EV fleet as a mobile storage

- EVs are grouped under an EV aggregator who tracks down their behaviour and optimizes their (dis)charging schedules. Each EV can be controllably (dis)charged into the grid when parked, which enables energy arbitrage. EVs drive and park interchangeably and change several types of charging stations (CS). Consider a fleet consisting of 2 mil. EVs with the same behaviour every day.
- Relevant EV daily behaviour considers several parameters:
  - EVs' status (parking/driving),
  - EVs' trip type while driving,
  - CSs' type while parked.
- Relevant EV technical parameters:
  - Battery capacity: 50 kWh,
  - OBC: 8 kW,
  - Ch/dch efficiency: 100%.
- EVs start and end he day fully charged.

Number	CS type	Installed power
1	Home	4 kW
2	Work	8 kW
3	Public	12 kW
Number	**Trip type**	**Average power**
4	Commuting	8 kW
5	Business	4 kW
6	Leisure	10 kW

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EV behaviour data

Hour	Status	Trip type	CS type	Hour	Status	Trip type	CS type
1	Parked	-	Home	13	Parked	-	Work
2	Parked	-	Home	14	Parked	-	Work
3	Parked	-	Home	15	Driving	Home	-
4	Parked	-	Home	16	Parked	-	Home
5	Driving	Comm.	-	17	Driving	Leisure	-
6	Parked	-	Work	18	Parked	-	Public
7	Parked	-	Work	19	Parked	-	Public
8	Driving	Business	-	20	Driving	Leisure	-
9	Parked	-	Public	21	Parked	-	Home
10	Driving	Business	-	22	Parked	-	Home
11	Parked	-	Work	23	Parked	-	Home
12	Parked	-	Work	24	Parked	-	Home

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EV task

- Determine operational cost of the EV fleet during one year under:
  - A) Uncontrolled or dumb charging,
  - B) Unidirectionally controlled or grid-to-vehicle G2V charging,
  - C) Bidirectionally controlled or vehicle-to-grid V2G charging.
- Which one provides the least cost solution?
- Can you compare the upper modes with other flexibility providers such as demand response and energy storage?
- What if efficiency is taken into account?

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EV task

D. Calculate operational cost of the EV fleet under dumb charging with efficiency of charging and discharging (both mobility and V2G) of 90%.

- Use daily price curve composed of four main segments:
  - Night valley (22:00-05:00): low tariff 20 €/MW (0.02 €/kW),
  - Morning peak (06:00-10:00): high tariff 50 €/MW (0.05 €/kW),
  - Day valley (11:00-16:00): low tariff 20 €/MW (0.02 €/kW),
  - Evening peak (16:00-21:00): high tariff 50 €/MW (0.05 €/kW).

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Hour	Trip power	CS power	To EV	DOD	Price	Hour	Trip power	CS power	To EV	DOD	Price
1	-	4 kW			20	13	-	8 kW			20
2	-	4 kW			20	14	-	8 kW			20
3	-	4 kW			20	15	8	-			20
4	-	4 kW			20	16	-	4 kW			20
5	8 kW	-			20	17	10 kW	-			50
6	-	8 kW			50	18	-	12 kW			50
7	-	8 kW			50	19	-	12 kW			50
8	4 kW	-			50	20	10 kW	-			50
9	-	12 kW			50	21	-	4 kW			50
10	4 kW	-			50	22	-	4 kW			20
11	-	8 kW			20	23	-	4 kW			20
12	-	8 kW			20	24	-	4 kW			20

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A) Uncontrolled charging

- Efficiency = 100%

Hour	Trip power	CS power	To EV	DOD	Price	Hour	Trip power	CS power	To EV	DOD	Price
1	-	4 kW	0	0	20	13	-	8 kW	0	0	20
2	-	4 kW	0	0	20	14	-	8 kW	0	0	20
3	-	4 kW	0	0	20	15	8	-	-8	8	20
4	-	4 kW	0	0	20	16	-	4 kW	4	4	20
5	8 kW	-	-8	8	20	17	10 kW	-	-10	14	50
6	-	8 kW	8	0	50	18	-	12 kW	8	6	50
7	-	8 kW	0	0	50	19	-	12 kW	6	0	50
8	4 kW	-	-4	4	50	20	10 kW	-	-10	10	50
9	-	12 kW	4	0	50	21	-	4 kW	4	6	50
10	4 kW	-	-4	4	50	22	-	4 kW	4	2	20
11	-	8 kW	4	0	20	23	-	4 kW	2	0	20
12	-	8 kW	0	0	20	24	-	4 kW	0	0	20

