

DTU

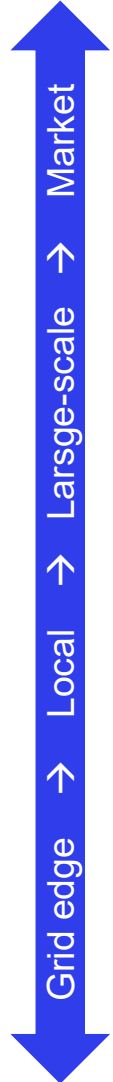


Henrik W. Bindner

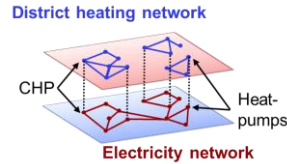
2025.11.27, Emobility Cyprus, University of Cyprus

Building the flexibility options for tomorrow

Division for Power and Energy System

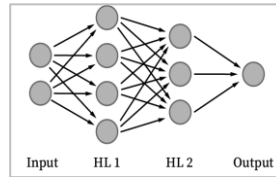


Energy Markets and Analytics



- Market designs for sector coupling
- Data markets
- Investment model for power flexibility services
- DSO-markets
- Peer-to-peer markets

Power Systems



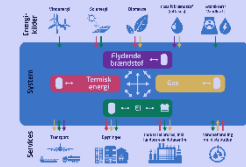
- RES-dominated power system stability, analysis, and control
- Energy islands, HVDC and offshore wind
- Cyber-physical energy systems
- Trustworthy AI for power system operations
- Real-time numerical methods and Quantum Computing

Power-to-X and Storage



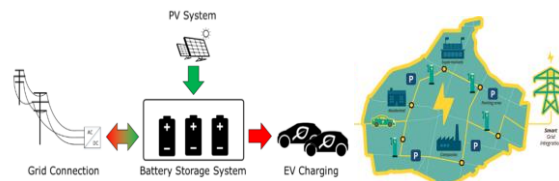
- Power-to-X and battery plants
- Flexibility, hybridization and grid integration
- Advanced physical modelling, testing and validation
- Advanced diagnostics and data driven state estimation
- Secure and optimal operation, scale-up and use cases

Distributed Energy Systems



- Active distribution networks planning, operation and integration
- Flexibility integration in system operation, control and planning
- Sector coupling and multi-energy system design and operation
- Cyber-physical energy/power systems modelling and testing
- Local energy systems, design, control and integration

E-mobility and Prosumer Integration



- Flexibility from electrical transportation and V2G
- Experimental characterization of electric vehicles and drives
- EV battery degradation and usage patterns
- Microgrids and behind-the-meter applications
- Charging infrastructure design and operation

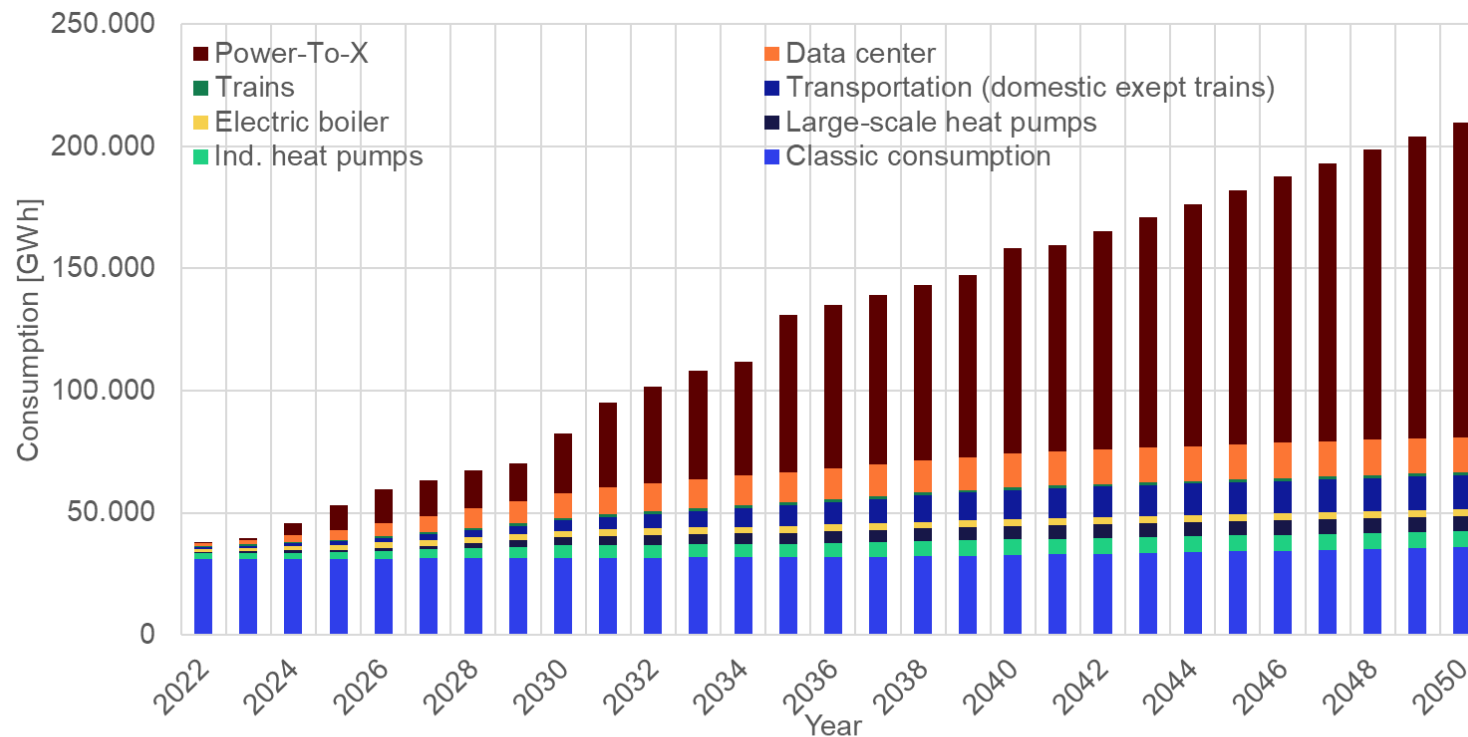
Outline

- Introduction
- Status on EV development in Denmark
- Development of charging patterns
- Flexibility
- Conclusions

Introduction

An evolving landscape in DNs

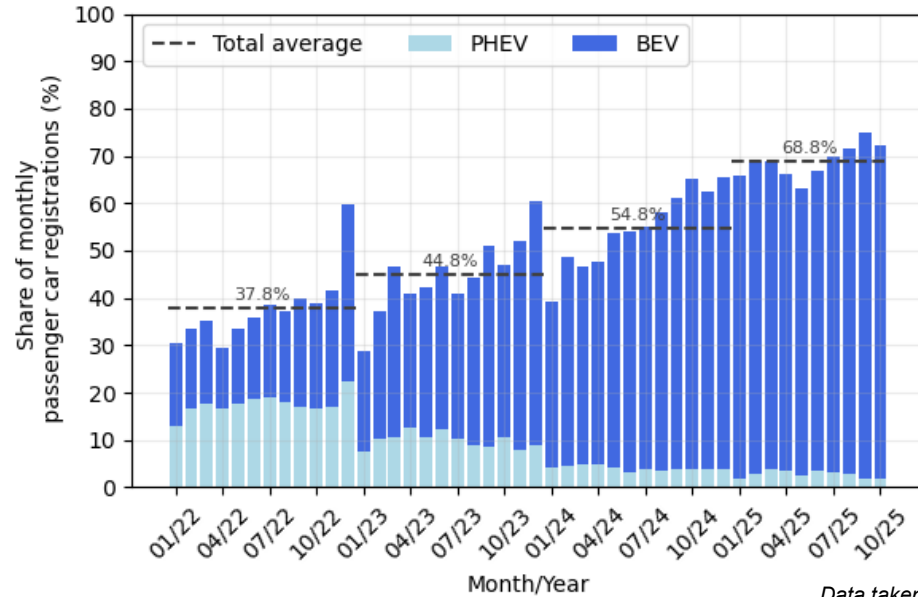
- Electrification in Denmark is accelerating



