ENEL 890AO: Computational Methods in Electrical Engineering

Introduction of Electric Vehicle

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Faculty of Engineering

U of R

Electric Vehicle (EV) and EV charging

- Electric cars vs Petrol cars

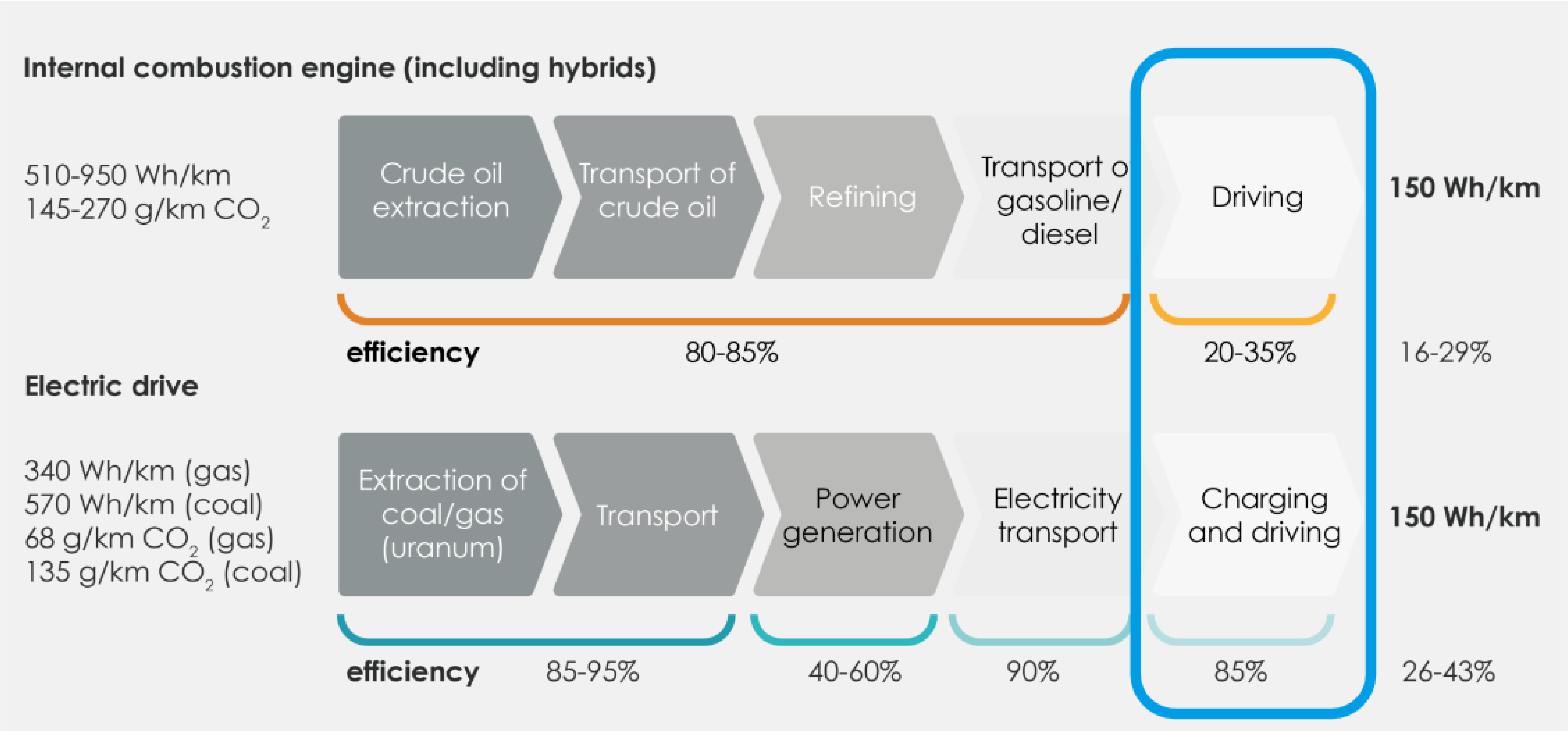
Advantages

- Sustainability
- Efficiency
- Convenience
- Economy

Sustainability

https://www.solarpowerrocks.com/affordable-solar/how-much-solar-do-i-need-to-charge-my-electric-car/

