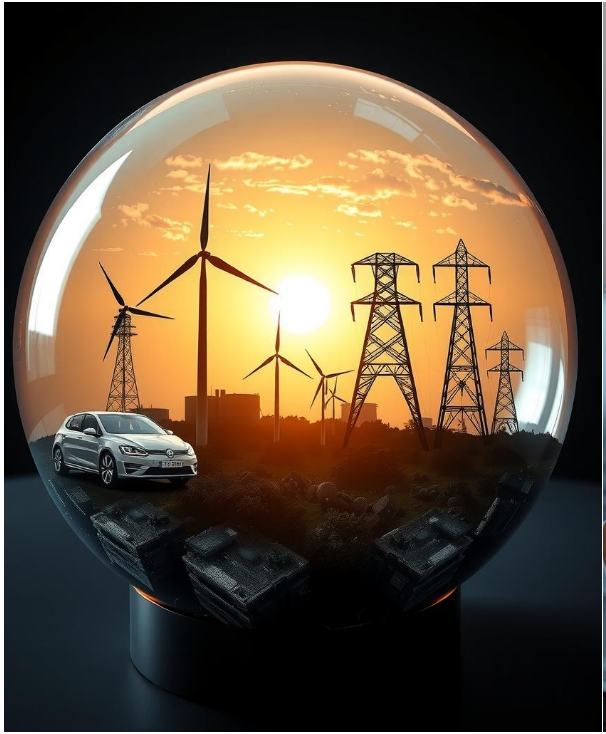
Seminar on energy system

Lisa Göransson
Associate professor
Chalmers University of Technology

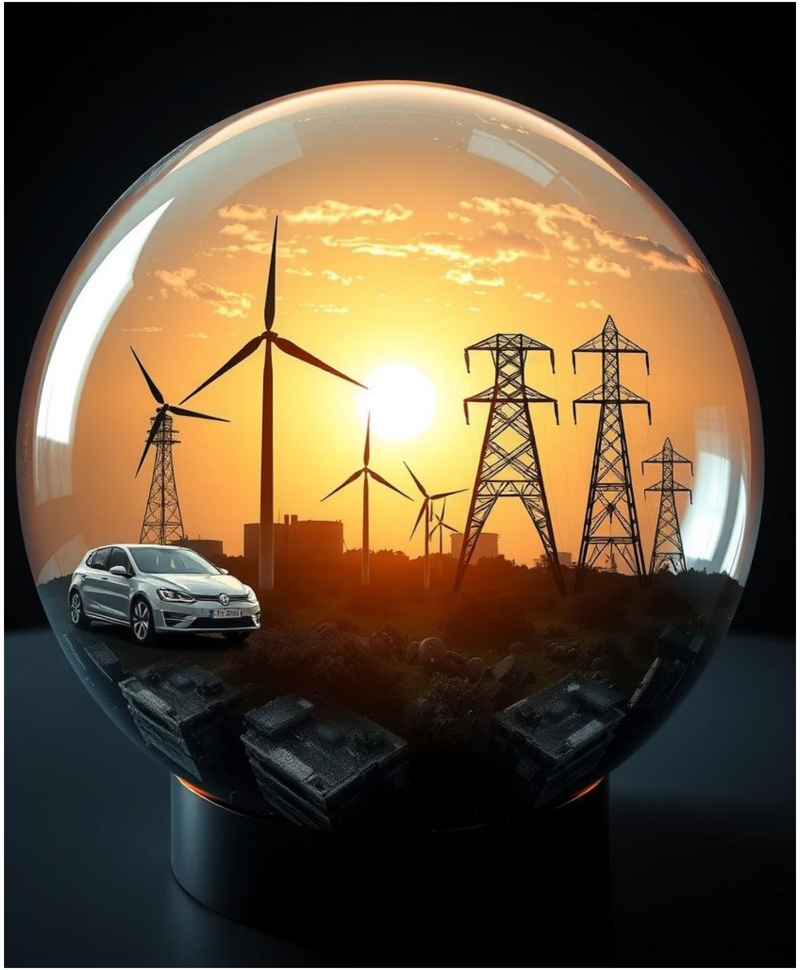



REPORTS
REPORTS

Agenda

- Electricity systems of the future
  - Was it better in the good old days?
- What’s behind our analyses?
  - Who can you trust?
- Managing variations in the electricity system
  - What do we do if the wind is not blowing?

Beehive
Lecture
Questions



Was it better in the good old days?

- What do you expcte from a future Swedish electricity system around year 2050?
  - Electricity demand?
  - Electricity prices?
  - Supply technologies?
  - Storage?

MISTRA ELECTRIFICATION

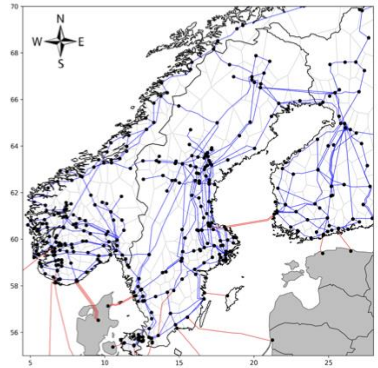
Ett framtida elsystem med och utan kärnkraft – vad är skillnaden?

Lisa Göransson, Filip Johnsson
Institutionen för Rymd-, geo- och miljövetenskap, avdelning Energiteknik, Chalmers

2023-07-05

MISTRA ELECTRIFICATION

Tre elsystem som kan möta omställningen av industri- och transportsektorerna



Lisa Göransson, Filip Johnsson, Simon Öberg, Joel Bertilsson, Luis Kuhrmann, Niclas Mattsson
Institutionen för Rymd-, geo- och miljövetenskap, avdelning Energiteknik, Chalmers

