V2G for hourly power supply

- Impact and value in the future Scandinavian energy system-

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Introduction

- Vehicle 2 Grid (V2G) = Power supply from Battery Electric Vehicles (EVs)
- End-use flexibility enables intermittent renewables & lower grid investments
- V2G in electricity spot price market
  - Income > Degradation cost + Investment cost
  - Income = Sales price - Charging price
  - Lowers fluctuations in electricity price
- This study
  - Quantify degradation cost of V2G
  - Analyse value and effect of V2G in Scandinavia

Electric Vehicles in Norway

Norway per 31.03.2018 (population 5M)

- Electric vehicles (EVs)
  - 154 087 (6% of car fleet)
  - 38% of new car sales
- Plug-in hybrid: 74 265

4 most popular EVs

1. Nissan Leaf: 37 956 (from EUR 29 000)
2. Volkswagen e-Golf: 24 889
3. Tesla Model S: 16 321 (from EUR 65 900)
4. BMW i3: 15 187

EVs Sweden – 12 446 (population 10M)

EVs Denmark – 8 765 (population 6M)

Battery Degradation

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Cycle-life model for graphite-$LiFePO_4$ cells

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> 400 citing papers

Battery Degradation

- Degradation model described in Wang et al., 2011

$$Q = BA_h^{\rho} \exp\left(\frac{-E_a}{RT}\right)$$

Battery capacity loss [%]

where

$$A_h = N\,DoDC$$

$$E_a = 31500 - 370.3C_{rate}$$

$$B = \exp(9.263 + 1.226\exp^{-0.2797C_{rate}})$$

$$\rho = 0.50$$

$$R = 8.314$$

$$C_{rate} = \frac{E1000}{VtKC}$$

Battery Degradation

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Depth of Discharge

« how deep battery is discharged»

Battery Degradation

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where

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Product of cycle number

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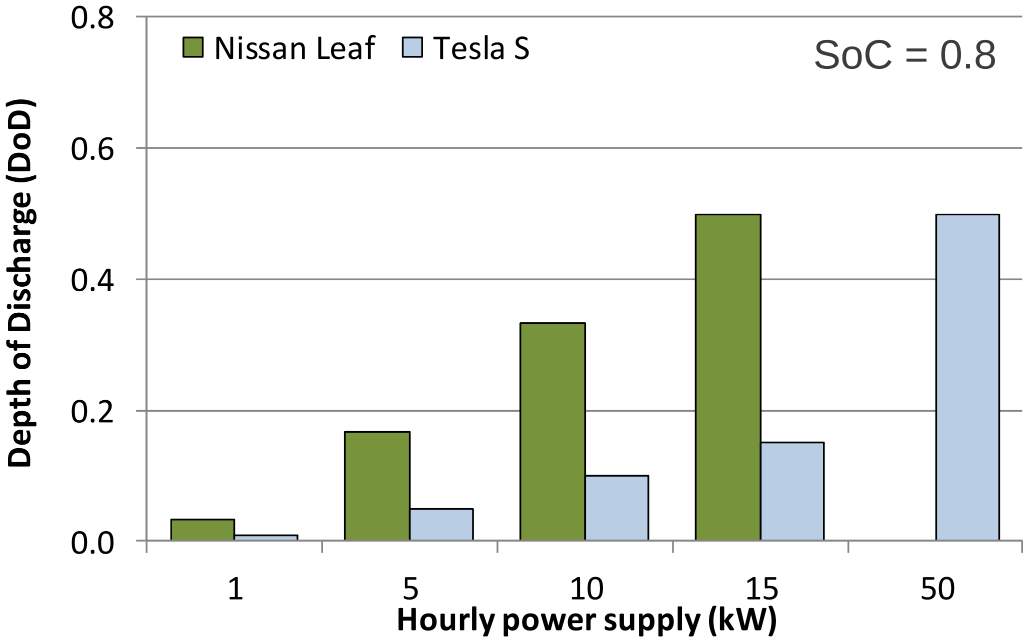
$$C_{rate} = \frac{E\,1000}{V\,t\,K\,C}$$

Battery Degradation

Vehicle assumptions

		Nissan Leaf	Tesla S
Capacity	kWh	30	100
Cell capacity (C)	Ah	33	3
Temperature (T)	K	288	288
Time (t)	h	1	1
Par. Connections (K)	-	2	72
SOC	-	0.8	0.8

Depth of Discharge (DoD) depends on power supply & State of Charge (SoC)