Efficiency



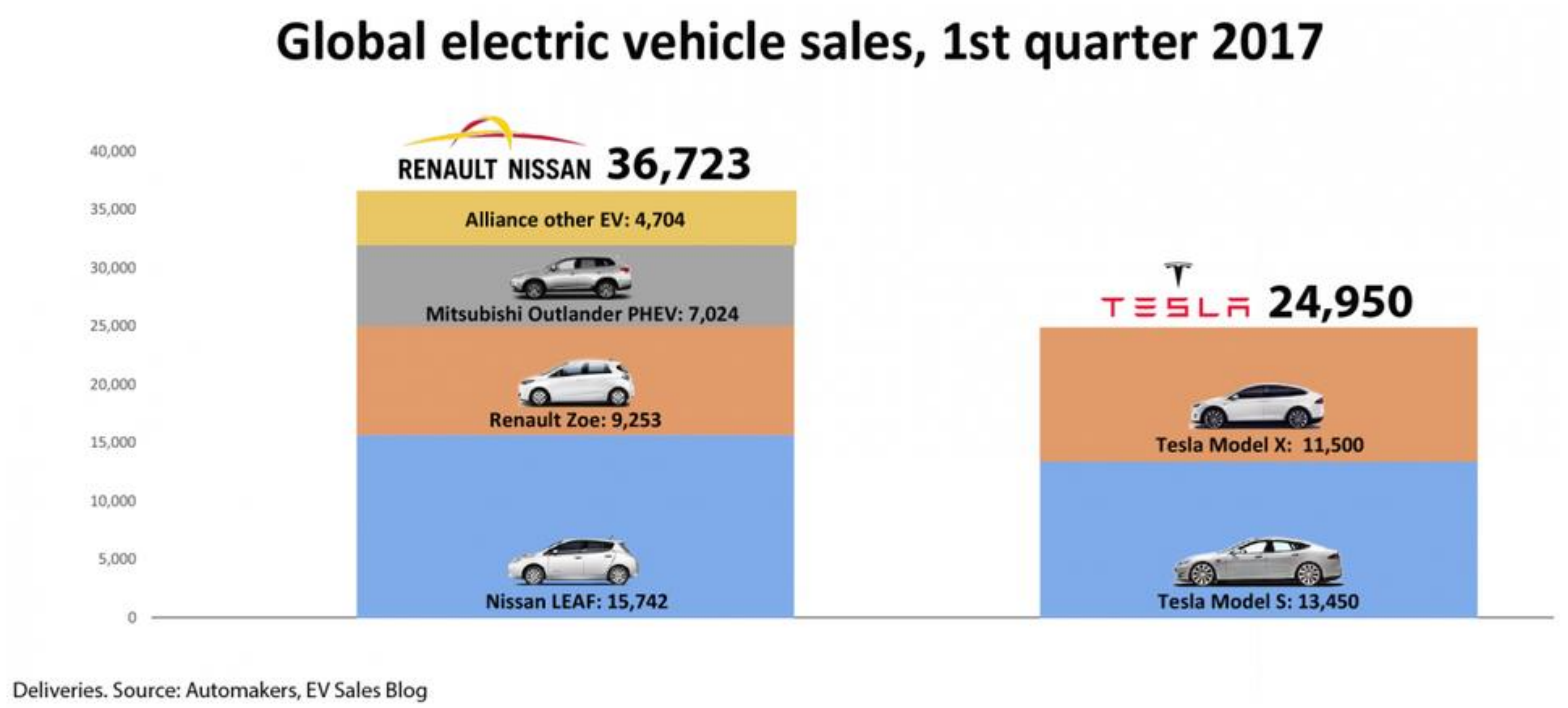
Internal combustion engine (including hybrids)
510-950 Wh/km
145-270 g/km CO_2
Crude oil extraction
Transport of crude oil
Refining
Transport o gasoline/ diesel
Driving
150 Wh/km
efficiency
80-85%
20-35%
16-29%
Electric drive
340 Wh/km (gas)
570 Wh/km (coal)
68 g/km CO_2 (gas)
135 g/km CO_2 (coal)
Extraction of coal/gas (uranum)
Transport
Power generation
Electricity transport
Charging and driving
150 Wh/km
efficiency
85-95%
40-60%
90%
85%
26-43%

Lower total cost of ownership

- Higher purchase price, but
- Lower maintenance costs
- Lower taxes
- Cheaper fuel (electricity)
- Government subsidy

- Emission Calculator Tool: https://afdc.energy.gov/vehicles/electric_emissions.html

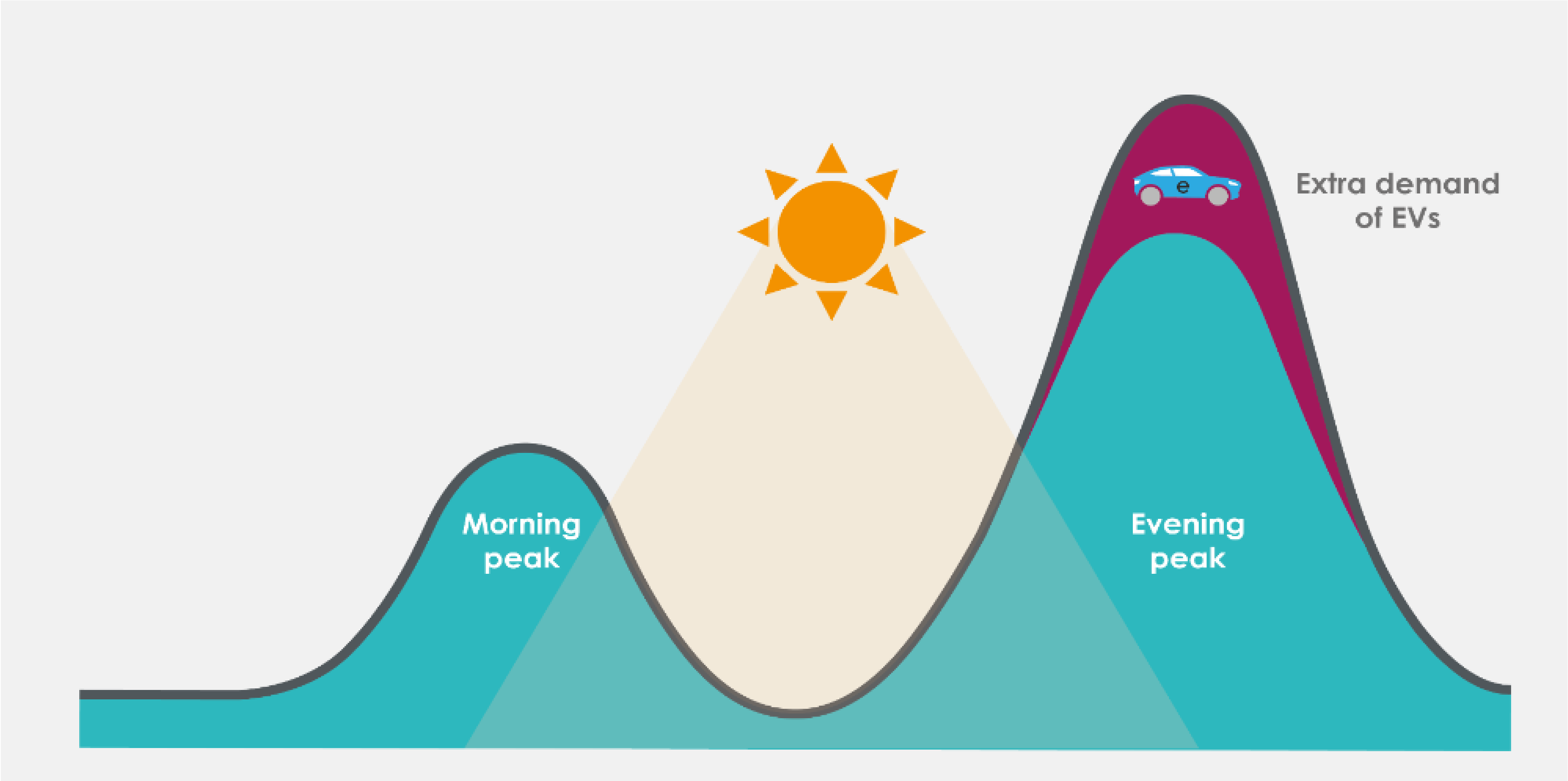
- Fuel Economy Tool: http://www.fueleconomy.gov/feg/Find.do?action=sbsSelect
  - compare the ‘2018 Honda Civic 4Dr, 2.0 L, 4 cyl, Automatic’ and the ‘2018 Tesla Model S AWD - 75D’.
  - 33.7 kWh (121 MJ) is equivalent to one gallon gas fuel
  - 259 miles is about 417 km