Peiyuan Chen
Institutionen för Elkraftteknik, Chalmers

2025-05-19

Background

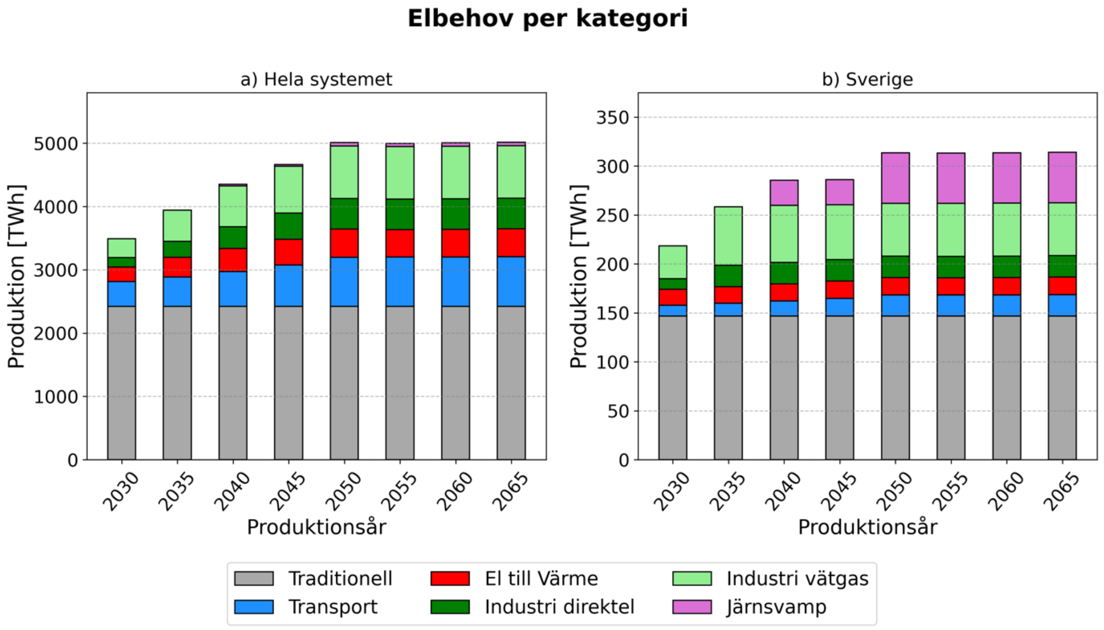
- Electrification of the industrial and transport sectors is central to meeting Sweden's climate goals
  - Entails major changes in the electricity system that affect many
  - Need for knowledge about and images of possible futures for the possibility of adaptation
  - As complete a picture as possible!
- Several decisions are made that affect the conditions for succeeding in this
  - Financing of new nuclear power
  - Ban on offshore wind in the southern Baltic Sea
  - Electricity market design
- The impact assessment of the impact of decisions on the electricity system is often very limited
  - The political argumentation sometimes contradicts what we see in research
  - Three cases that can meet the transition
  - At the lowest cost
  - Ban on offshore wind in the southern Baltic Sea
  - With a ban on offshore wind in the southern Baltic Sea and new nuclear power

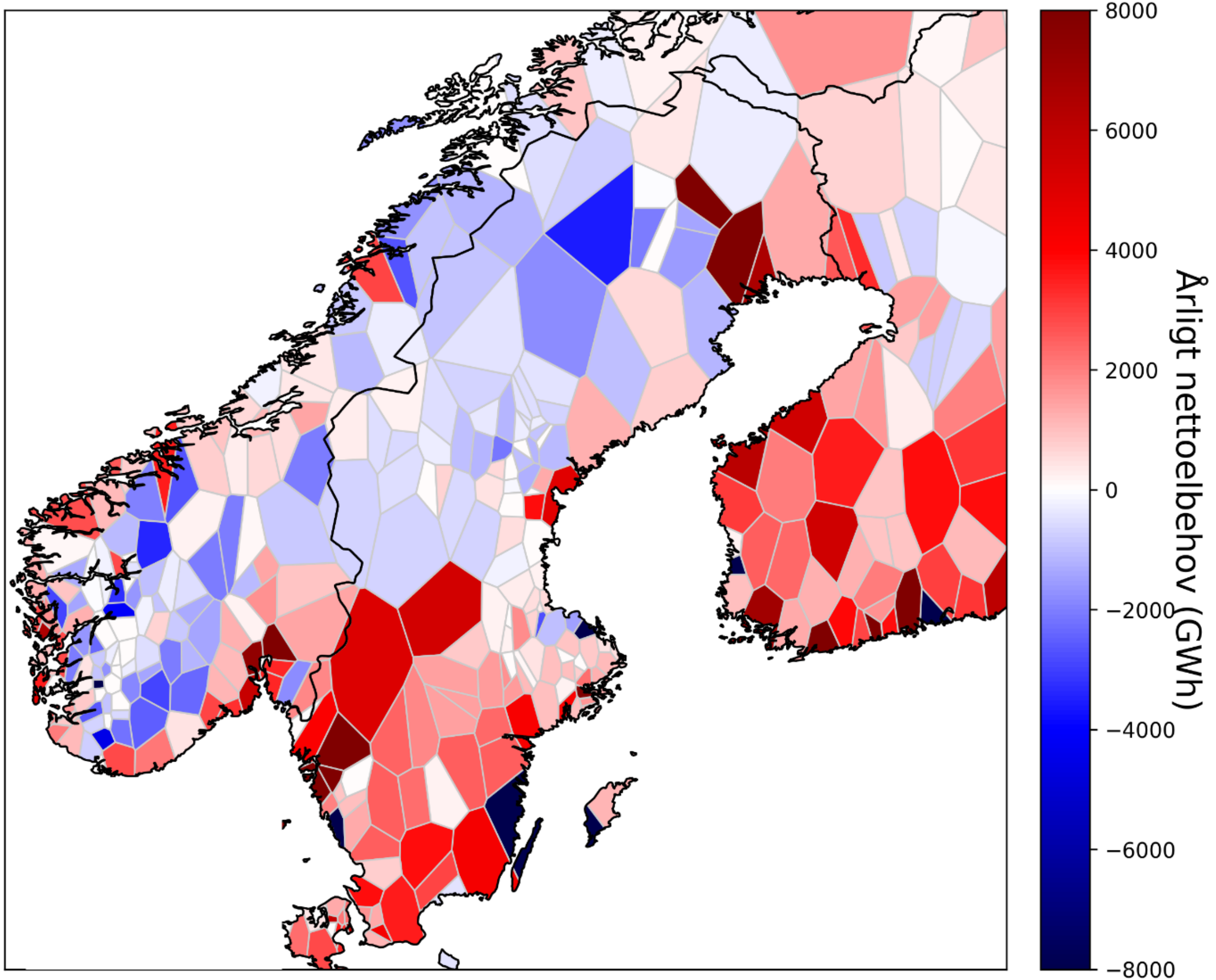
Electricity demand

Direct or indirect electrification of industry sector by 2035 in Sweden

Calculated demands of electricity and hydrogen based on current production volumes of steel and 1/3 of refineries

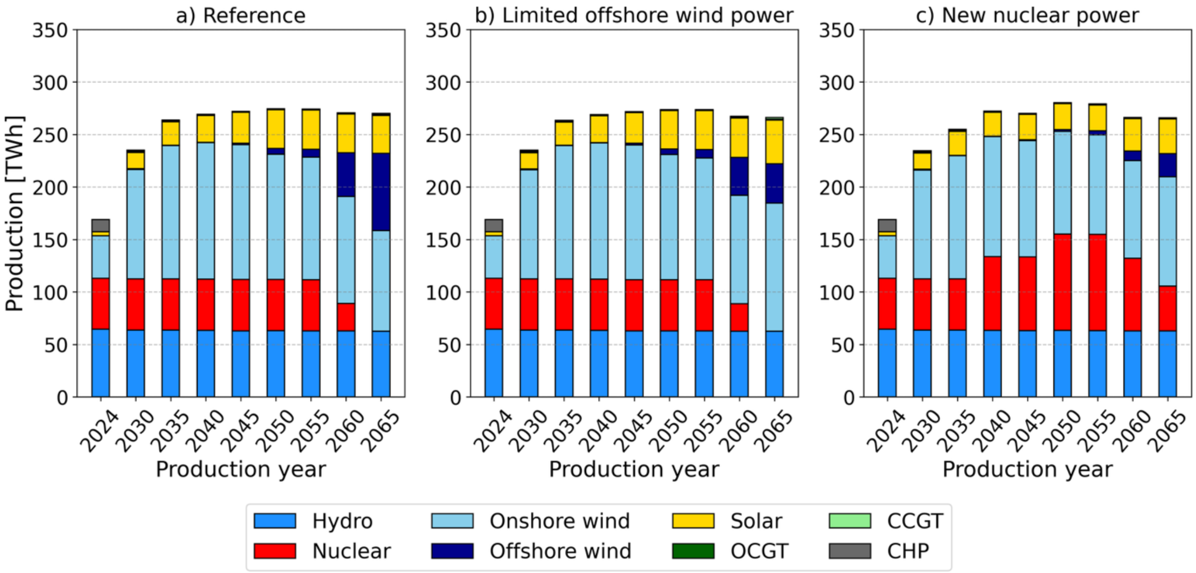
Close to doubling of annual electricity demand