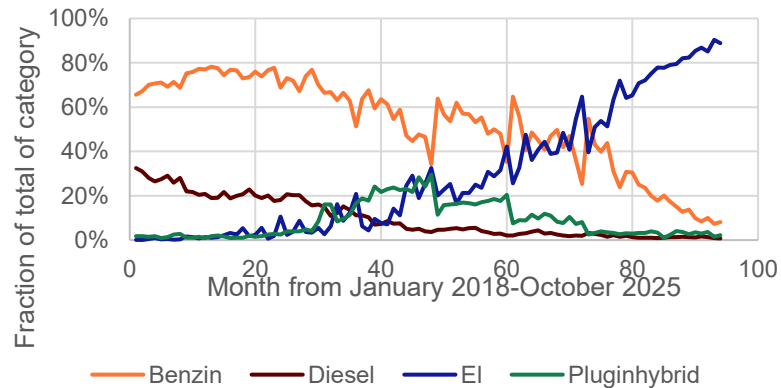
Source: Danish Energy Agency, Analyseforudsætninger til Energinet 2022 (AF22), May 2023

<https://ens.dk/service/fremskrivninger-analyser-modeller/analyseforudsætninger-til-energinet>

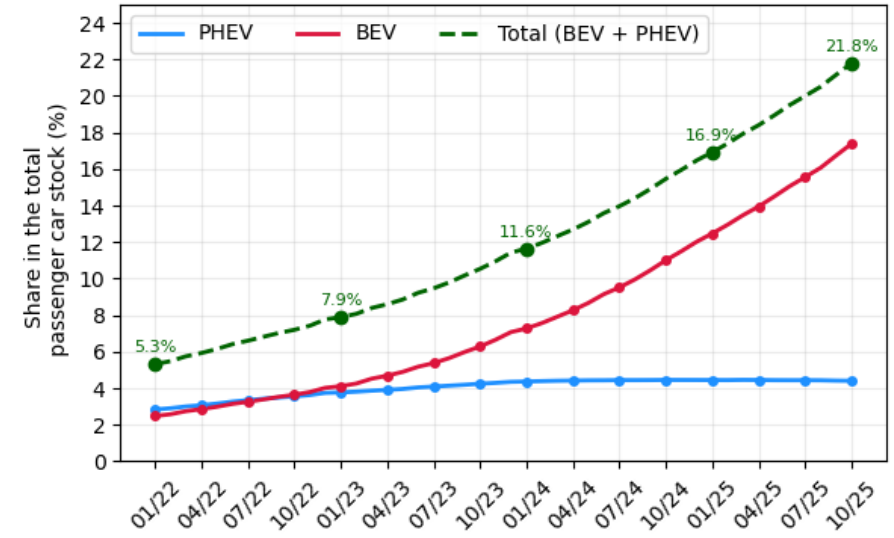
EVs are taking off (now for real)



Cars, private

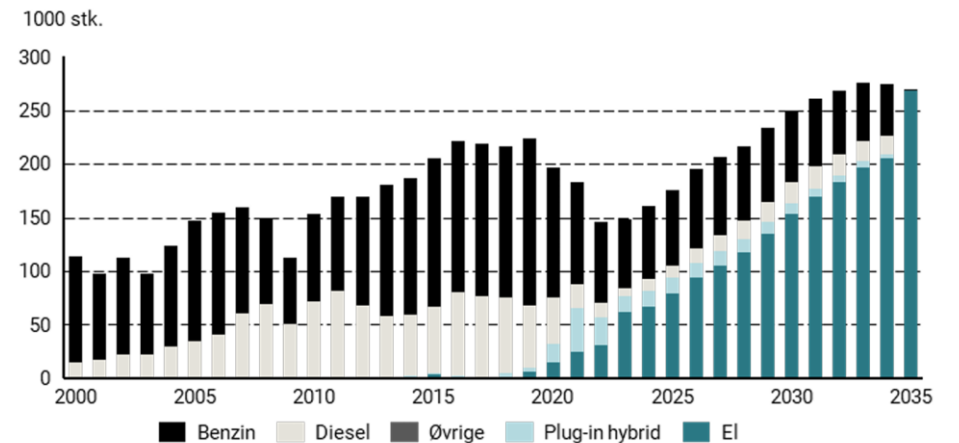


Source: Danmarks Statistik, Nov 2025



Figur 21.5

Salg af nye personbiler, 1.000 stk.



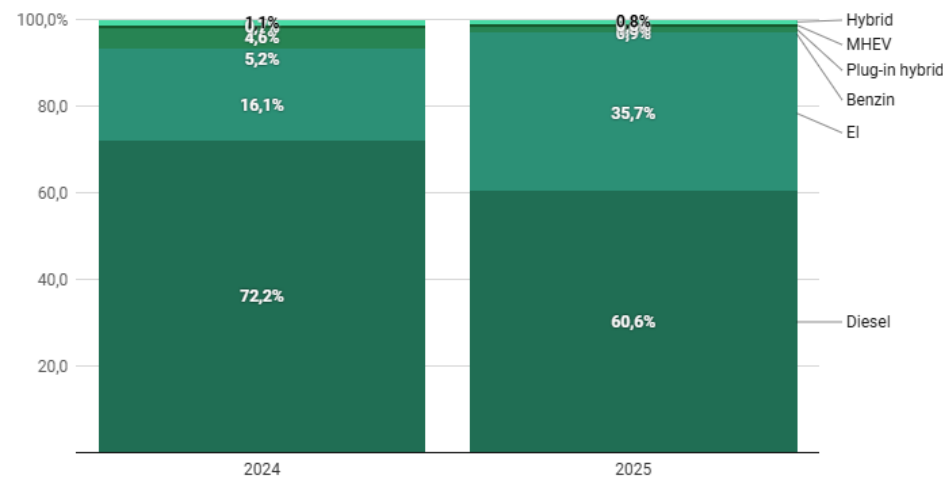
Source: Danish Energy Agency: Klimastatus og -fremskrivninger 2024

Commercial vehicles

- The commercial vehicles are also being electrified
- New Small lorries are dominated by electric propulsion
- The fraction of new vans that are electric has doubled in last year and is now 36%
- Even large trucks are beginning to be electric

Drivmiddelfordeling september 2024 vs. 2025

Varebiler, fordelt på drivmiddel

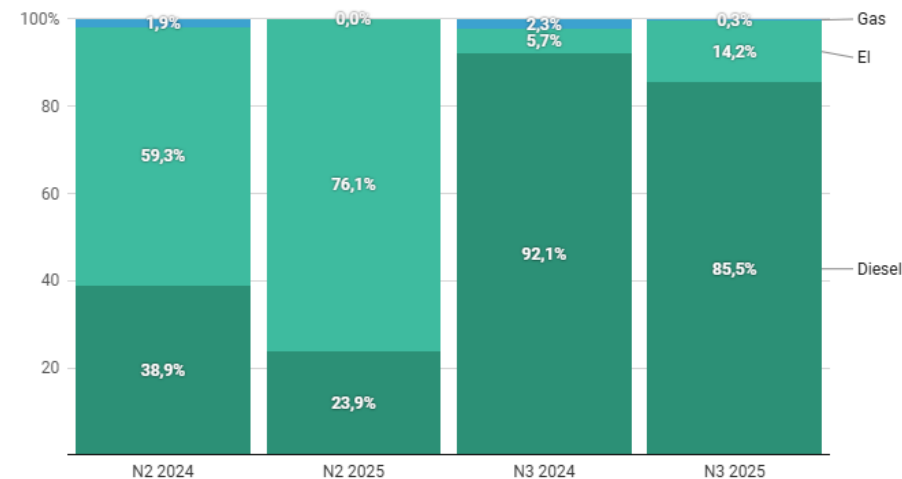


(Baseret på nyregistreringer)