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A) Uncontrolled charging

- Efficiency = 100%

Hour	To EV	Price	Cost	Hour	To EV	Price	Cost
1	0	20		13	0	20	
2	0	20		14	0	20	
3	0	20		15	-8	20	
4	0	20		16	4	20	0,08
5	-8	20		17	-10	50	
6	8	50	0,4	18	8	50	0,4
7	0	50		19	6	50	0,3
8	-4	50		20	-10	50	
9	4	50	0,2	21	4	50	0,2
10	-4	50		22	4	20	0,08
11	4	20	0,08	23	2	20	0,04
12	0	20		24	0	20	

$$\sum_{1}^{24} Energy = 44\ \text{kWh}$$

For 1 EV in 1 day:

$$\sum_{1}^{24} Cost = 1{,}78\ €$$

For 1 EV in 1 year:

$$365 * \sum_{1}^{24} Cost = 649{,}7\ €$$

For EV fleet in 1 year:

$$2\ \text{mill.} * 365 * \sum_{1}^{24} Cost = 1{,}3\ \text{bil.}\ €$$

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B) Unidirectional charging

- Efficiency = 100%

Hour	Trip power	CS power	To EV	DOD	Price	Hour	Trip power	CS power	To EV	DOD	Price
1	-	4 kW	0	0	20	13	-	8 kW	0	0	20
2	-	4 kW	0	0	20	14	-	8 kW	0	0	20
3	-	4 kW	0	0	20	15	8	-	-8	8	20
4	-	4 kW	0	0	20	16	-	4 kW	4	4	20
5	8 kW	-	-8	8	20	17	10 kW	-	-10	14	50
6	-	8 kW	0	8	50	18	-	12 kW	8	6	50
7	-	8 kW	0	8	50	19	-	12 kW	0	6	50
8	4 kW	-	-4	12	50	20	10 kW	-	-10	16	50
9	-	12 kW	0	12	50	21	-	4 kW	4	12	50
10	4 kW	-	-4	16	50	22	-	4 kW	4	8	20
11	-	8 kW	8	8	20	23	-	4 kW	4	4	20
12	-	8 kW	8	0	20	24	-	4 kW	4	0	20

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B) Unidirectional charging

- Efficiency = 100%

Hour	To EV	Price	Cost	Hour	To EV	Price	Cost
1	0	20		13	0	20	
2	0	20		14	0	20	
3	0	20		15	-8	20	
4	0	20		16	4	20	0,08
5	-8	20		17	-10	50	
6	0	50		18	8	50	0,4
7	0	50		19	0	50	
8	-4	50		20	-10	50	
9	0	50		21	4	50	0,2
10	-4	50		22	4	20	0,08
11	8	20	0,16	23	4	20	0,08
12	8	20	0,16	24	4	20	0,08

$$\sum_{1}^{24} Energy = 44\ \text{kWh}$$

For 1 EV in 1 day:

$$\sum_{1}^{24} Cost = 1,24€$$

For 1 EV in 1 year:

$$365 * \sum_{1}^{24} Cost = 452,6\ €$$

For EV fleet in 1 year:

$$2\ \text{mil.} * 365 * \sum_{1}^{24} Cost = 0,91\ \text{bil.}\ €$$

Savings: ≈30%

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C) Bidirectional charging

- Efficiency = 100%

Hour	Trip power	CS power	To EV	DOD	Price	Hour	Trip power	CS power	To EV	DOD	Price
1	-	4 kW	0	0	20	13	-	8 kW	8	8	20
2	-	4 kW	0	0	20	14	-	8 kW	8	0	20
3	-	4 kW	0	0	20	15	8	-	-8	8	20
4	-	4 kW	0	0	20	16	-	4 kW	4	4	20
5	8 kW	-	-8	8	20	17	10 kW	-	-10	-14	50
6	-	8 kW	-8	16	50	18	-	12 kW	8	6	50
7	-	8 kW	-8	24	50	19	-	12 kW	0	6	50
8	4 kW	-	-4	28	50	20	10 kW	-	-10	16	50
9	-	12 kW	0	28	50	21	-	4 kW	4	12	50
10	4 kW	-	-4	32	50	22	-	4 kW	4	8	20
11	-	8 kW	8	24	20	23	-	4 kW	4	4	20
12	-	8 kW	8	16	20	24	-	4 kW	4	0	20