8000
6000
4000
2000
0
−2000
−4000
−6000
−8000
Årligt nettoelbehov (GWh)

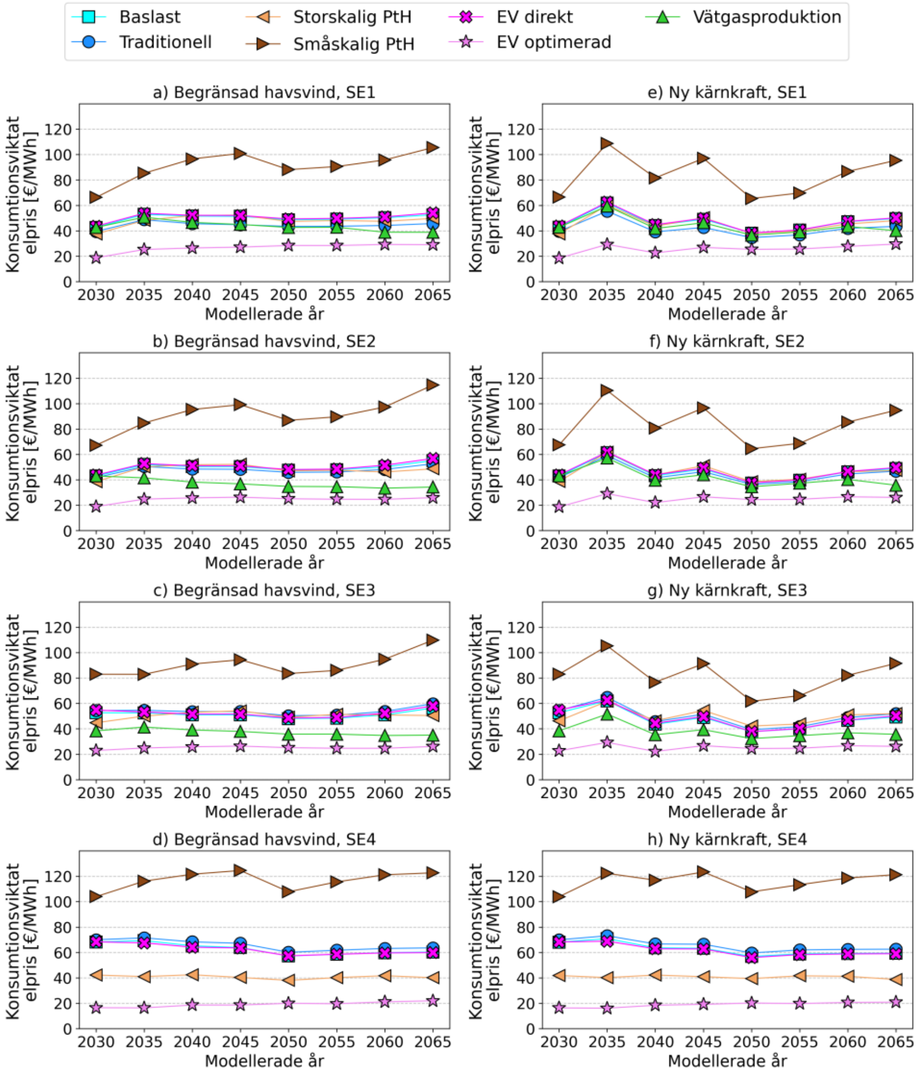
Production mix

- Doubling of onshore wind power by 2035
- 50% VRE by 2035
- New nuclear power replaces wind and solar power in Sweden
- +1600 MEUR/yr with new nuclear power
- Offshore wind power can reduce strain on onshore wind power to low additional cost