DoD for 5 kWh power supply

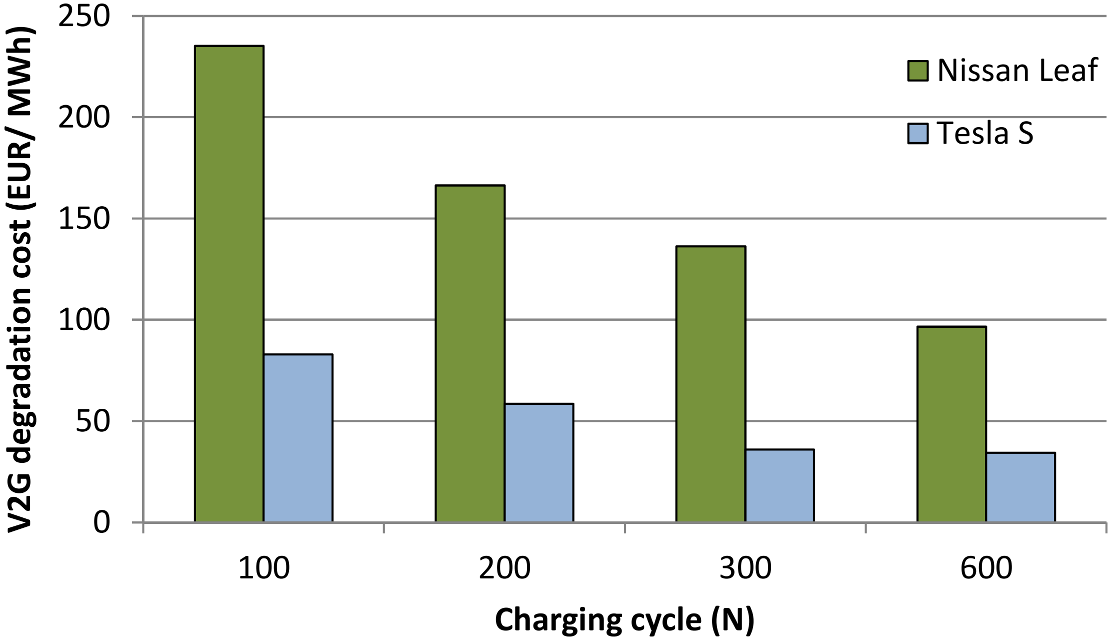
- Leaf - 0.17
- Tesla - 0.05

Hourly power supply for DoD = 0.5

- Leaf - 15 kWh
- Tesla - 50 kWh

→ Tesla can provide more power to the grid than Nissan due to battery size

V2G degradation cost depends on previous vehicle use and type of vehicle



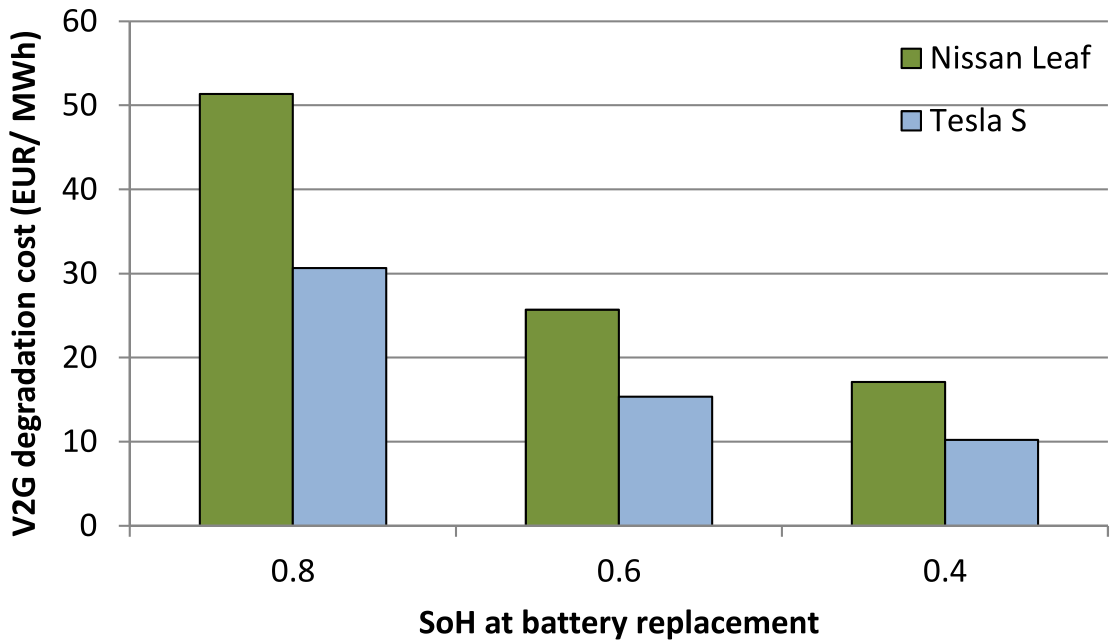
Battery replacement
- State of Health (SoH) = 80%

Battery replacement cost
- Nissan Leaf
  - 5 500 USD = 4 873 EUR
  - 4873/ 30 kWh = 162 EUR/ kWh

