NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

Energy Research Institute @ NTU

INTERNATIONAL Microgrid SYMPOSIUMS

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DC microgrid powered EV charging station *versus* public grid powered EV charging station

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cnrs GDR Groupement de recherche

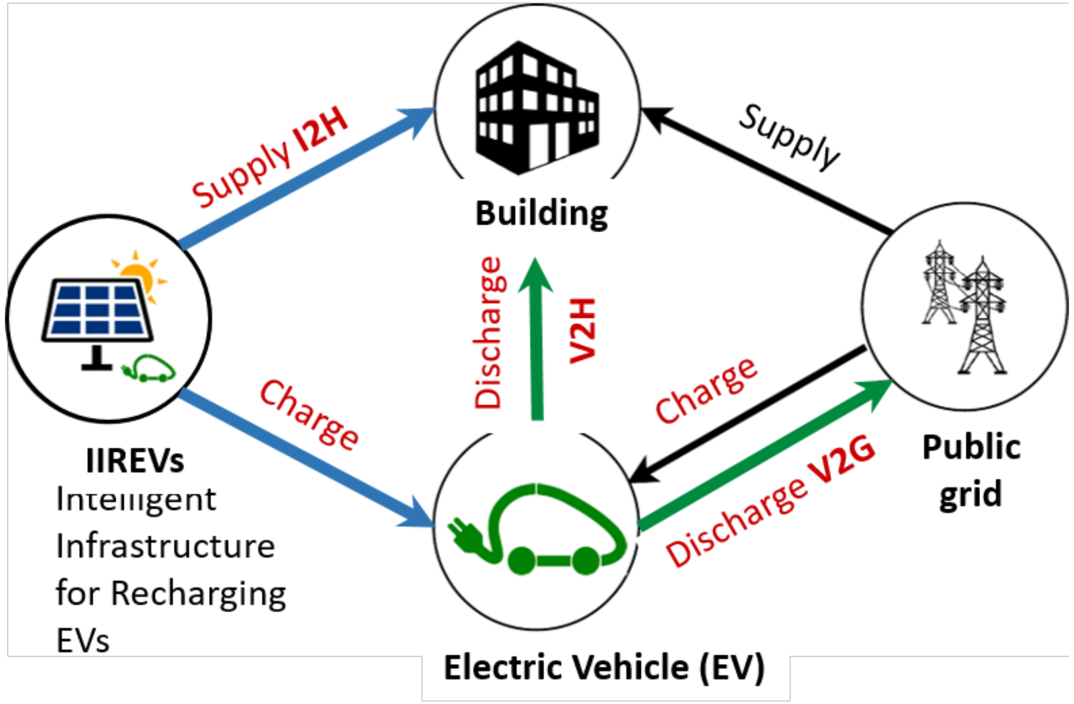
SEEDS Systèmes d'énergie électrique dans leurs dimensions sociétales

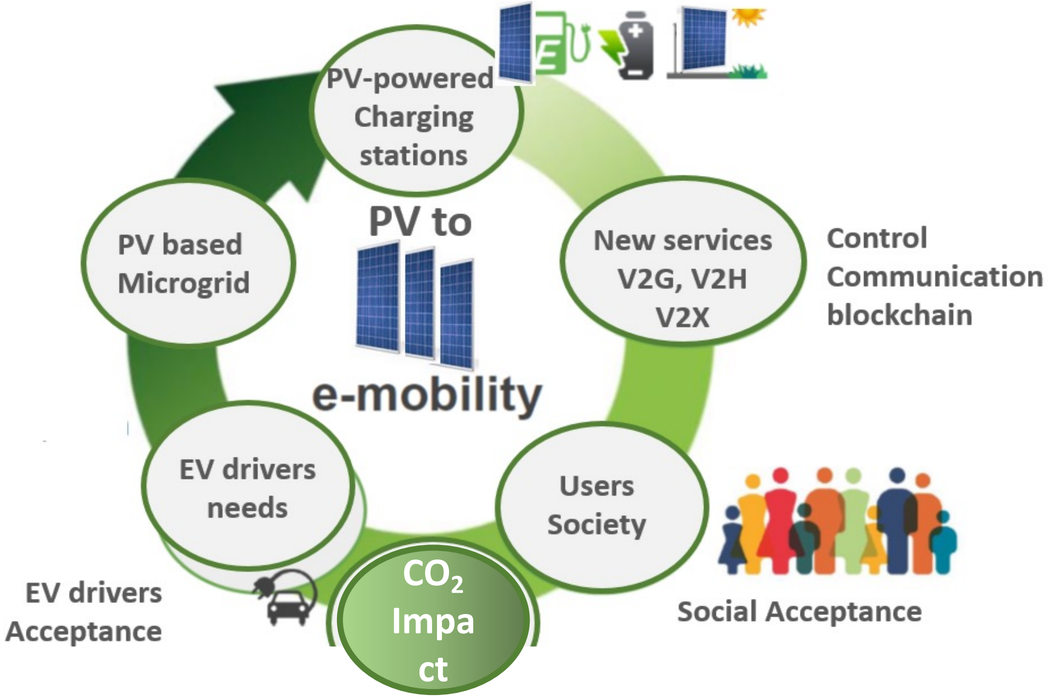
IEA PVPS

Outline

1. Context and motivation

- Stock growth of electric vehicles (EVs)
  - Battery Electric Vehicle (BEV) & Plug-in Hybrid Electric Vehicle (PHEV)
- Growth of charging infrastructures for low-duty vehicles (LDVs)
  - Most of EV owners have access to at least one private charger at home and/or workplace
  - Slow chargers represent the main deployment
- Microgrid powered EV charging station *versus* public grid powered EV charging station





2. Public grid impact considering electromobility

- French public grid (2019)
  - 537.7 TWh total energy production
  - 135.328 GW total installed power
- Scenarios
  - Number of EVs
  - Daily trip (km)
  - Simultaneous charge
- Energy demand
- Power demand
  - Fast charge
  - Ultra-fast charge
- Random distribution of peak hour charging power for 10 million Evs
  - 10% simultaneity → 25.18 GW → 18.5%
  - Solution ? Energy mix

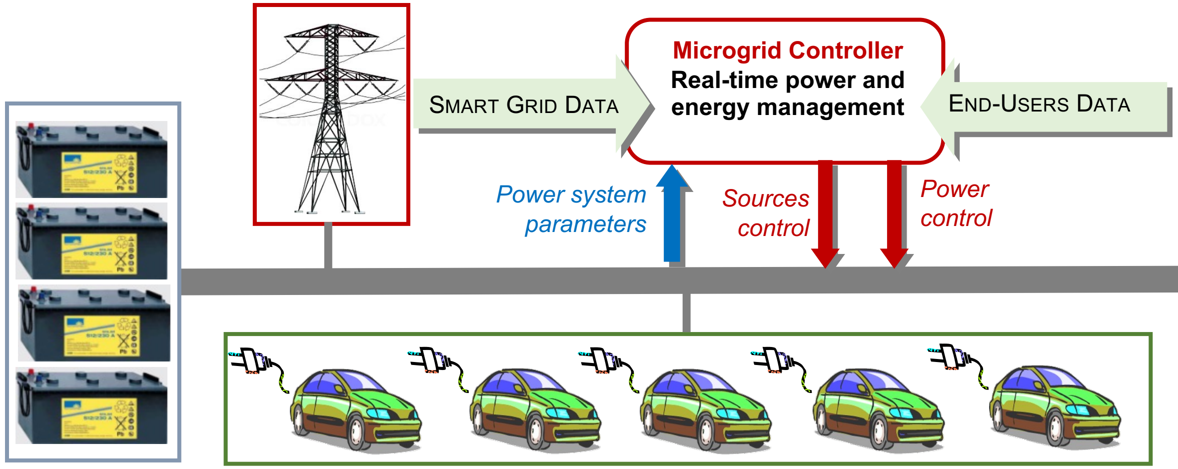
HYPOTHESES		ENERGY		POWER					
				Required power for domestic charge power (2,3kW)			Required power for slow charge power (7kW)		
Number of EVs	Daily trip in km at average consumption of 15kWh/100km	Total energy recharging GWh/year	Total energy recharging / total energy production %	GW	10% simultaneous power	% installed power	GW	10% simultaneous power	% installed power
1 000 000.00	20.00	1 095.00	0.20	2.30	0.23	0.17	7.00	0.70	0.52
	40.00	2 190.00	0.41						
	60.00	3 285.00	0.61						
5 000 000.00	20.00	5 475.00	1.02	11.50	1.15	0.85	35.00	3.50	2.59
	40.00	10 950.00	2.04						
	60.00	16 425.00	3.05						
15 000 000.00	20.00	16 425.00	3.05	34.50	3.45	2.55	105.00	10.50	7.76
	40.00	32 850.00	6.11						
	60.00	49 275.00	9.16						