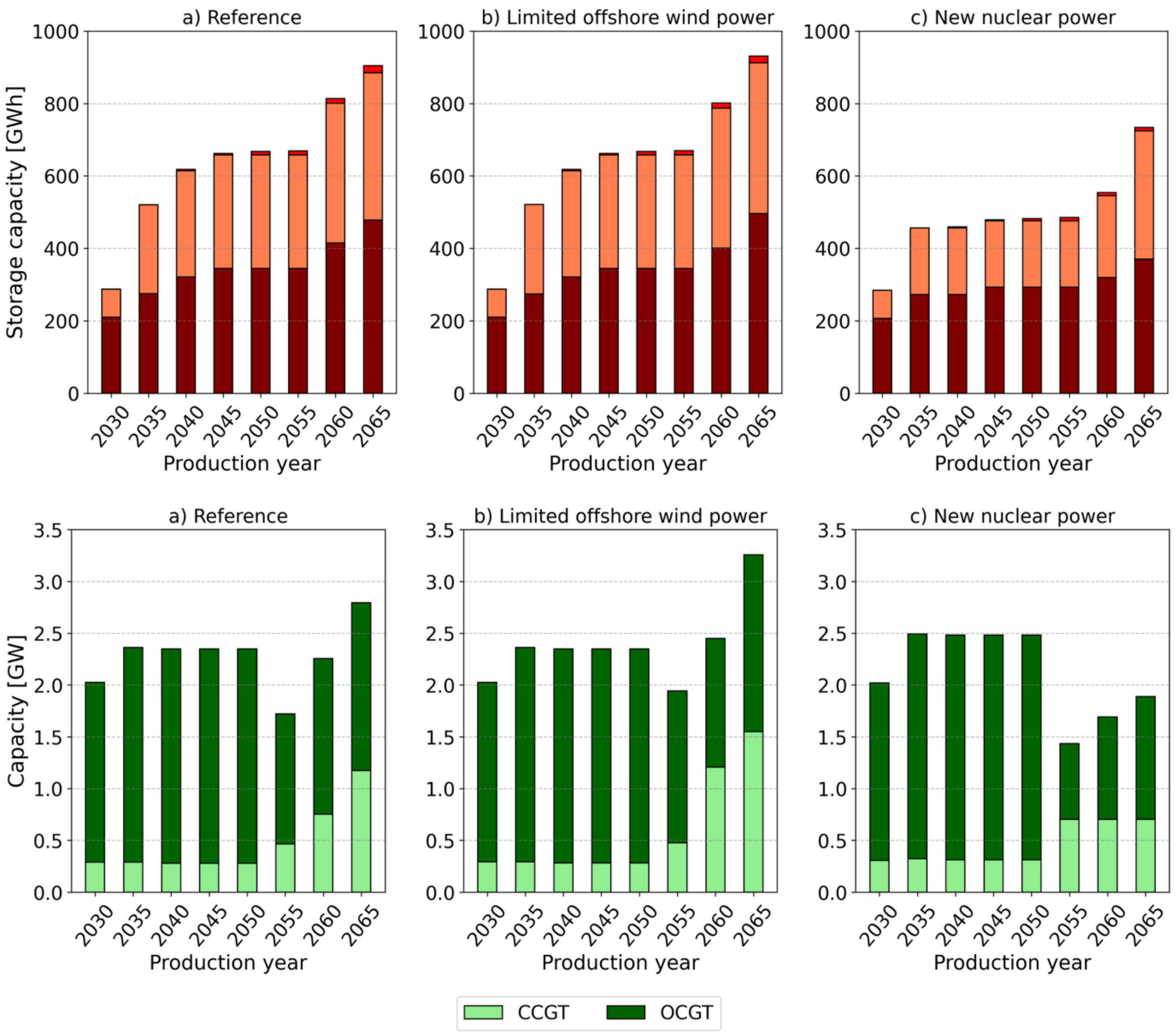
Consumption-weighted electricity price

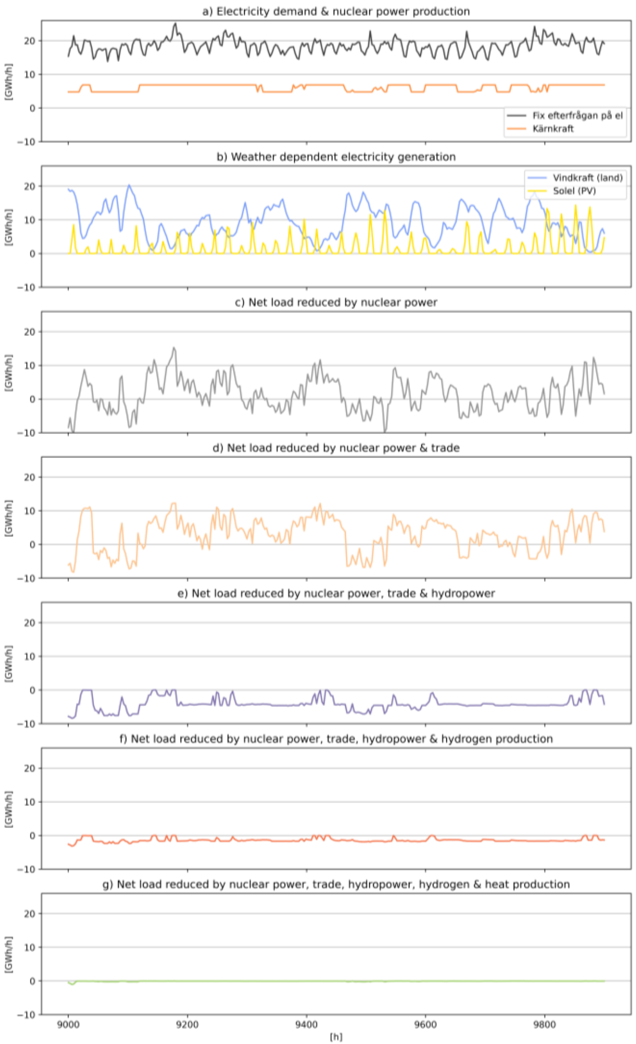
- Different electricity consumers experience different electricity prices
- Highest price for electricity for heating demand in winter
  - Heat pumps in DH < Ind Heat pumps
- Lowest electricity prices for electricity for electric cars and hydrogen
- New nuclear power gives 10 years of low electricity prices but initially higher electricity prices



Investments in flexibility

- Heat storage
  - Replace HP in 1-2 days
- Hydrogen storage
  - Meet demand 3-4 days
  - 50 % over capacity of electrolyser
  - Reduced by new nuclear power
- Batteries from 2050
- Gasturbines
  - High inital need for OCGT
  - More CCGT as existing nuclear is phased out
- Costs for this are included!
  - Power reserve of 1,1 GW without new nuclear (52 MEUR/yr)



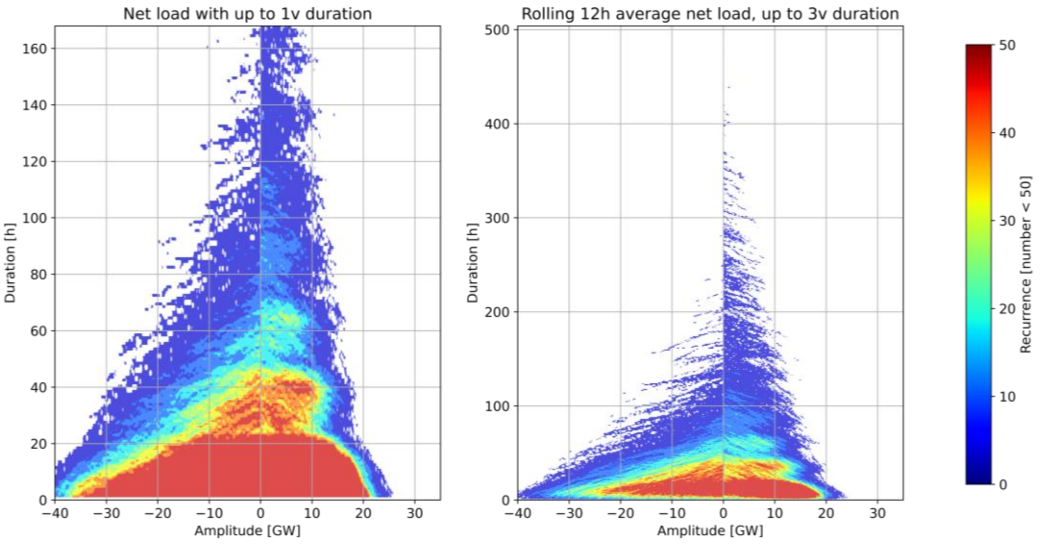


a) Electricity demand & nuclear power production
Fix efterfrågan på el
Kärnkraft
b) Weather dependent electricity generation
Vindkraft (land)
Solel (PV)
c) Net load reduced by nuclear power
d) Net load reduced by nuclear power & trade
e) Net load reduced by nuclear power, trade & hydropower
f) Net load reduced by nuclear power, trade, hydropower & hydrogen production
g) Net load reduced by nuclear power, trade, hydropower, hydrogen & heat production
[GWh/h]
[h]

CHALMERS

Extreme net load events

- Power sufficiency
  - Maximum load over 40 years is 29,5 GW
  - Maximum net load over 40 years is 27 GW
  - Maximum net load for modeled years is 24 GW
  - Short duration & low recurrence
  - Individual HP + EV
- Longer high net load events
  - 17 GW for 3 days (40 years)
  - 15 GW for 3 days (modeled years)
  - Hydropower + existing nuclear power
  - Hydropower + gasturbines w. fuel storage



