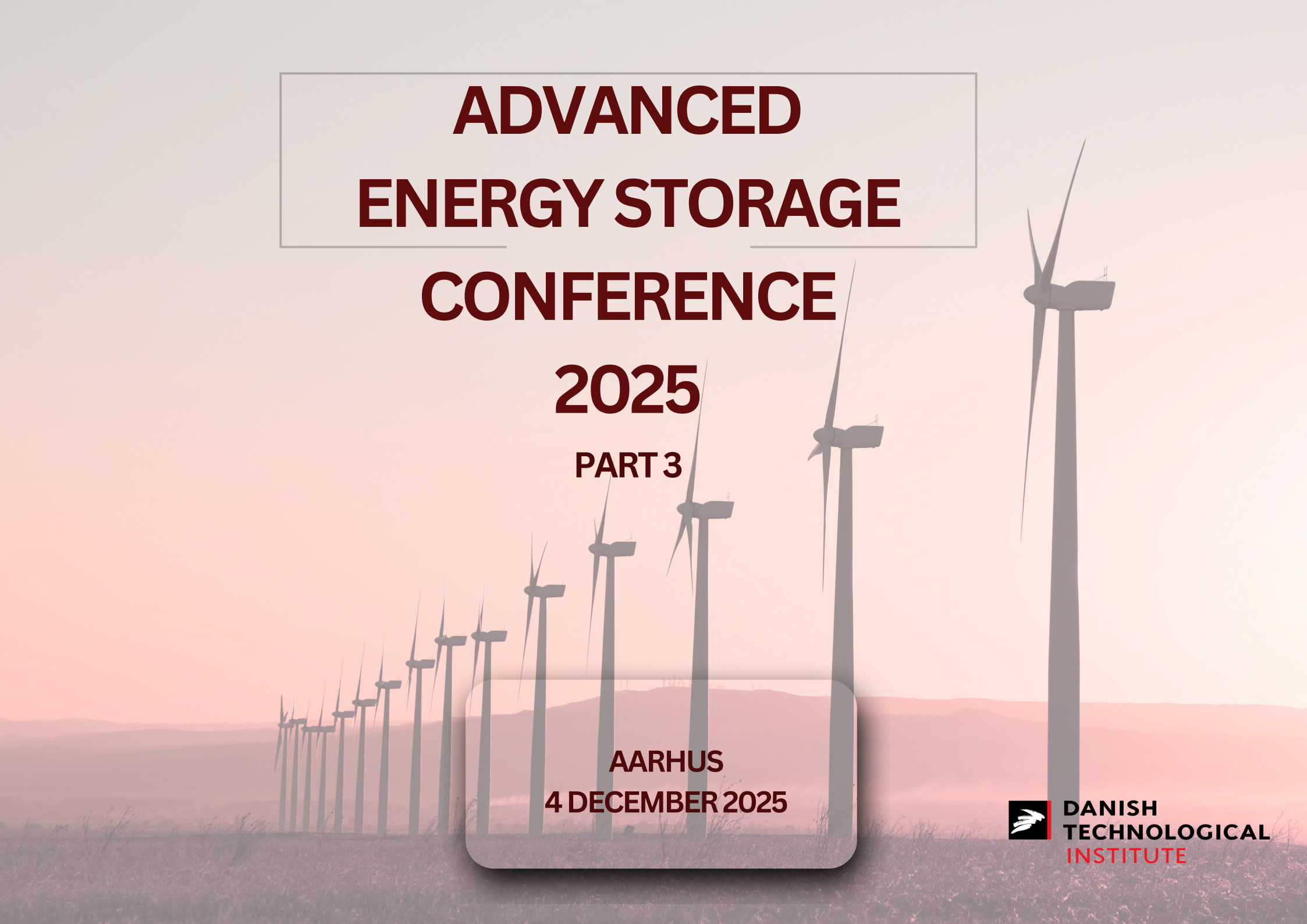
ADVANCED ENERGY STORAGE CONFERENCE 2025

PART 3

AARHUS
4 DECEMBER 2025



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ADVANCED ENERGY STORAGE CONFERENCE 2025

Reliable by Design: Co-Optimizing EMS and BESS to Protect Critical Loads

Zahra Eshafani, Aarhus University

RELIABLE BY DESIGN: CO-OPTIMIZING EMS AND BESS TO PROTECT CRITICAL LOADS

DESIGNING STORAGE-DRIVEN RESILIENCE FOR CRITICAL LOADS

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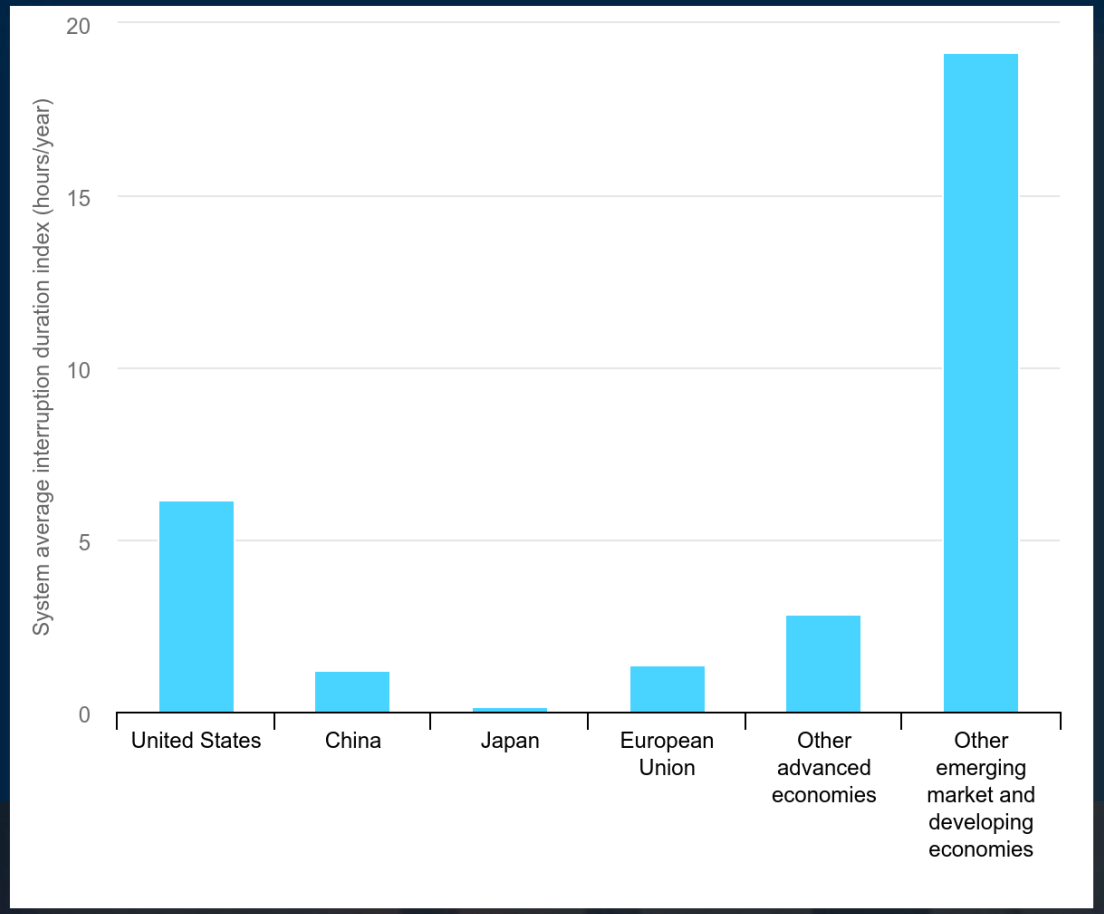
RELIABILITY NEEDS A NEW DESIGN APPROACH



Source: International Energy Agency (IEA). SAIDI measured in hours/customer/year.

Last update: April 2025

- Rising grid stress from **aging assets** + **electrification.**
- **Outages** widespread & costly.
- **Critical loads** require guaranteed continuity.
- **Resilience** rarely quantified in existing control methods.

PHOTO BY DAVID SHANKBONE, WIKIMEDIA COMMONS

WHAT WE NEED FROM BESS UNDER MODERN GRID CONDITIONS

Essential functions driven by stability challenges, climate extremes, and uncertainty.

Fast Stability Support

Millisecond active/reactive response to fast disturbances and inverter-driven instability.

Continuity for Critical Loads

Maintain power through faults, transitions, blackouts, and grid reconnection events.

Real-Time Resilience Core

Controlled Islanding & Recovery

Support seamless islanding, reserve management, and black-start capability.

Variability Buffering Without Compromising Resilience

Absorb renewable fluctuations and peak load events while preserving autonomy for critical loads.

ZAHRA ESFAHANI
ASSISTANT PROFESSOR

WHY EMS–BESS CO-DESIGN IS NOW ESSENTIAL

Turning resilience requirements into operational reality.

From System Challenges to Co-Optimized BESS Operation

The Requirement

- ✓ Fast stability support
- ✓ Continuity for critical loads
- ✓ Controlled islanding & recovery
- ✓ Resilience-preserving variability buffering

The Gap

- ✓ These behaviors do NOT emerge automatically.
- ✓ Default operating modes prioritize energy, not resilience.
- ✓ Response modes must be scheduled, not assumed.
- ✓ Critical loads need prioritization rules.
- ✓ Resilience is not measured today.

What the EMS Must Co-Optimize

- ✓ Dynamic SOC reserve strategy
- ✓ Fast control mode scheduling
- ✓ Critical load prioritization
- ✓ Degradation-aware dispatch
- ✓ Forecast-integrated operation
- ✓ Embedded resilience KPIs

ZAHRA ESFAHANI
ASSISTANT PROFESSOR

CRITICAL LOADS

- Load served during a grid outage
- Usually different from typical load (Different shape, magnitude, peak timing)
- Will impact technology selection and size for providing backup power
- Sites may not be known during initial assessments and may need to be estimated
- There may be different levels of critical loads: (Some that are very critical and need to be met all the time), (Some that are nice to have and can be met when there is excess generation.)

ESTIMATING CRITICAL LOAD

PERCENTAGE OF TYPICAL LOAD ESTIMATE

- Can be larger or smaller than typical load
- Easy to estimate if typical load is known
- Same shape as typical load.