Grafik: Mobility Denmark • Kilde: Bilstatistik.dk • Lavet med Datawrapper

Drivmiddelfordeling september 2024 vs. 2025

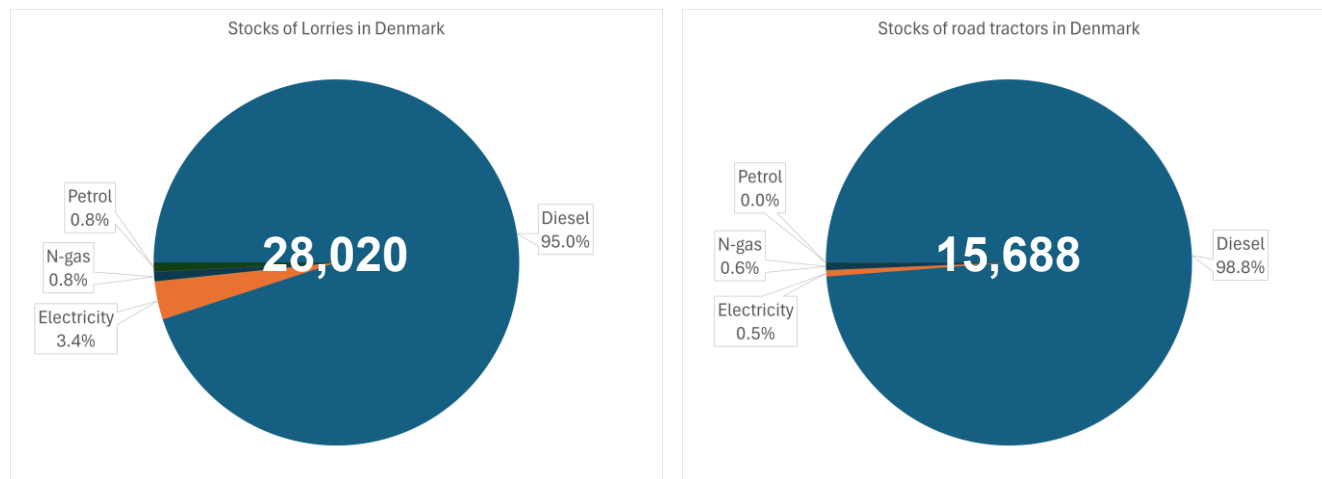
N2 + N3 lastbiler, fordelt på drivmiddel



(Baseret på nyregistreringer)

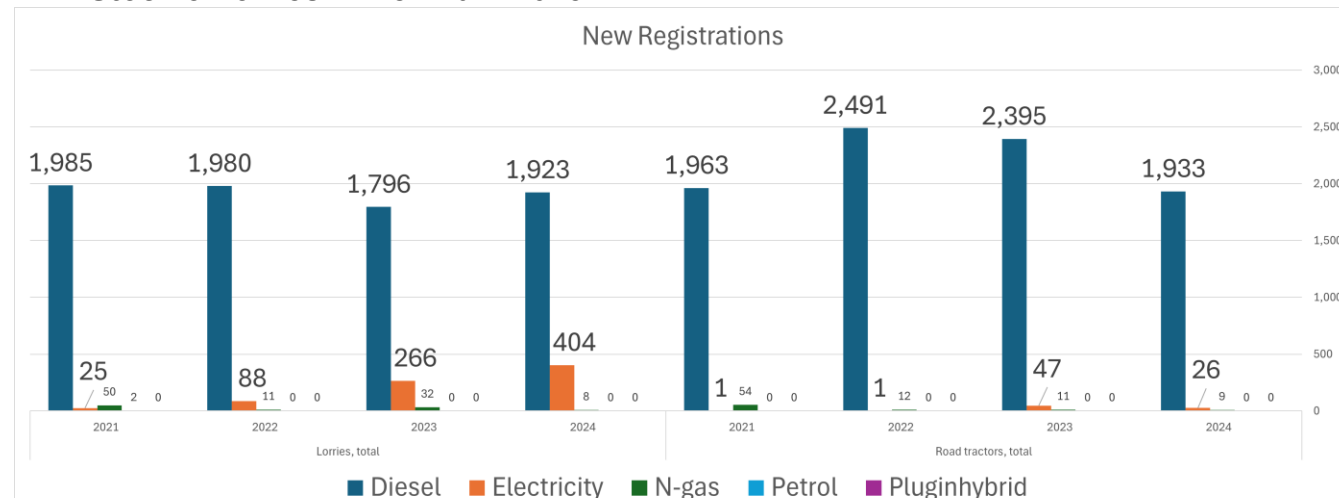
Grafik: Mobility Denmark • Kilde: Bilstatistik.dk • Lavet med Datawrapper

Heavy duty vehicle (HDV) electrification in Denmark

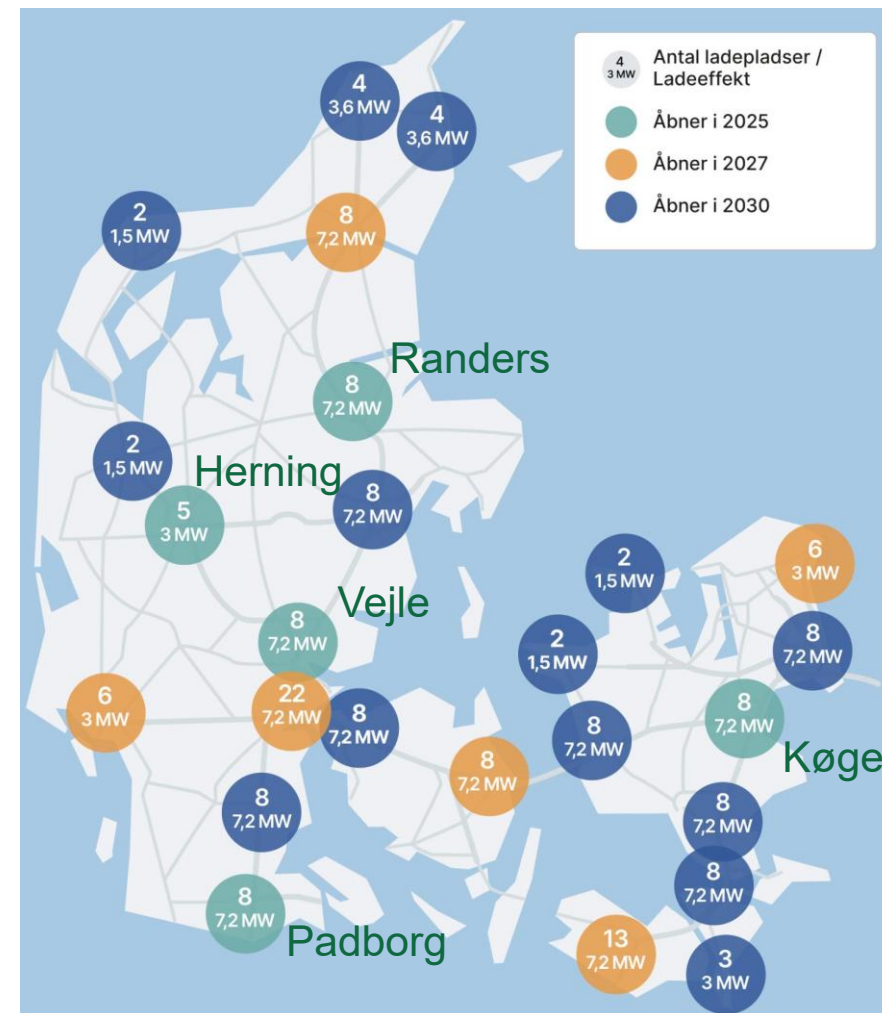


Stock of lorries in Denmark 2025

Stock of road tractors in Denmark 2025



New registrations of heavy vehicles by propellant



Charging infrastructure plan for heavy transport

Triggers for the development

- EVs have a significant rebate from registration taxes that are very high in Denmark
- You can have the electricity taxes lifted
 - 0.90DKK/kWh ~ 0.12€/kWh
- The infrastructure has been developed at the same time
 - There are more than 30000 public charging points
 - 4000 of them are fast chargers (>100kW)
 - They are privately owned and operated

