kW) |
|---|---|---|---|
| Single | – – – – – | 0h – 24h | 0.145 |
| Bi-Hourly | *Off-Peak* | 1h–7h; 23h–24h | 0.099 |
| | *Peak* | 8h–22h | 0.185 |
| Tri-Hourly | *Off-Peak* | 1h–7h; 23h–24h | 0.096 |
| | *Partial–Peak* | 8h; 11h–17h; 22h | 0.156 |
| | *Peak* | 9h–11h; 18h–21h | 0.272 |

GAMS IBM CPLEX



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# TEST AND RESULTS

**Smart contracts:**

- **CPL: Charging power limitation**
- **MSL: Maximum SOC limitation**
- **PSC: proportional spending charging**

**Base case: total operational cost (TOC) of C2441.38 and peak power of 1147.91 MW.**

**MSL consistently has the best outcomes across all OFs, resulting 17% cheaper than RTP.**

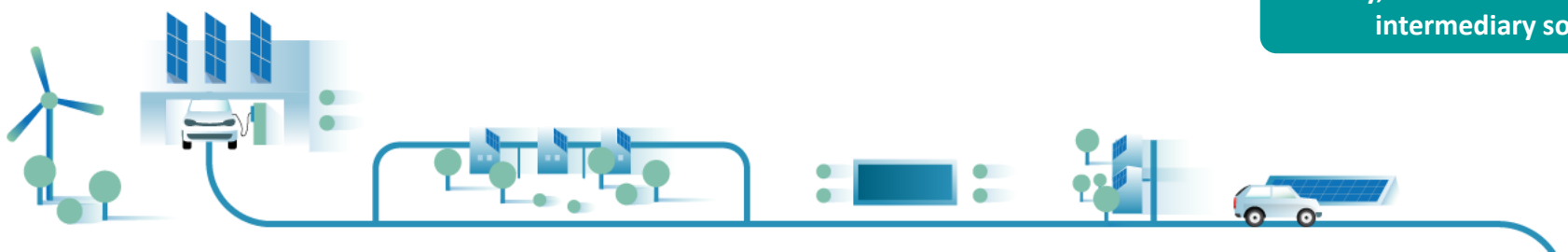
**BaU (OF (1)) forces the charges when the EV arrives, most EVs arrive at peak hours.**

**RTP– OF (3) results 17% more expensive when compared with MSL (Tri-H) – OF(3)**

TABLE II
TOC OF EACH OF COMBINATION FOR THE 100% SOC REQUIREMENT

| | Total Operating Cost | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ToU | | RTP | CPL | | MSL | | PSC | |
| | Bi-H | Tri-H | Market Spot-H | Bi-H | Tri-H | Bi-H | Tri-H | Bi-H | Tri-H |
| | € | € | € | € | € | € | € | € | € |
| OF (1) | 2464.1 | 3042.6 | 2497.67 | 2307.8 | 2715.3 | 1720.6 | 1717.8 | 2156.0 | 2393.9 |
| OF (2) | 1695.3 | 1651.6 | 1994.99 | 1690.3 | 1649.0 | 1690.5 | 1645.1 | 1695.3 | 1652.8 |
| OF (3) | 1695.3 | 1651.6 | 1996.70 | 1690.3 | 1649.0 | 1690.5 | 1645.1 | 1695.3 | 1652.8 |
| OF (4) | 1695.3 | 1651.6 | 1994.99 | 1690.3 | 1649.0 | 1690.5 | 1645.1 | 1695.3 | 1652.8 |
| OF (5) | 1696.5 | 1655.6 | 1995.30 | 1691.5 | 1653.0 | 1691.1 | 1647.4 | 1696.5 | 1656.8 |

**Finally, both CPL and PSC represent intermediary solutions**



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# TEST AND RESULTS

All tested DR programs provide significant profit to the EV user when paired with the OF (6).