One charging cycle
- Nissan 10 MWh/ 36 km
- Tesla 30 MWh/ 108 km

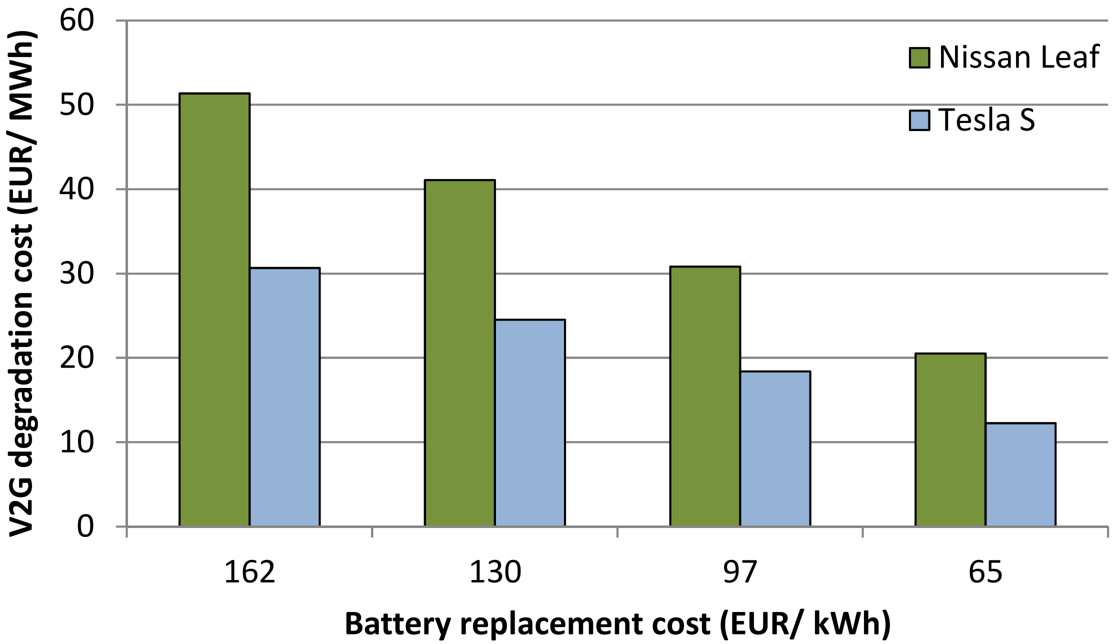
→ Degradation cost decreases with previous vehicle use & battery size