HYPOTHESES		ENERGY		POWER					
				Required power for fast charge power (22kW)			Required power for ultra-fast power (50kW)		
Number of EVs	Daily trip in km at average consumption of 15kWh/100km	Total energy recharging GWh/year	Total energy recharging / total energy production %	GW	10% simultaneous power	% installed power	GW	10% simultaneous power	% installed power
1 000 000.00	20.00	1 095.00	0.20	22.00	2.20	1.63	50.00	5.00	3.69
	40.00	2 190.00	0.41						
	60.00	3 285.00	0.61						
5 000 000.00	20.00	5 475.00	1.02	110.00	11.00	8.13	250.00	25.00	18.47
	40.00	10 950.00	2.04						
	60.00	16 425.00	3.05						
15 000 000.00	20.00	16 425.00	3.05	330.00	33.00	24.39	750.00	75.00	55.42
	40.00	32 850.00	6.11						
	60.00	49 275.00	9.16						

3. DC microgrid powered EV charging stations

Under what conditions can PV-based microgrid help recharge EVs?

- PV system 29.8kWp
- Storage 17.76kWh / 7kW (max)
- Public grid limit 22kW (max)

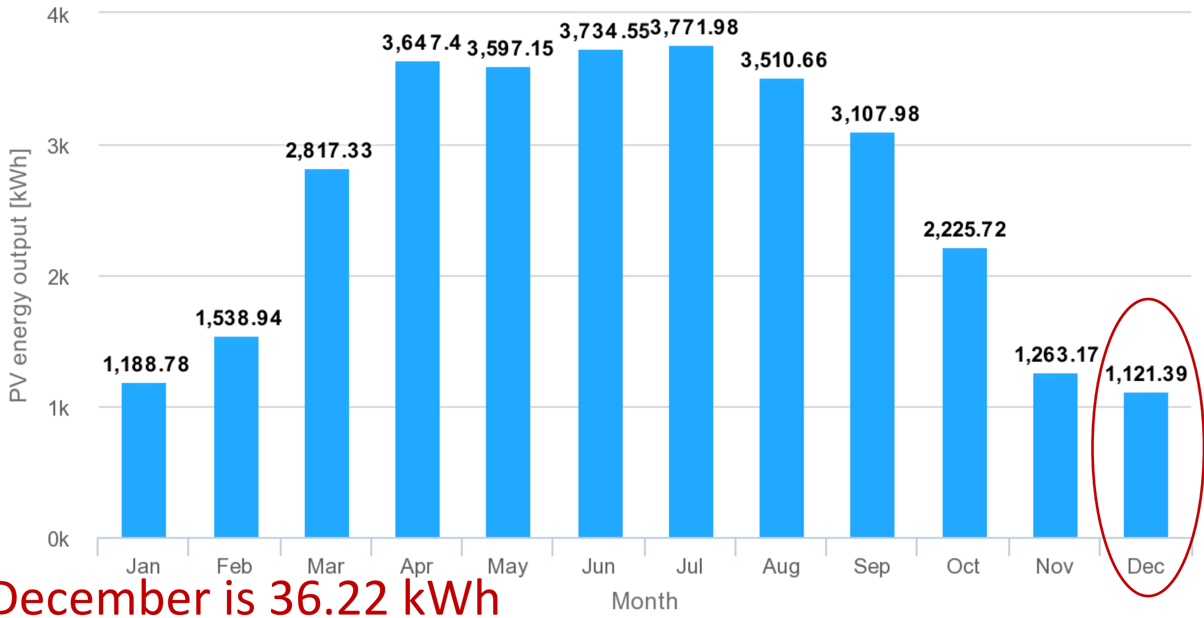


Provided inputs:

Latitude/Longitude:	49.402, 2.796
Horizon:	Calculated
Database used:	PVGIS-SARAH
PV technology:	Crystalline silicon
PV installed:	29.8 kWp
System loss:	14 %

Simulation outputs

Slope angle:	35 °
Azimuth angle:	0 °
Yearly PV energy production:	31525.04 kWh
Yearly in-plane irradiation:	1314.64 kWh/
Year-to-year variability:	1250.66 kWh
Changes in output due to:	
Angle of incidence:	-3.06 %
Spectral effects:	1.71 %
Temperature and low irradiance:	-5.1 %
Total loss:	-19.53 %