Within the hour

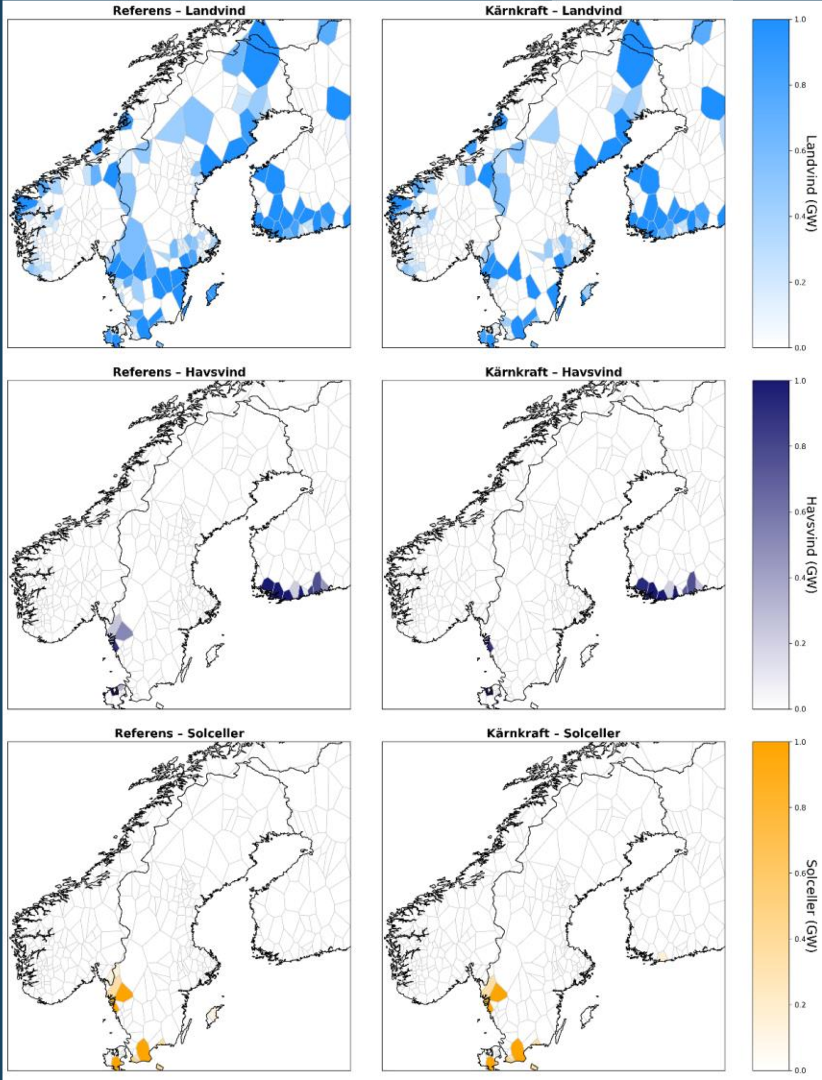
- Ramps of VRE
  - Solar PV has highest ramps
  - Worst ramps do not occur the same hour
  - 3 GW/GWh more without new nuclear power
- Fast feed-in of active power in case of a fault
  - Compensate for loss of inertia
  - 1/3 of Nordic 1450 MW
  - Sustain for 20 min
- 3,6 GW / 3,2 GWh of batteries for approx 40 MEUR/yr

	Without new nuclear				With new nuclear			
	SE4	SE3	SE2	SE1	SE4	SE3	SE2	SE1
Wind power (land) [GW]	2,53	5,00	1,32	1,33	2,53	3,44	1,17	1,33
Wind power (sea) [GW]	0,55	0	0	0	0,18	0	0	0
Solar (PV) [GW]	3,61	7,74	0	0	3,61	3,89	0	0
Load [GW]	0,12	0,28	0,039	0,019	0,12	0,28	0,039	0,019
Total [GW]	3,28	5,68	1,36	1,35	3,38	2,73	1,21	1,35

CHALMERS

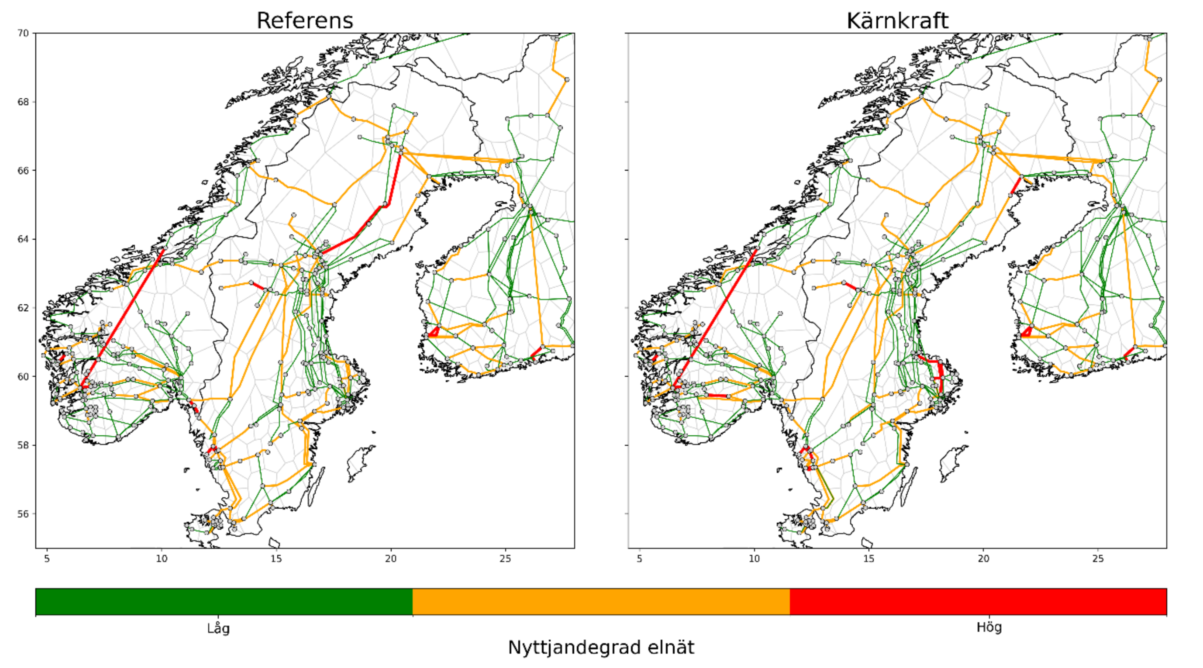
Transmission grid constraints

- Low impact on installed capacity and annual generation
  - Location within price area adapted to grid constraints
  - Mucher low solar PV capacity
- With limited temporal scope gives lower cost of new nuclear power (+770 MEUR/yr)
  - Build the system to fit level of nuclear capacity
- New nuclear power reduce onshore wind power in south Sweden