Global electric vehicle sales, 1st quarter 2017
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
RENAULT NISSAN 36,723
Alliance other EV: 4,704
Mitsubishi Outlander PHEV: 7,024
Renault Zoe: 9,253
Nissan LEAF: 15,742
TESLA 24,950
Tesla Model X: 11,500
Tesla Model S: 13,450
Deliveries. Source: Automakers, EV Sales Blog

Basic EV charging

- Onboard charger: 1.9 – 22 kW
- DC offboard charger: 50 – 350 kW
- Charging level
  - Level 1: 0 – 10 kW
  - Level 2: 10 – 50 kW
  - Level 3: 50 – 350 kW

Impact on power system



Possible solutions

- Grid capacity expansion (expensive)
- Controlled battery charging or Smart charging
- Incentive to user
- Rewarded for flexible load pattern

Smart Charging

- Smart charging is a series of intelligent functionalities to control the EV charging power in order to create a flexible, sustainable, low cost and efficient charging environment.

Benefits of smart charging

- Increase the flexibility of charging
- Higher utilization rates of fixed assets
- Efficient utilization of energy in distribution network
- Make electric vehicles more sustainable
- Provide new revenue streams to EV owners

V2G

- Using the electric vehicle battery to feed power back to the grid using a bidirectional EV charger

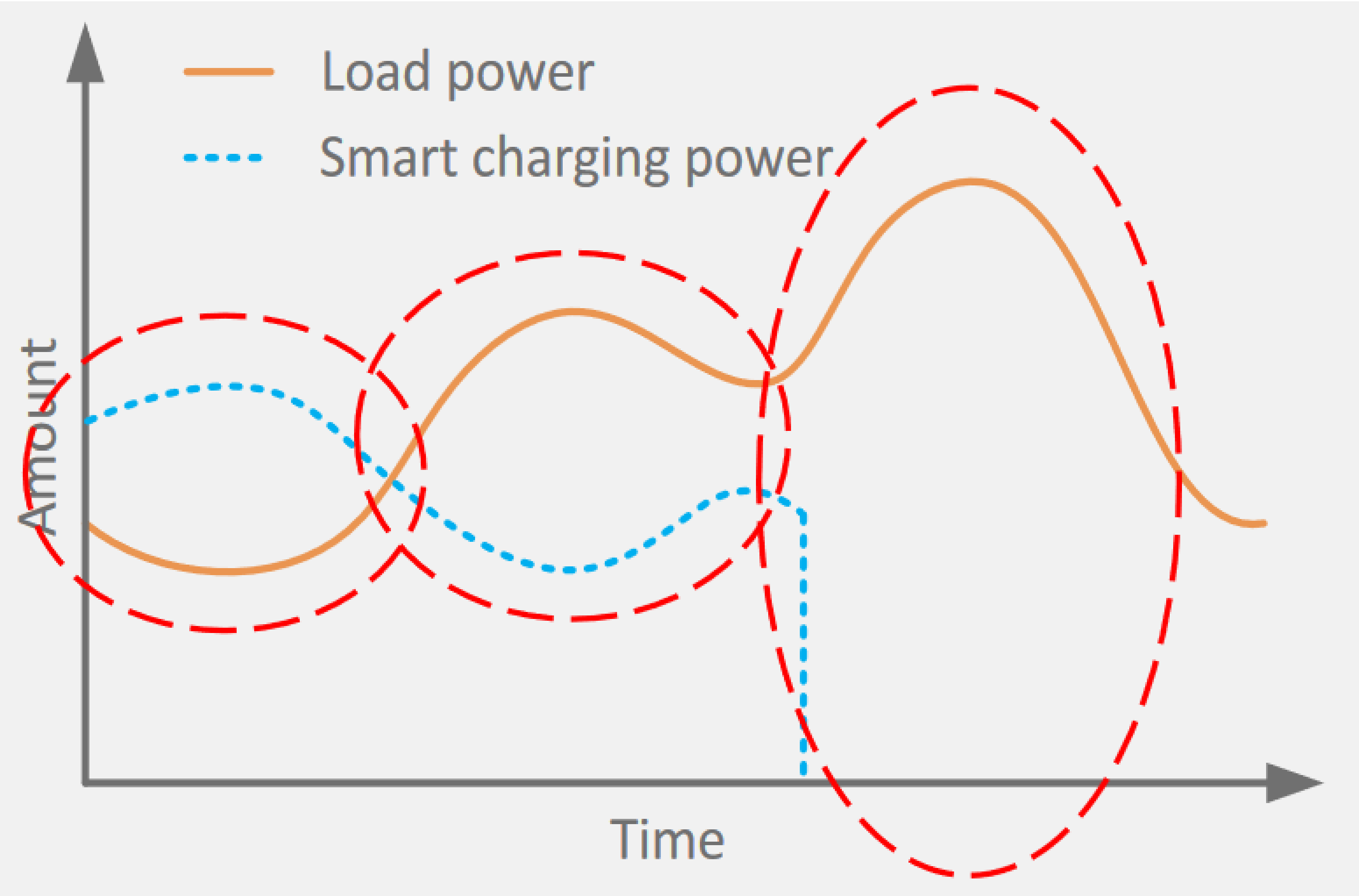
V2G advantages and challenges

- Advantage
  - Storage for renewables
  - Reduce peak demand
  - Emergency power
  - Ancillary services
- Challenges
  - Bidirectional charger
  - Battery degradation
  - ICT infrastructure
  - Standardization and regulatory framework
  - Lack of incentives for user