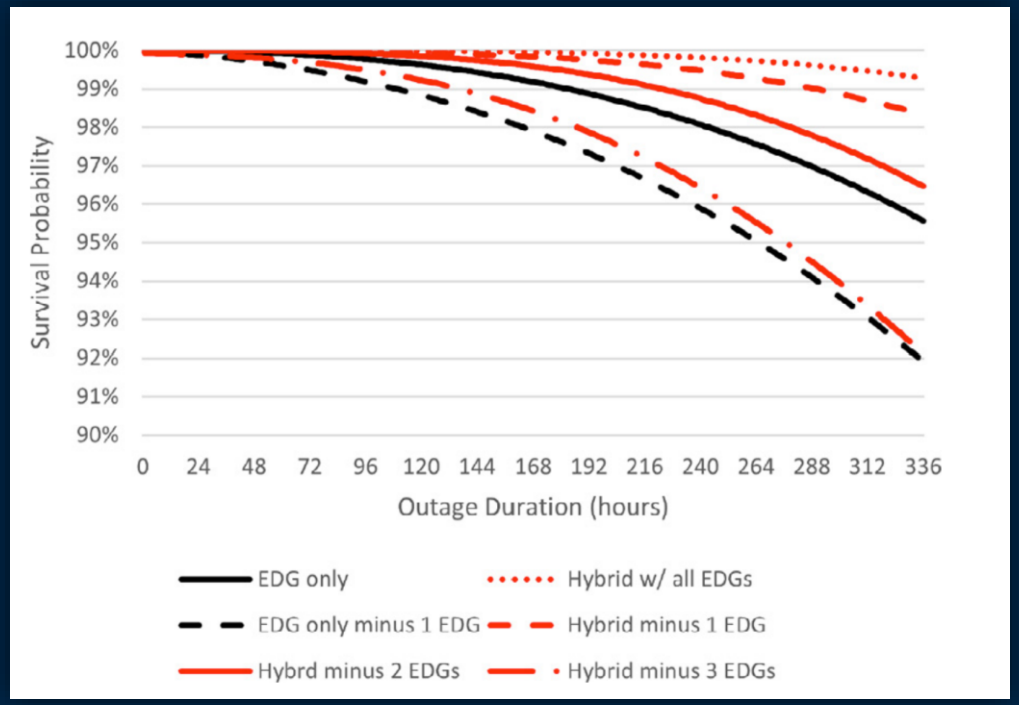
METERED CRITICAL LOAD

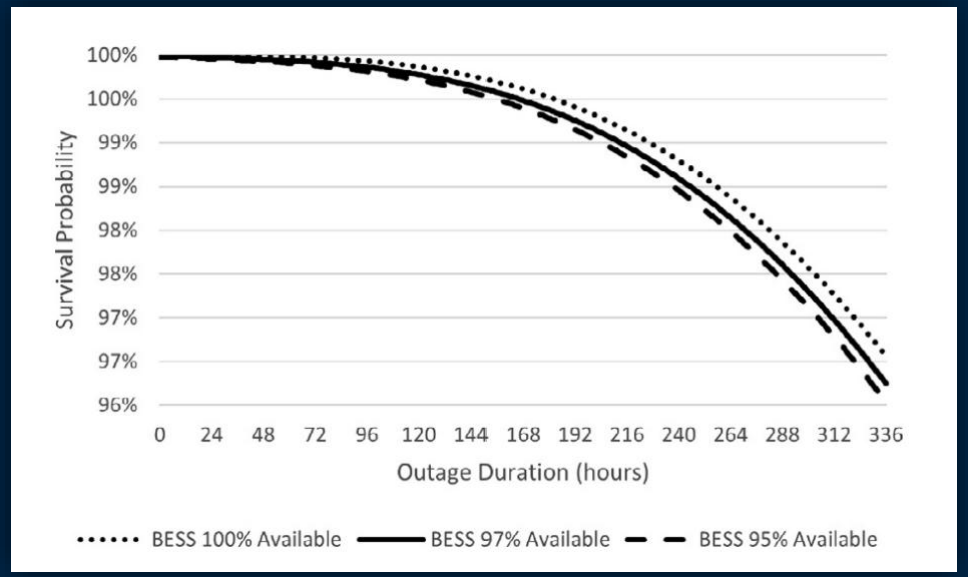
- Most accurate
- Could be obtained from submeters of critical facilities or critical load panel(s)
- May have different shape (and time of peak).

MODELED PLUG LOADS

- Works well of critical load is only comprised of a few components.

REAL-WORLD EVIDENCE: BESS DRAMATICALLY IMPROVES OUTAGE SURVIVAL





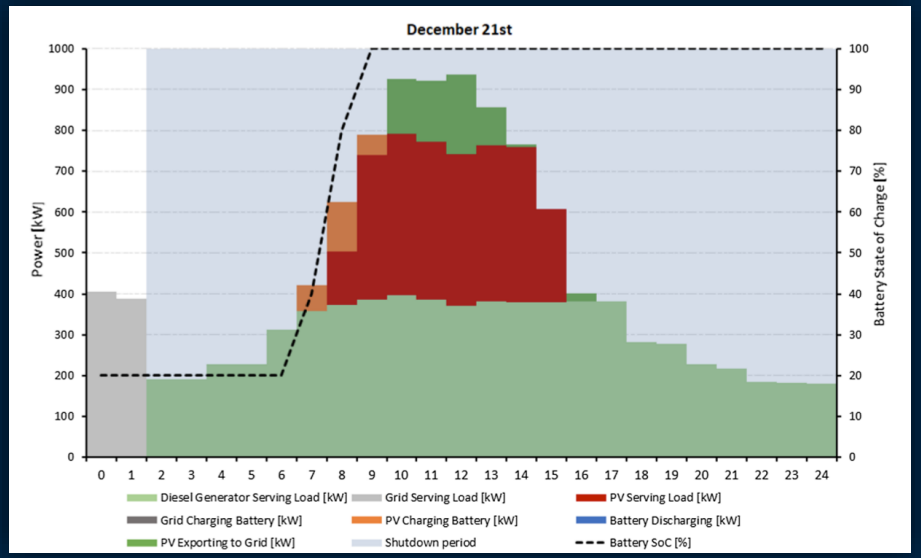
Survivability or the probability of meeting 100% of the critical load for outages up to 14 days (336 hours) as a function of BESS is availability

- **Hybrid microgrid with PV + BESS shows much higher survival probability** for all outage durations up to two weeks compared with diesel-only backup.
- **Storage + EMS dispatch keep SOC available for long outages,** turning batteries from simple energy buffers into a resilience resource.
- **Critical loads are explicitly modelled and prioritised,** so survival is defined as *all critical loads served*, not just "some power".