Average daily PV production for December is 36.22 kWh

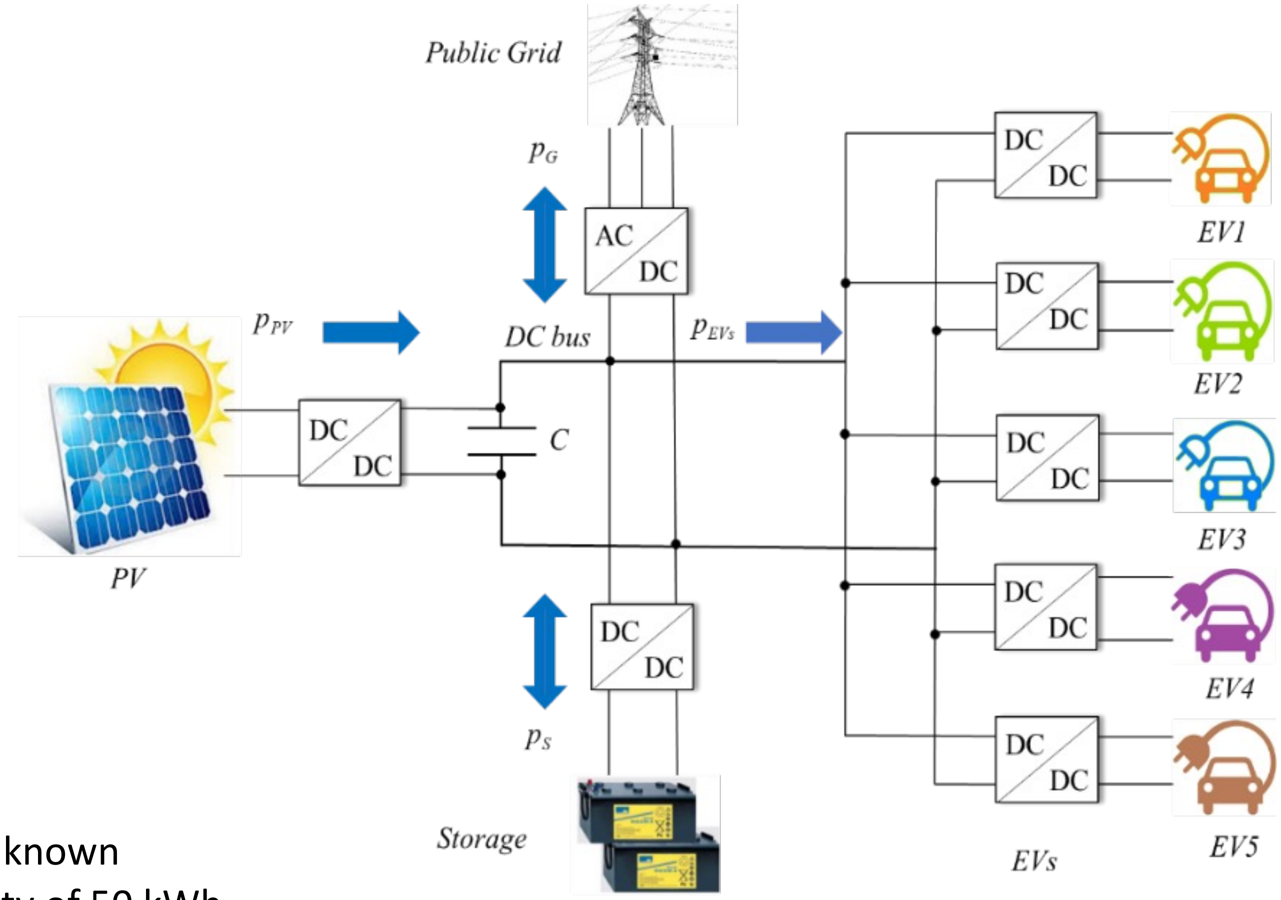
Case studies

- Goal
  - Analyze the quantity of PV energy *versus* the public grid energy
  - Discuss the conditions under which the PV-based microgrid powered charging station really allows full benefit from renewable energies

- Driver profile
  - Daily urban/peri-urban trip 20km - 40km
  - EV urban consumption
    - Eco-drive 10kWh/100km
    - Normal drive 15kWh/100km
  - Average daily needed charge
    - Eco-drive 2kWh - 4kWh
    - Normal drive 3kWh - 6kWh

- Charging mode
  - Slow charging
  - Fast charging

- Assumptions
  - Initial SOC_{EV} and desired final SOC_{EV} for each EV are known
  - All 5 EVs are equipped with the same battery capacity of 50 kWh



Case 1: slow charging mode operation for all 5 EVs

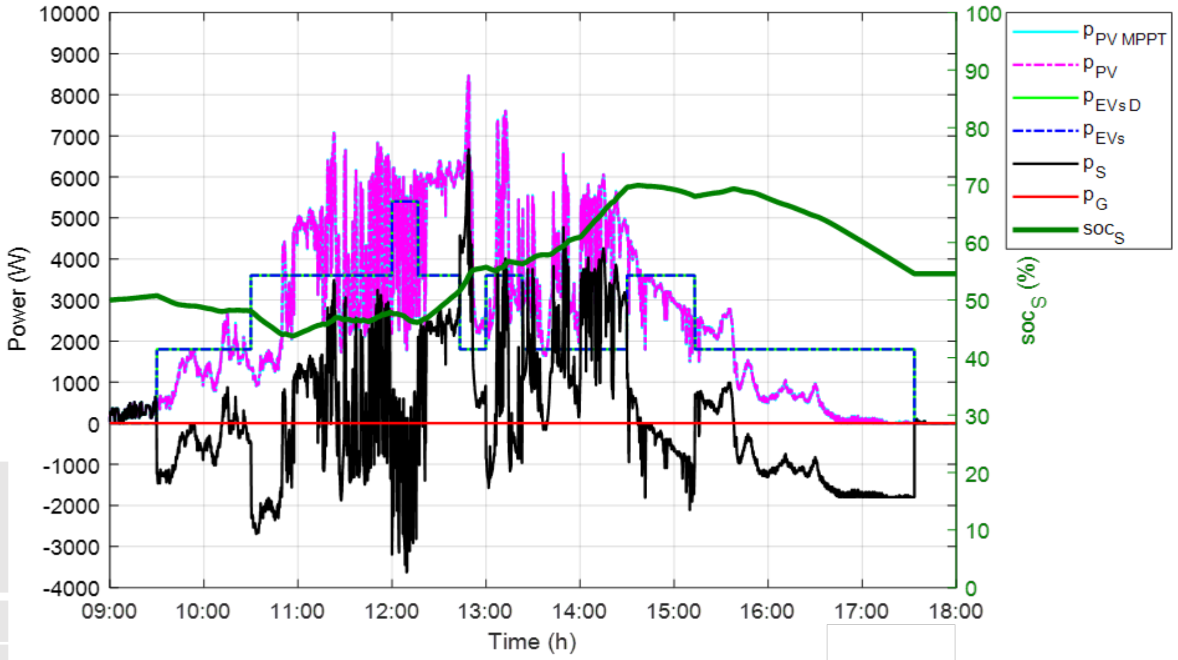
- 5 EVs to charge
- Initial and desired final EV SOC known
- Charging power (slow mode) 1.8 kW
- Arrival of Evs
  - EV1: 09:30 EV2: 10:30 EV3: 12:00 EV4: 13:00 EV5: 14:30

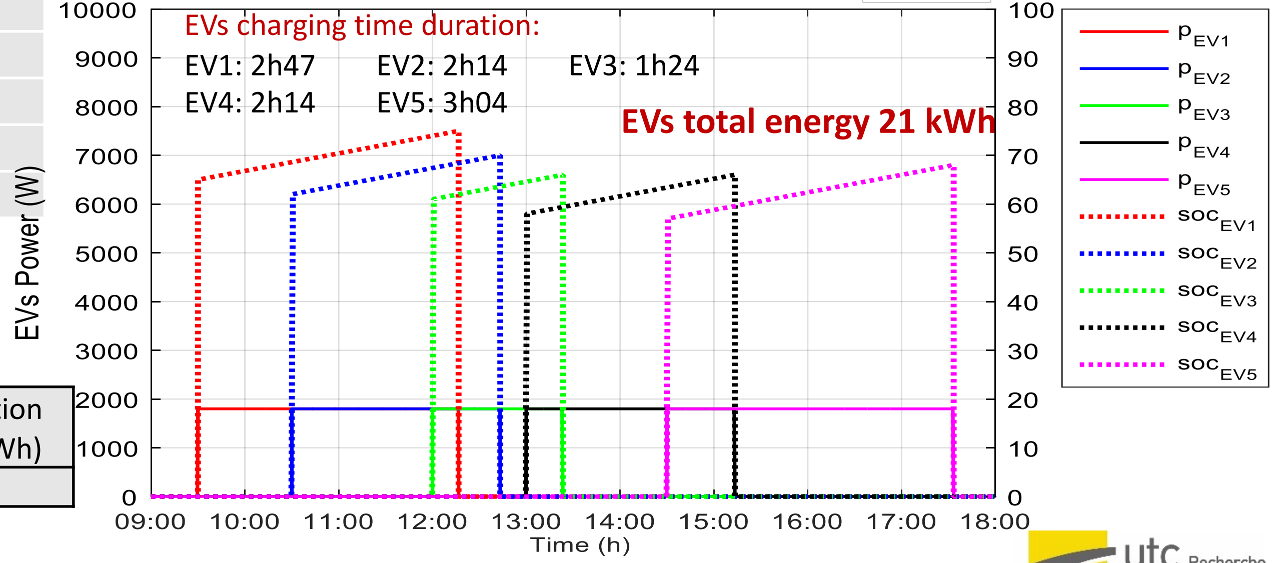
EVs energy flow

EVs	EV energy demand	EV energy received		PV energy		Storage discharging energy		Grid supply energy	
	kWh	kWh	%	kWh	%	kWh	%	kWh	%
EV1	5	5	100	3.79	**75.80**	1.21	24.20	0	**0**
EV2	4	4	100	3.31	**82.75**	0.69	17.25	0	**0**
EV3	2.5	2.5	100	2.28	**91.20**	0.22	8.80	0	**0**
EV4	4	4	100	3.72	**93.00**	0.28	7.00	0	**0**
EV5	5.5	5.5	100	2.70	**49.10**	2.80	50.90	0	**0**

