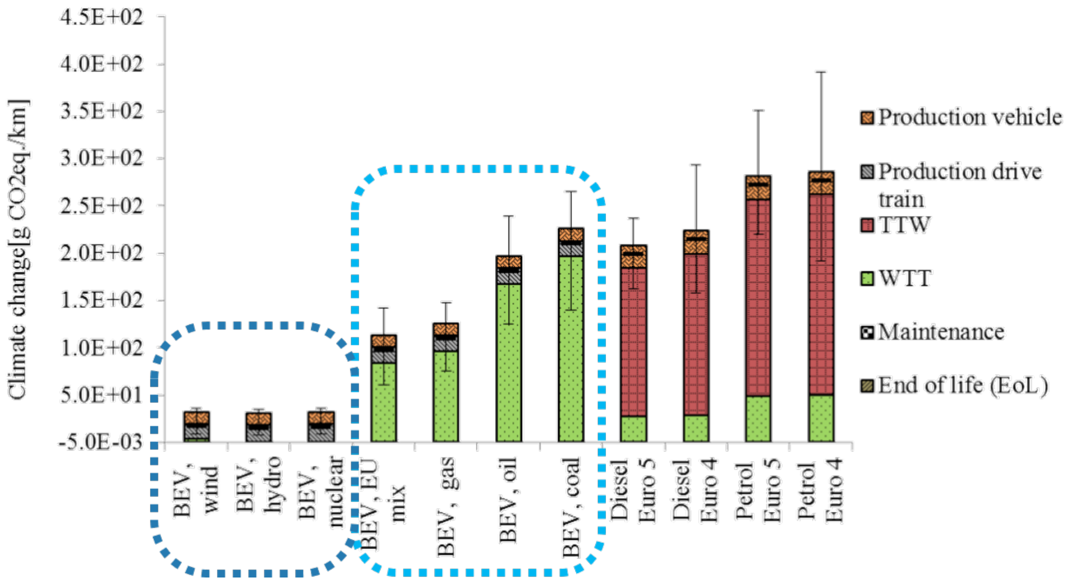
Electric cars: Technology

Lecture notes: Lecture 4.4

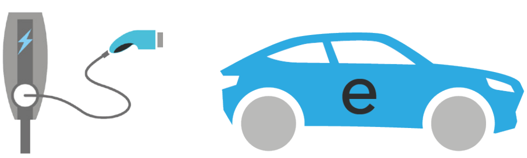
Why do we have to use renewable sources of electricity to charge electric cars in the future?



Source [open access journal]: 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*.

In this graph, we can see the equivalent carbon-dioxide emissions from a lifecycle assessment which includes the emissions due to

1. Vehicle production
2. The well-to-wheel emissions for the fuel (Well to tank, WTT and tank to wheel, TTW)
3. Vehicle maintenance
4. End-of-life recycling of the vehicle



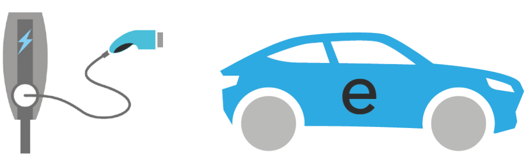
The graph has three parts:

- The emissions for different combustion engine cars are shown on the right side
- The middle part shows the emissions for battery electric cars charged from different emitting electricity generation sources
- The left part shows the emissions for battery electric cars charged from different non-emitting (maybe renewable) electricity generation sources

We can clearly see that electric vehicles have far lower emissions from a life cycle perspective even when charged from an electricity grid dominated by fossil fuels. However, if the electricity itself is generated from non-emitting sources like wind, hydro or nuclear, then the net life cycle emissions of the electric vehicle are further lowered and well to tank emissions become zero. It is hence necessary to use renewable sources of electricity to charge electric cars in the future.

EV charging from wind and solar energy

Charging from wind energy	Charging from solar energy
Wind power is typically generated today using onshore or offshore wind farms that are located far away from where electric vehicles are charged. This means that the power must be transported long distances between the supply and the EV load.	Solar panels have the benefit that they can be installed on the rooftop of buildings, besides being installed as solar farms. Therefore, solar power can be generated close to where electric vehicles will be charged, thus reducing the transmission losses.
A wind turbine is typically rated in the order of megawatts while an EV charger is normally working in the order of kilowatts. This shows the big difference in power scales and the potential of one wind turbine to charge several hundred cars.	Rooftop solar PV systems are typically rated in the order of kilowatts which is similar to the power rating of an EV charger.
Wind generation is maximum in winter and in the night time. Hence, wind generation is ideally suited for charging electric cars at homes in the night.	In contrast to wind generation, solar generation is maximum in the daytime and in summer. Hence, solar generation is ideally suited for charging cars at workplaces during the day.