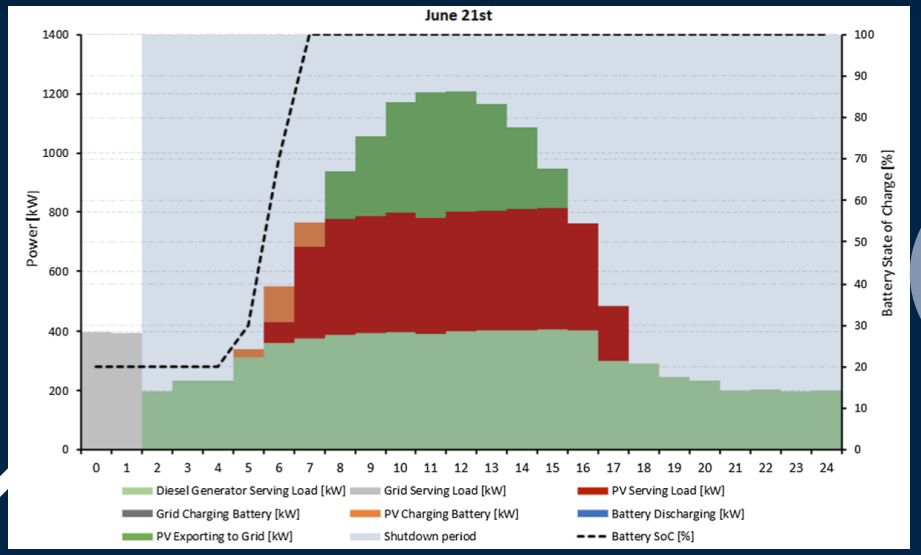
Ref: NREL Documentation

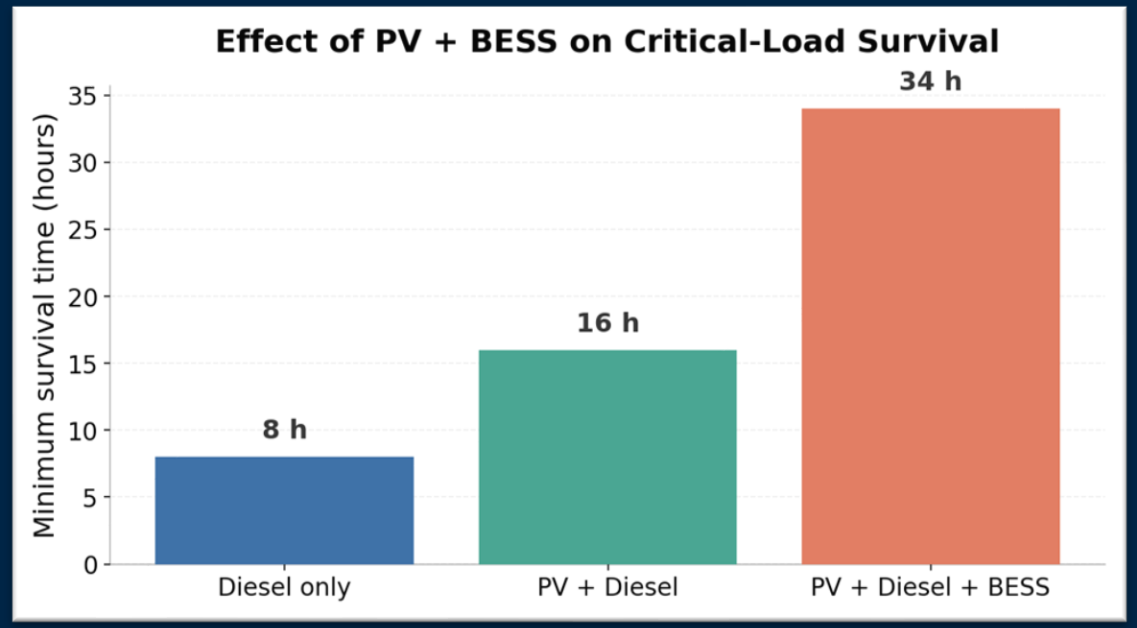
EUROPEAN CASE: BESS GREATLY EXTENDS CRITICAL-LOAD SURVIVAL DURING OUTAGES

Winter Case_Energy dispatch on with a shutdown at 2 a.m for 24 h



Summer Case_Energy dispatch on with a shutdown at 2 a.m for 24 h





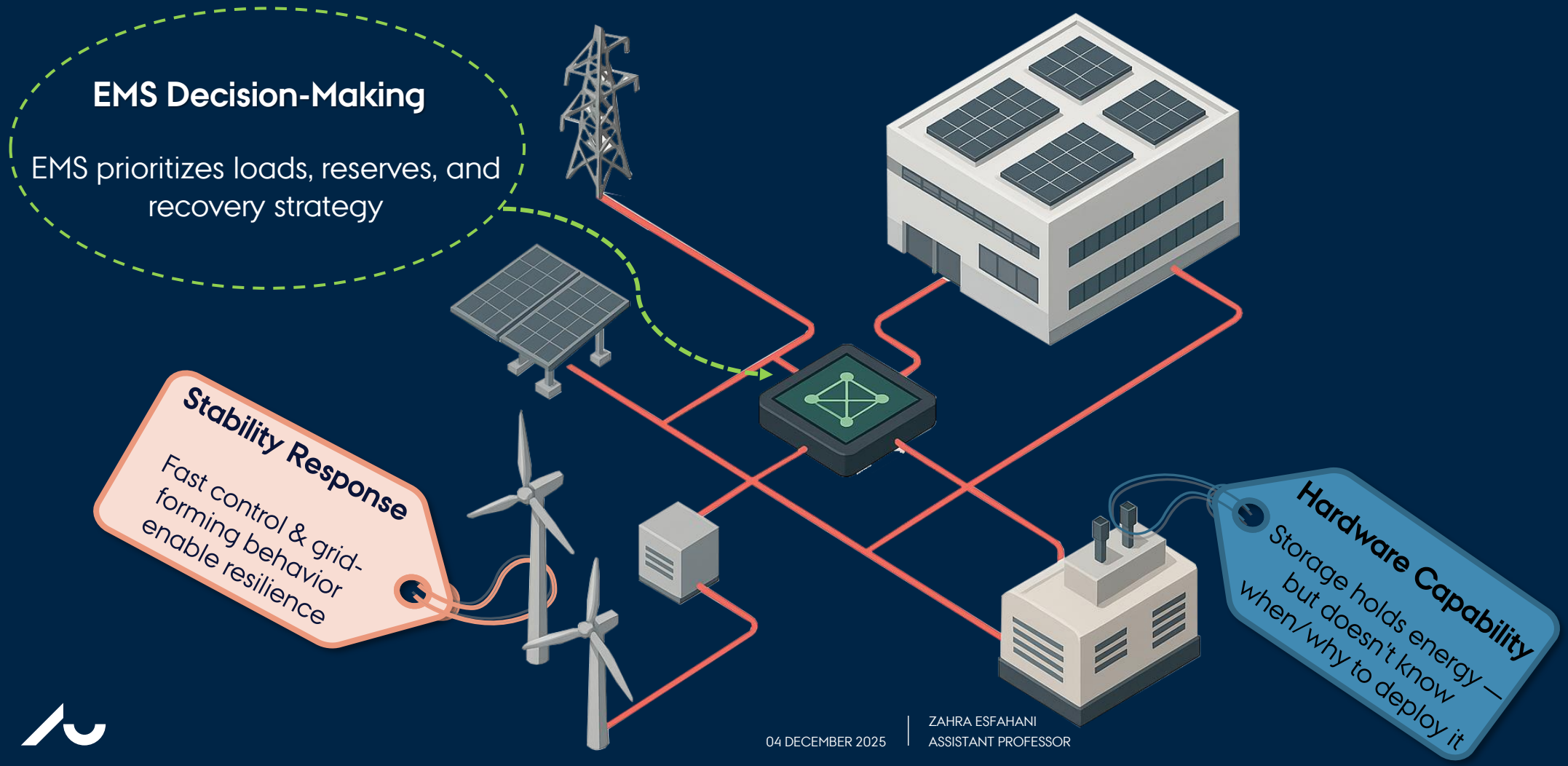
BESS as a Resilience Enabler

1. BESS transforms an outage from "hours" to "more than a full day" of critical-load coverage.
2. PV + BESS reduces diesel runtime significantly, lowering fuel consumption and O&M during islanding.
3. Seasonal differences show that EMS must schedule storage with foresight — resilience is not automatic.

04 DECEMBER 2025 | ZAHRA ESFAHANI
ASSISTANT PROFESSOR

WHAT ACTUALLY DRIVES BESS-BASED RESILIENCE?

Resilience is a control problem, not a hardware capacity problem.



ZAHRA ESFAHANI
ASSISTANT PROFESSOR

WHAT ACTUALLY DRIVES BESS-BASED RESILIENCE?

Drivers & Opportunities

- **Falling battery cost** + market growth
- **Digitalization** & data availability
- **Remote/off-grid** electrification demand
- Need for **outage resilience**
- **Ancillary service** markets emerging

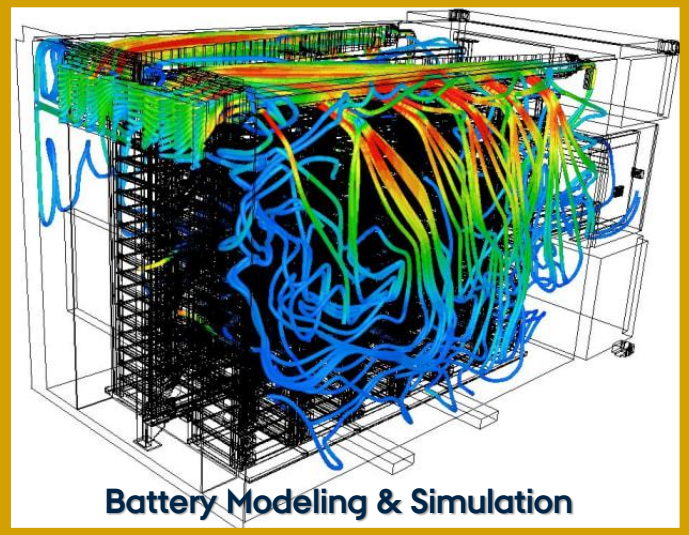
Present State of Operation

- Mostly **economic dispatch**, not resilience-driven
- **Static SOC reserve** thresholds
- Resilience **not measured nor rewarded**
- Limited **load prioritization** capability

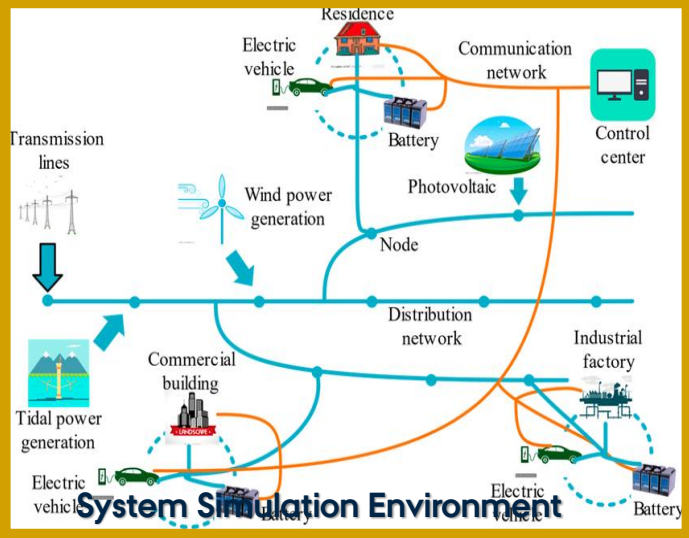
Research & Industry Needs

- **Dynamic SOC reserve** management
- **Fast control & grid-forming inverters**
- **Resilience KPIs & quantifiable metrics**
- **Critical-load prioritization rules**

FROM RESEARCH TO PRACTICE: TOOLS FOR RESILIENT BESS CONTROL


Battery Modeling & Simulation


EMS Dashboard & Operational Analytics



System Simulation Environment

Digital Twin for EMS Control Development

+ **Modelling & simulation tools** enable electro-thermal and degradation-aware BESS behavior understanding

+ **System-level simulators** allow reserve sizing, islanding strategy tests, and PV-BESS-diesel coordination

+ **Digital twins & hardware-in-loop** bridge design to reality, validating fast control and black-start strategies

+ **Operational dashboards & analytics** support real-time SOC management, load prioritization, and resilience KPIs

LEAPFROG: AFRICA AS TESTBED, EUROPE AS APPLICATION

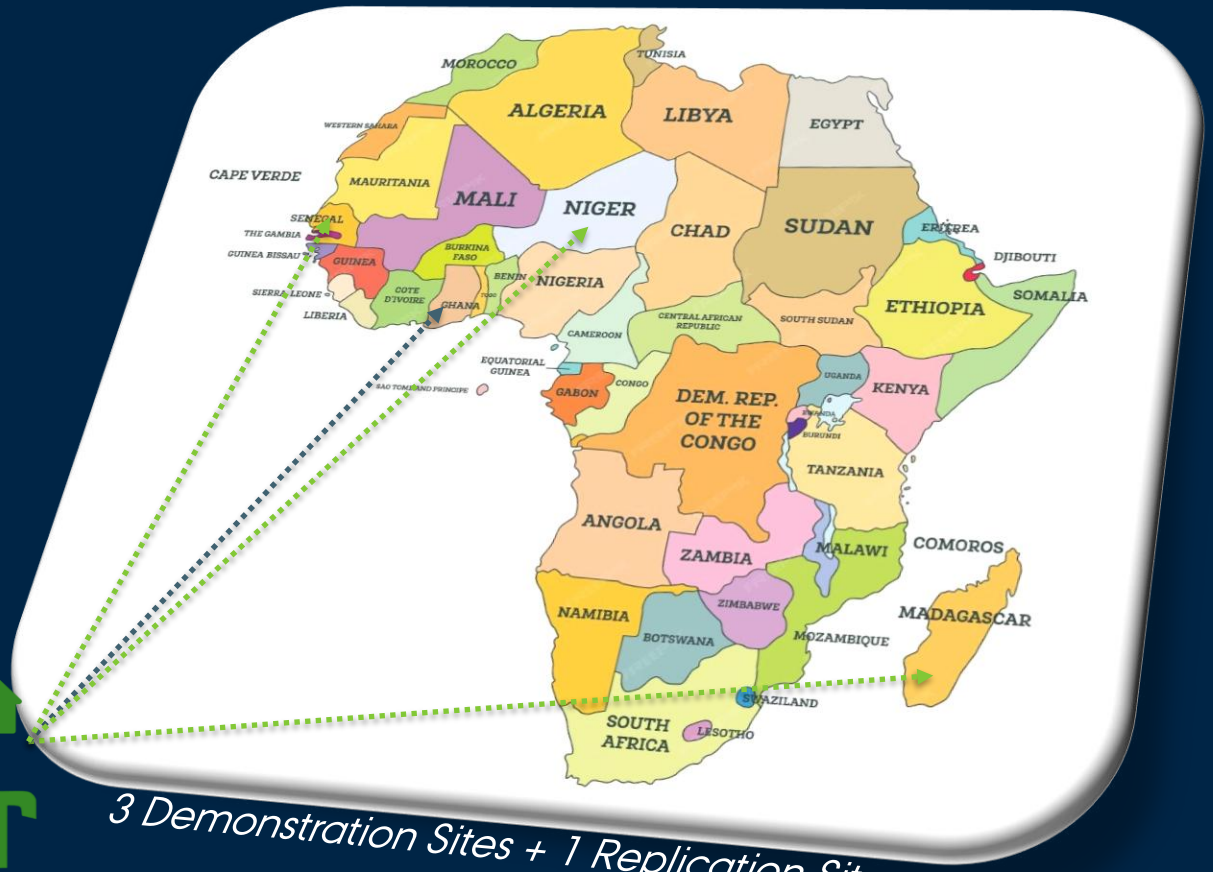
- ✓ Africa does not need to follow the 30-year path Europe took.
- ✓ With outages, weak grids and rapid growth, resilience is not optional — it's the starting point.
- ✓ This makes Africa the ideal environment for testing next-generation BESS control, which we later scale back into European critical-load applications.

WHERE WE APPLY THIS: REPOWER & AEP PROJECTS

AEP CONCEPT: ENERGY COMMUNITIES

Establishing a **Renewable Energy Park (REEP)** at this location will provide a model that can be replicated in other fringe communities as well as in other parts of the country and Africa.

REPOWER CONCEPT: PLUG & PLAY



3 Demonstration Sites + 1 Replication Site

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ASSISTANT PROFESSOR

CLOSING MESSAGE – RELIABLE BY DESIGN

- ❑ Resilience is a control problem — not just storage capacity.
- ❑ Co-optimized EMS+BESS can protect critical loads during long outages.
- ❑ Africa = innovation testbed, Europe = scale & deployment for critical facilities.