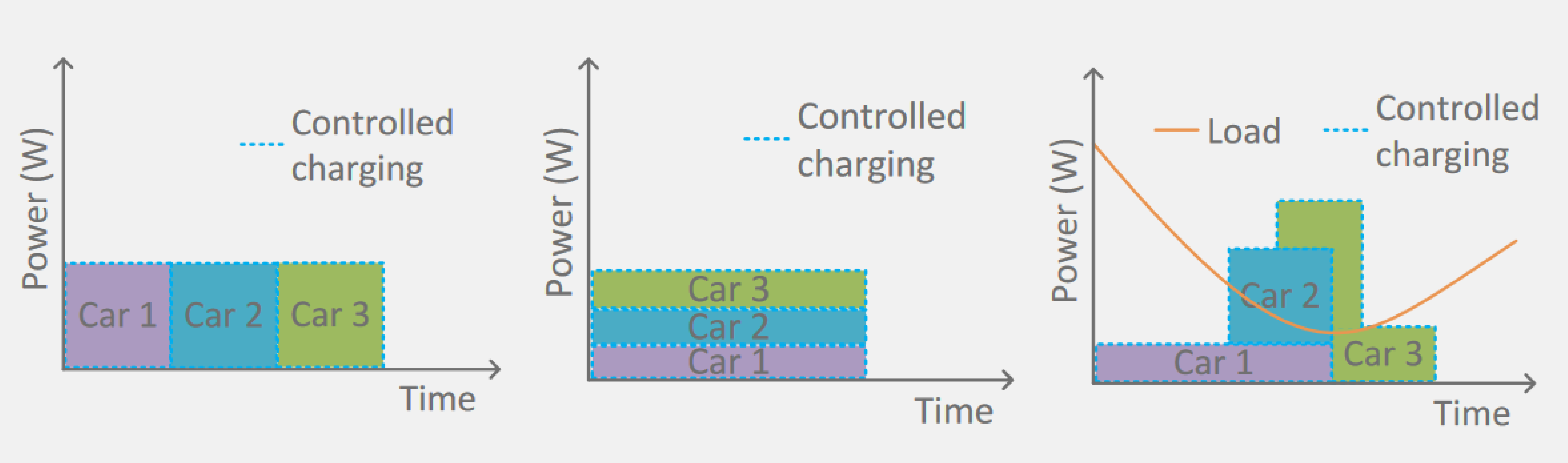
Example applications of smart charging

- Local load balancing
  - Adjust charging time/power according to load
  - Balance multiple charge points with priority
- Renewable energy utilization
- Price based charging
- Peak shaving
- Grid back up