System energy flow

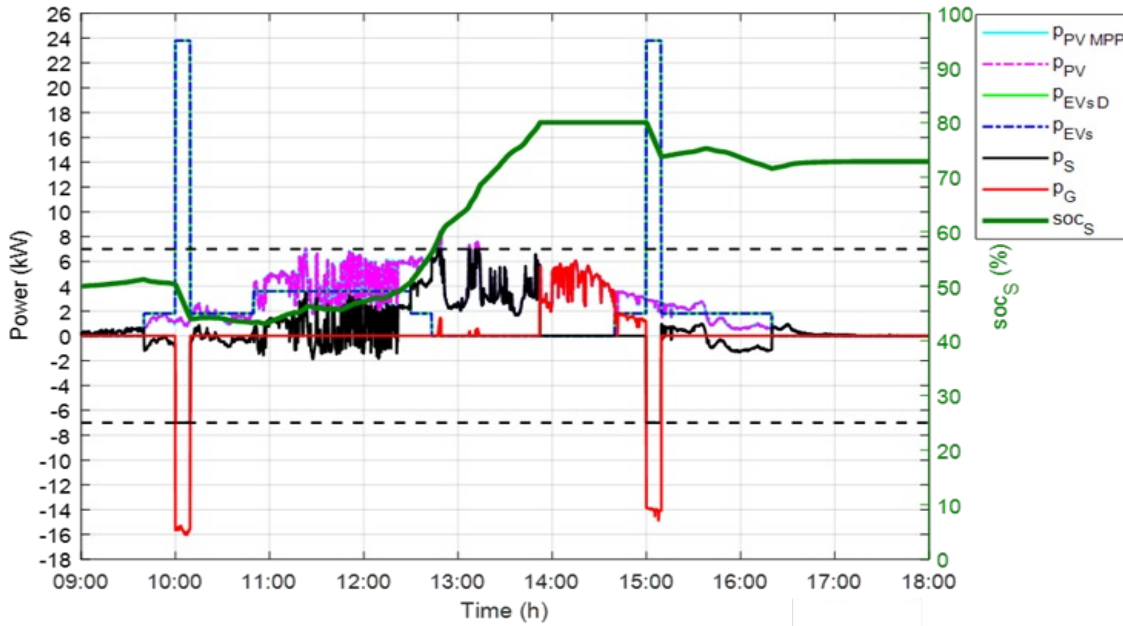
PV energy (kWh)	Storage discharging energy (kWh)	Storage charging energy (kWh)	Grid supply energy (kWh)	Grid injection energy (kWh)
21.81	5.20	6.00	**0**	**0**





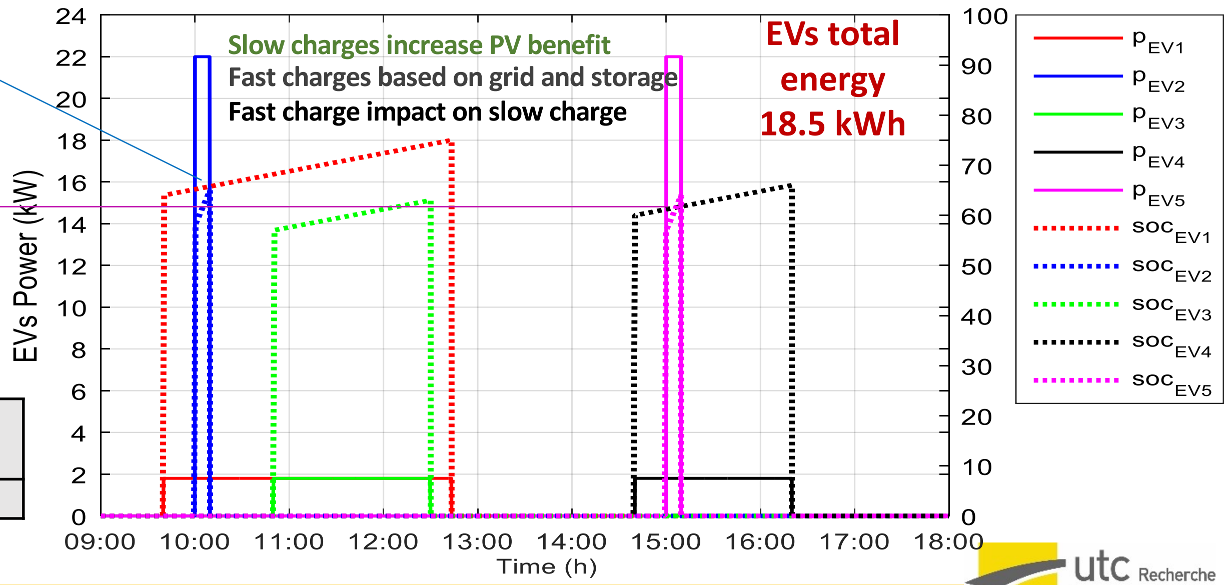
Case 2: slow and fast charging mode operation

- 5 EVs to charge
- Initial and desired final EV SOC known
- Charging power: slow 1.8 kW and fast 22kW
- Arrival of EVs
  - EV1: 09:40 EV2: 10:00 EV3: 10:50 EV4: 14:40 EV5: 15:00



EVs energy flow

EVs	EV energy demand	EV energy received		PV energy		Storage discharging energy		Grid supply energy	
	kWh	kWh	%	kWh	%	kWh	%	kWh	%
EV1	5.50	5.50	100	4.63	**84.18**	0.68	12.36	0.19	3.46
EV2	3.50	3.50	100	0.17	4.86	1.03	29.43	2.30	65.71
EV3	3.00	3.00	100	2.74	**91.33**	0.26	8.67	0	0
EV4	3.00	3.00	100	2.09	**69.67**	0.74	24.66	0.17	5.67
EV5	3.50	3.50	100	0.41	11.71	1.03	29.43	2.06	58.86