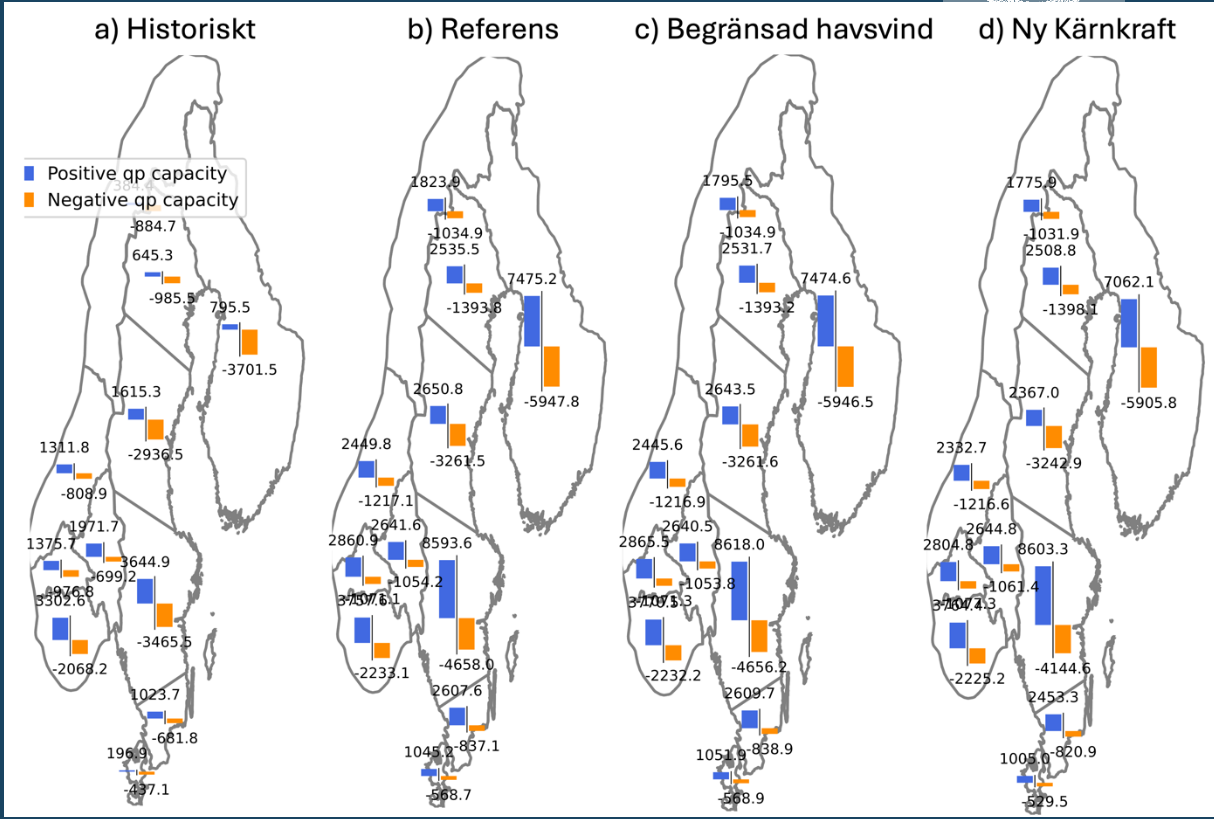
Utilization of transmission grid

- Medium to low utilization on average
- Combinations of hours with high and low utilization
- In model world location is adjusted to grid capacity
- New nuclear power has low impact on utilization



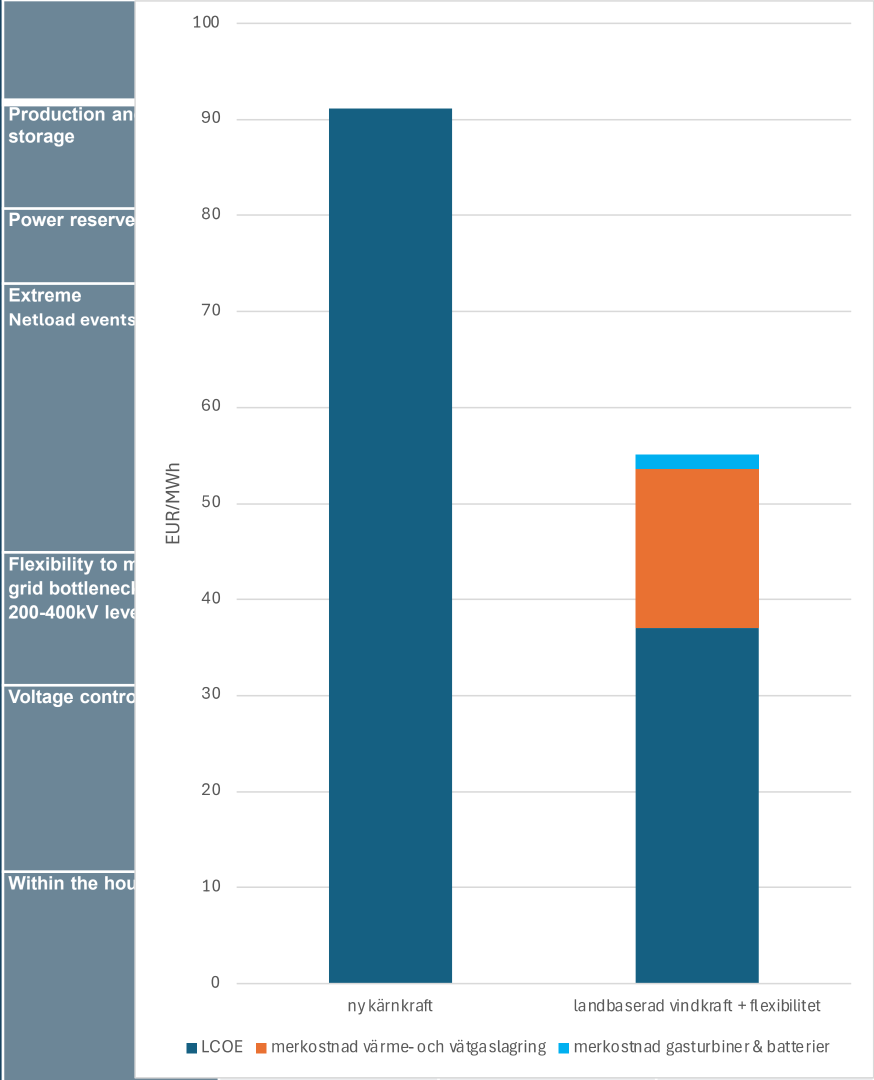
Reactive power compensation

- Reactive power compensation under stable conditions is done with shunt capacitors and shunt reactors
- Change in location of loads and generation gives changed needs
- Substantial increase in all future cases
- Without new nuclear power
  - +1120 MVAr shunt capacitors
  - +620 MVAr shunt reactors
  - 2 MEUR/yr



Conclusions

- More storage, battery and gasturbine capacity is needed in a future SE electricity system without new nuclear power
- High importance to map these needs and create incentives / regulations to put these in place
- The cost of these components is significantly smaller than the additional cost from new nuclear power
- Future work includes
  - Dynamic reactive power compensation (n-1)
  - Anlaysis of impedence and need to compensate for “weak grid”



Questions?

Podcast:

https://open.spotify.com/show/7IbnPZtxydOtMRZ3u56rMc?si=eebf8ddf858547ea

Report:

https://research.chalmers.se/publication/546563/file/546563_Fulltext.pdf

Who can you trust?

- What do you check when you get results from a new energy system study?