Next step: operationalize resilience — measure it, schedule it, deploy it.

THANKS FOR YOUR ATTENTION

Q &A

04 DECEMBER 2025
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ASSISTANT PROFESSOR

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Tackling Electricuty Fluctuation with Smart Heat Storage in District Heating

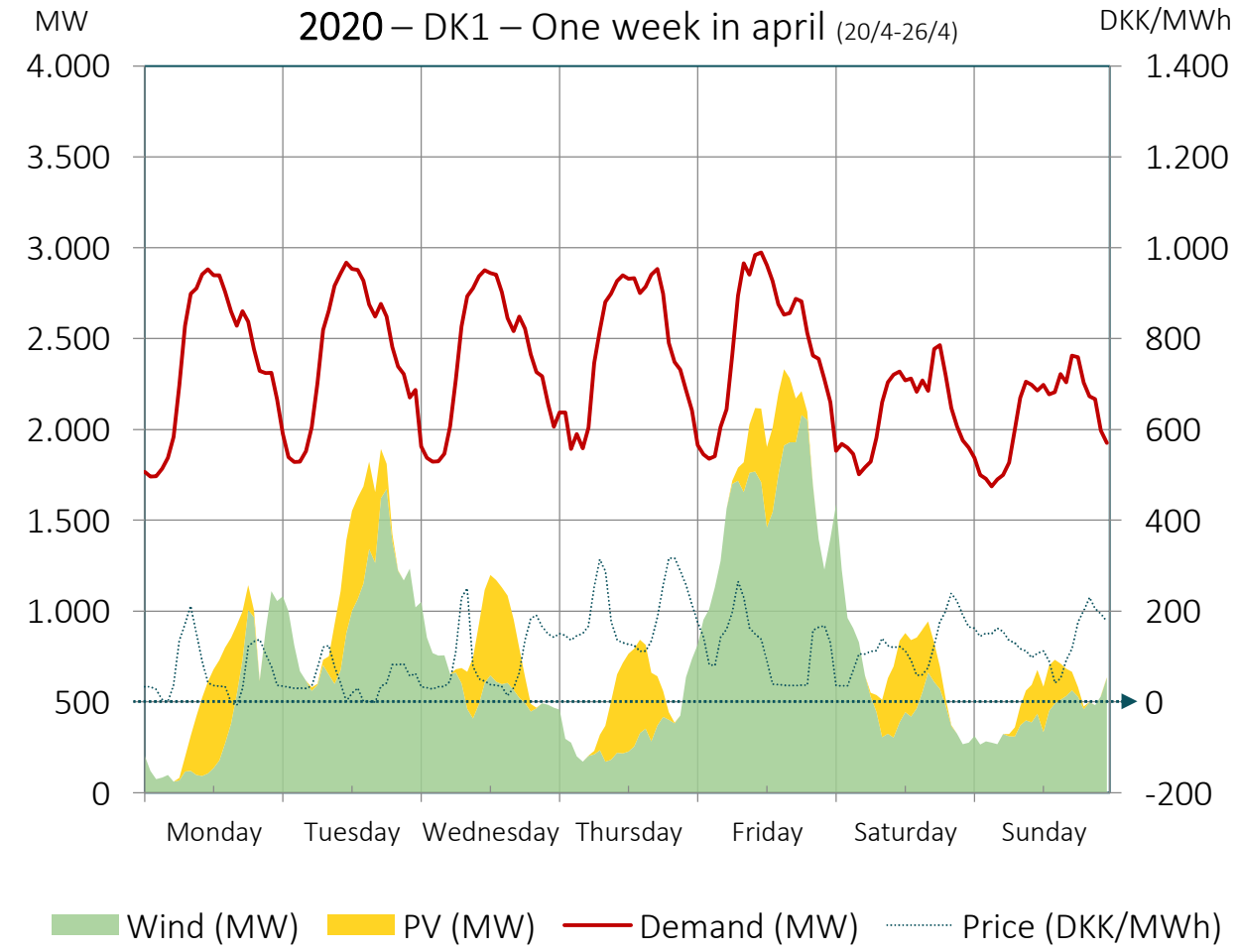
Jesper Koch, Dansk Fjernvarme

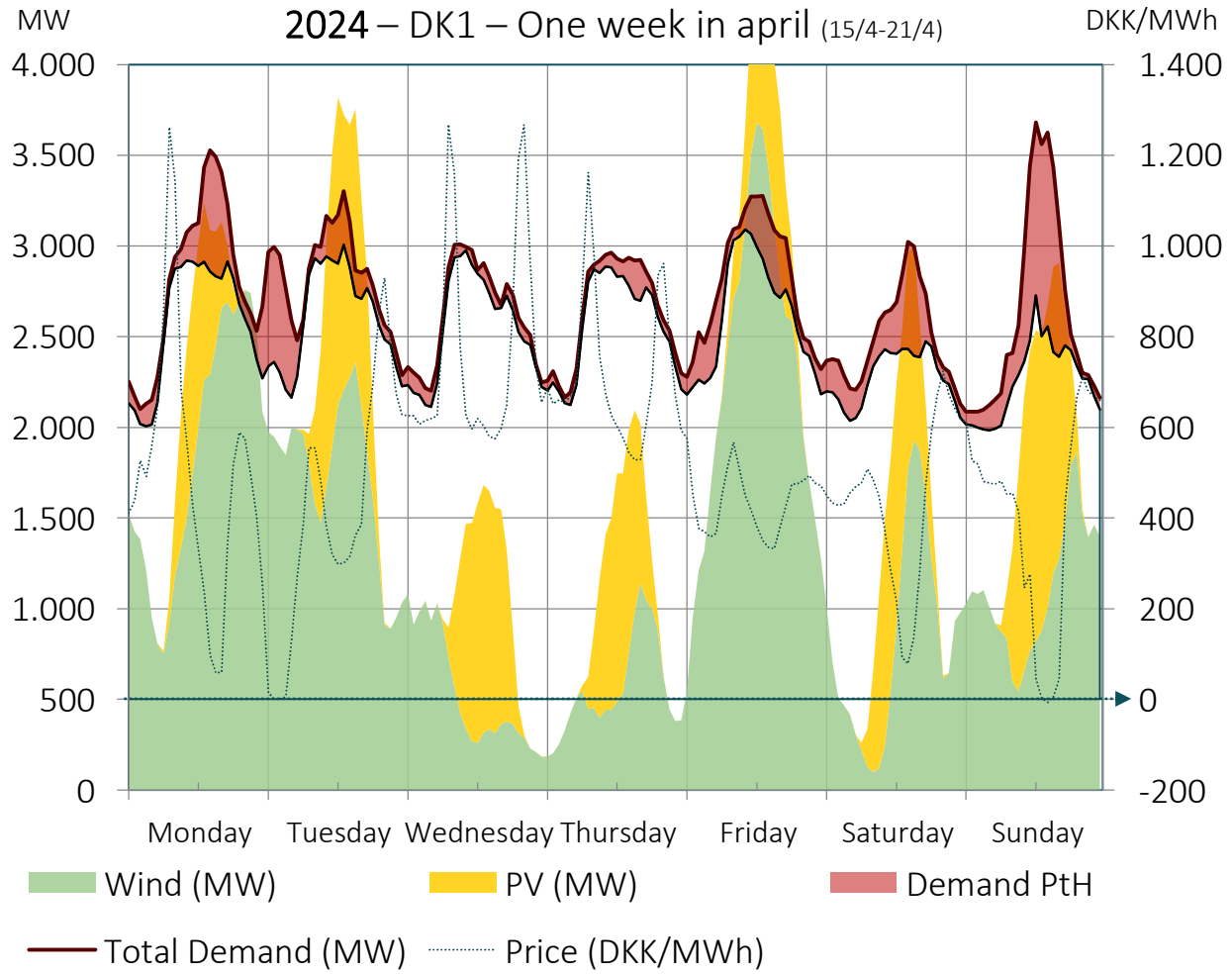
Tackling electricity fluctuation with smart heat storage in District Heating

4th of December 2025 – Teknologisk Institut

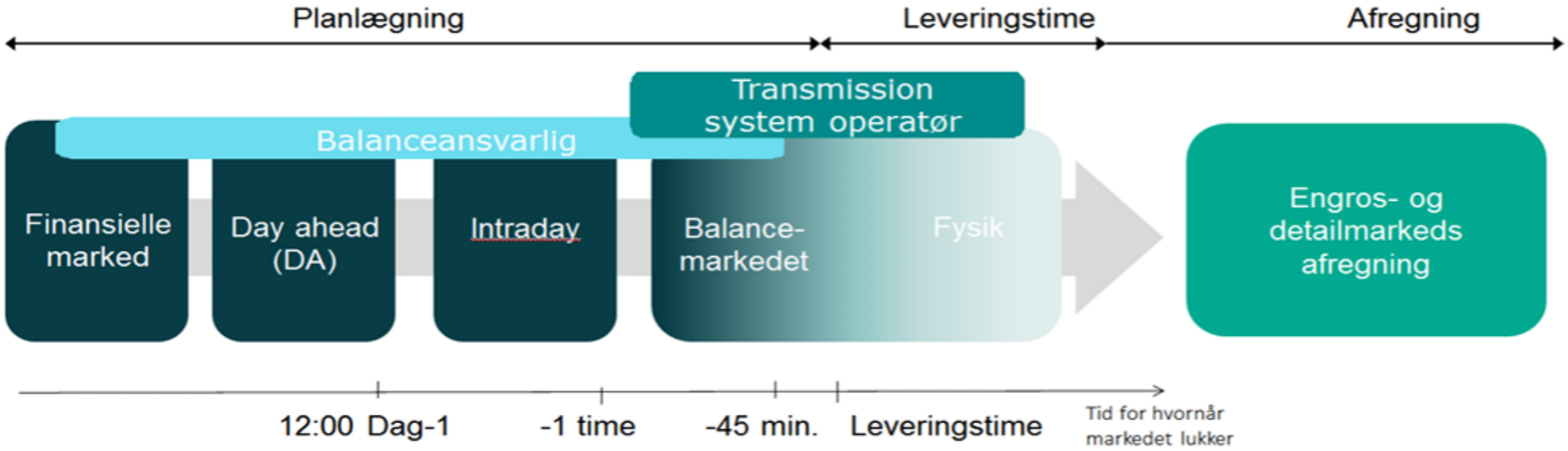
Jesper Koch, Dansk Fjernvarme

POWER TO HEAT (PTH) IN DISTRICT HEATING





Several market places to deal with electricity for a DH!