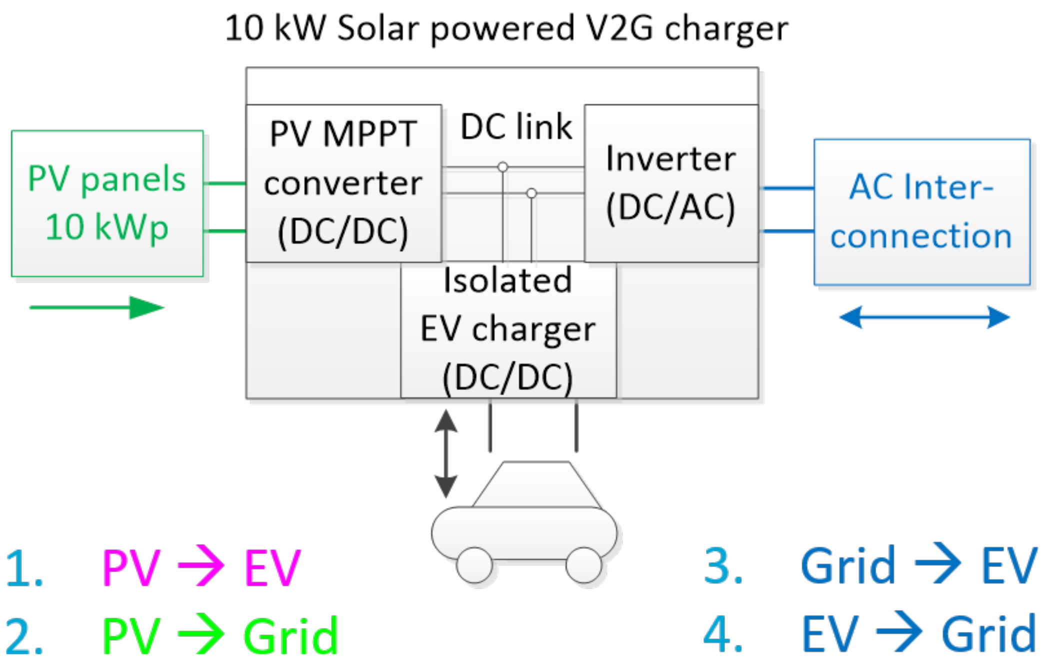


Power converters

From a power conversion perspective, generators used in wind turbines typically produce variable frequency AC power. Two back to back AC-to-DC and DC-to-AC power converters are used to convert the variable frequency AC power to high voltage or medium voltage 50Hz or 60Hz AC power used for long distance power transmission. This power is then stepped down to low voltage AC power, and the EV can then be charged using AC or DC charging.

The simplest way to realize a solar powered EV charging station is to use a solar inverter. A DC- to-DC power converter operates the solar panels at the maximum power point. Then, a DC-AC inverter converts the DC power to 50Hz or 60Hz AC power for AC charging of the EV. There is, however, one disadvantage with this method. Photovoltaic panels and the EV battery are both fundamentally direct current or DC by nature. And in this method, the DC power is unnecessarily converted to AC and back.

Hence, a more efficient way to charge EV from PV is to use an isolated DC-to-DC converter and directly charge the EV from PV using DC charging as shown in the figure.



There are three power converters, a DC-to-DC converter for the solar panels, a DC-DC isolated converter for the electric car and a DC-to-AC inverter to connect to the AC grid.

- Using this design, direct DC charging of EV from PV can be realized.
- Secondly, if there is no electric car, then the system acts as a solar inverter and feeds PV power to the grid.
- Third, if there is no solar power, the system operates as a conventional DC charger and charges the EV from the grid.
- Finally, the charger is bidirectional and capable of vehicle-to-grid. So the EV can not only charge from the grid, it can feed power back to the grid as well.

The unique aspect of combining solar charging and vehicle-to-grid is that the electric car battery can now be used as a storage for renewable electricity.

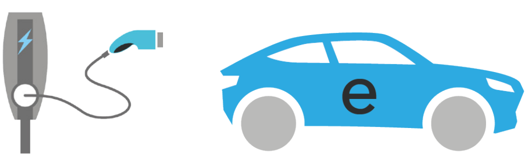
Overcoming variability in renewable energy generation

The main challenge with powering electric cars from renewable energy is the variability in generation.

Using a combination of solar and wind

A solution to overcome this variation is to size the wind and solar installation such that we are guaranteed of sufficient energy even when the sunshine and wind are minimal. The disadvantage is that this can cause overproduction and wastage of power when the solar insolation and/or wind speeds are maximum. By optimally sizing a PV and wind hybrid system, then the variability in PV generation can be partially balanced by the variability in wind generation resulting in a net system with minimal wastage of power.

In the graph, we can see a system with different percentage of total renewable generation (40% to 100%) and which percentage of that is wind or solar generation. It can be seen that the energy wastage increases as more renewables are used to supply the load due to mismatch between renewable generation and load demand. However, the power wastage can be drastically reduced when an optimally combination of both wind and solar generation is used.