Eksempel på beregning af bilafgift 2025

Eksempel i 2025 på en Plug-in hybrid til 300.000 kr. stålpris inkl. moms med et CO₂-udslip på 120 g/km

1. Værdiberegning: 300.000 kr. inkl. moms (afgiftspligtig værdi)

25% x 71.955 kr. = 17.989 kr. (afgift)

85% x (223.553-71.955) = 128.858 kr. (afgift)

150% x (296.800-223.553) = 109.871 kr. (afgift)

Basisafgift efter værdiberegning: 17.989 kr. + 128.858 kr. + 109.871 kr. = **256.618 kr.**

2. CO₂-tillæg: 31 x 280 kr. = 8.680

Totalafgift før indfasning og bundfradrag: = **265.298 kr.**

Bundfradrag (alle biler):

265.298 kr. - 23.985 kr. = **241.313 kr.**

3. Indfasning: 65% x 241.313 kr. = **156.853 kr.**

4. Bundfradrag (lavemissionsbiler):

Totalafgift: 156.853 kr. - 45.000 kr. = **111.853 kr.**

TOTALPRIS

300.000 kr. + 111.853 kr. = **411.853 kr.**



Total electricity
consumption from 2,7
mio EVs (45 km/day)



9 TWh/year

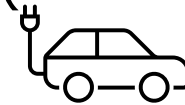
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+ 25 %

**To the Danish electricity
consumption**



Total charging
power for 2,7 mio
EVs (11 kW)



30 GW

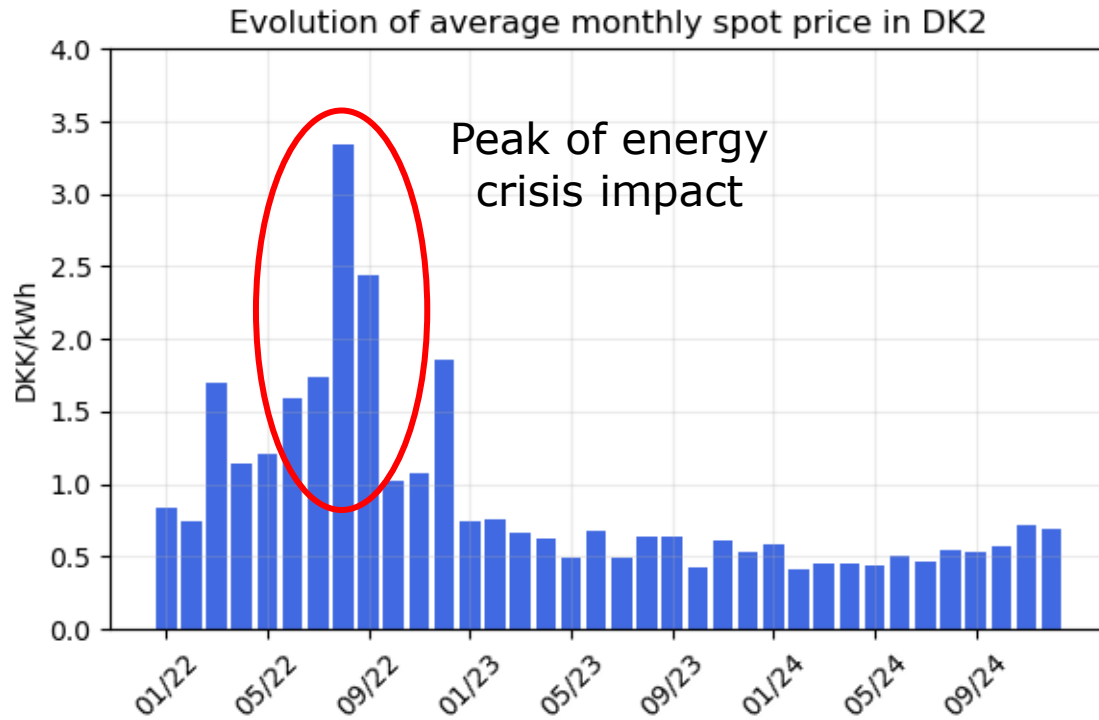
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+ 600 %