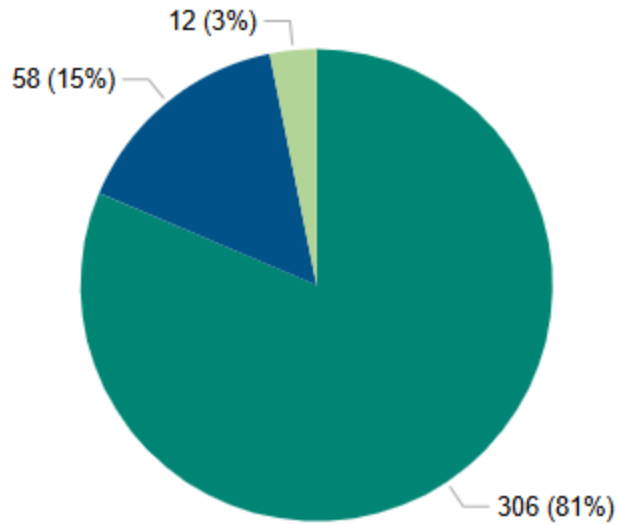
- The electricity market is much more than Nord Pool Spot
- The price for delivery increases the closer you get to the operating hour
- Day Ahead ¤ Manual Regulation Power ¤ Automatic Frequency Support
- The volume is largest Day Ahead and only 30 MW for frequency support
- And in addition, there is payment for Reserves and Black Start

https://energinet.dk/el/elmarkedet/

DH in Denmark

- 377 district heating companies that supply 99 per cent. of Danish district heating
- They supply heat to 1.98 million households (67 per cent of all households) and 3.7 million people (2025)
- Produces approx. 60 per cent of Denmark's thermal electricity production from cogeneration
- Delivers district cooling
- New players in DH with Power-to-X, Carbon capture and Datacenters

Ownership by number of companies



Consumer owned Municipality owned Other ownership

Number | Heat sale

Municipality: Alle

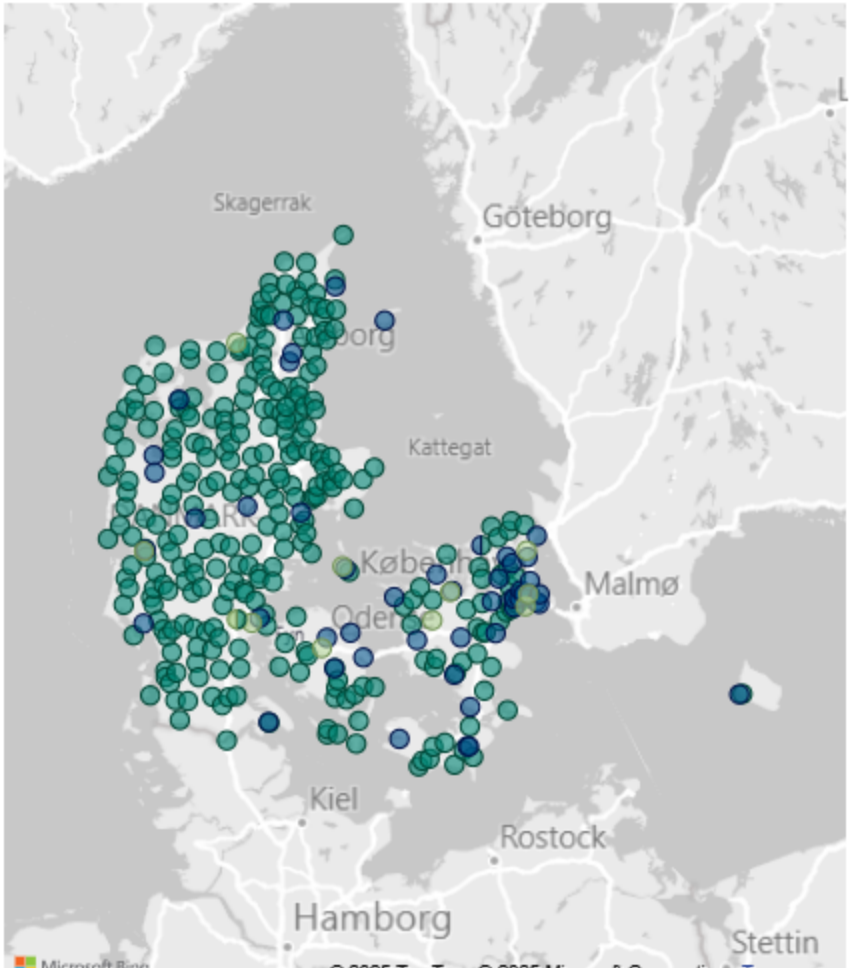
Country: Denmark

Source: Danish District Heating Association's member database

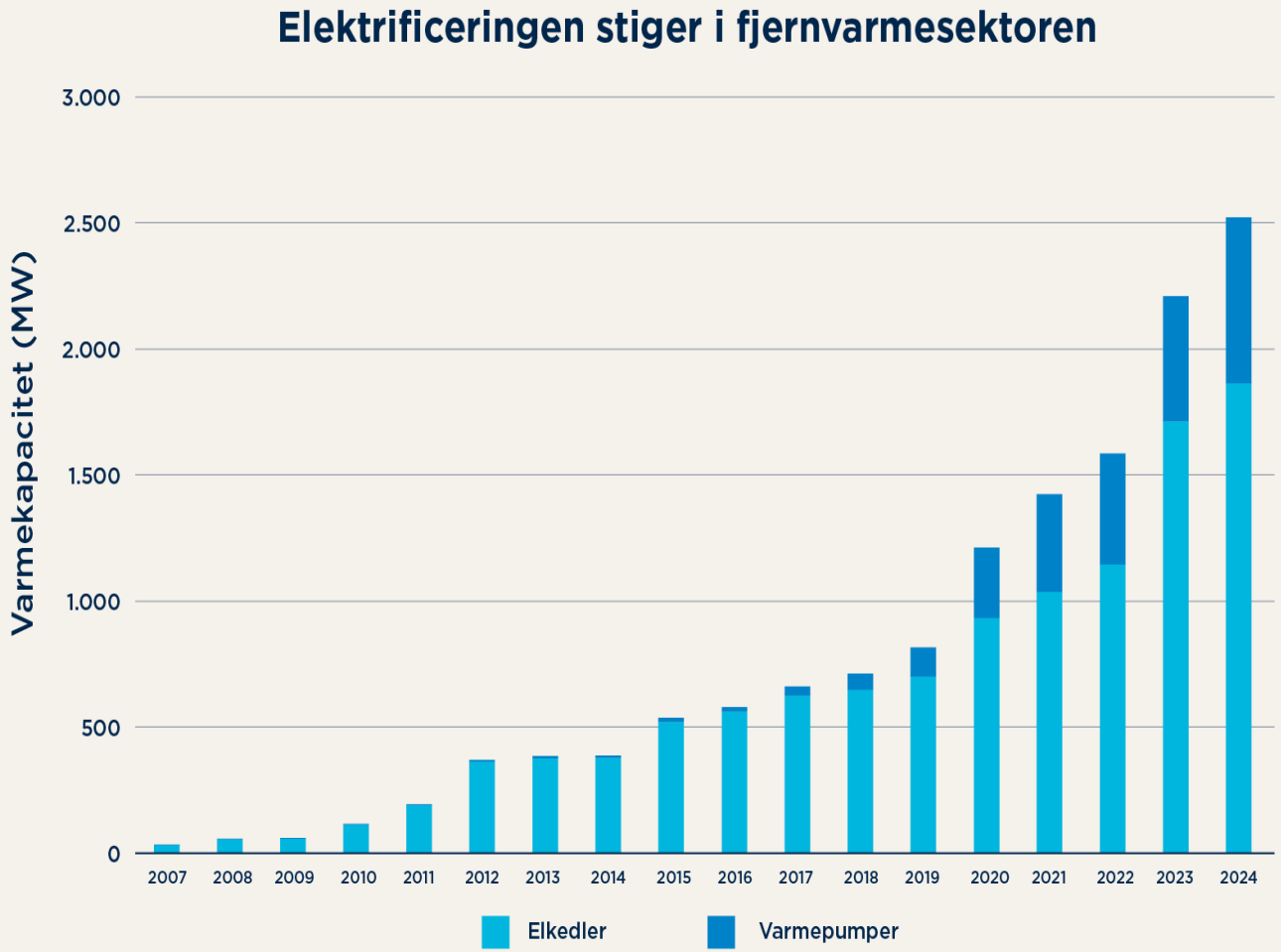
Note: Other ownership includes, among others, private ownership. Heat sales only

Map of members of Danish District Heating Association

Number of companies in visualisation: 376



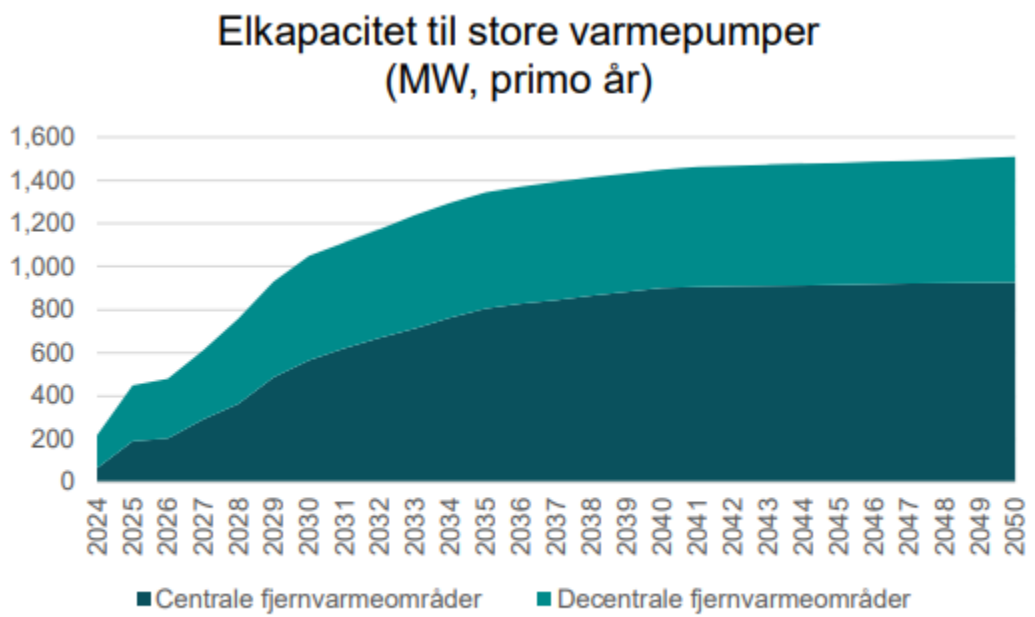
Electriciy consumption 5 times higher from 2019 to 2024 - much more in pipeline!



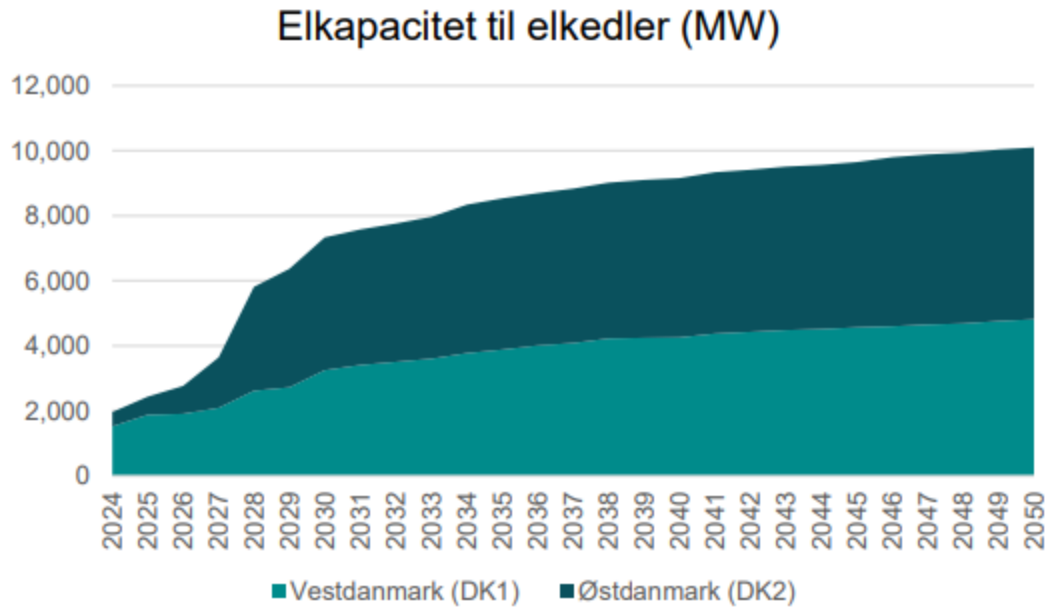
Kilde: Energiproducenttællingen for 2024, Energistyrelsen.