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C) Bidirectional charging

$$\sum_{1}^{24} En\_V2G = 16\ \text{kWh}$$

- Efficiency = 100%

Hour	To EV	Price	Cost	Hour	To EV	Price	Cost
1	0	20		13	8	20	0,16
2	0	20		14	8	20	0,16
3	0	20		15	-8	20	
4	0	20		16	4	20	0,08
5	-8	20		17	-10	50	
6	-8	50	-0,4	18	8	50	0,4
7	-8	50	-0,4	19	0	50	
8	-4	50		20	-10	50	
9	0	50		21	4	50	0,2
10	-4	50		22	4	20	0,08
11	8	20	0,16	23	4	20	0,08
12	8	20	0,16	24	4	20	0,08

$$\sum_{1}^{24} En\_cons = 44\ \text{kWh}$$

For 1 EV in 1 day:

$$\sum_{1}^{24} Cost = 0{,}76€$$

For 1 EV in 1 year:

$$365 * \sum_{1}^{24} Cost = 277{,}4\ €$$

For EV fleet in 1 year:

$$2\ \text{mil.} * 365 * \sum_{1}^{24} Cost = 0{,}55\ \text{bil.}\ €$$

Savings: ≈60%

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D) Uncontrolled charging

- Efficiency = 90%

Hour	Trip power	CS power	From grid	To EV	DOD	Hour	Trip power	CS power	From grid	To EV	DOD
1	-	4 kW	0	0	0	13	-	8 kW	0	0	0
2	-	4 kW	0	0	0	14	-	8 kW	0	0	0
3	-	4 kW	0	0	0	15	8	-	-	-8,89	8,89
4	-	4 kW	0	0	0	16	-	4 kW	4	3,6	5,29
5	8 kW	-	-	-8,89	8,89	17	10 kW	-	-	-11,11	16,40
6	-	8 kW	8	7,2	1,69	18	-	12 kW	8	7,2	9,2
7	-	8 kW	1,88	1,69	0	19	-	12 kW	8	7,2	2
8	4 kW	-	-	-4,44	4,44	20	10 kW	-	-	-11,11	13,11
9	-	12 kW	4,93	4,44	0	21	-	4 kW	4	3,6	9,51
10	4 kW	-	-	-4,44	4,44	22	-	4 kW	4	3,6	5,91
11	-	8 kW	4,93	4,44	0	23	-	4 kW	4	3,6	2,31
12	-	8 kW	0	0	0	24	-	4 kW	2,86	2,57	0

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D) Uncontrolled charging

- Efficiency = 90%

Hour	From grid	Price	Cost	Hour	From grid	Price	Cost
1	0	20		13	0	20	
2	0	20		14	0	20	
3	0	20		15	-	20	
4	0	20		16	4	20	0,08
5	-	20		17	-	50	
6	8	50	0,4	18	8	50	0,4
7	1,88	50	0,094	19	8	50	0,4
8	-	50		20	-	50	
9	4,93	50	0,247	21	4	50	0,2
10	-	50		22	4	20	0,08
11	4,93	20	0,099	23	4	20	0,08
12	0	20		24	2,86	20	0,057

$$\sum_{1}^{24} En\_cons = 54{,}6\ \text{kWh}$$

For 1 EV in 1 day:

$$\sum_{1}^{24} Cost = 2{,}137€$$

For 1 EV in 1 year:

$$365 * \sum_{1}^{24} Cost = 780{,}078\ €$$

For EV fleet in 1 year:

$$2\ \text{mil.} * 365 * \sum_{1}^{24} Cost = 1{,}56\ \text{bil.}\ €$$

Cost increase: ≈20%

Energy increase: ≈24%

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