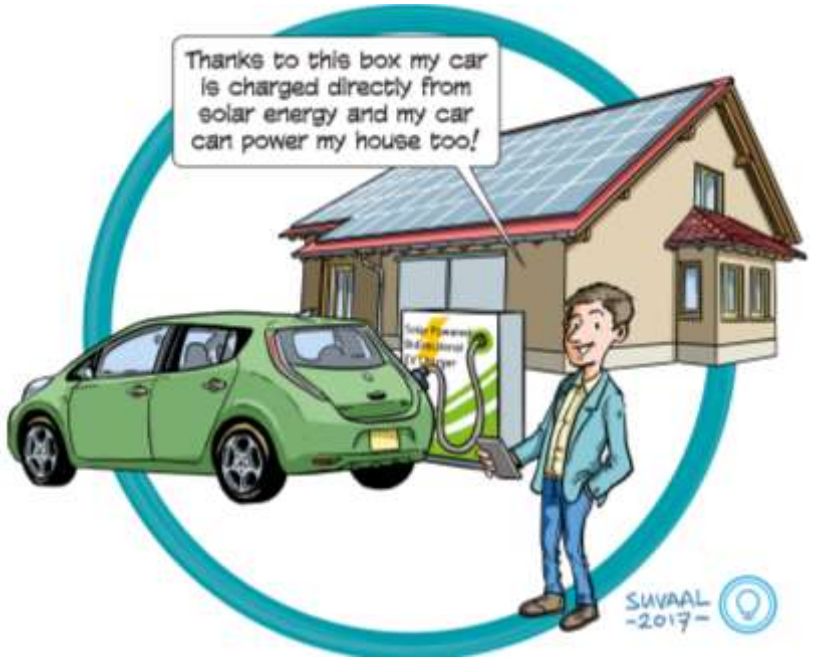
Direct solar EV charging with V2G and intelligent EMS



Dr. Gautham Ram (Assistant Professor, TU Delft)

Prof.dr.ir. Pavol Bauer (TU Delft) & Menno Kardolus (PRE)

DC systems, Energy conversion & Storage Group

DCE&S
DC systems, Energy conversion & Storage

50 members (http://www.dcs.ewi.tudelft.nl/)

- 4 Full professors
- 8 associate & assistant professors
- 9 postdocs & researchers
- 7 technicians
- 22 PhD students

Prof. Pavol Bauer

Research pillars

- Electric mobility & electro-mechanics
- Power electronics
- DC grids & Energy storage
- High voltage DC systems & materials

TU Delft

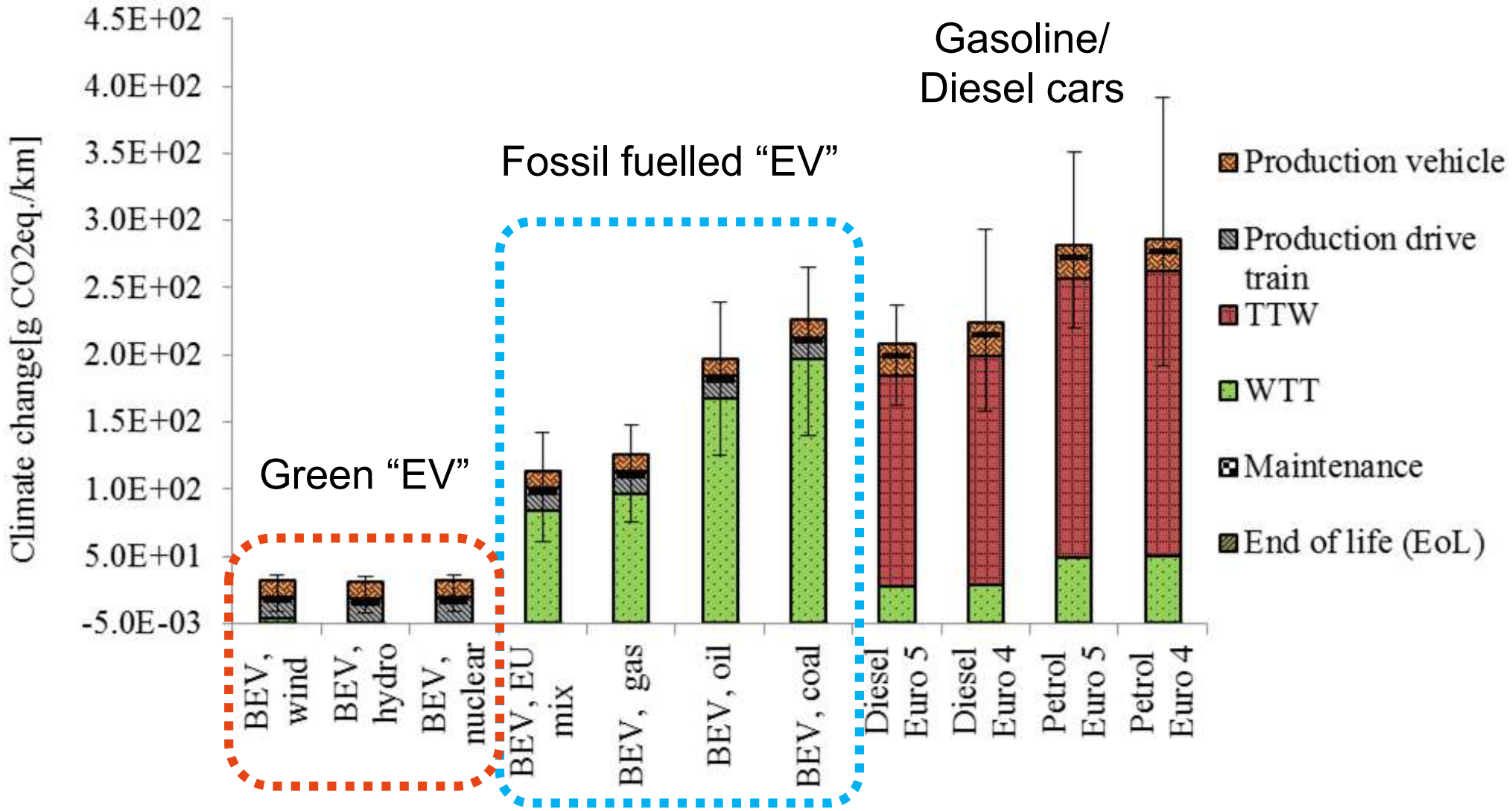
Coal power plants or electric cars?