Big Heat Pumps and electric Boilers

From 20 pct el in 2025 to 65 pct in 2040



Figur 5: Udvikling i elkapacitet for store varmepumper i hhv. centrale og decentrale fjernvarmeområder (MW).



Figur 7: Udvikling i elkapacitet for elkedler til fjernvarmeproduktion i hhv. Vest- og Østdanmark (MW).

Big Heat pumps:
From <1000 MW-heat to 4500 MW-Heat in 2040

Electric Boilers:
From 2000 MW-Heat to 9.000 MW-Heat i 2040

Source: Analyseforudsætninger til Energinet (AF25)

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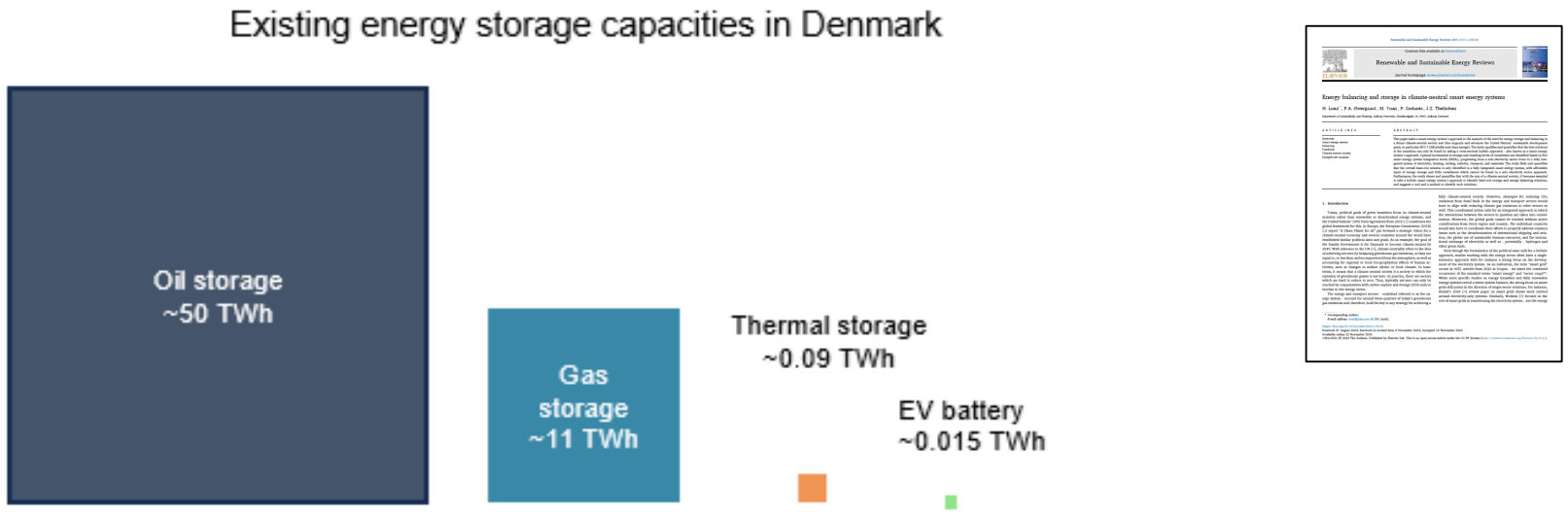
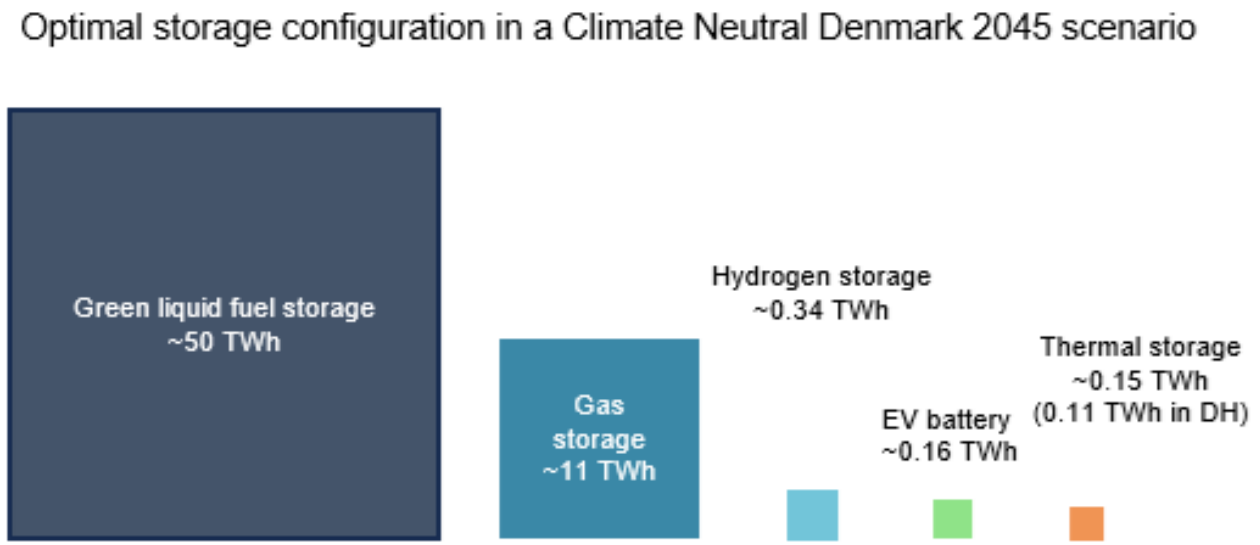
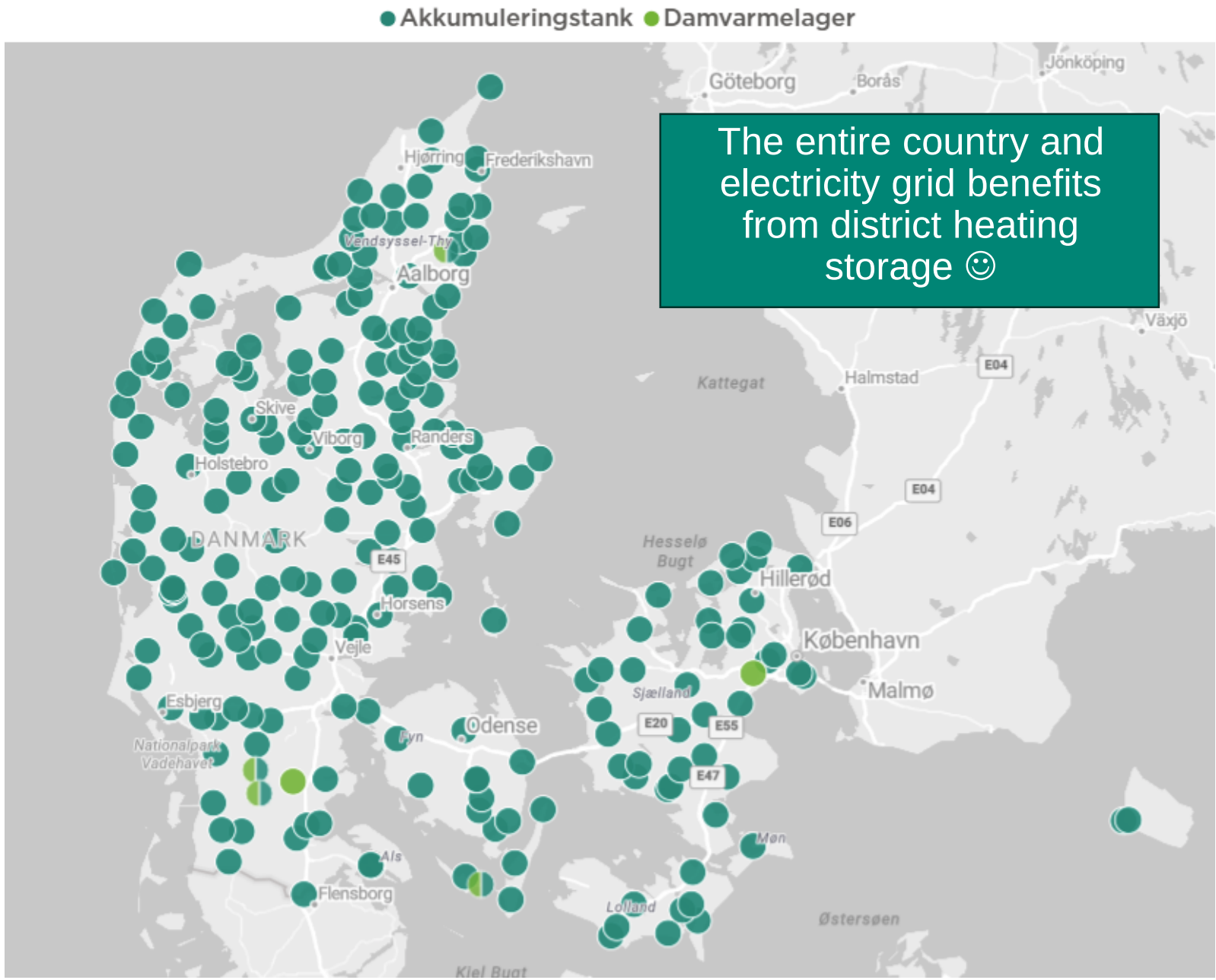
The need for storage in a climate-neutral Denmark