V2G degradation cost depends on State of Health (SoH) at battery replacement



→ **Degradation cost is proportional SoH at replacement**

V2G degradation cost depends on battery replacement cost



Average cycle number

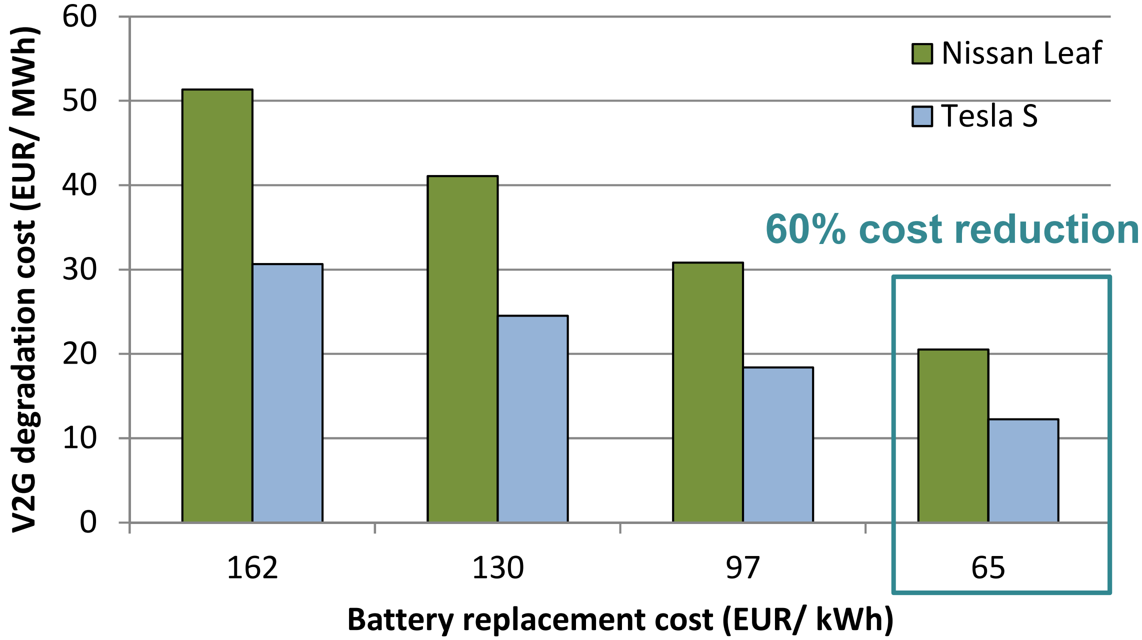
- Nissan N = 2100
- Tesla N = 725

Battery replacement cost

- New battery cost
- Value of used batteries

→ **Degradation cost is proportional with battery replacement cost**

V2G degradation cost depends on battery replacement cost



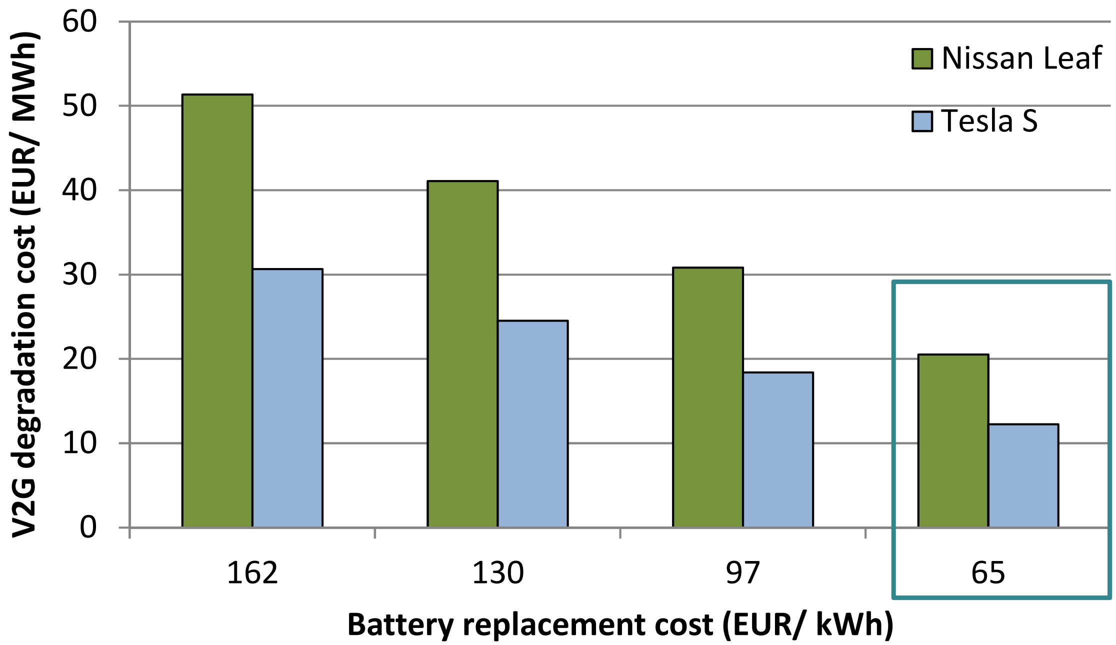
Optimistic V2G degradation cost

- Nissan - 21 EUR/ MWh
- Tesla -12 EUR/ MWh

Max price difference 10th June 2018 (EUR/ MWh)

- DK1 19
- DK2 104
- SE1-SE3 8
- SE4 24
- NO1-NO2,NO5 7
- NO3-NO4 8

V2G degradation cost depends on battery replacement cost



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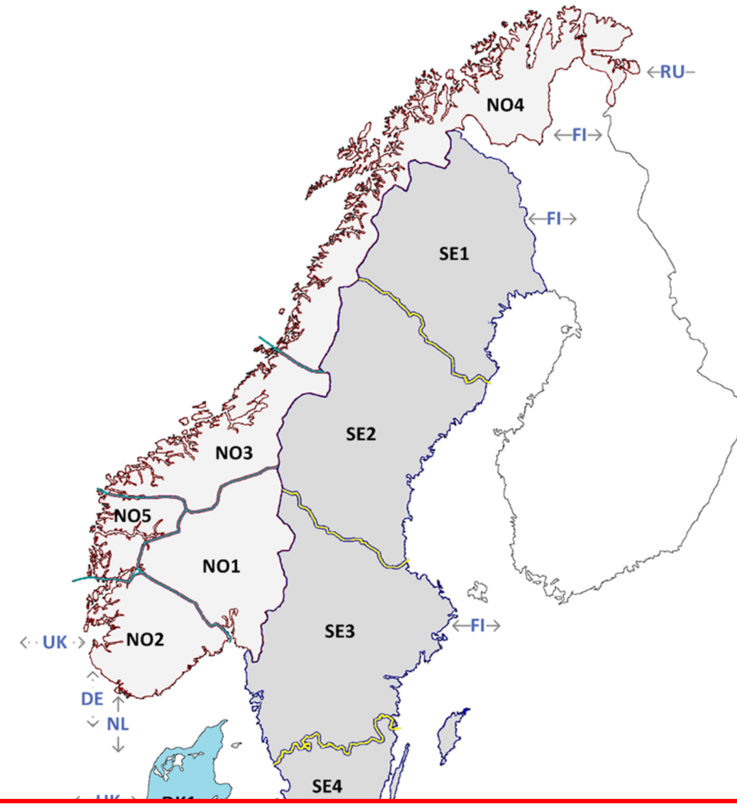
→ **Use of V2G depends on short-term price differences**