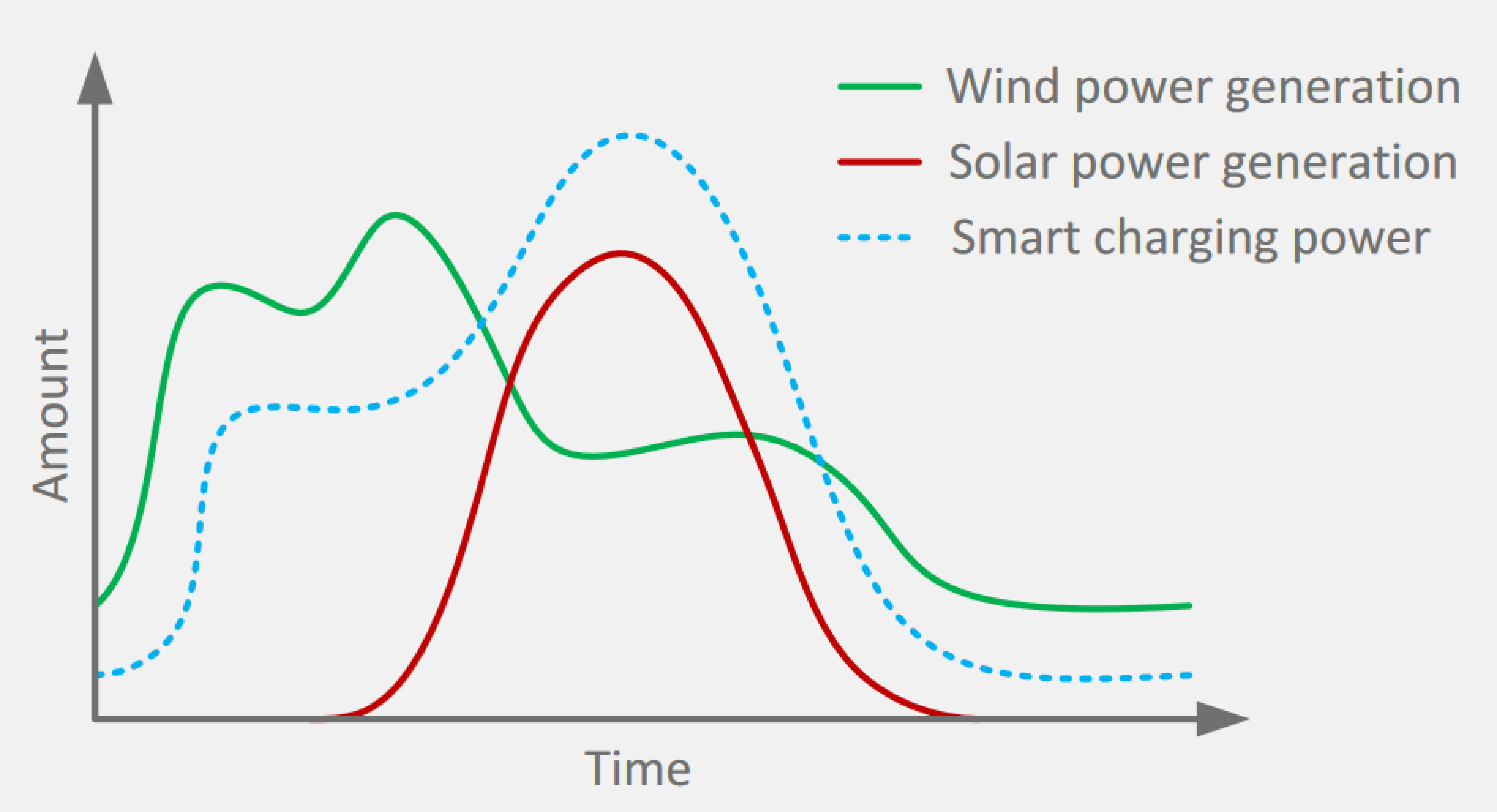
Load balancing



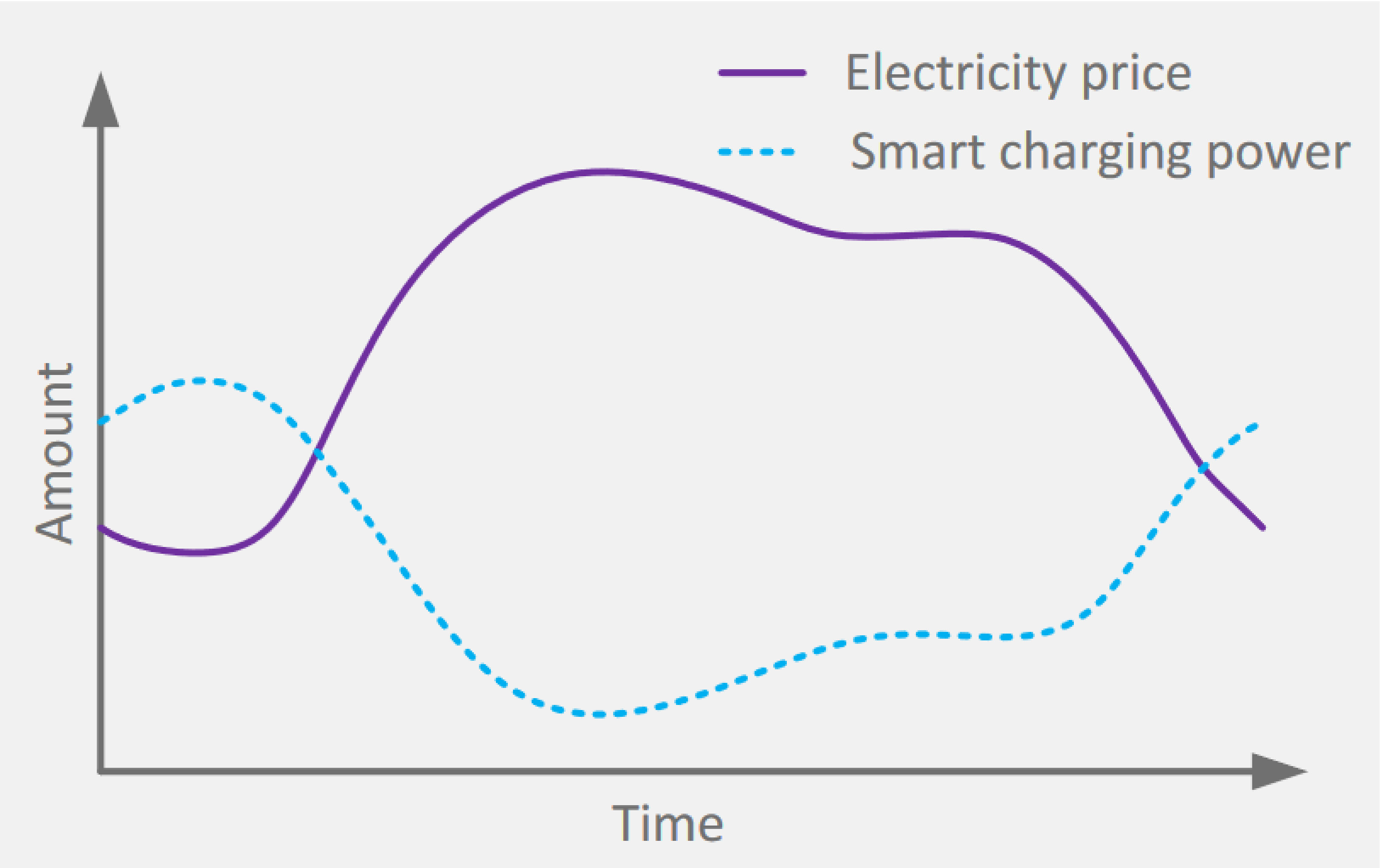
Load balancing



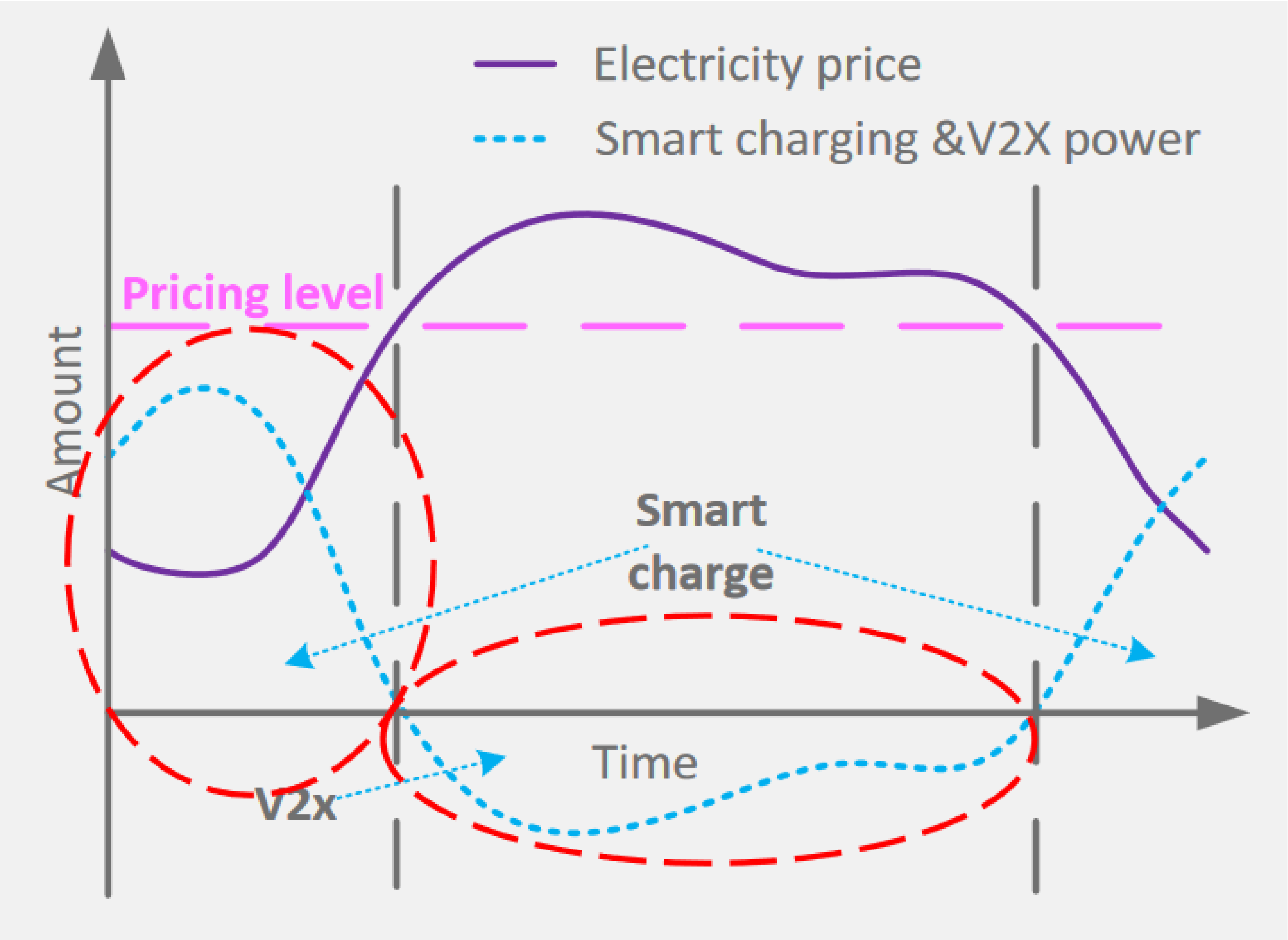
Renewable energy availability



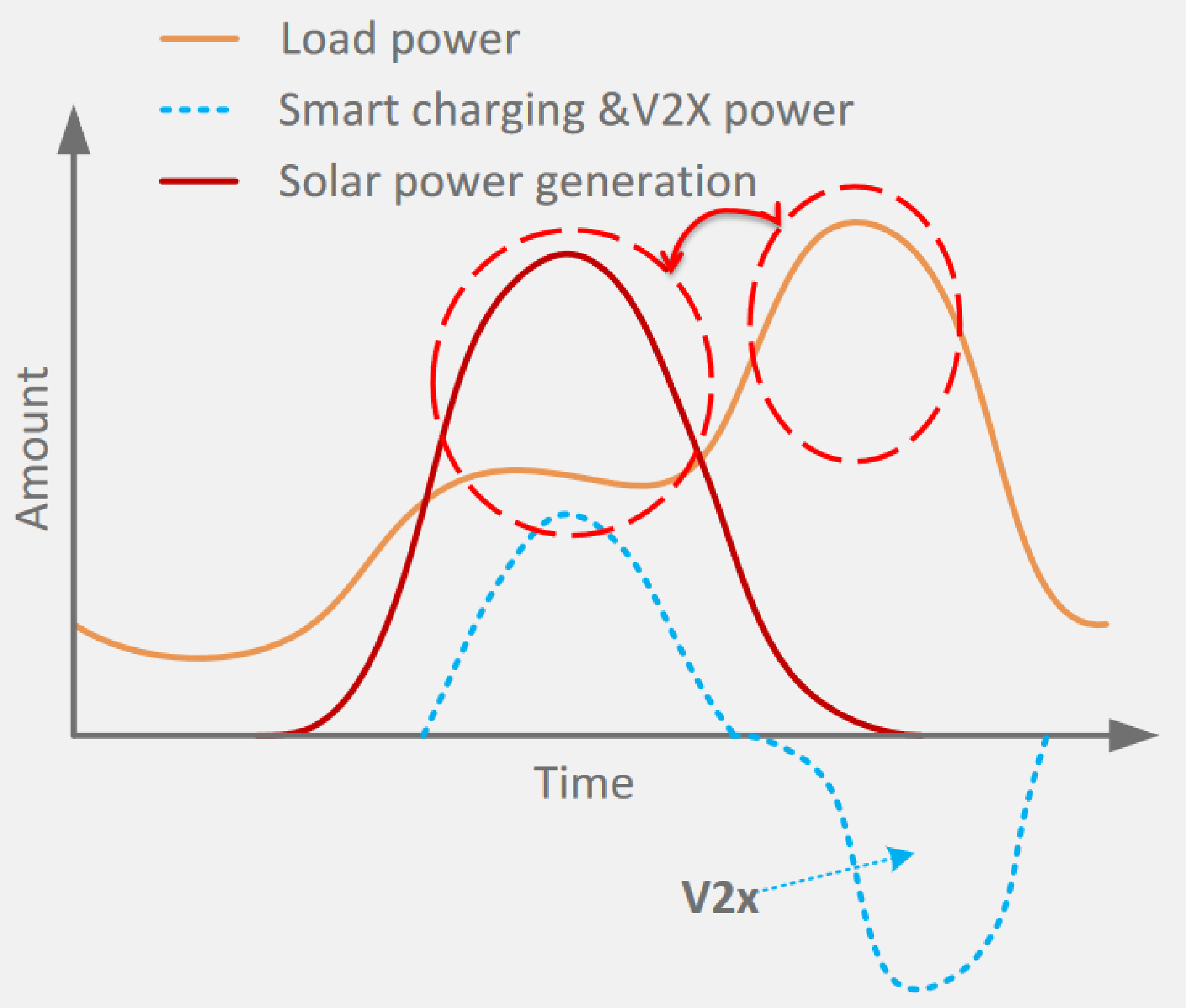
Price based charging



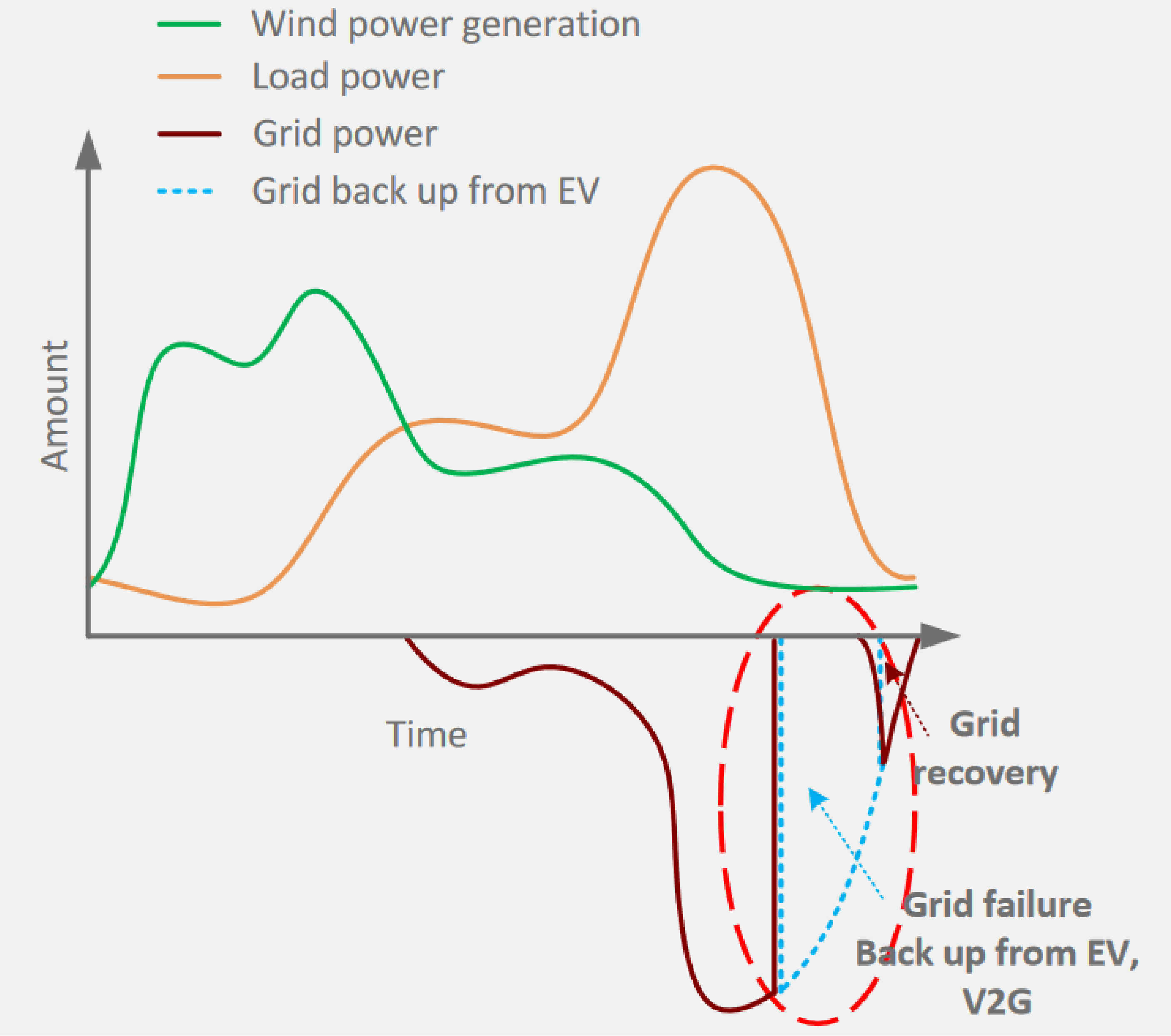