Image source: Tesla, Financial tribune

Making electric cars truly sustainable

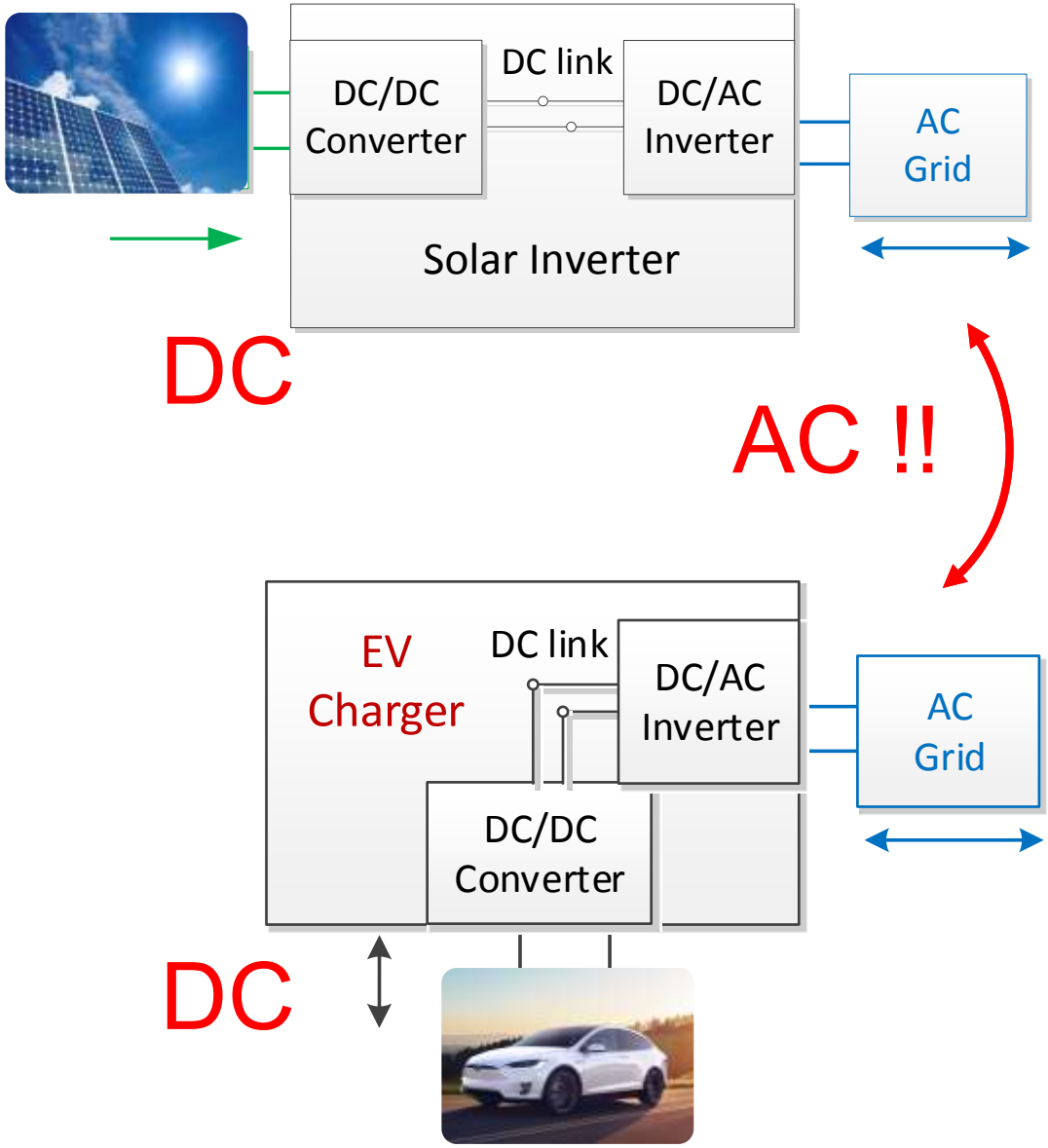
Image source: Tesla, Financial tribune

Charging EVs from renewable energy



Source - Messagie, M., Boureima, F. S., Coosemans, T., Macharis, C., & Mierlo, J. V. (2014). A range-based vehicle life cycle assessment incorporating variability in the environmental assessment of different vehicle technologies and fuels. *Energies*, *7*(3), 1467-1482.