Energy system model

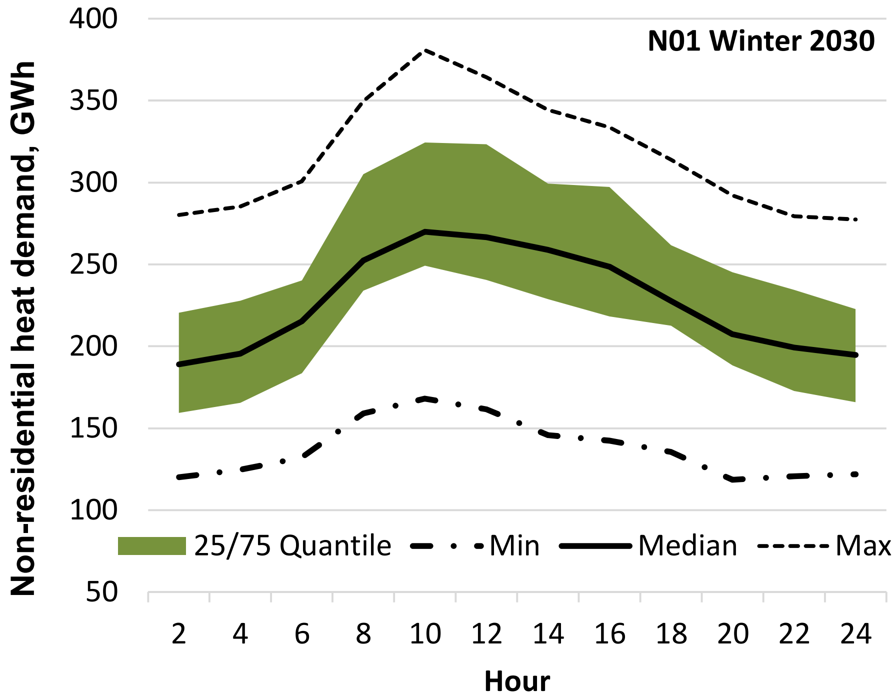
- TIMES-Scandinavia
  - Energy system in Denmark, Norway and Sweden
  - Sub regions: Spot price regions
  - Model period: 2010 – 2050
  - End-use sectors: Buildings, Industry and Transport
  - Supply sectors: Power, District heat, Hydrogen and Biomass



Provide investments and operation of energy system to meet the future demand for energy services at a lowest possible cost

Stochastic modelling of short-term uncertainty

- 21 stochastic scenarios to capture short-term uncertainty of
  - Hydropower production
  - Wind power production
  - PV production
  - Heat demand
  - Power prices outside Scandinavia
- Minimise investment costs + expected operational costs



→ Investments are feasible and consider 21 different operational situations

Modelling of V2G

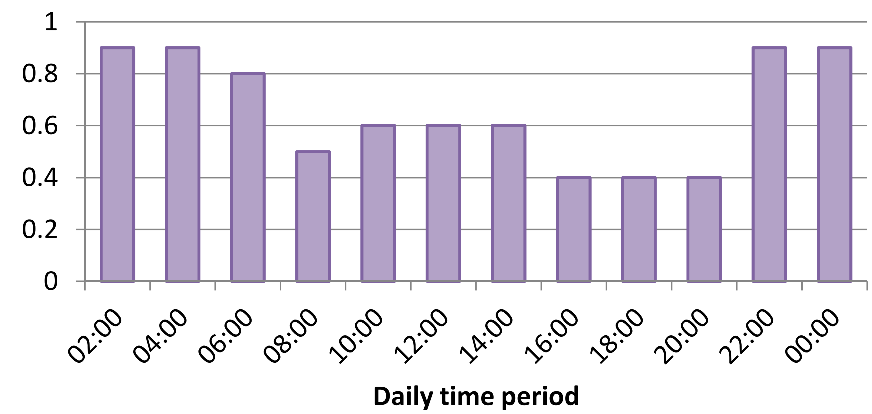
- **Two types of electric vehicles**
  - Long distance «Tesla»
  - Short distance «Nissan»