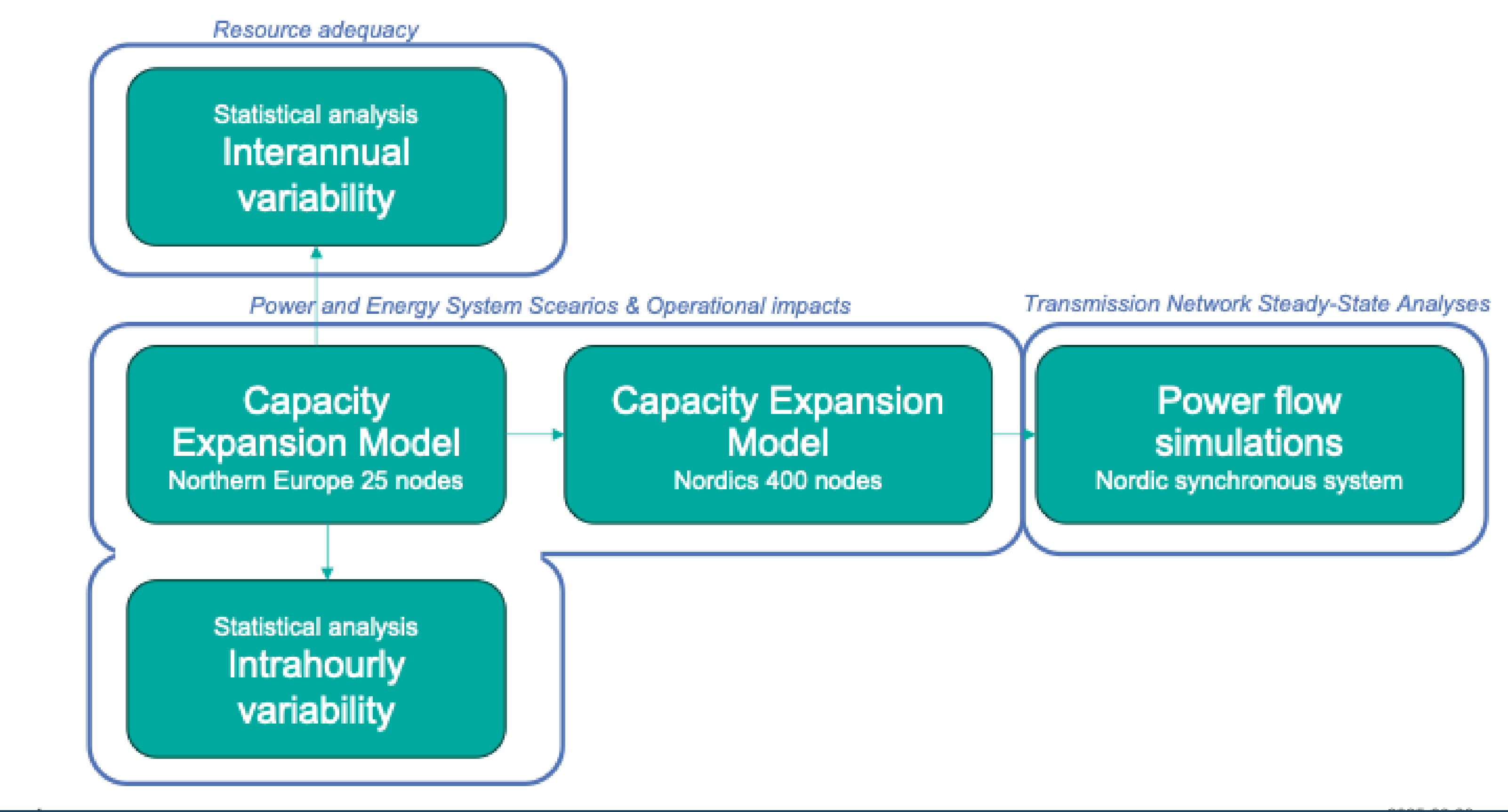
“All models are wrong but some are useful”

- There are many models out there
- Some models have different purpose and complement each other
- Some models are of worse quality

- What is the input data used?
- What is the model structure?

Input data

- Technology costs
  - Openly available
  - Impartial and well known actors
  - Same/few sources to be comparable
- Weather data
  - Detailed resource description
    - Based on at least 30 years
    - High geographical resolution
    - Hourly
  - Wet and dry year in the analysis, or normal year

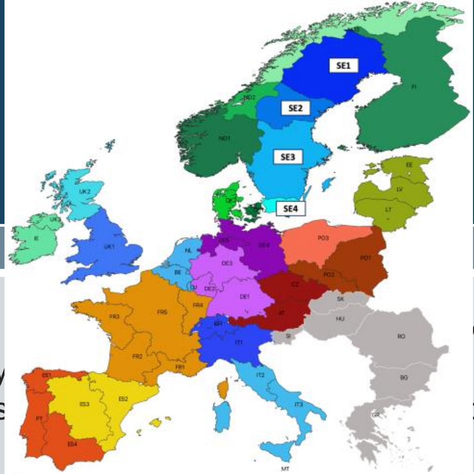

Resource adequacy
Statistical analysis
Interannual variability
Power and Energy System Scearios & Operational impacts
Transmission Network Steady-State Analyses
Capacity Expansion Model
Northern Europe 25 nodes
Capacity Expansion Model
Nordics 400 nodes
Power flow simulations
Nordic synchronous system
Statistical analysis
Intrahourly variability

Model structure

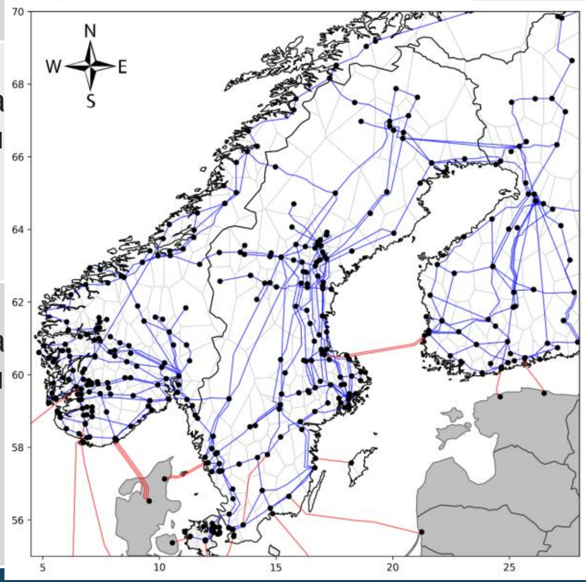
- Optimization or simulation model?
- What is the objective function?
- Whose perspective does it represent?
- What is predetermined and what is decided by the model?
- If multiple steps, how do these link?
- Technology scope, geographical scope, temporal scope
- Geographical resolution, temporal resolution

Modeling framework

CHALMERS



Model	Aim	Geography	Time	
ELLI	Minimizing the cost to society to meet demand	Large part of Europe divided into 25 bidding zones	Every 5 years 2065 Two weather y 2920 time clus per year	production mix over time ydrogen storage and heat cost of electricity and
EHUB	Minimizing the cost to society to meet demand	Nordic synchronous system divided into 400 nodes	2050 A weather yea 3h time resolu	w electricity orage ssion grid capacity
Power flow model	Simulate flows of active and reactive power	Nordic synchronous system divided into 400 nodes	2050 A weather yea 3h time resolu	culated electrical ply with physical d reactive power in power a stable state



SvK analysis
How does the system operate?
System operator prespective
30 weather years, hourly

Energimyndigheten / Profu
How can demand in all sectors be met to lowest cost?
Social planner perspective
1 normal year, 16 timesteps