Price based charging



Peak shaving



Grid backup



Wind power generation
Load power
Grid power
Grid back up from EV
Amount
Time
Grid recovery
Grid failure
Back up from EV, V2G

Example: price-based charging

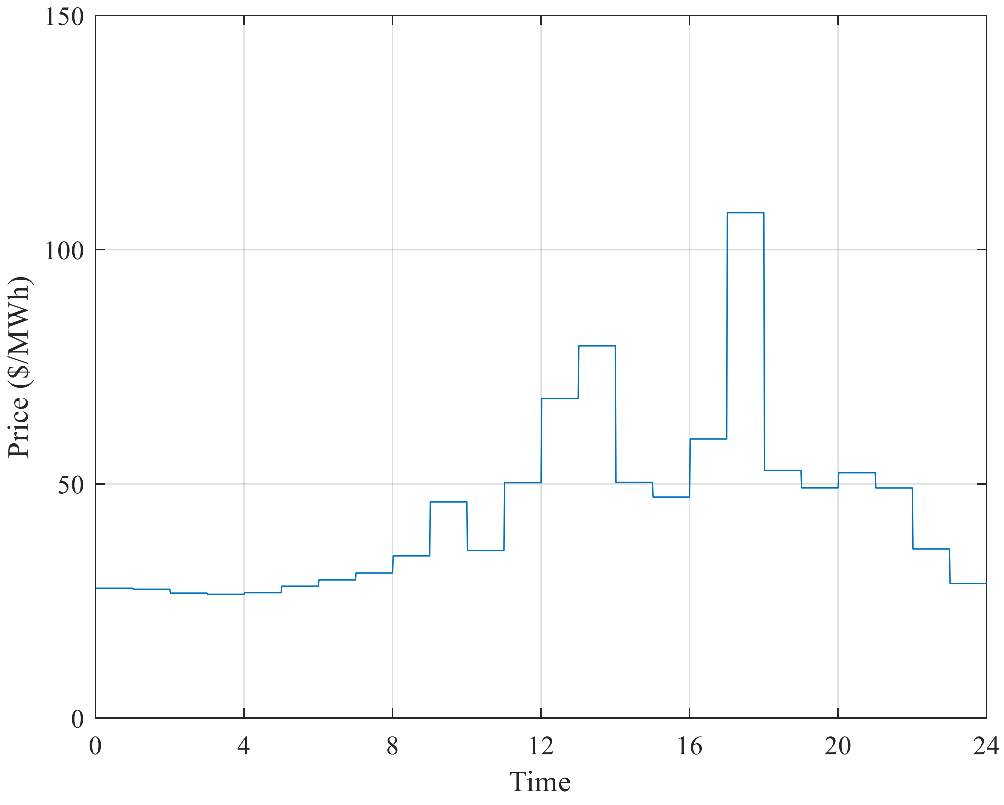
- Capacity: 100 kWh
- Rated charging demand: 10 kW
- State-of-charge (SOC): Available capacity expressed as a percentage of some reference, sometimes its rated capacity. (e.g., empty 0%, full 100%)

Example: price-based charging

Suppose you have a EV with a capacity of 100 kWh. The rated power of the charger is 10 kW.