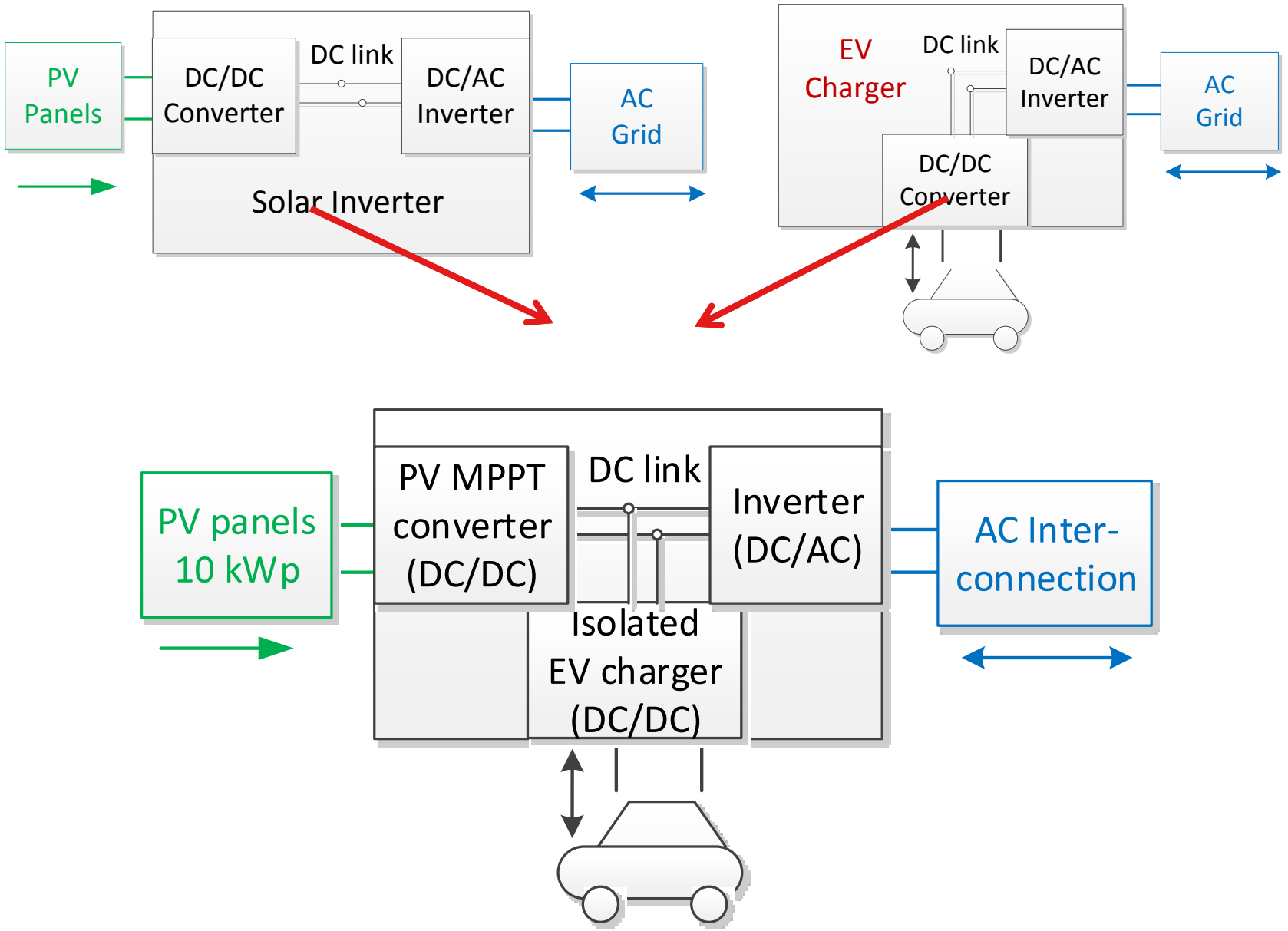
EV charging from PV : Today



PV Inverter

EV Charger

Integrated DC solution



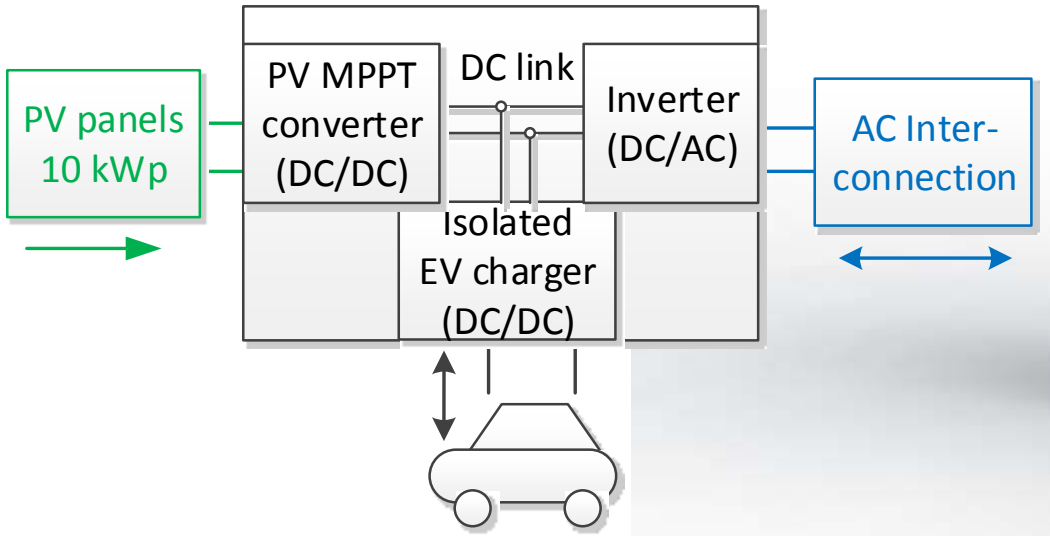
Charging of EV from PV : Our solution

tki switch2 smartgrids

TU Delft Delft University of Technology

PRE power developers

last mile solutions



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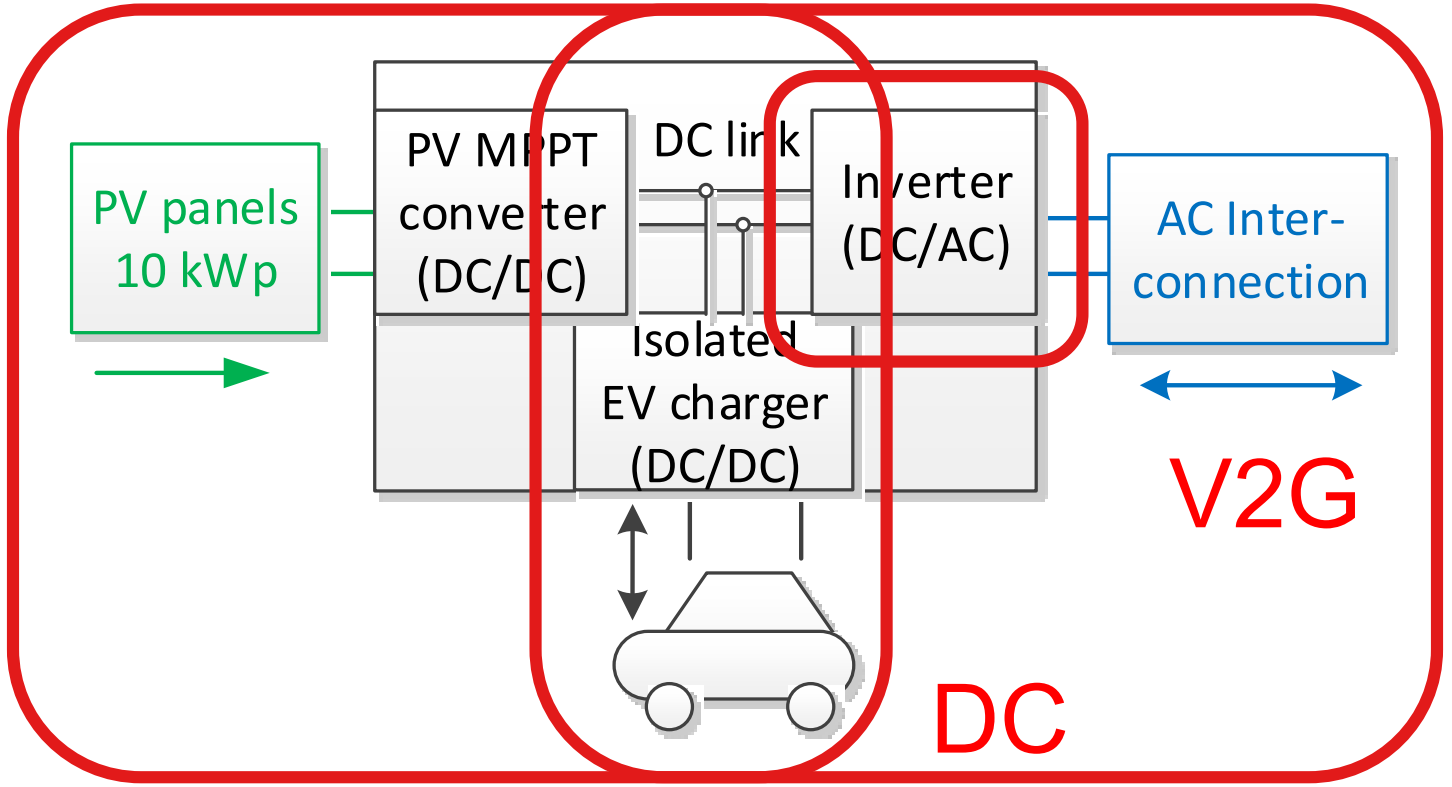
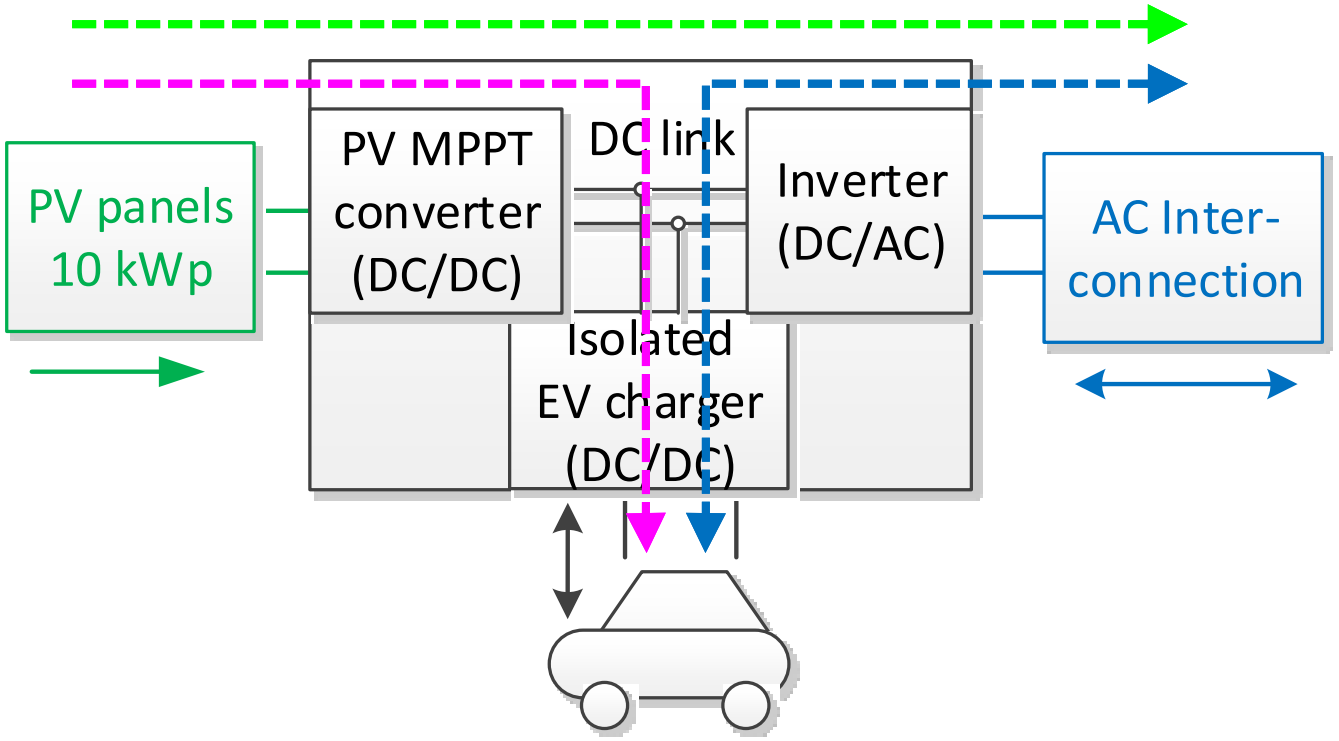
Integrated DC solution