- **Model constraint**

$$\alpha_i(\sum EV_i) - V2G_i \geq 0$$

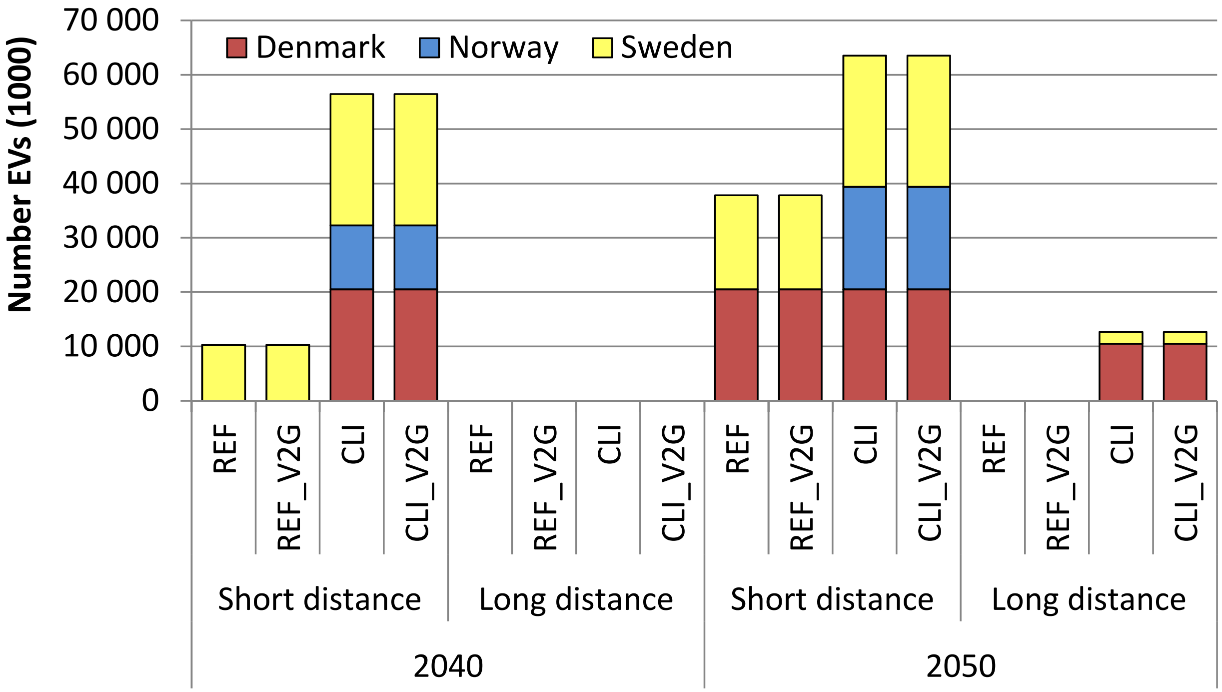
- **Alfa depends on**
  - Vehicle type i
  - Depth of Discharge (DoD)
  - Share of Grid connected EV's

- **Grid connection assumptions**



- **V2G is modelled as a storage option**
  - Operational cost = Degradation cost
  - Loss 10%