**To the peak power of
Denmarks**

Introduction: the changing landscape in DNs

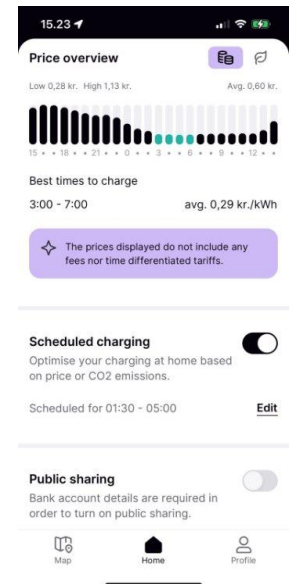
Electricity prices variability



The crazy times

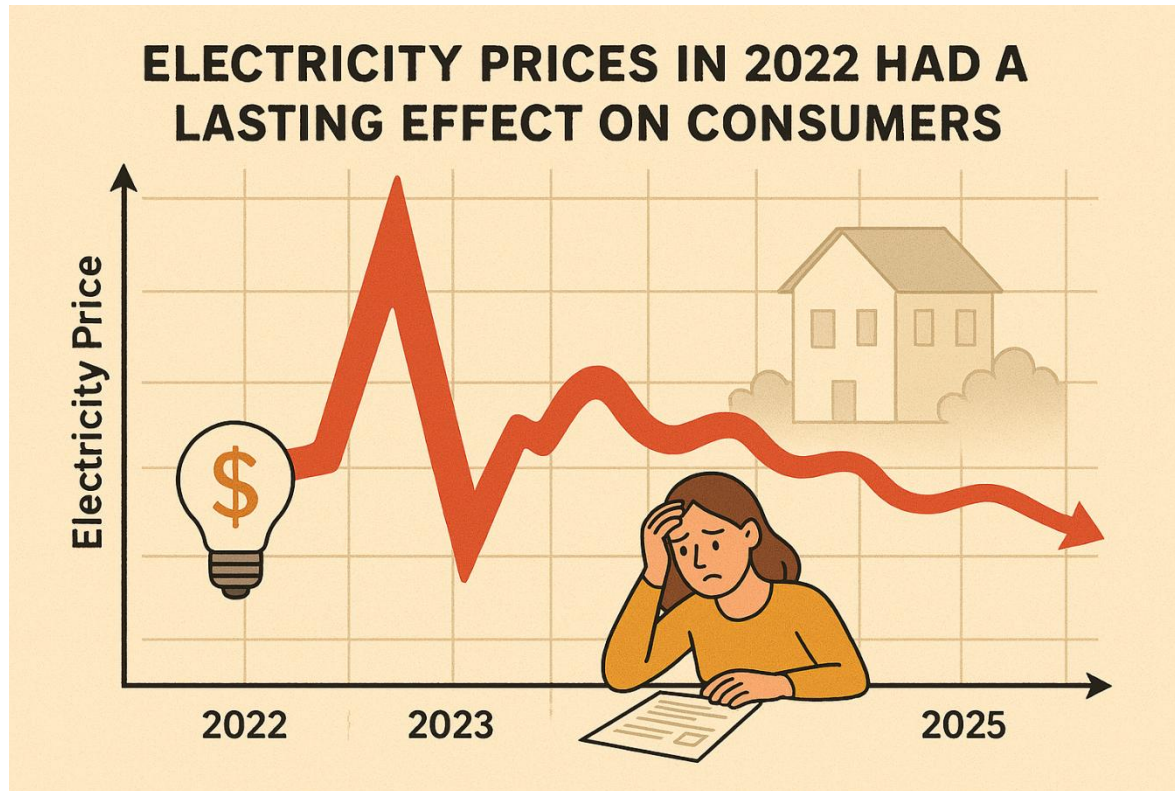


Price awareness



Introduction: the changing landscape in DNs

Electricity prices variability

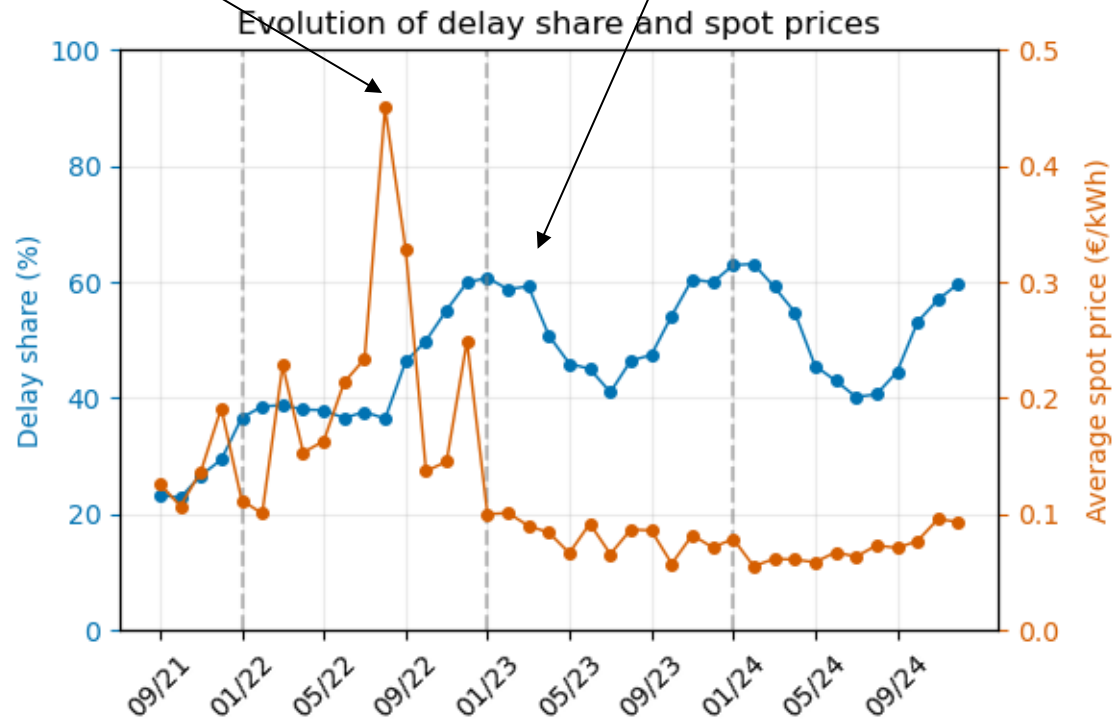


Residential EV charging flexibility in Denmark

Use of functionality vs spot prices

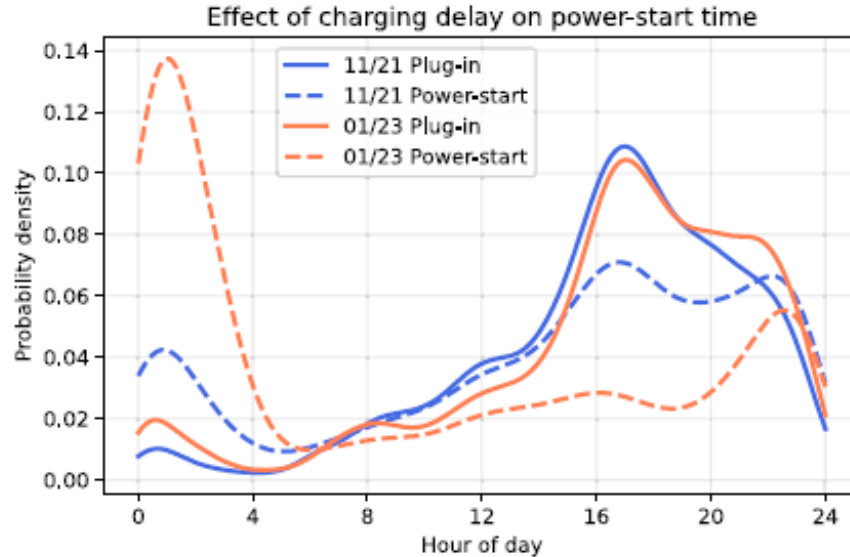
Peak of energy crisis

Permanent increase
after a few months

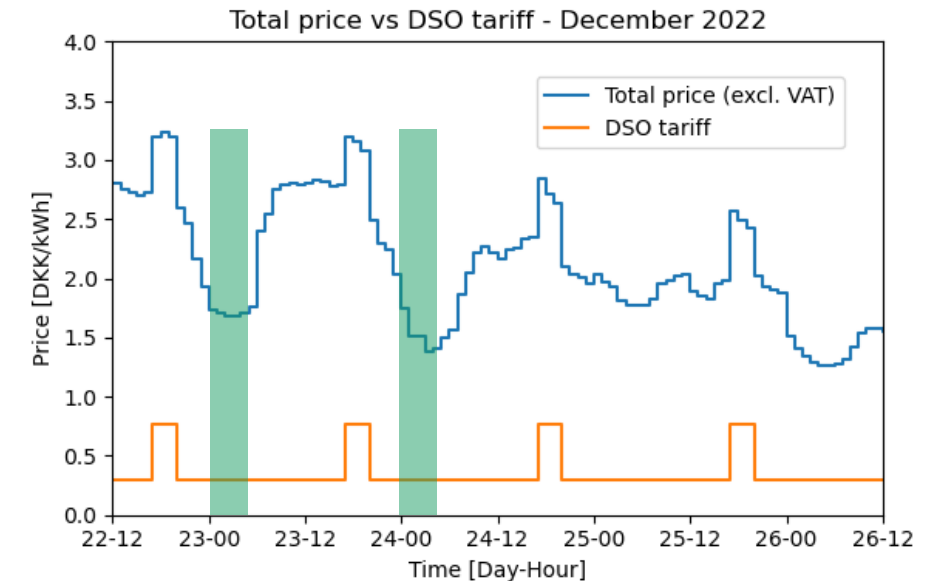
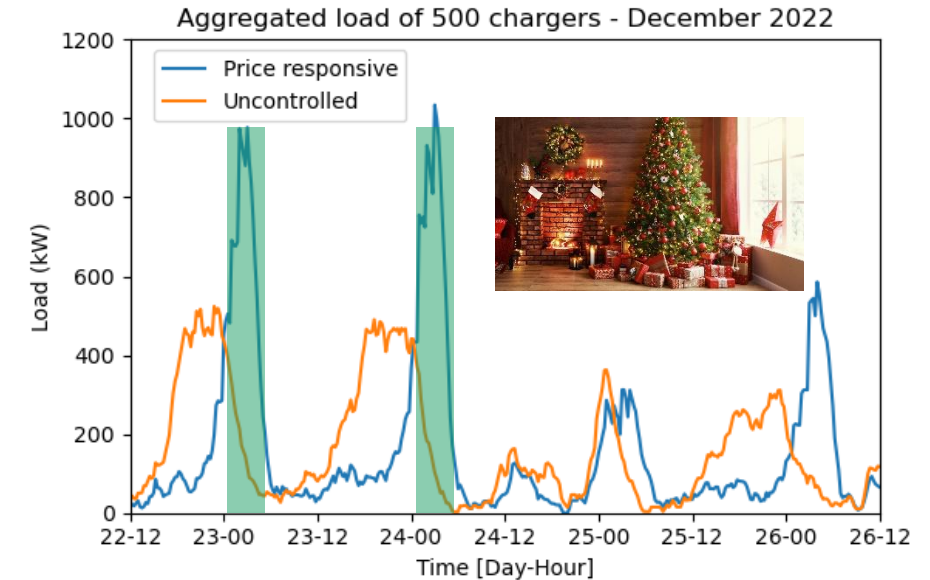