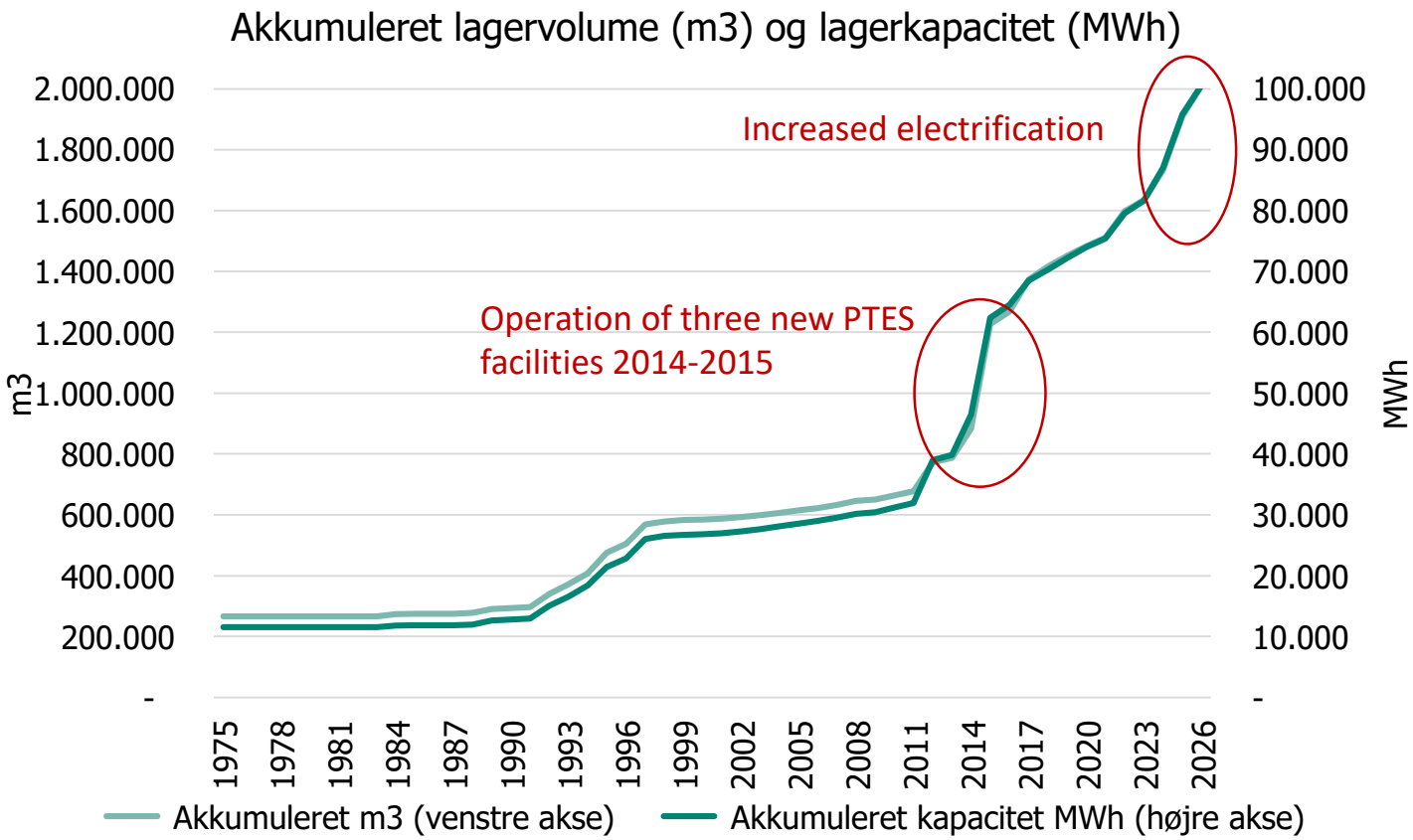




Source: Dansk Fjernvarme medlemsundersøgelse maj 2025

Capacity and volume over time ~ ”1½ mio e-cars”

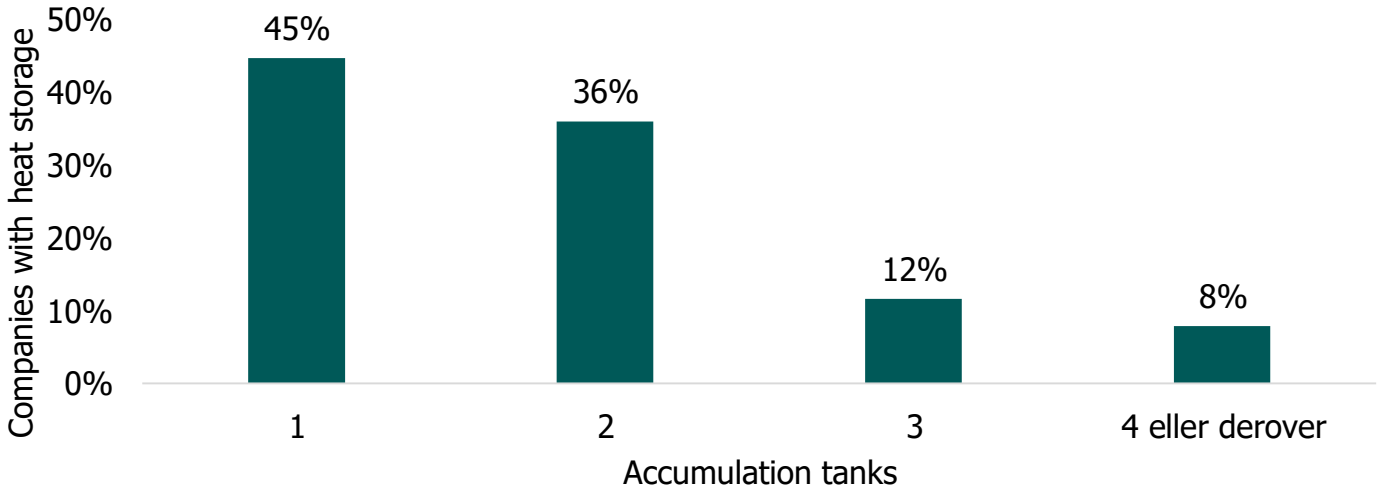
- First tank in 1975 → 449 storage facilities in 2025
- Approximately **2 million m³ or 100 GWh** district heating storage in total excluding the contribution from district heating pipes
- Total district heating storage most likely larger – not everyone has responded

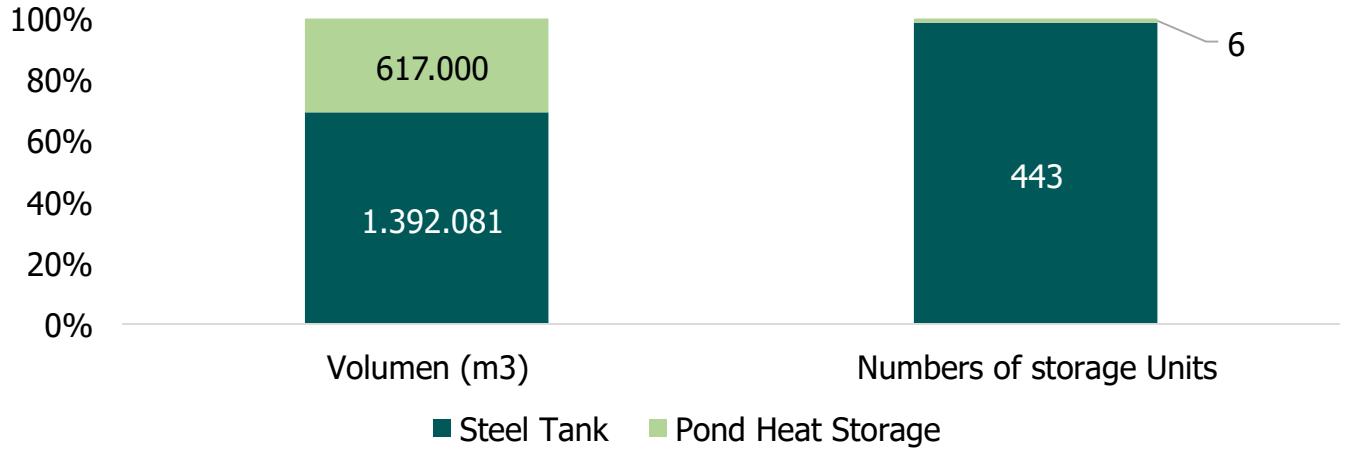


Source: Dansk Fjernvarme medlemsundersøgelse maj 2025

Most companies with heat storage technologies have one or two facilities

- Many of the companies with heat storage technologies have two accumulation tanks (TTES facilities)
- Data for 449 tanks distributed across 206 companies
- The average size for accumulations tanks is approximately 3,200 m³
- The six PTES facilities (damvarmelagre) account for approximately 1/3 of the total volume

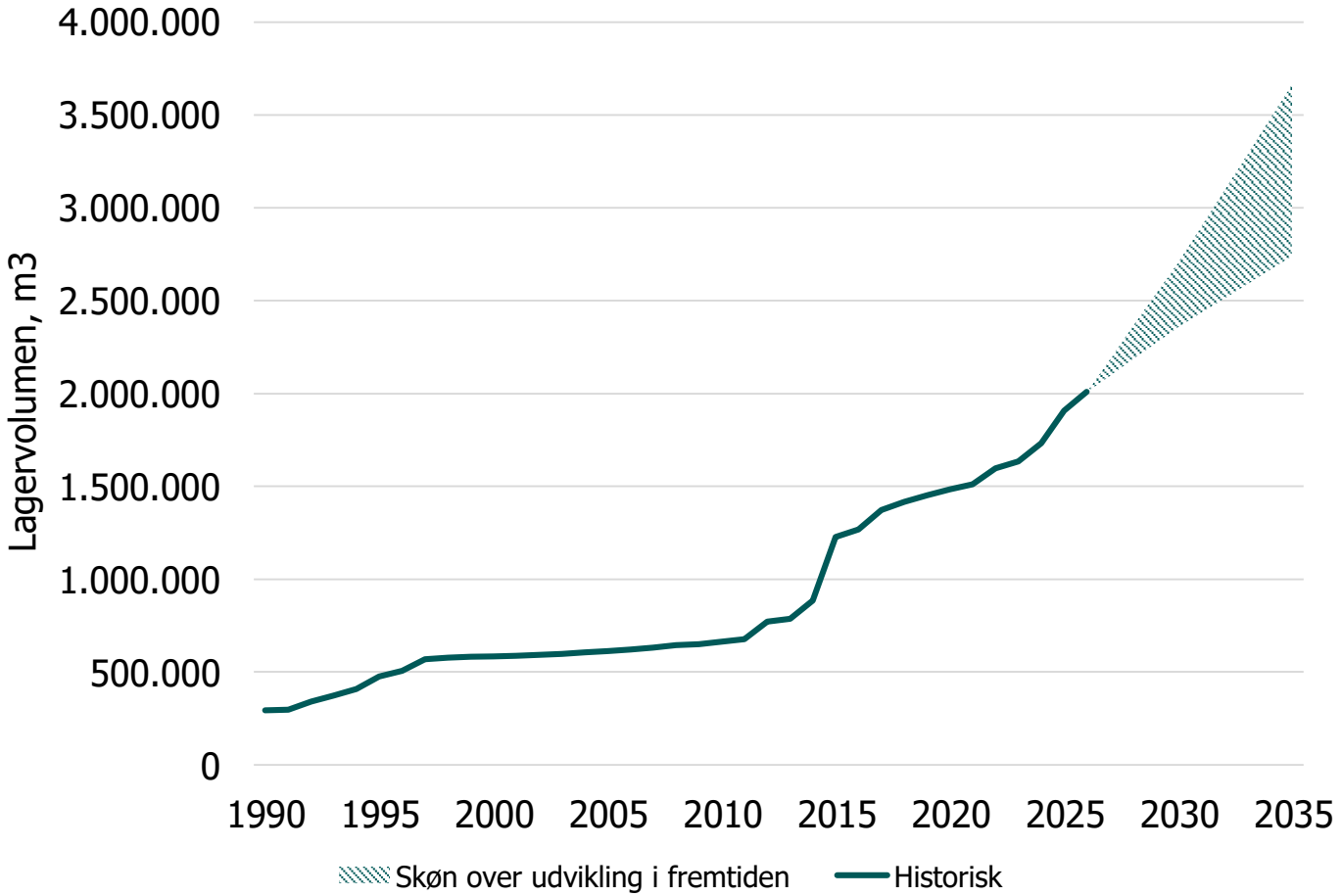




Source: Dansk Fjernvarme medlemsundersøgelse maj 2025

Significant expected increase in the future

- Total storage volume is expected to increase by up to 80 percent by 2035. At company level, this could represent several-fold increases
- Nearly 50 pct. have invested in accumulation tanks simultaneously with electric boilers and heat pumps within the last five years
- Electrification/The electricity market is driving the development!