Results- Availability of V2G has no impact on cost-optimal number of EVs



REF

- No CO_2 restrictions

CLI

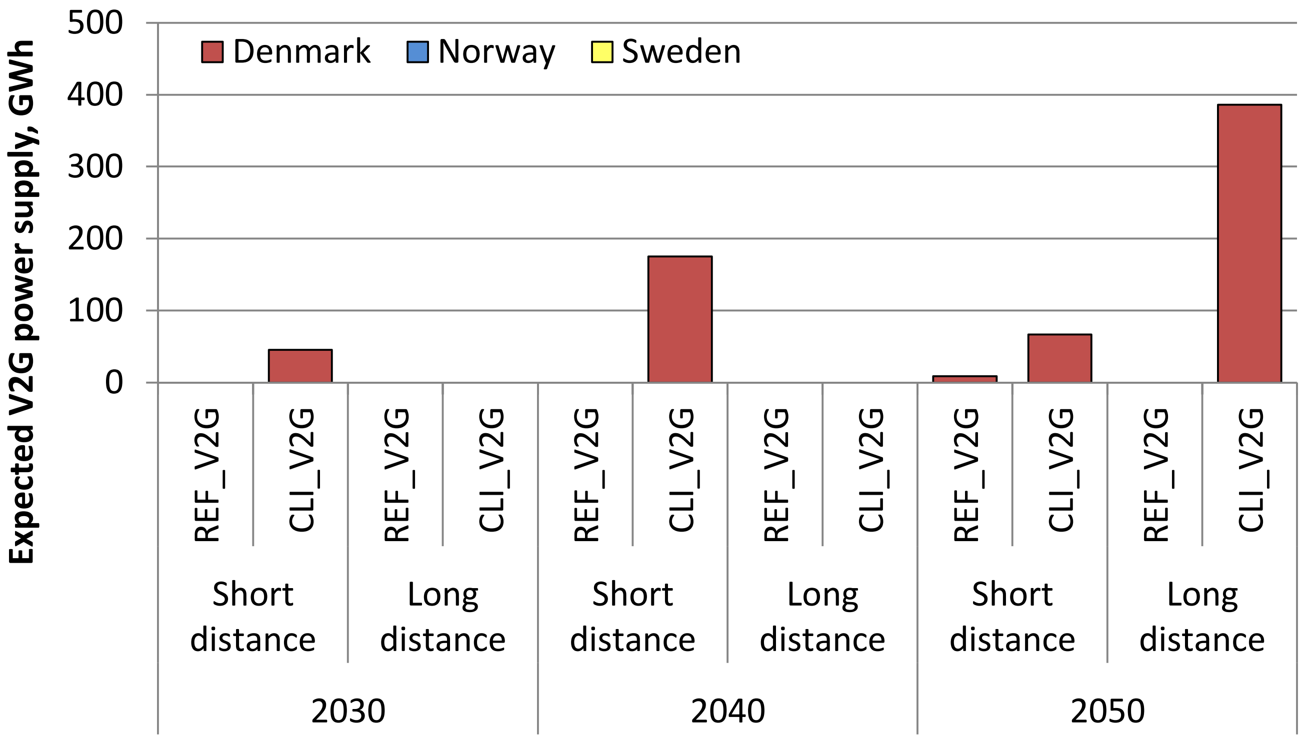
- Climate neutrality

Assumptions

- Annual driving length
  - 15 000 km

→ **Long distance EVs are only cost-optimal with climate neutrality**

Results- Only V2G in Denmark among the Scandinavian countries



REF

- No CO_2 restrictions

CLI

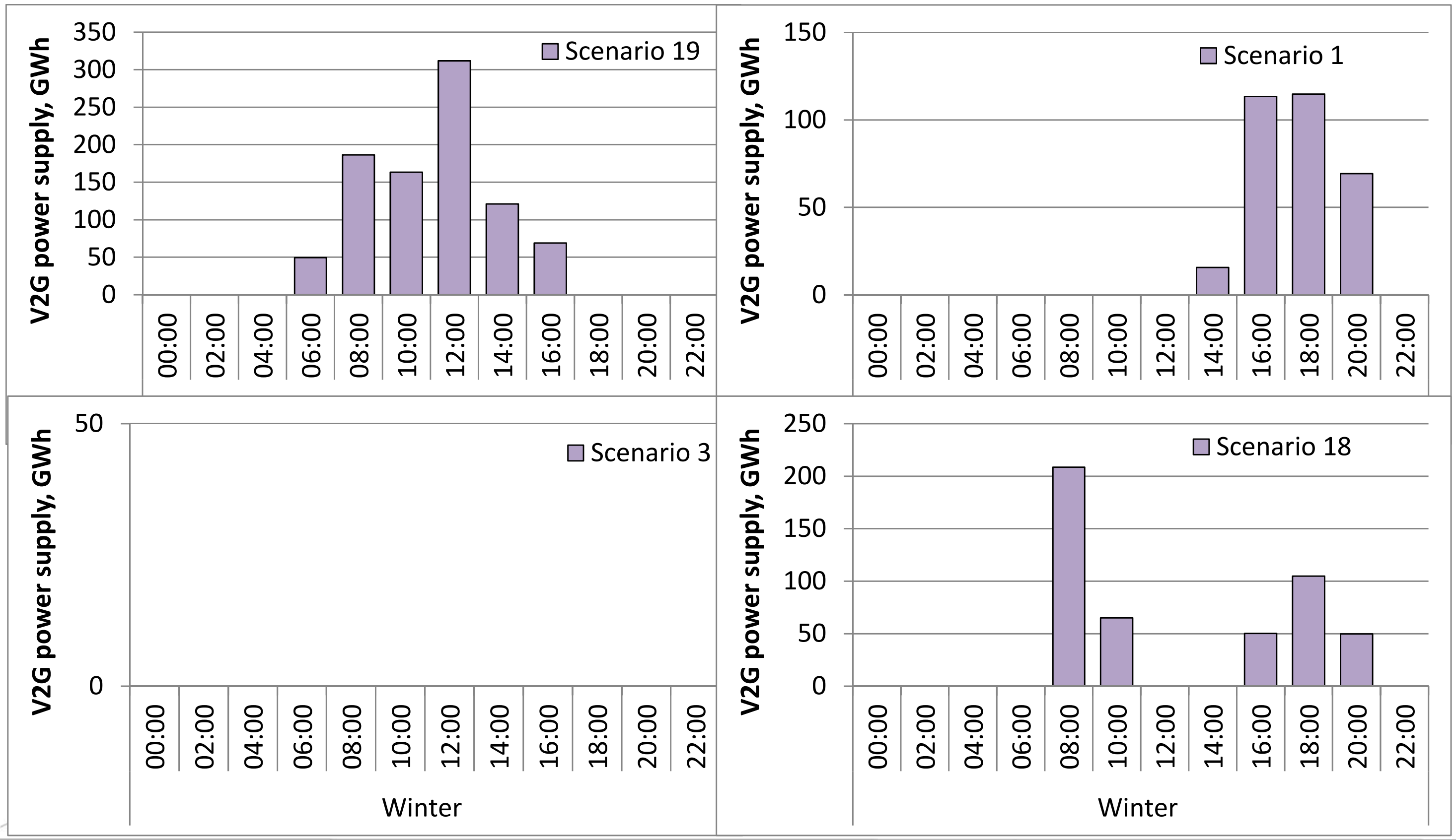
- Climate neutrality

Long distance

- Expected: 386 GWh
- Minimum: 0 GWh
- Maximum: 1338 GWh (Scenario 19)

→ **V2G from long-distance vehicles is the preferable option**

Results- Use of V2G depends on operational conditions (renewable production & heat demand)



Figure

- DK1
- Winter
- 2050
- Long distance

No use of V2G in a deterministic model!