- DC-DC connection of EV-PV → Improved efficiency
- Only one DC/AC converter → Lower cost of converter
- Bi-directional capability → Charge / V2G



Integrated DC solution & 4 power flows

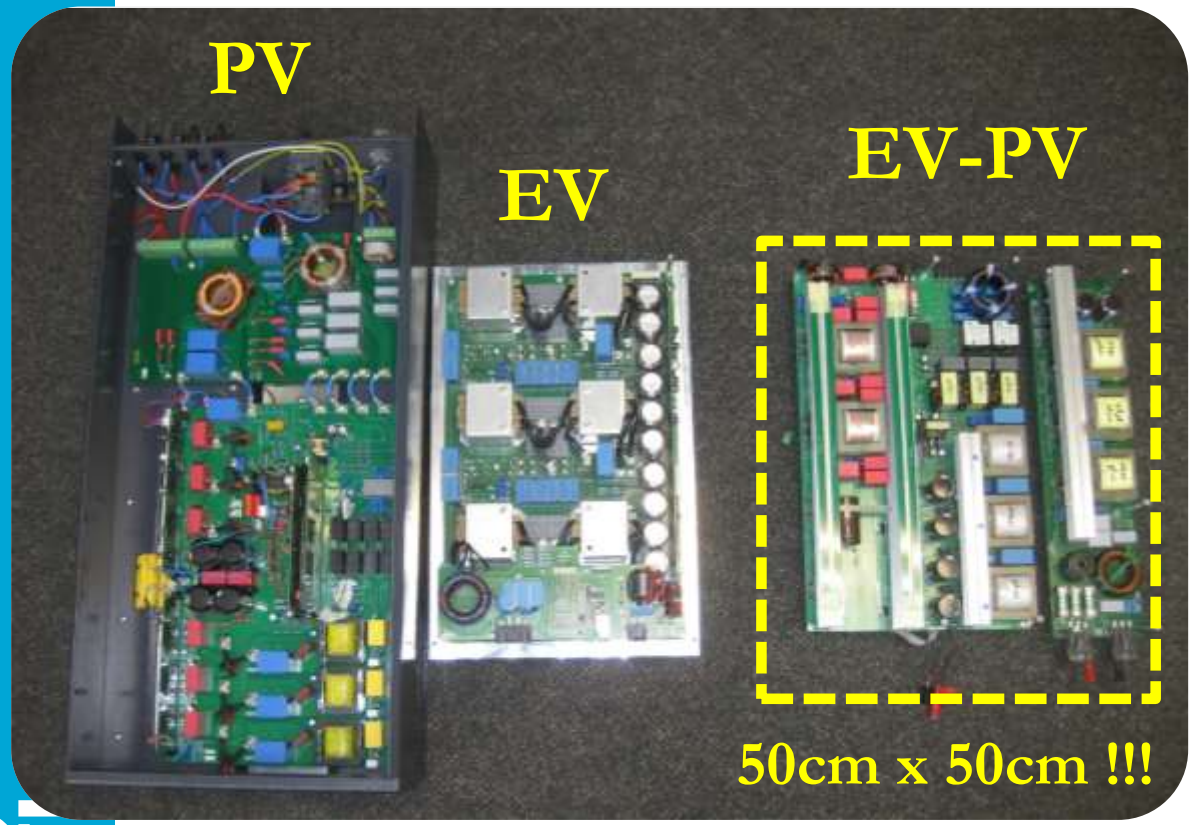
- DC-DC connection of EV-PV → Improved efficiency
- Only one DC/AC converter → Lower cost of converter
- Bi-directional capability → Charge / V2G
- Four power flows → Easy power management