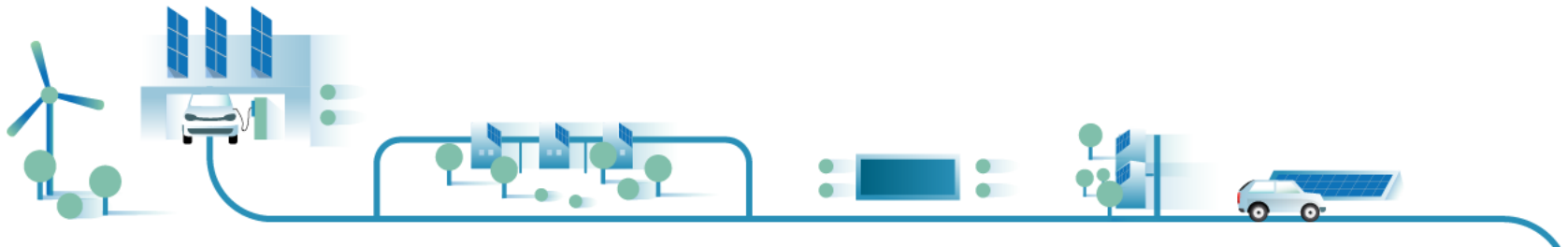
TABLE III
TOC COMPARISON BETWEEN V2G DR PROGRAM AND WITHOUT V2G, WITH 100% SOC REQUIREMENT

| | Total Operating Cost | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ToU | | RTP | CPL | | MSL | | PSC | |
| | Bi-H | Tri-H | Market Spot-H | Bi-H | Tri-H | Bi-H | Tri-H | Bi-H | Tri-H |
| | € | € | € | € | € | € | € | € | € |
| OF (1) | 2464.10 | 3042.60 | 2434.33 | 2307.80 | 2715.30 | 1720.60 | 1717.80 | 2156.00 | 2393.90 |
| OF (6) | -248.20 | -1023.70 | 785.78 | -250.60 | -1019.40 | -253.72 | -1031.50 | -246.60 | -1013.20 |

With SoC requirement of 80%, in less monetary compensation for the EV owner.

TABLE IV
TOC COMPARISON BETWEEN V2G DR PROGRAM AND WITHOUT V2G, WITH 80% SOC REQUIREMENT

| | Total Operating Cost | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ToU | | RTP | CPL | | MSL | | PSC | |
| | Bi-H | Tri-H | Market Spot-H | Bi-H | Tri-H | Bi-H | Tri-H | Bi-H | Tri-H |
| | € | € | € | € | € | € | € | € | € |
| OF (1) | 2376.70 | 2457.96 | 2311.70 | 2280.50 | 2630.70 | 1633.25 | 1633.18 | 2068.70 | 2309.30 |
| OF (6) | -181.11 | -921.62 | 737.54 | -183.50 | -918.33 | -186.63 | -929.35 | -179.17 | -906.82 |



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# TEST AND RESULTS

Related to the Peak Power results It is apparent that RTP displays the worst outcomes out of all the DR programs.

Considering that the variability of the prices through the day and the OF gives more importance to the price instead of the peak power, the EVs charging will be scheduled as much as possible to the hour of the lowest price.

CPL combined with the peak reduction objective function OF (4) provides the best overall result, leading to a roughly 36% peak power reduction in comparison with the NP position.