Results- V2G influences electricity price

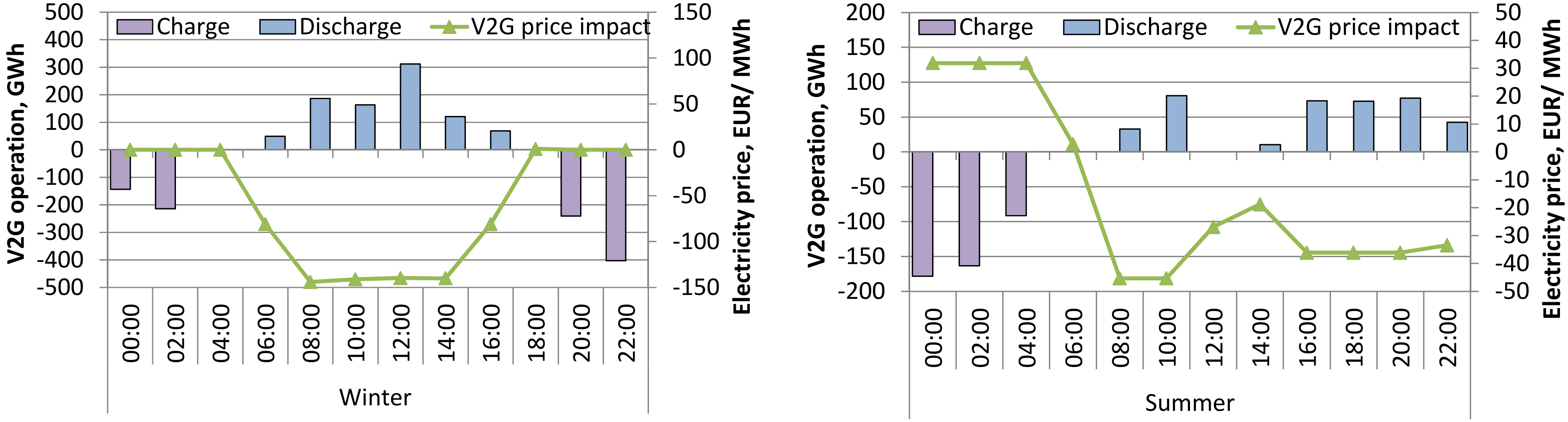
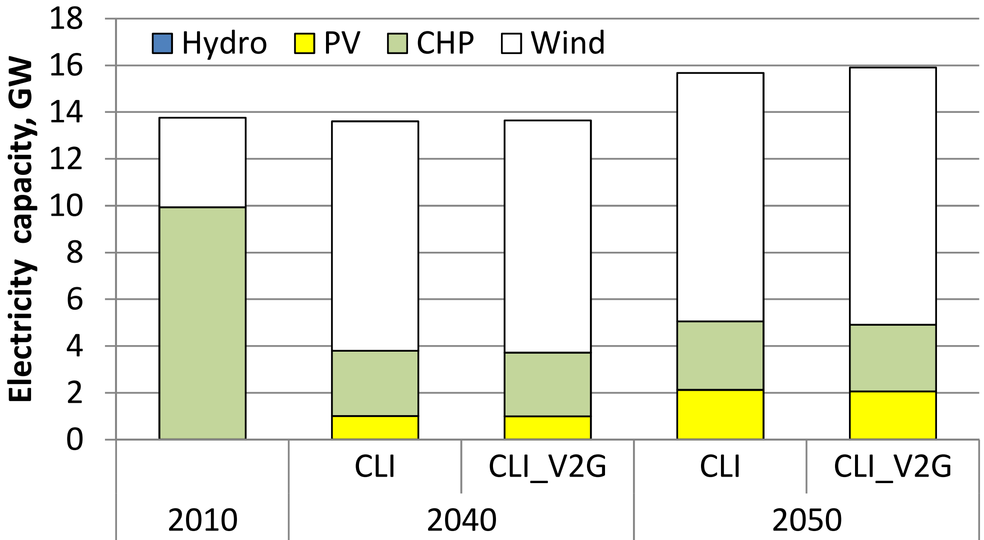


Figure: Operation of V2G in Scenario 19, DK1 2050

Results- V2G has a limited effect on electricity capacity in Denmark



	2010	2040 CLI	2040 CLI_V2G	2050 CLI	2050 CLI_V2G
Wind	3.82	9.81	9.94	10.61	11.00
CHP	9.92	2.79	2.72	2.93	2.84
PV	0.01	1.00	0.98	2.13	2.06
Hydro	0.01	0.01	0.01	0.01	0.01

- In 2050, V2G results in
  - 4% more wind power
  - 3% lower PV
  - 3% lower CHP
- V2G also gives lower investments in electricity based heating capacity

Concluding remarks

- **V2G degradation decreases with EV battery size**
  - "Tesla S" has 40% lower degradation cost than "Nissan Leaf"
- **V2G degradation cost is highly depend battery replacement cost and State of Health at replacement**
- **Optimistic V2G degradation cost assumptions in Scandinavia**
  - V2G only utilised in Denmark
  - Use of V2G increases with climate neutrality
  - V2G influences electricity prices, electricity generation capacity and heating capacity
- **Value of V2G cannot be addressed appropriately in a deterministic model- with one operational scenario only**

Thank you for your attention!

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