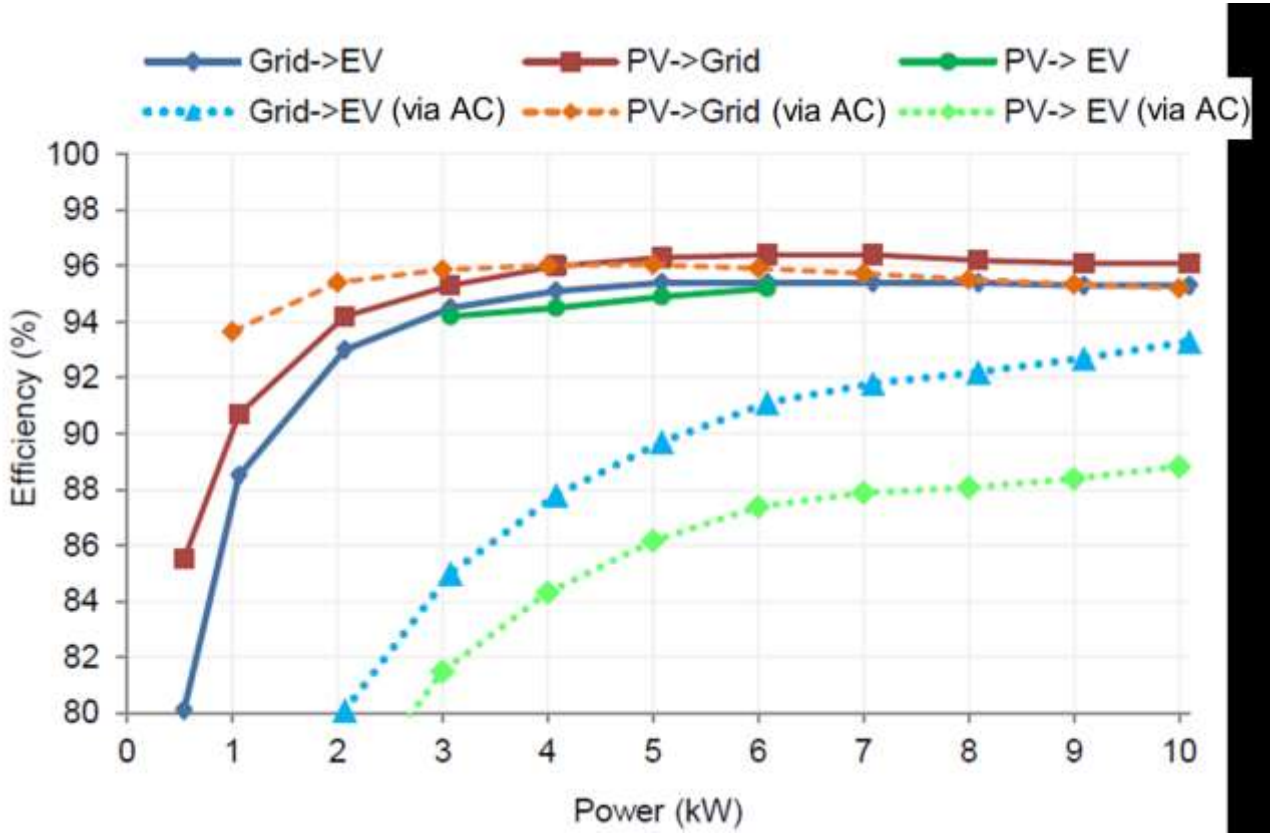


1. PV → EV
2. Grid → EV
3. EV → Grid
4. PV → Grid

3x Power density & Higher efficiency

- SiC MOSFET, diode
- Interleaving of converters
- Powdered alloy inductors





Testing with Nissan Leaf EV & commercial readiness

- Charging from PV & V2G with Nissan Leaf

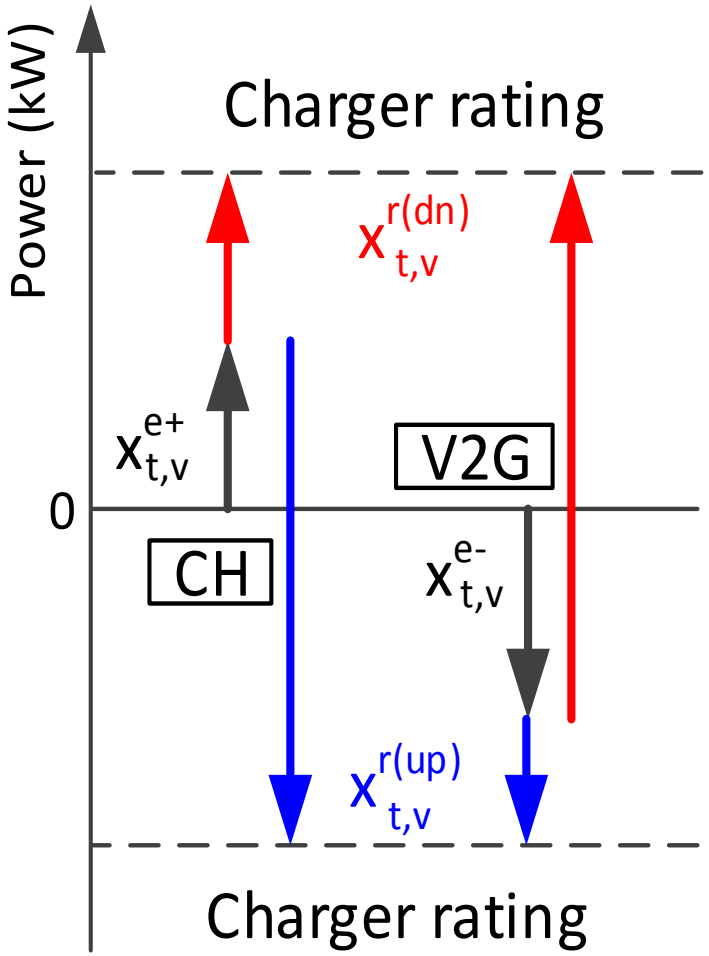
- V2G power module: PRE, www.pr-electronics.nl
- V2G cabinet with controller, connector:
  - Newmotion, https://newmotion.com
  - eNovates, https://www.enovates.com
  - OVO energy, https://www.ovoenergy.com

Smart charging = Energy Management System (EMS)