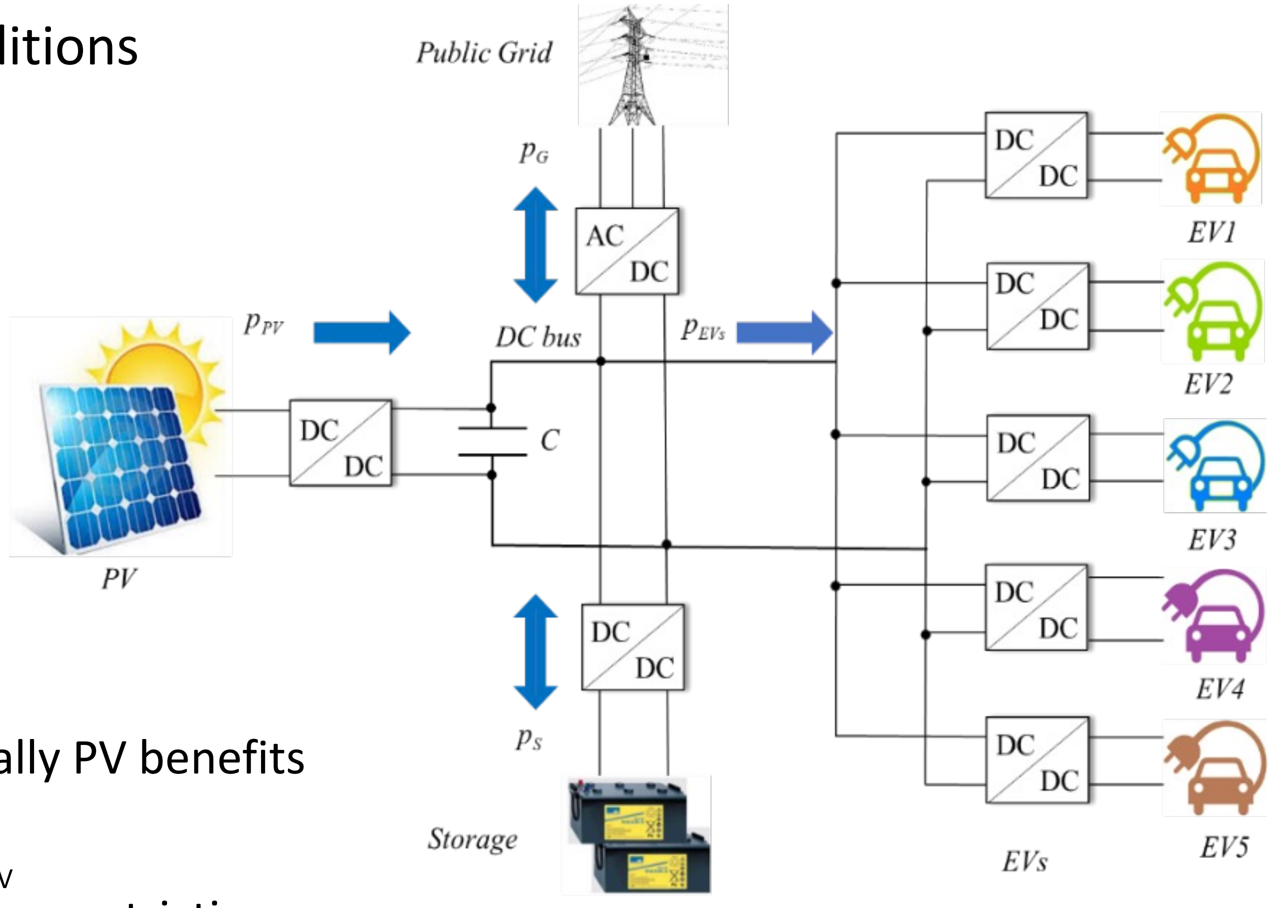


System energy flow

PV energy (kWh)	Storage discharging energy (kWh)	Storage charging energy (kWh)	Grid supply energy (kWh)	Grid injection energy (kWh)
21.81	3.74	7.80	**4.72**	**3.98**

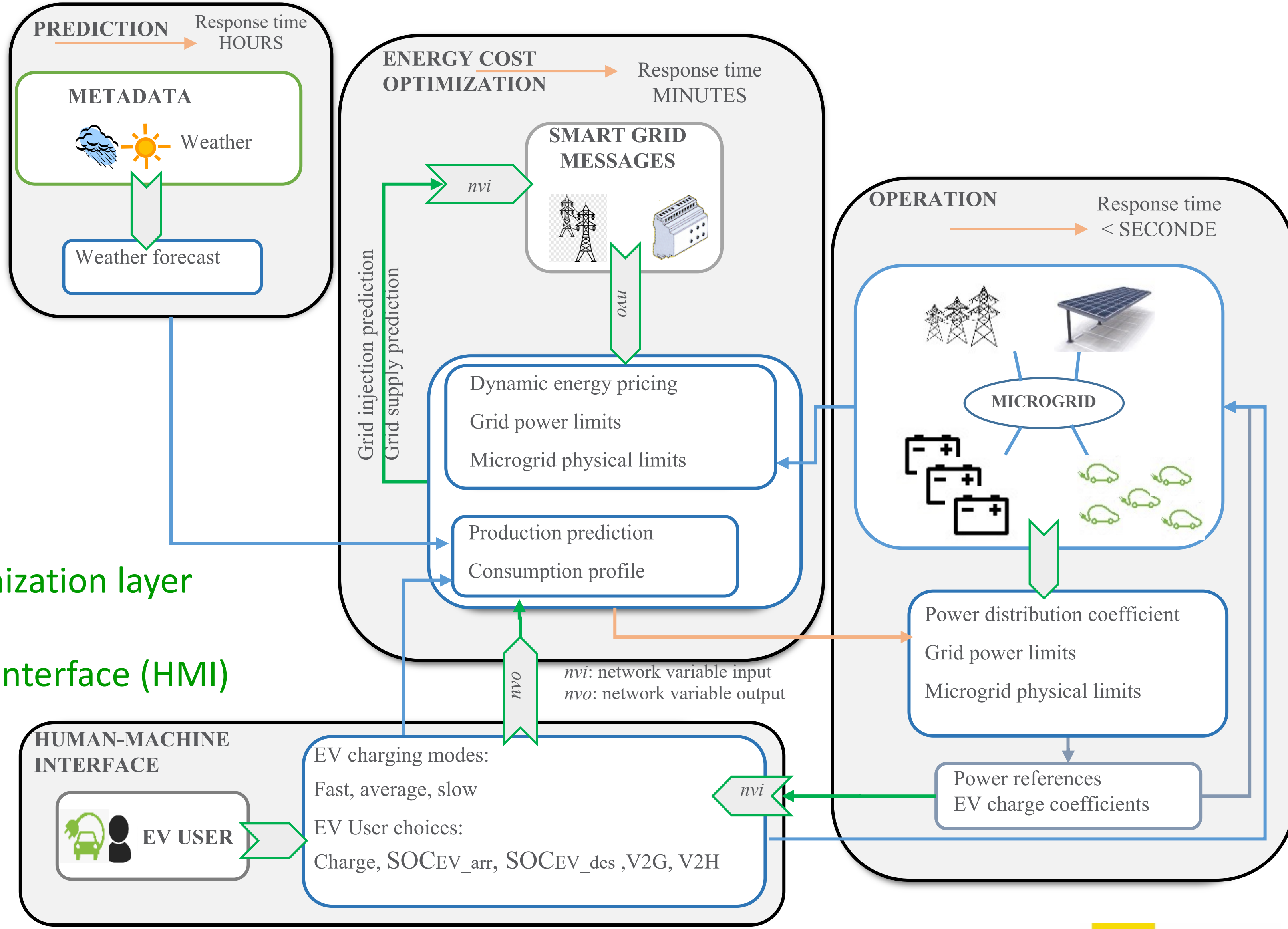
Results analysis and discussion

- How to increase the PV energy consumption for EVs charging?
- Preliminary requirements and feasibility conditions
  - Slow charging up to 7kW
    - Based mainly on PV energy and storage
    - Storage power limit up to 7kW
    - EV battery filling up to 6kWh
    - Acceptance relative to
      - Slow charging instead fast charging
      - Eco-drive instead normal drive
  - Fast charging from 7kW to 22kW
    - Based mainly on grid energy
    - Storage power limit up to 7kW
    - Acceptance relative to high charging price?
  - Charging terminal requirements
    - Constant power *vs* variable power
  - Known park time duration may increase drastically PV benefits
  - Communication interface required
    - User choices data and initial and desired final SOC_{EV}
  - Slow or fast charging for 10%< SOC_{EV} <100% → no restrictions
- Business model?
  - Influencing consumer behavior through charging pricing



4. Optimized DC microgrid for recharging EVs

- Energy management and optimization of energy costs
- Optimization of power flows in real time