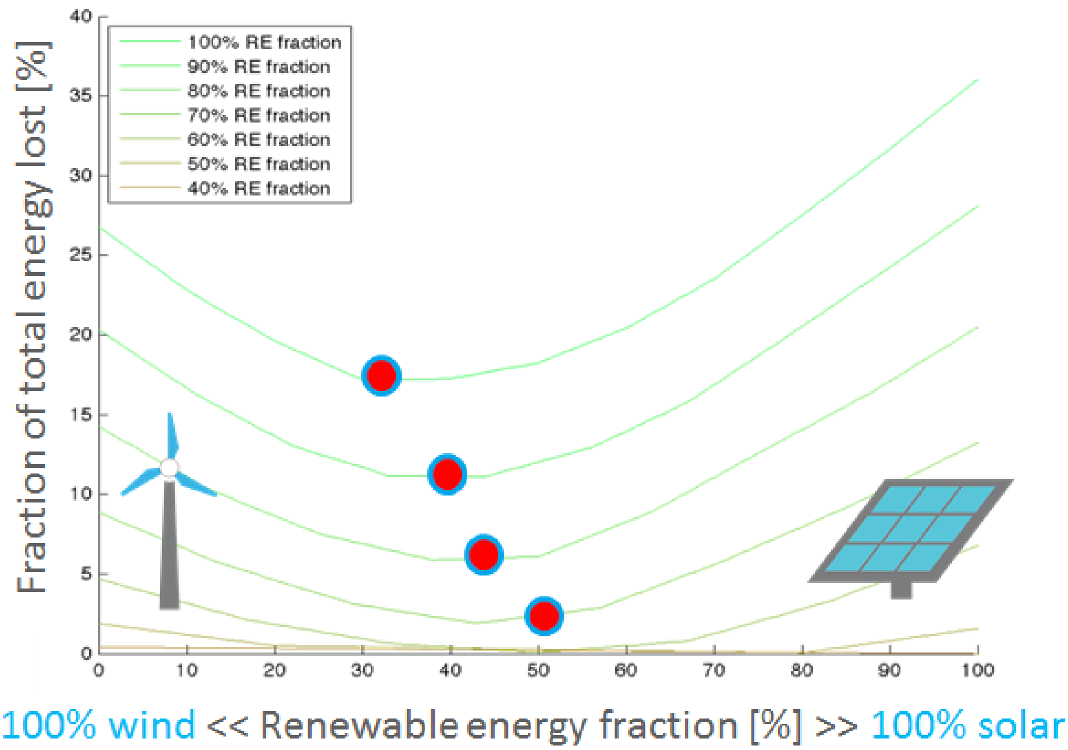


Image source: Arne Kaas, Pavol Bauer - Sustainable off-grid power for rural areas, Thesis, Delft University of Technology

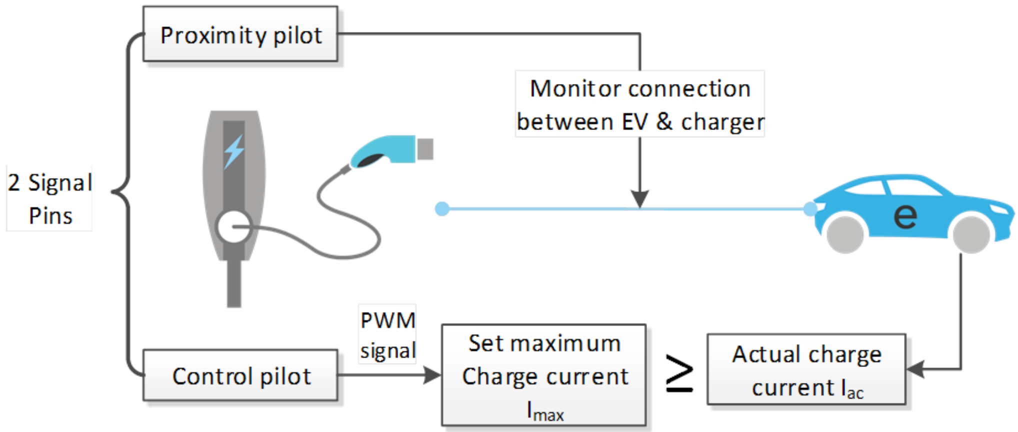
Smart charging

A second solution to help match renewable generation and EV charging is smart charging. When the solar and wind generation is high, the EV charging power can be increased and vice versa. This has the dual benefit of making EVs sustainable by using more green energy and reducing the stress on the grid due to large-scale renewable energy generation.

Smart charging on Type 1 and Type 2 AC chargers:

In case of AC charging, the pulse width modulation signal on the control pilot of

the Type 1 and Type 2 AC chargers can be continuously controlled to adjust the EV charging current based on solar or wind generation. For Chademo and combo DC charging, CAN and PLC communication can be respectively used to adjust the charging power.



The duty cycle of the pilot signals communicates the maximum current the Electric Vehicle Service Equipment (EVSE) is capable of supplying to the vehicle, Imax. The vehicle can then draw a charging current $I_{ac} <= I_{max}$.

The relationship between PWM duty cycle (in %) and current Imax is defined by two different equations depending on the current range specified;

Equation 1, for a 6- to 51-A service: $Duty\ cycle = I_{max} / 0.6$

Equation 2, for 51- to 80-A range: $Duty\ cycle = I_{max} / 2.5 + 64$

To demonstrate this relationship further, the table on the next page shows some of the common current ratings.

AC charging current	Duty cycle of PWM on control pilot
5	8.3%
15	25%
30	50%
65	90%
80	96%