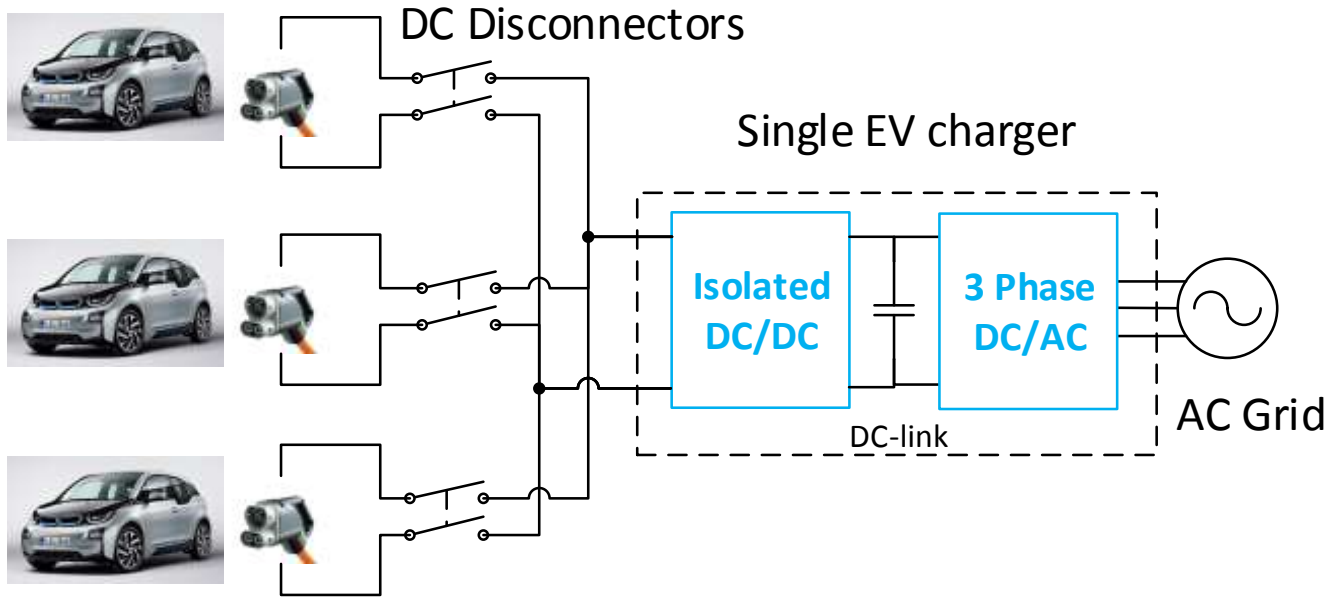
- Energy prices
- V2G
- Charging from PV
- Congestion management
- Frequency regulation
- Multiplexing of EV

Smart charging = Energy Management System (EMS)

Regulation services

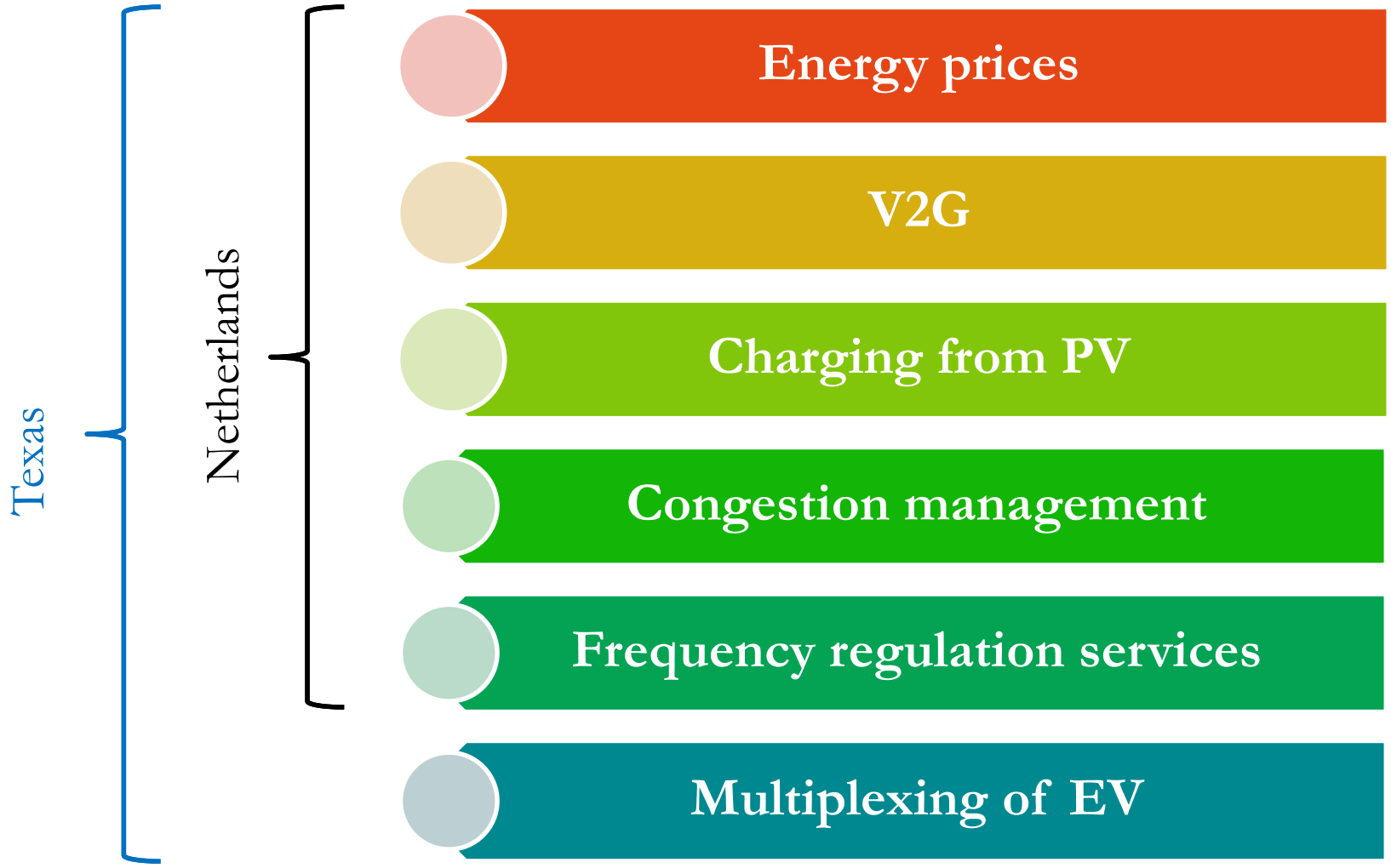


Use one charger for charging several EVs



Multiplexing of EV

Energy Management System (EMS)



D. van der Meer; G. R. Chandra Mouli; G. Morales-Espana; L.R. Elizondo; P. Bauer, "Energy Management System with PV Power Forecast to Optimally Charge EVs at the Workplace," in *IEEE Transactions on Industrial Informatics, 2017*

G. R. Chandra Mouli, R. Baldick, M.Kefayati, and P. Bauer, "Integrated PV Charging of EV Fleet Based on Dynamic Prices, V2G and Offer of Reserves", *IEEE Transactions on Smart Grids,* 2018