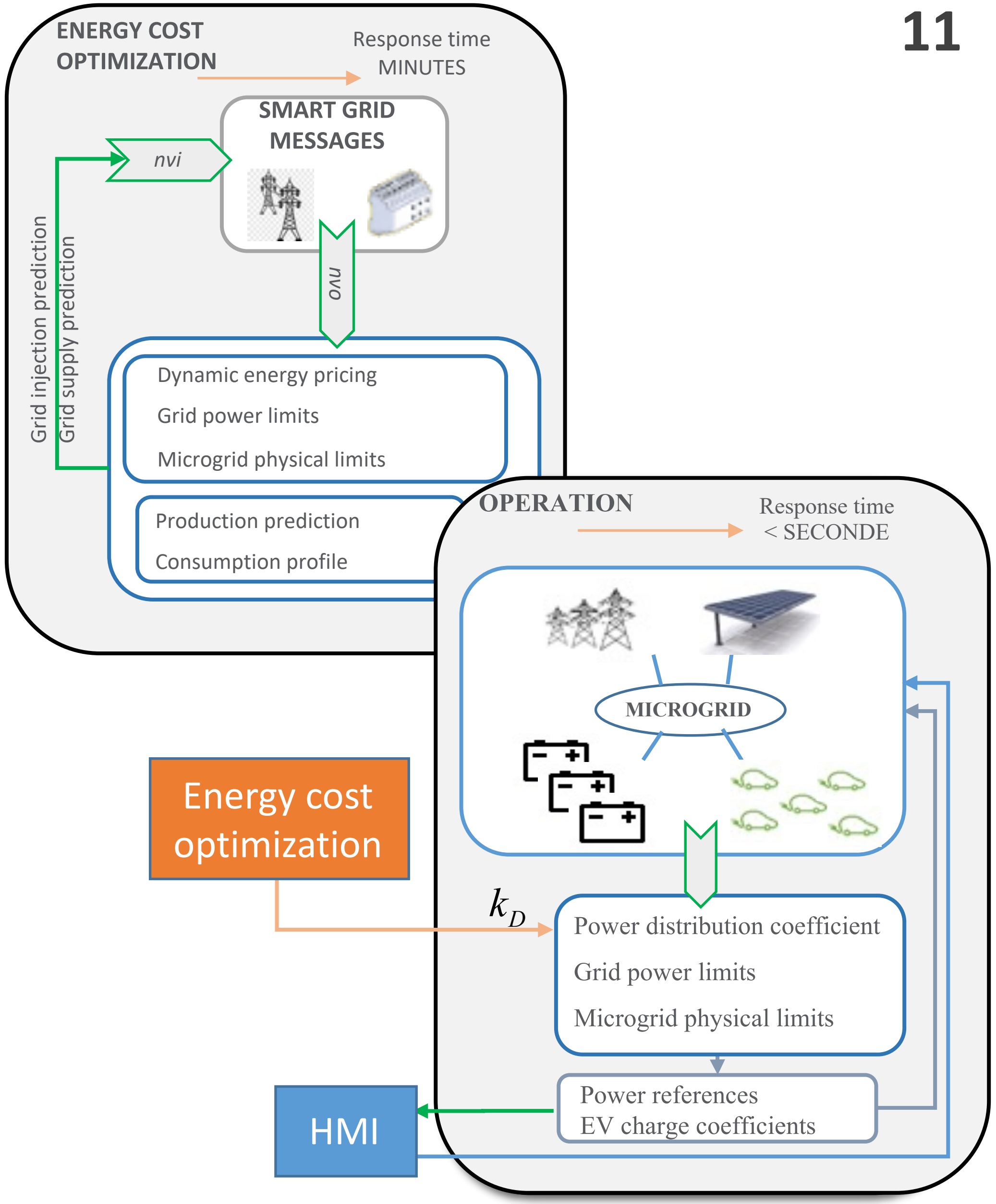
Predictive layer
Energy cost optimization layer
Operational layer
Human Machine Interface (HMI)

Cheikh-Mohamad, S.; Sechilariu, M.; Locment, F.; Krim, Y. PV-Powered Electric Vehicle Charging Stations: Preliminary Requirements and Feasibility Conditions. Appl. Sci. 2021, 11, 1770. https://doi.org/10.3390/app11041770

Energy costs optimization

- Optimization of energy costs and powers in real time
  - Interaction with HMI
  - Objective to minimize the total energy cost

- Optimization under different constraints
  - Storage protection (limits imposed)
  - Limits imposed by the public network (power absorbed and injected)
  - Conditions for limiting PV production
  - Conditions for limiting the load of EVs
  - Conditions imposed by VE users
  - Chosen charging modes
  - EV battery state of charge
  - Power balancing
- Result: power distribution coefficient
- Real-time control algorithm that takes into account the distribution coefficient and user data



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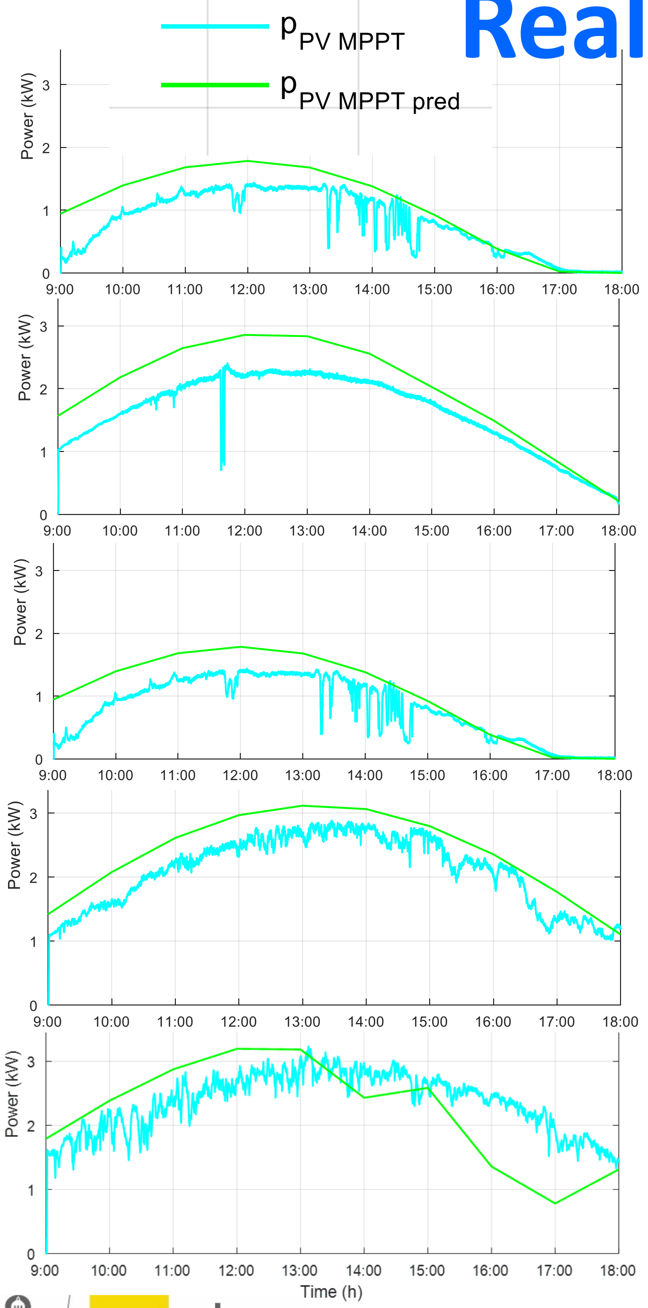
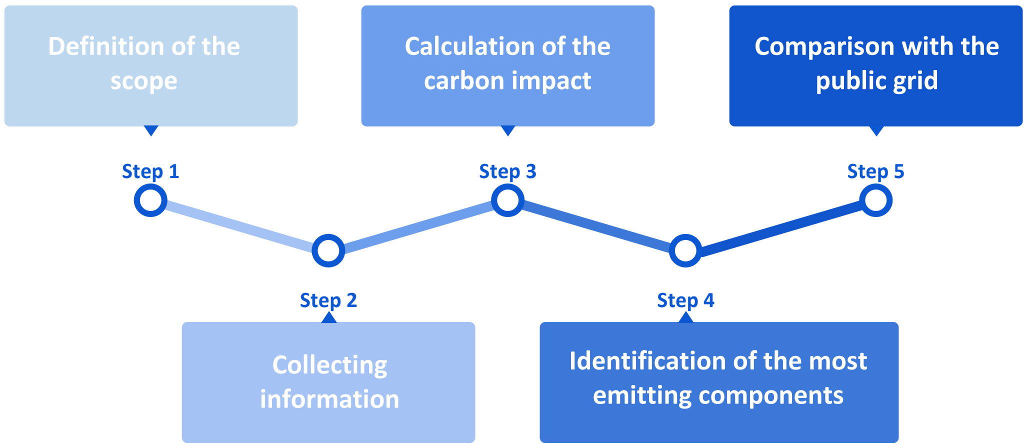
Real-time optimisation (experimental results)