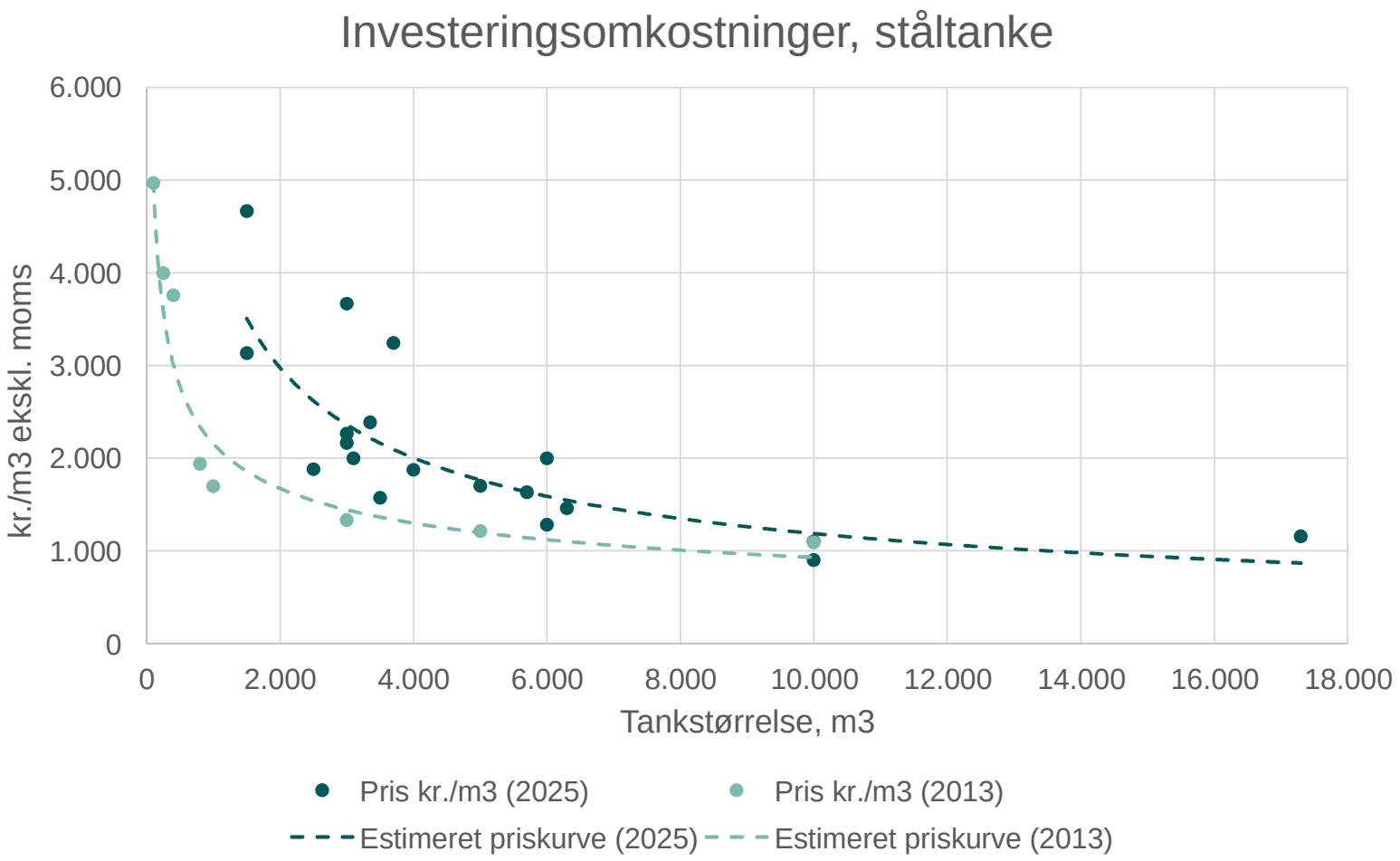


Note: Not everyone has responded, therefore a range has been estimated for future development

Source: Dansk Fjernvarme medlemsundersøgelse maj 2025

DANSK FJERNVARME

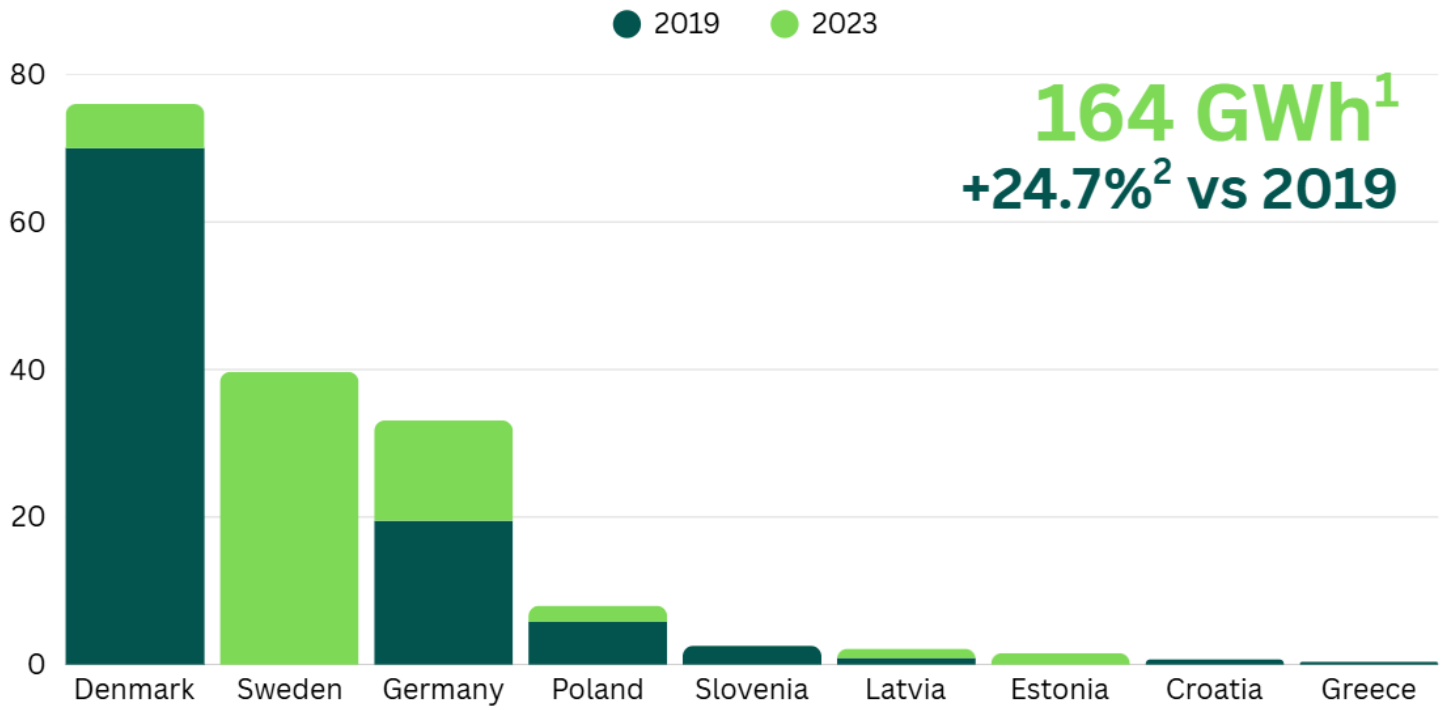
Investment costs for accumulation tanks - they have become slightly more expensive



Note: Prices are price-adjusted with price index for May 2025 (DST PRIS112). Data for 2013 is from PlanEnergi (2013)

Denmark at the forefront in Europe

Estimated storage capacities in district heating for 2023



[1] *Value for Denmark, Sweden, Germany, Poland, Slovenia, Latvia, Estonia, Croatia and Greece.*
[2] *No data available for Sweden in 2019, this country was excluded from the growth calculation to prevent overestimation.*

Source: Euroheat & Power

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What have we learned?

- Approximately **2 million m³ or 100 GWh district heating storage in total** that has been registered, but the figure is certainly larger!
- Expected **increase in total storage capacity of up to 80 percent by 2035**
- Electrification/the electricity market is driving the development
- Accumulation tanks have become slightly more expensive per energy unit

Final analysis expected to be published end of December 2025

DANSK FJERNVARME

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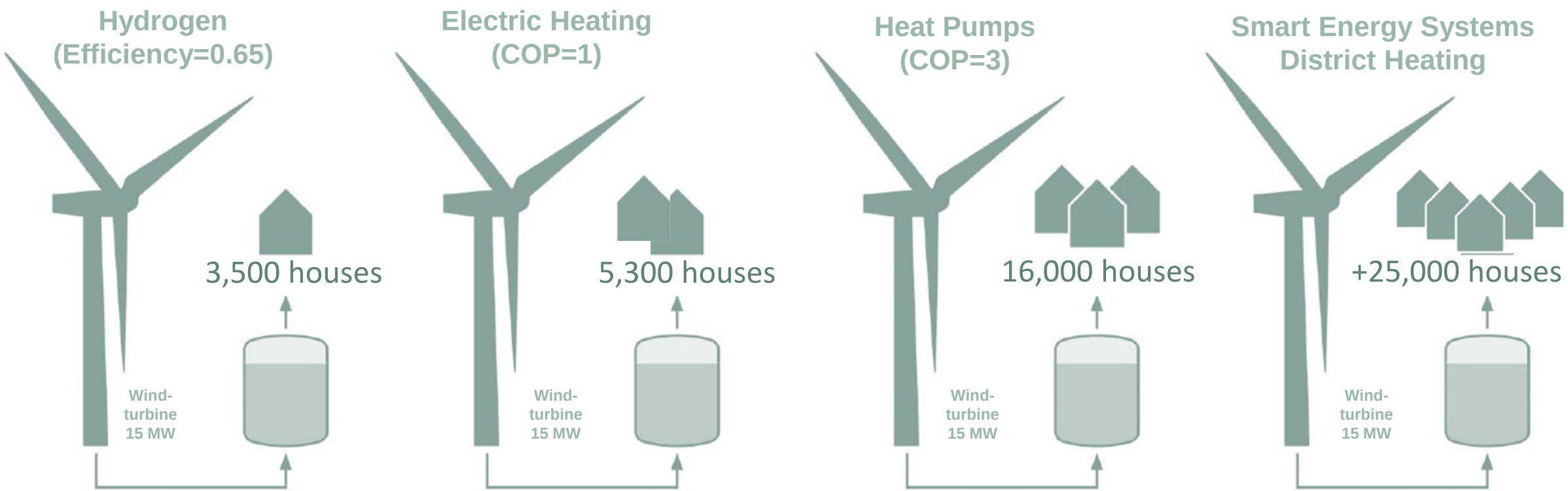
Sector Integration -> the most efficient way to ensure energy supply



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