Case Netherlands

- EV car park with
  - 4 EVs connected to one EV-PV charger
  - 4 EVs, 2EVs connected to two EV-PV charger, resp.
- Energy prices from APX

$$C_{net} = \text{Cost(EV charging)} - \text{Sales (PV power)}$$

	PV self consumption (%)	E_{grid} (kWh)	C_{tot} (€)	Cost reduction (%)
Uncontrolled charging	73.65	39.61	2.181	
Optimal charging	82.41	27.07	-0.4022	118.44

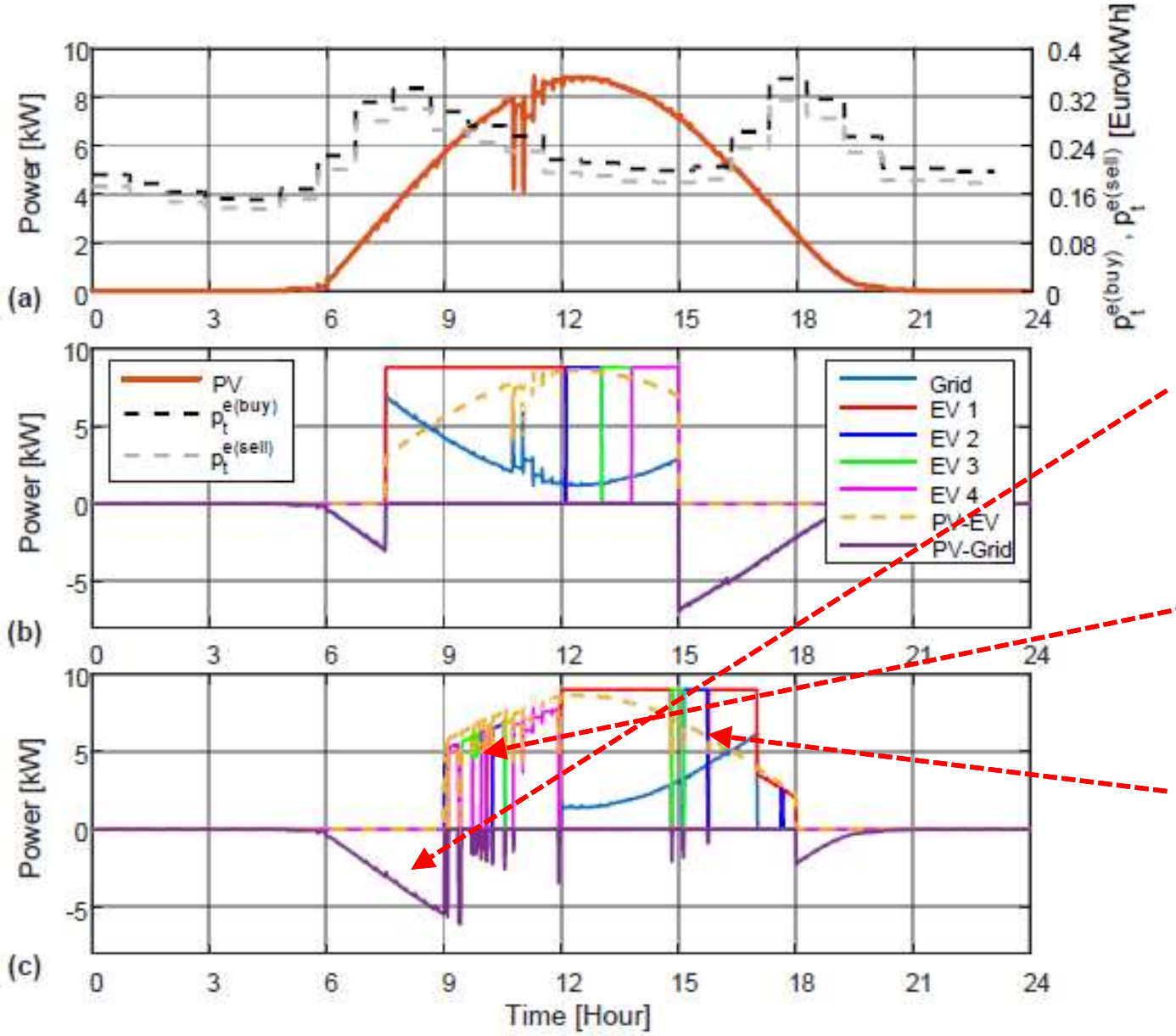
	PV self consumption (%)	E_{grid} (kWh)	C_{tot} (€)	Cost reduction (%)
Uncontrolled charging	58.04	94.24	-1.468	
Optimal charging	66.32	75.20	-7.743	427.45

Case Netherlands

PV & Prices

Uncontrolled charging

Smart charging



High prices
→ Charging delayed
→ PV sold

EV follows PV

Low prices
→ Charge from grid

Case Texas

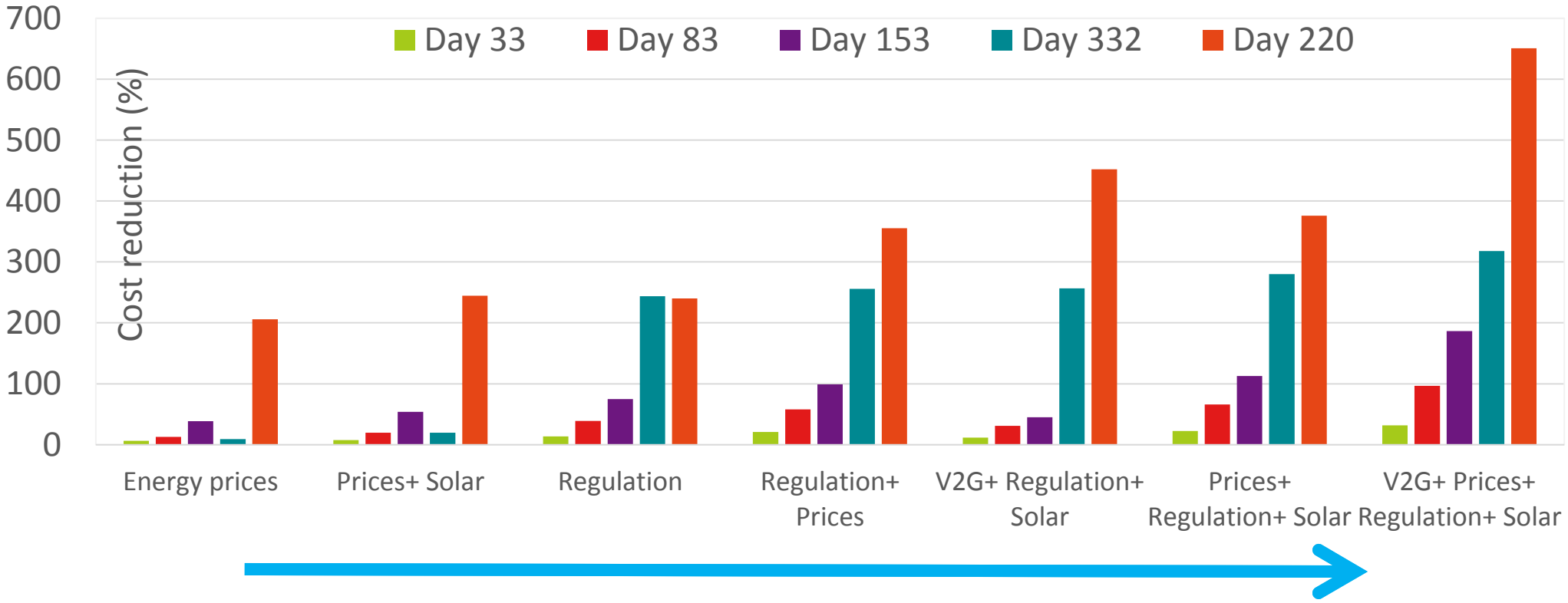
- EV car park with 6 EV and 4 Chargers
- Yearly simulation: 32 - 651% cost reduction, Avg. 158% ☺