In your neighborhood hourly real-time price (RTP) is applied for electricity usage.

When you arrive home the SOC is 10%, you need to determine the hourly EV charging schedule to minimize the electricity cost.



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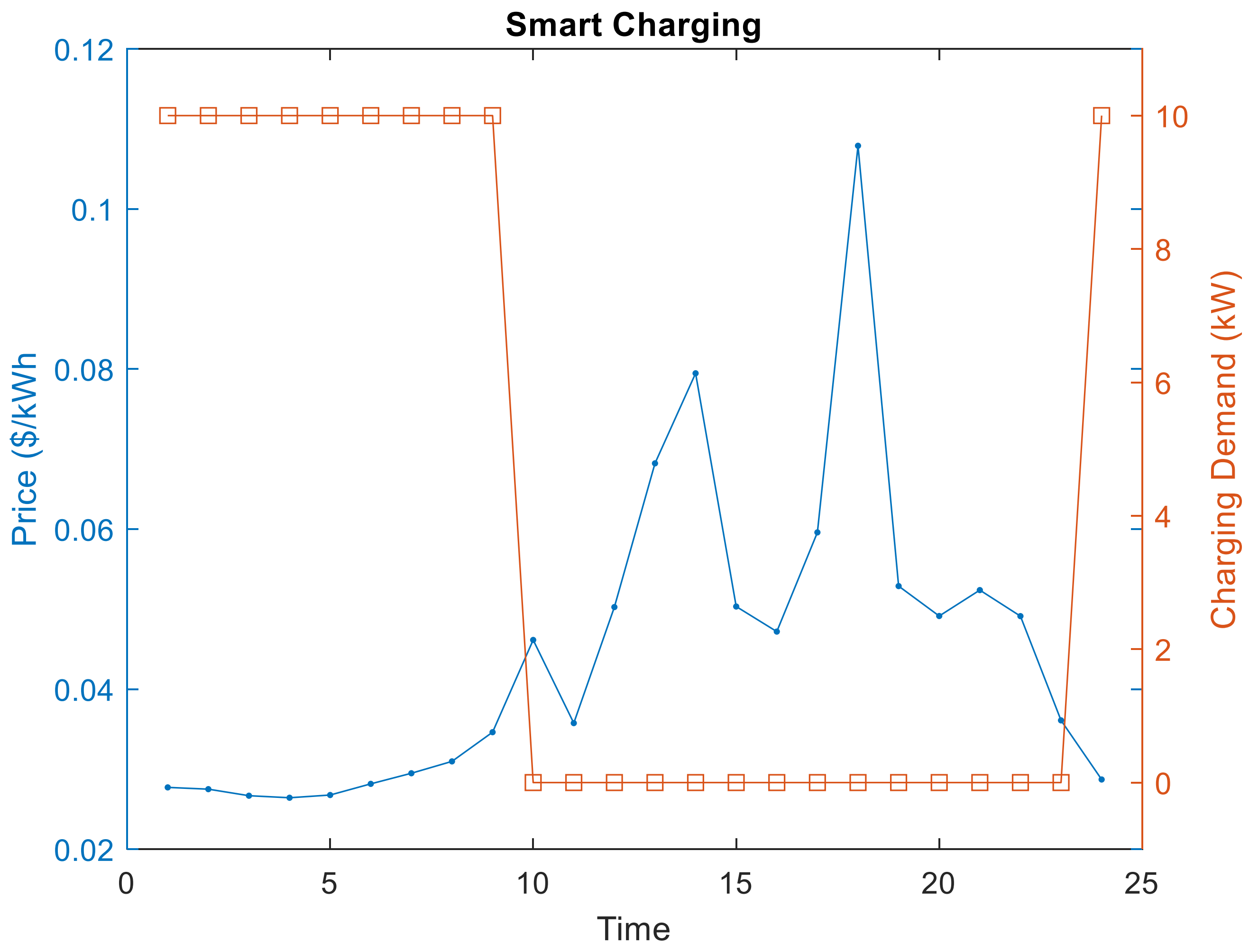
Formulation Steps

- Encode decisions/actions as decision variables whose values we are seeking
- Identify the relevant problem data
- Express constraints on the values of the decision variables as mathematical relationships (inequalities) between the variables and problem data
- Express the objective function as a function of the decision variables and the problem data


Smart Charging
0.12
0.1
0.08
0.06
0.04
0.02
Price ($/kWh
0
5
10
15
20
25
Time
10
8
6
4
2
0
Charging Demand (kW)

Python code

```
import pandas as pd
import cvxpy as cp
import matplotlib.pyplot as plt

# read .csv
mp = pd.read_csv("hourlyprice.csv",header=None)
# convert dataframe to array
p = mp.values
p = p[0]
p = p/1000
```

```
n = 24
# Construct the problem.
q = cp.Variable(n)
objective = cp.Minimize(p*q)
constraints = [0 <= q, q <= 10, sum(q)==90]
prob = cp.Problem(objective, constraints)

# The optimal objective value is returned by `prob.solve()`.
result = prob.solve()

# The optimal value for x is stored in `x.value`.
print(q.value)
plt.plot(p)
plt.figure()
plt.plot(q.value)
```

Matlab code

```
filename = 'hourlyprice.csv';
p = csvread(filename);
p = p';
p = p/1000; % $/kWh
n=24;
cvx_begin
variable q(n)
    minimize( q'*p )
    subject to
        q<=10;
        q>=0;
        sum(q) == 100;
cvx_end
```

```
%% plot
t=1:24;
[hAx,hLine1,hLine2] = plotyy(t,p,t,q);
title('Smart Charging')
xlabel('Time')
ylabel(hAx(1),'Price ($/kWh')
ylabel(hAx(2),'Charging Demand (kW)')
set(hAx(2),'YLim',[-1 11])
set(hLine1,'Marker','.')
set(hLine2,'Marker','s')
```