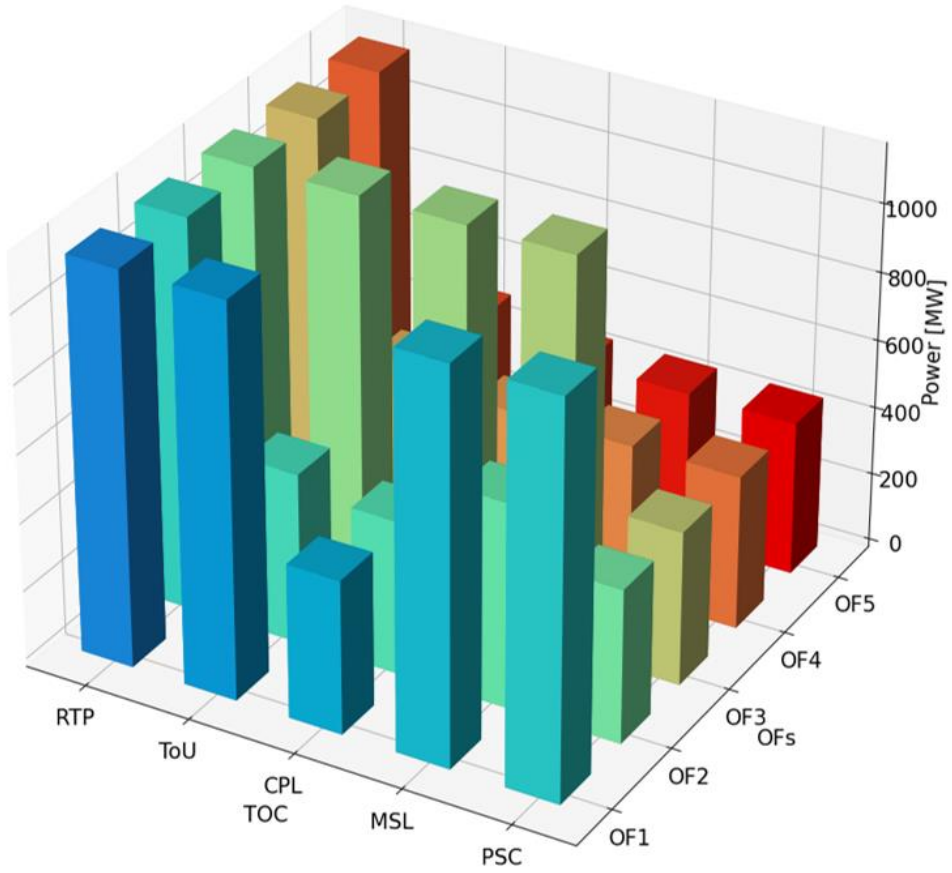
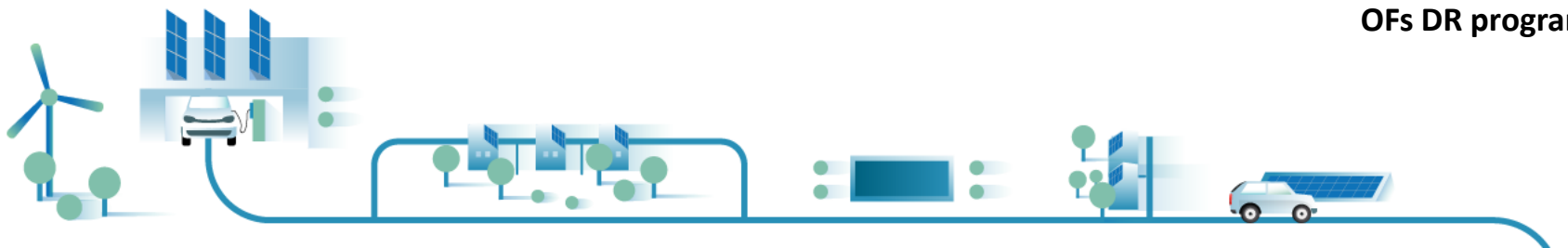
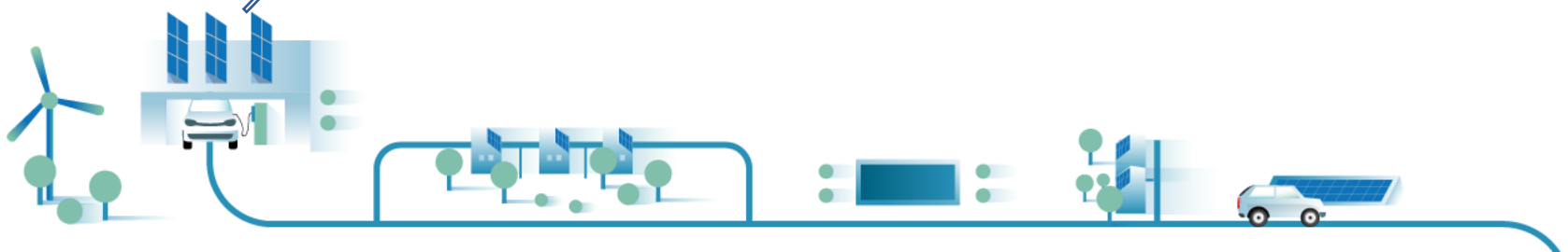



**Fig. 1. Peak Power Values obtained from every OFs DR program combinations for 80%**



# CONCLUSIONS

- DR programs are especially effective in the case of OFs with less cost since the latter already minimise the charging that could occur during the DR program's time intervals of operation
- The peak power is directly correlated with how the EV demand is attended, but it has no impact on the overall total operation cost, as this peak can occur either in peak or off-peak periods
- RTP is a complex choice for customers, seeing as its performance depends entirely on aspects that may affect the market prices.
- Time-of-Use (ToU) is very beneficial when paired with cost-centered OFs. This is important because the ToU program is already widely used
- MSL, PSC, CPL programs are very interchangeable and really depend on the travel profile of the participant.



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