Price-responsive loads – EVs

No Christmas
peak from EVs

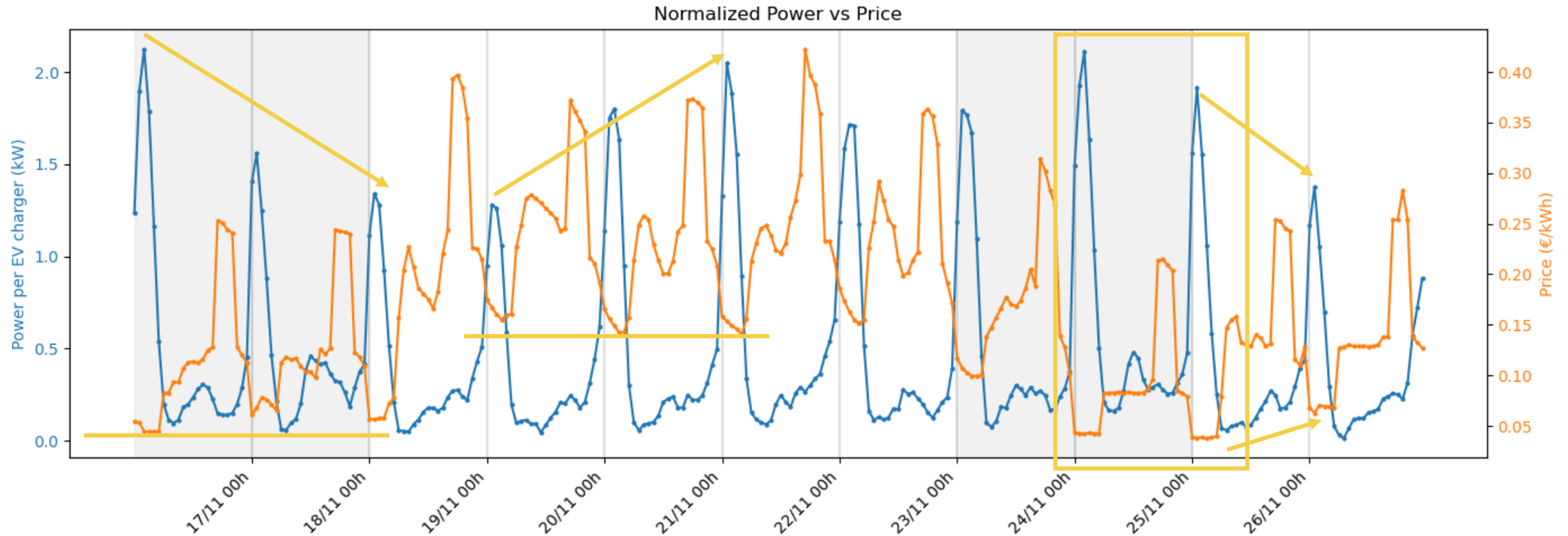


- EV users are increasingly responding to prices -> same for household appliances ?
- Peaks move towards early morning hours
- EVs do not seem to impact Christmas peaks (more data needed)



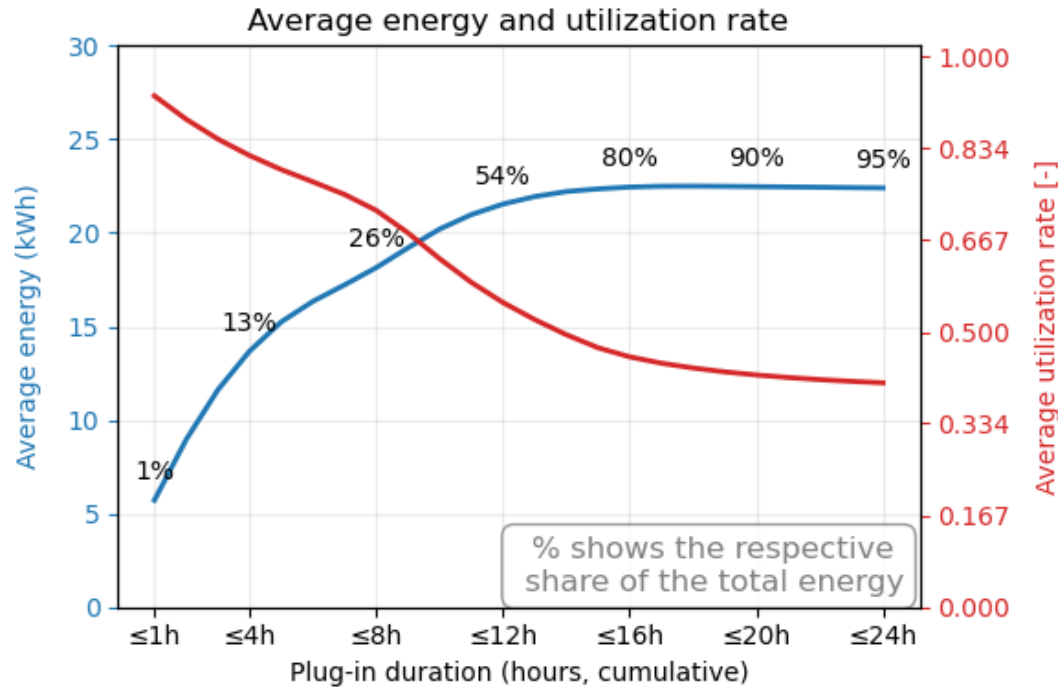
Residential EV charging flexibility in Denmark