Case operation			Grid cost (c€)	Storage cost (c€)	Total cost (c€)
Case 1	27/10/2021 High irradiations with fluctuations	Real-time exp w/o opt	83	6	89
		Real-time exp with opt	50	6	56
		Optimization for real conditions	33	5	38
Case 2	22/03/2022 High irradiations w/o fluctuations	Real-time exp w/o opt	5	7	12
		Real-time exp with opt	-22	4	-18
		Optimization for real conditions	-71	4	-67
Case 3	08/11/2021 Low irradiations with fluctuations	Real-time exp w/o opt	132	5	137
		Real-time exp with opt	67	5	72
		Optimization for real conditions	26	5	31
Case 4	10/04/2022 High irradiations with low fluctuations	Real-time exp w/o opt	18	11	29
		Real-time exp with opt	-148	5	-143
		Optimization for real conditions	-154	5	-149
Case 5	14/05/2022 High irradiations with low fluctuations	Real-time exp w/o opt	0	11	11
		Real-time exp with opt	-161	5	-156
		Optimization for real conditions	-172	5	-167

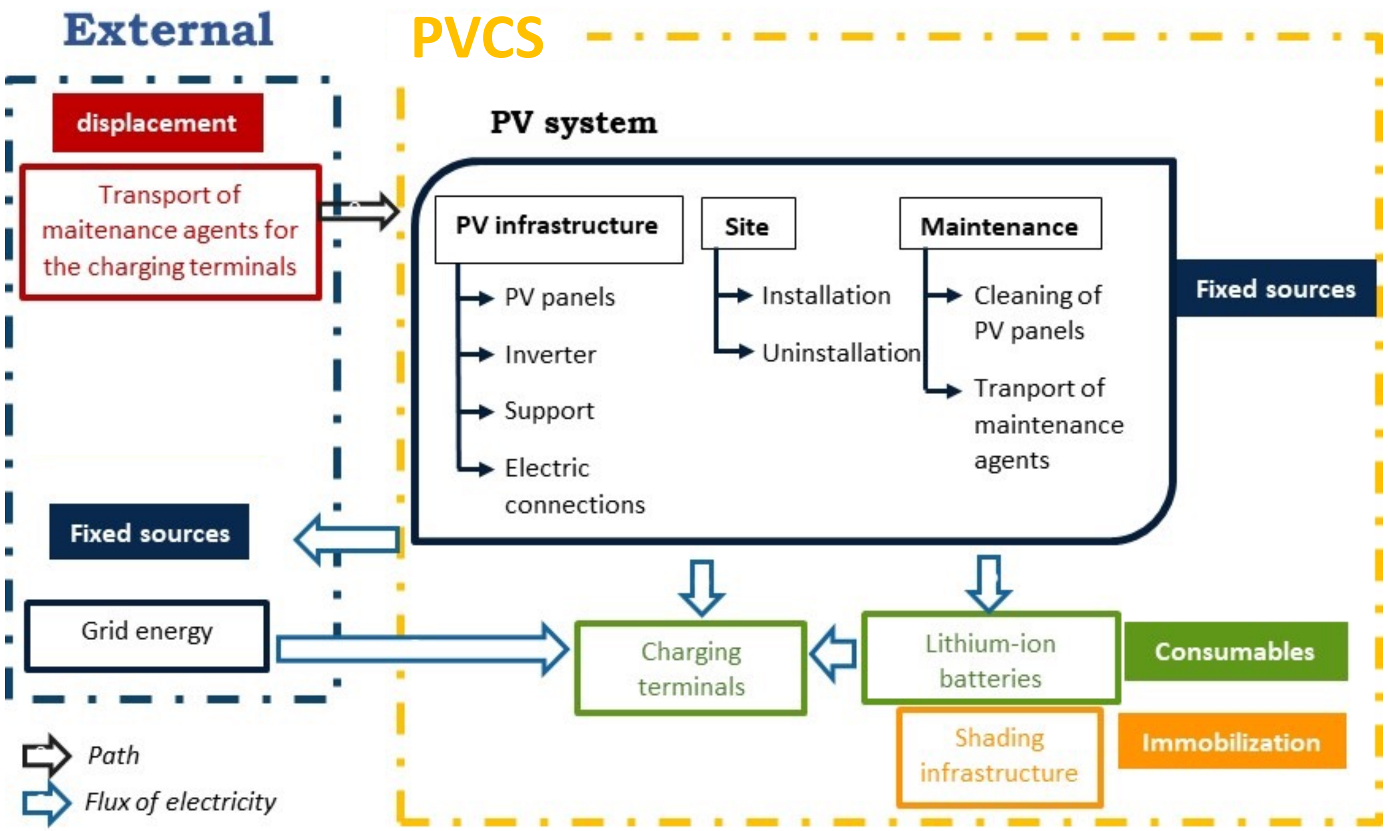
5. Impact CO_2: DC microgrid versus public grid

- Methodology



30 years | 10 years | 15 years | 10 years

- Study boundaries



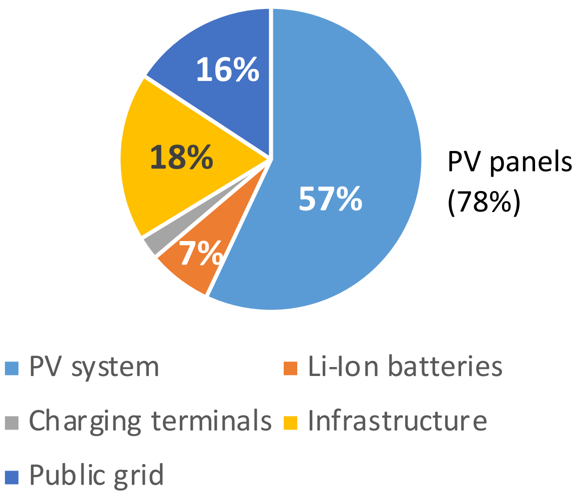
Case study

- Located in Compiegne, France
- 5 suspended charging terminals (CTs)
- Shade covering 10 parking places
- Area of PV modules: 124 m^2 (70 PV Panels)
- Peak power of the PV system: 28 kWp
- Power of the inverters: 28.2 * 0.9 = 25.38 kVA
- Battery capacity equal to 22 kWh, with recycling by pyrometallurgy
- Electricity supplied over 30 years: estimated at 1.257 GWh including 307.476 MWh from the public grid
- Occupancy rate of CTs is arbitrarily fixed, reflecting the arrivals and departures of 10 EVs throughout the day as given below

Time	08:00-10:00	10:00-12:00	12:00-14:00	14:00-16:00	16:00-18:00
Nb of EVs charging at 22 kW	0	1	0	1	1
Nb of EVs charging at 2.3 kW	2	4	2	4	3

Case study

- Comparison with public grid charging station
- Average French public grid energy mix 59,9 gCO_2eq/kWh
- Average European grid 420 gCO_2eq/kWh
- Public grid charging station (PGCS)
  - 59,9 gCO_2eq/kWh
- PV-powered charging station (PVCS)
  - 68 gCO_2eq/kWh with PV at 40 gCO_2eq/kWh



- Reduce the carbon impact of PVCS
  - S2: PV at 25 gCO2eq/kWh and recycled materials
  - S3: PV at 10.6 gCO2eq/kWh and recycled materials