Charging Strategy	AVERAGE RATE	UNCONTROLLED	OPTIMAL
C^{ar}, C^{imm}, C^{opt} ($)	37.9	29.0	-15.3
$C^{imm}_{\%}, C^{opt}_{\%}$ (%)		31.72	158.63

Case	Bidirectional V2G	Energy prices	Regulation services	PV forecast
Case 1	✗	✗	✓	✗
Case 2	✗	✓	✗	✗
Case 3	✗	✓	✓	✗
Case 4	✗	✓	✗	✓
Case 5	✓	✗	✓	✓
Case 6	✗	✓	✓	✓
OPTIMAL	✓	✓	✓	✓

Case Texas

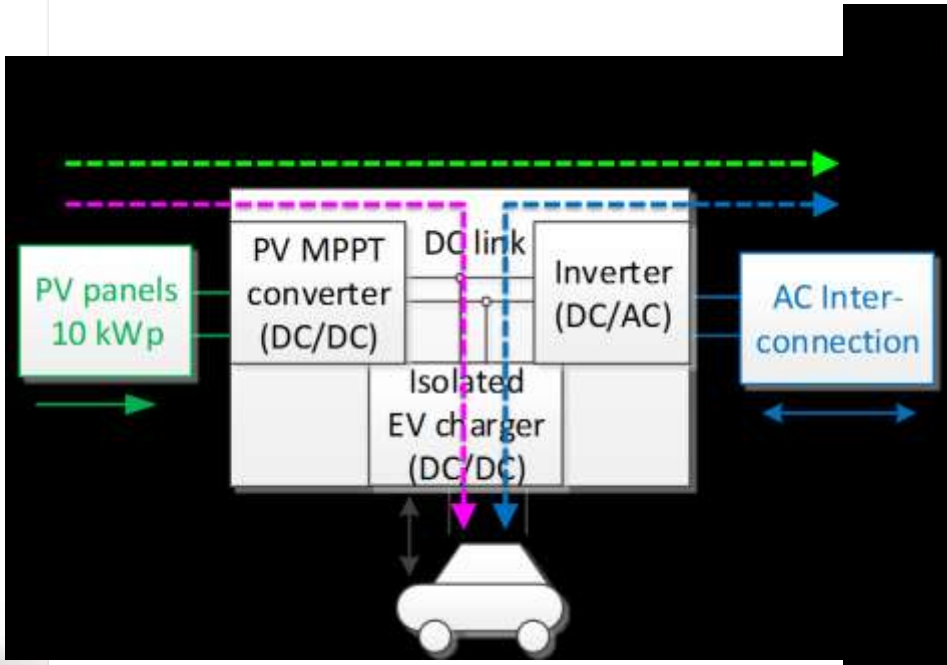
- EV car park with 6 EV and 4 Chargers
- Yearly simulation: 32 - 651% cost reduction, Avg. 158% ☺

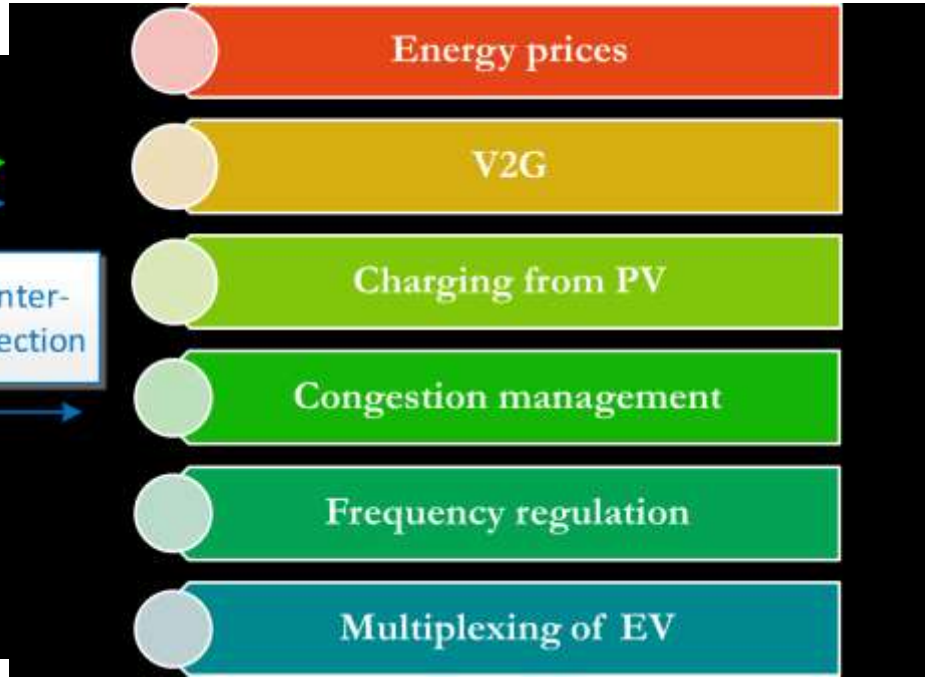


Combining smart charging applications is way forward

Conclusions

- World's first solar V2G EV charger: Mobility + Energy transition
- 4 power flows: Energy Neutral → Power Neutral
- Smart charging of EVs must combine multiple applications





Recognition received

1. ‘Most Significant Innovation in Electric Vehicles’ Award from IDtechEx, 2018
2. Selected ‘Best Tech Idea of 2018’ by magazine KIJK
3. Featured on Dutch TV NPO1, in series ‘Breakthrough’ on Een Vandaag 2017
4. Showcased in TU Delft research exhibition ‘digit 2017’
5. Among three finalists for the ‘emove360° award in 2017