User reaction to prices



Residential EV charging in Denmark

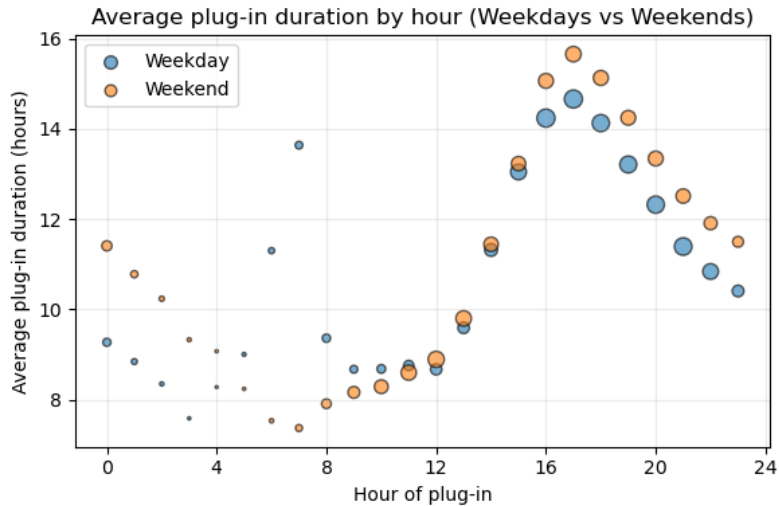
Charger utilization rate



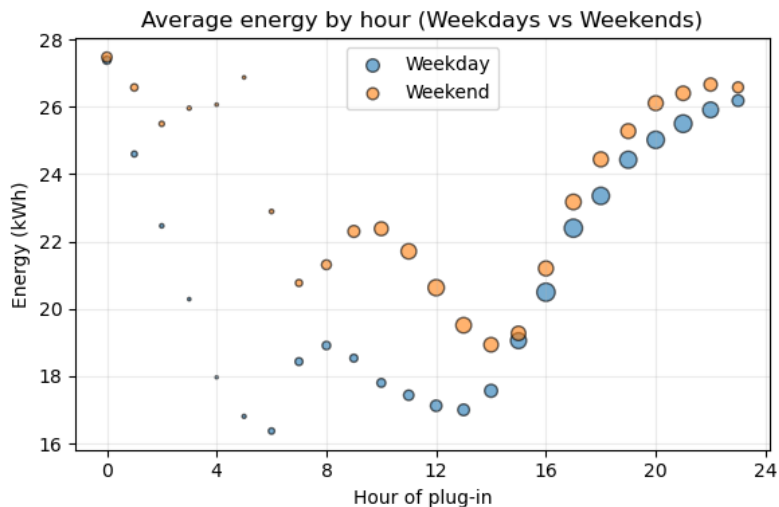
- Short sessions are practically inflexible (~20% of total)
- Noticeable flexibility in sessions longer than 6-8 h
- These sessions have also much larger energy needs

Residential EV charging in Denmark

Duration per hour of day



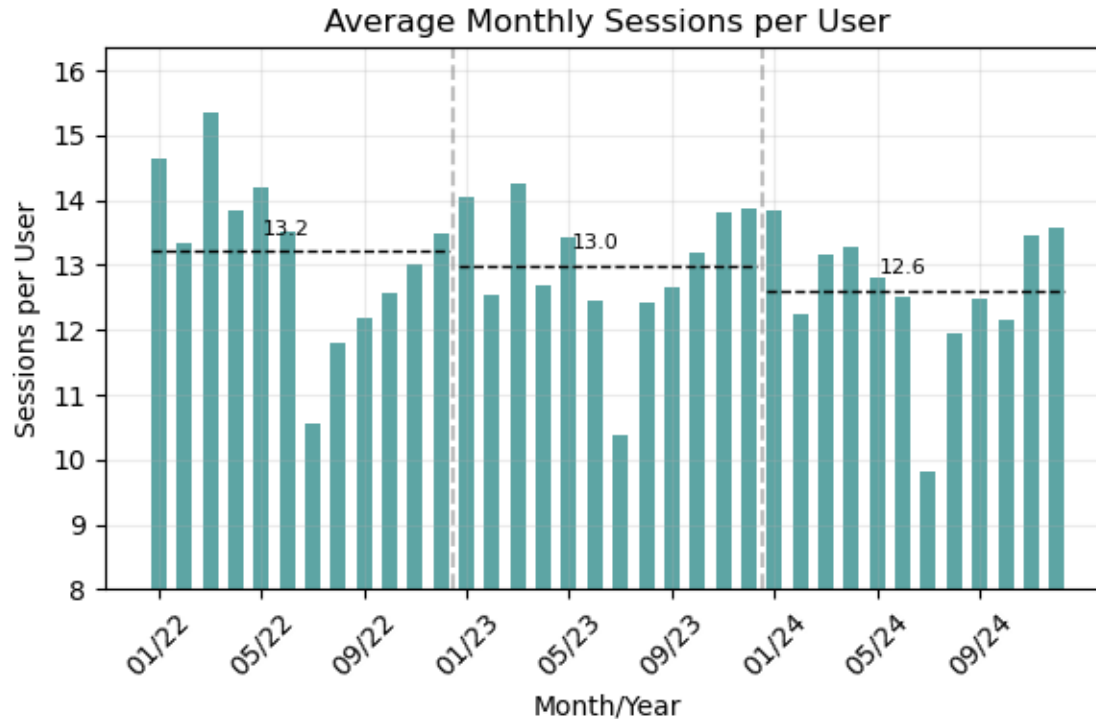
- Plug-in duration varies over the day
- Sinusoidal pattern => alignment to morning plug-out
- Plugging after 15 => overnight sessions
- Plugging 8-12 => unplug before midnight



- Midday sessions on weekdays are on average ~8kWh smaller
- The later the plug-in time, the larger the sessions in energy
- Higher energy at midday on weekends compared to weekdays

Residential EV charging in Denmark

Monthly sessions number evolution



- The number of sessions per month range from ~12 to 14
- July is an outlier due to summer holidays (~10)
- Small year-to-year decrease

DN-level congestion management

Clashing stakeholder interests?



TSO

- DER flexibility reduces system costs
- TN congestion may pose restrictions
- DER flexibility may be used for handling TN congestion



DSO

- Safe and secure operation of the DN
- DER flexibility more of a “threat”
- Long planning horizons and reinforcement times
- DN congestion largely due to DER flexibility itself



Flexible users

- Want (and pay for) unrestricted access*
- Utilize their flexibility wherever most profitable
- Minimize discomfort

DSO's requirements for (flex-based) solutions

- Requirements to flex-based solutions
 - **Solve the problems!**
 - High reliability
 - Same or lower costs than reinforcement
 - Can be operated
 - Not too complex
- Tools for identifying overloads/voltage issues
 - Online operation/Planning time scale
 - Characterization of issue: time of day, duration etc.
 - Fit for flex or reinforcement: flex available, temporary/permanent issue