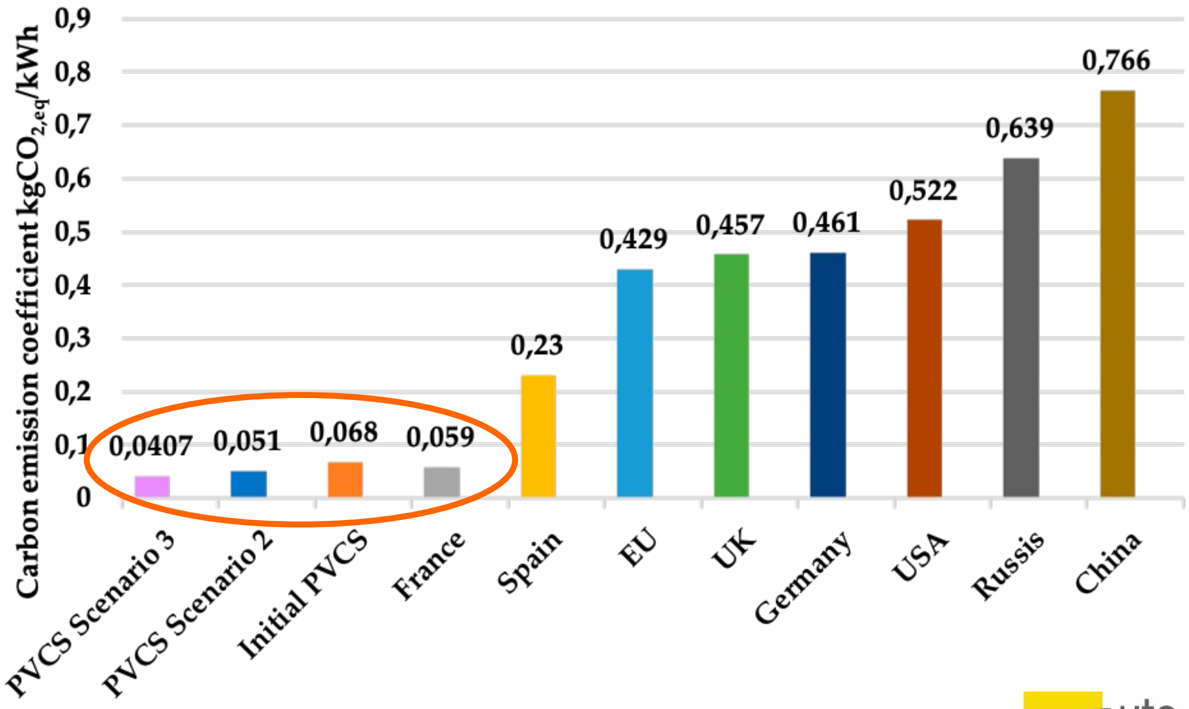
$$Imp_n(\,kgCO_{2eq}) = CO_{2,n}\,(kgCO_{2eq}/\text{kWh}) \cdot Q_n(\text{kWh})$$

$$Imp_{PVCS} = \;85\;961\;kgCO_{2eq}$$

with PV at 40 gCO_2eq/kWh

$$Imp_{PGCS} = Imp_{CT,sus} + Imp_{PG}$$
$$Imp_{PGCS} = 77\;436\;kgCO_{2eq}$$

French public grid

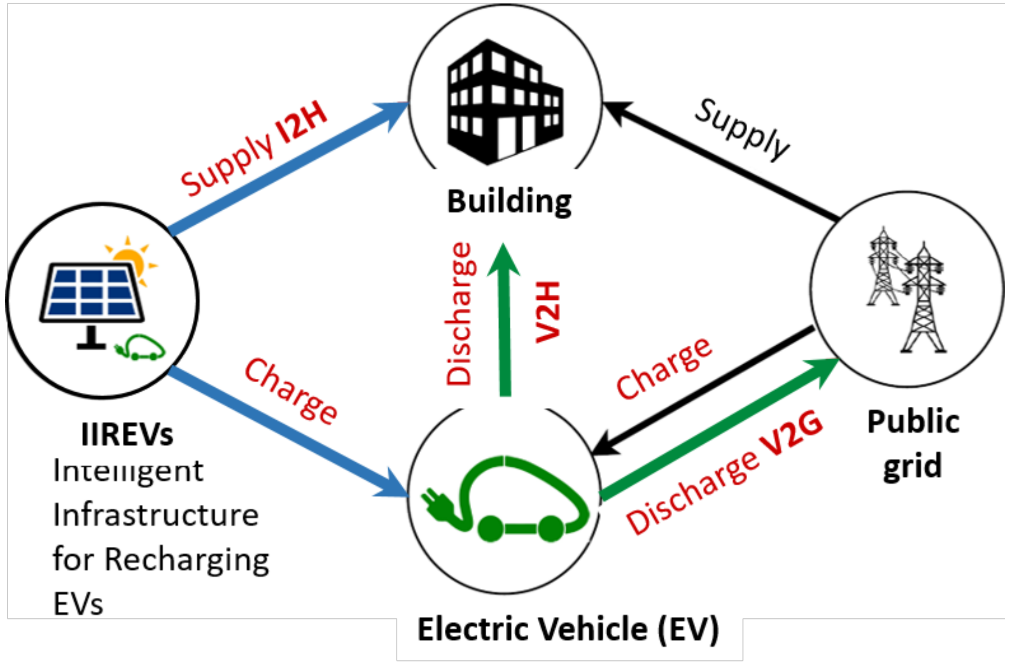


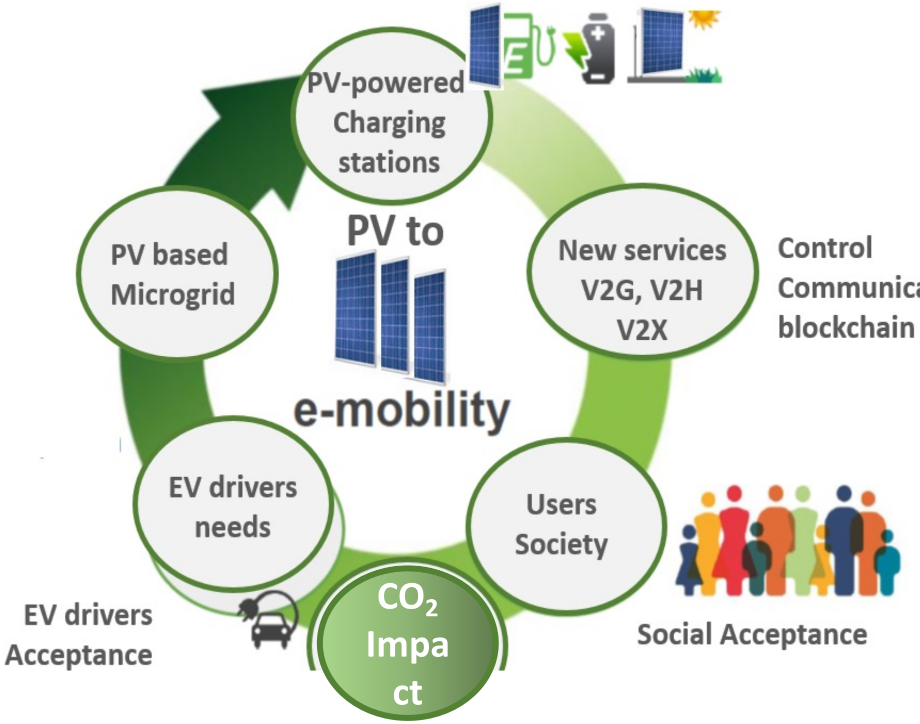
6. Conclusions and perspectives

- Microgrid-powered charging stations properly sized and combined with an eco-responsible drivers' profile represents one of the realistic solution for the e-mobility
- Results
  - EV charging demand is not constrained during the daylight
  - EV user can charge in slow or fast mode depending on the time duration and desired final SOC
- For an average daily urban/peri-urban trip of 20-40 km the PV benefits increase if
  - Daily EV charging instead of weekly
  - Slow charging mode instead of fast charging
  - Variable power changing instead constant power
- Optimized microgrid-powered charging stations
  - Better charging operation to increase PV benefits
- Impact CO_2 less important then public grid charging station
- Further works
  - Social acceptance, incentive business models
  - New services associated with PV-powered EV charging stations (V2H and V2G)

DC microgrid powered EV charging stations

Thank you for your attention





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