DN-level congestion management

Mechanisms in Denmark



Time-of-use (ToU) tariffs

Variable network usage prices to reduced demand peaks



Local flexibility markets

DSOs buy flexibility services to resolve congestions



Bilateral agreements

Direct agreements between DSOs and customers



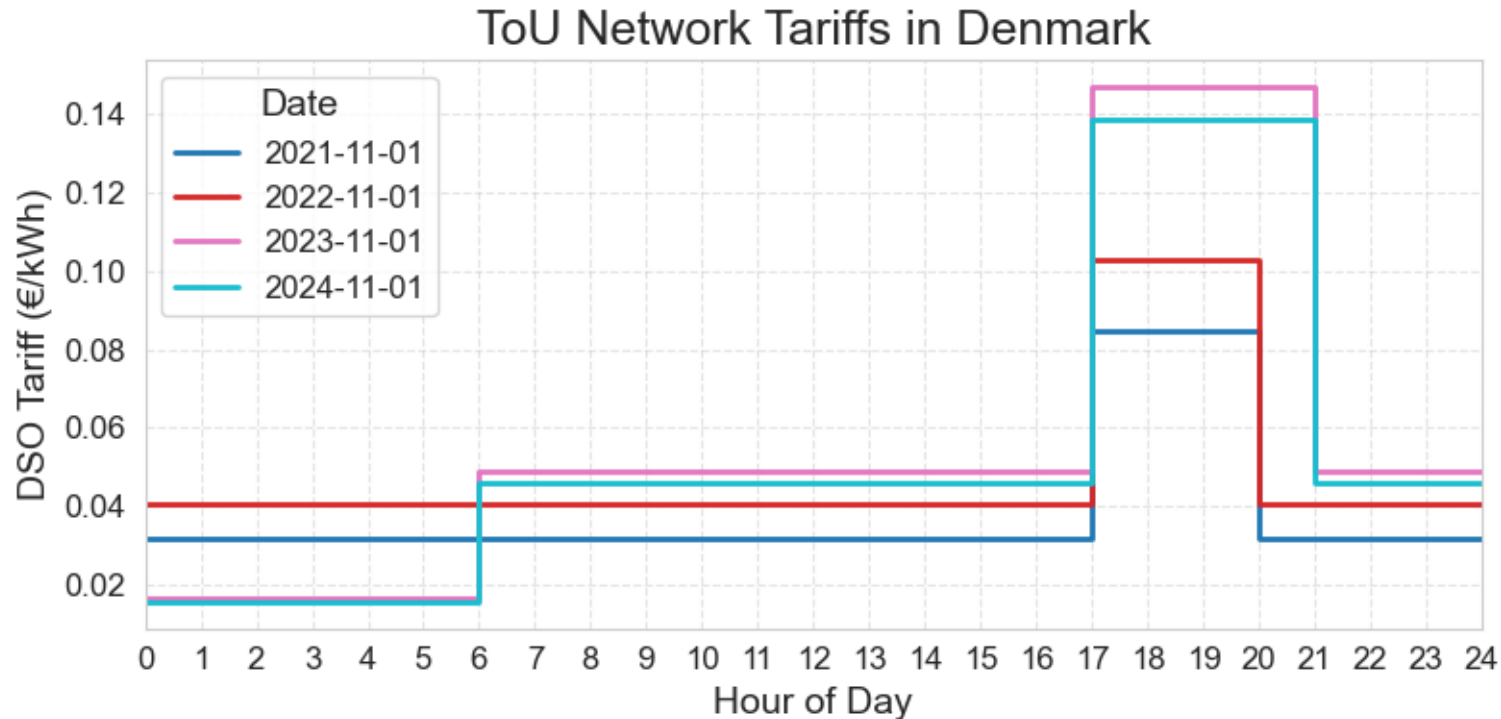
Outsourcing

DSOs outsource the safe network operation to “flexibility experts”

DN-level congestion management

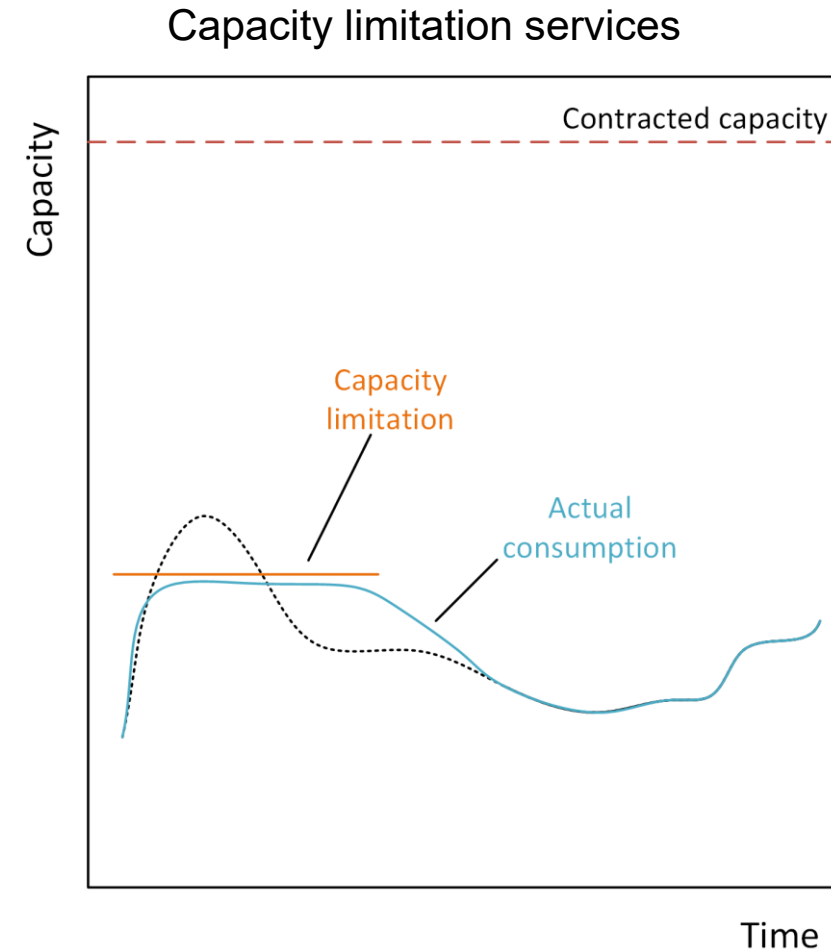
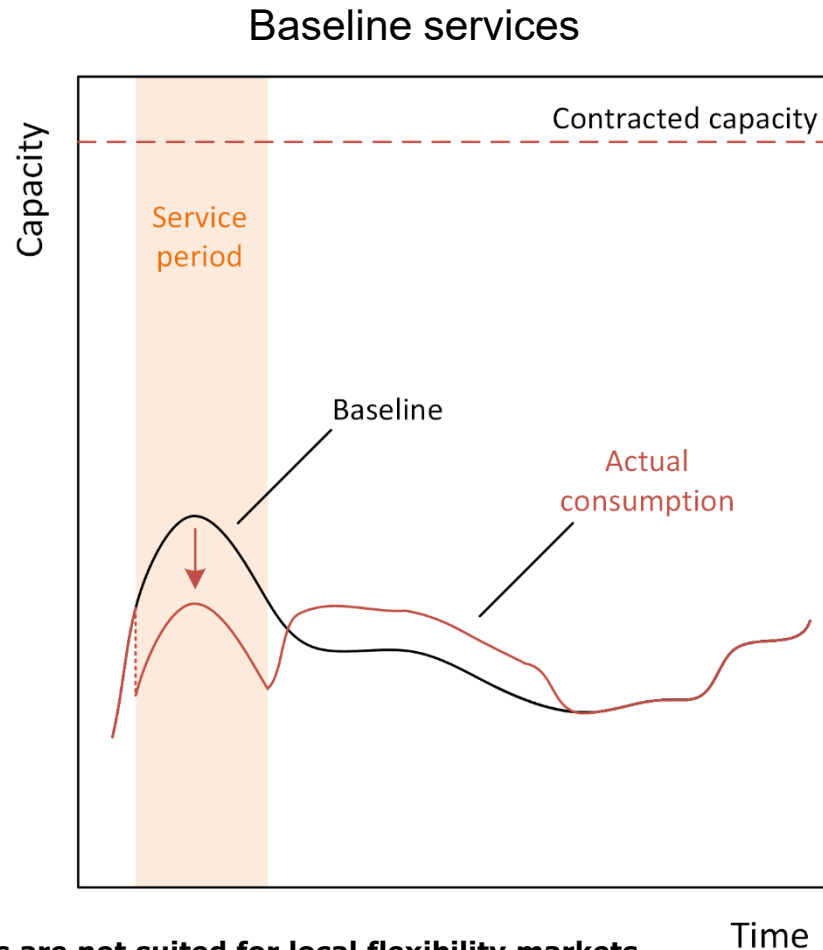
Time-of-use network tariffs

Average spot price
0.05-0.10 €/kWh



- An example from the largest DSO in Denmark (Radius, CPH area)
- 2-level tariff in 2021 and 2022
- 3-level tariff adopted in 2023
- This price structure reinforces the existing spot price pattern => higher incentive for night charging

Local Flexibility Markets design options and challenges



Ziras et al. **Why baselines are not suited for local flexibility markets,**
Renewable and Sustainable Energy Reviews, vol. 135, 2021, 110357.

Conclusions

- The shift to EVs in Denmark is happening **very fast**
- The development reaches a **tipping point** (in DK and NO) with rapid transition of sales from ICE vehicles to EV
- The charging infrastructure has been developed **concurrently** by private entities
- The charging patterns are still be developing over **significantly over time**
- People have realised the benefits of charging during low price periods
 - Achieved either through delayed charging or through energy retailer optimizing
- This leads to **synchronization**
 - There are already now cases with load peaks due to sincronized charging
- There is a large **flexibility potential** (that is already now being used for price optimization)
- The grid operators have to **request** flexibility
 - They have to **know the state of their network**
 - The services has to **benefit** the DSO
 - The services have to be **tradable and verifiable**
- The flexibility can **easily** be provided by flexibility service providers
- In Denmark there is still experimentation on how to do it!