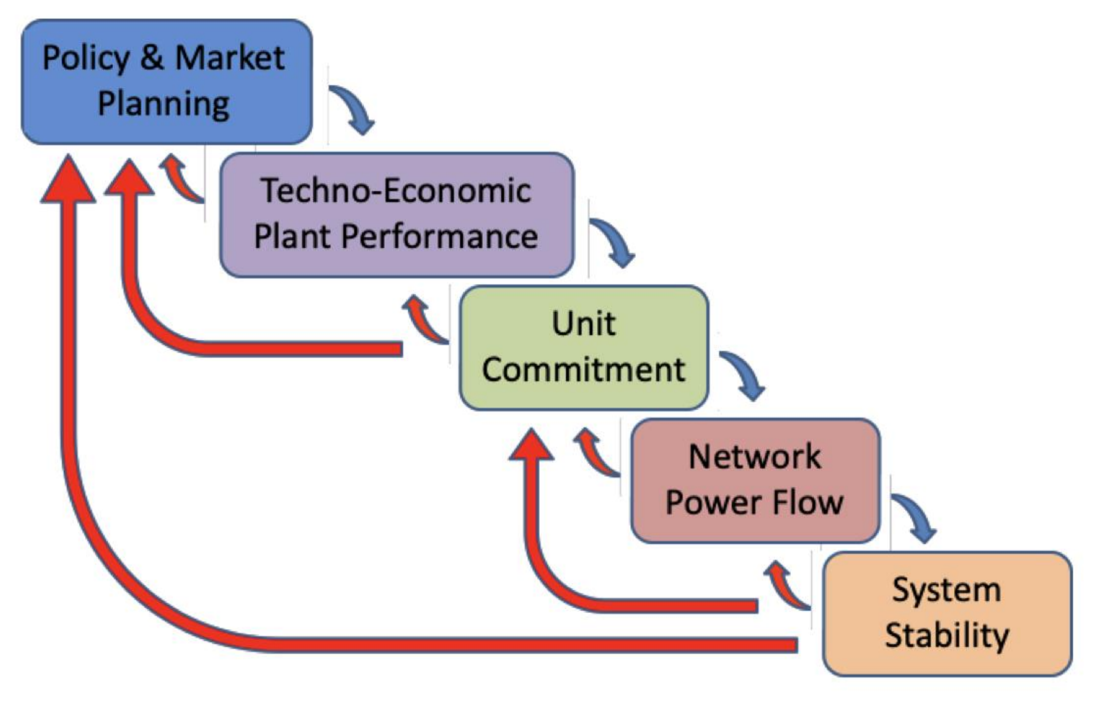
Svenskt Näringsliv
What will the system look like?
Actor & system perspective
1 dry year, hourly
Often static surrounding

Chalmers
How can electricity be met to lowest cost for society?
Social planner perspective
Wet+dry year, 3-hourly
Dynamic surrounding

Recommended modelling practice

IEA Checklists on

- Power and Energy System Scenarios
- Resource Adequacy Estimates
- Capacity Value
- Transmission network steady state analyses
- Distribution Grid Studies
- Operational Impact
- Network Simulations and Dynamics



Questions?

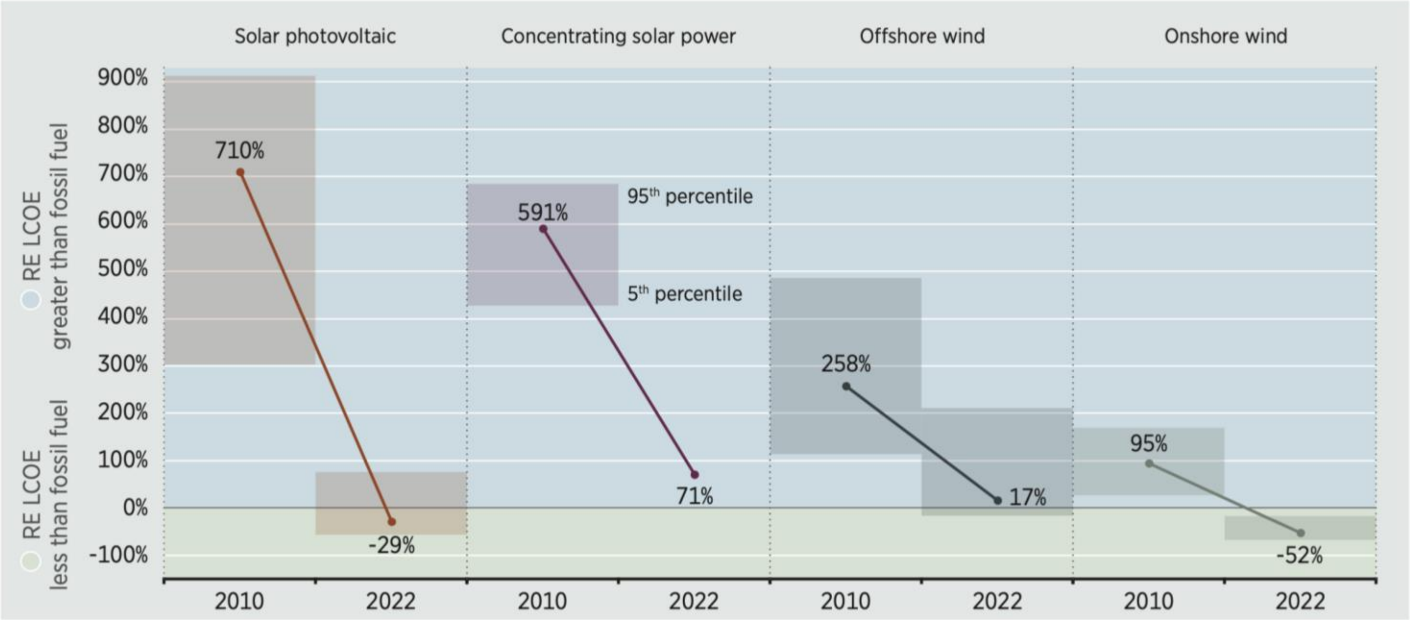
Podcast:

https://open.spotify.com/show/7IbnPZtxydOtMRZ3u56rMc?si=eebf8ddf858547ea

What do we do when the wind is not blowing?

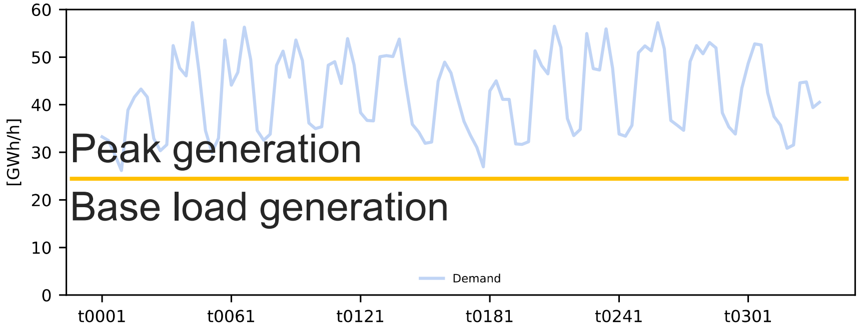
Why flexibility?

Figure S.1 Change in competitiveness of solar and wind by country based on global weighted average LCOE, 2010-2022

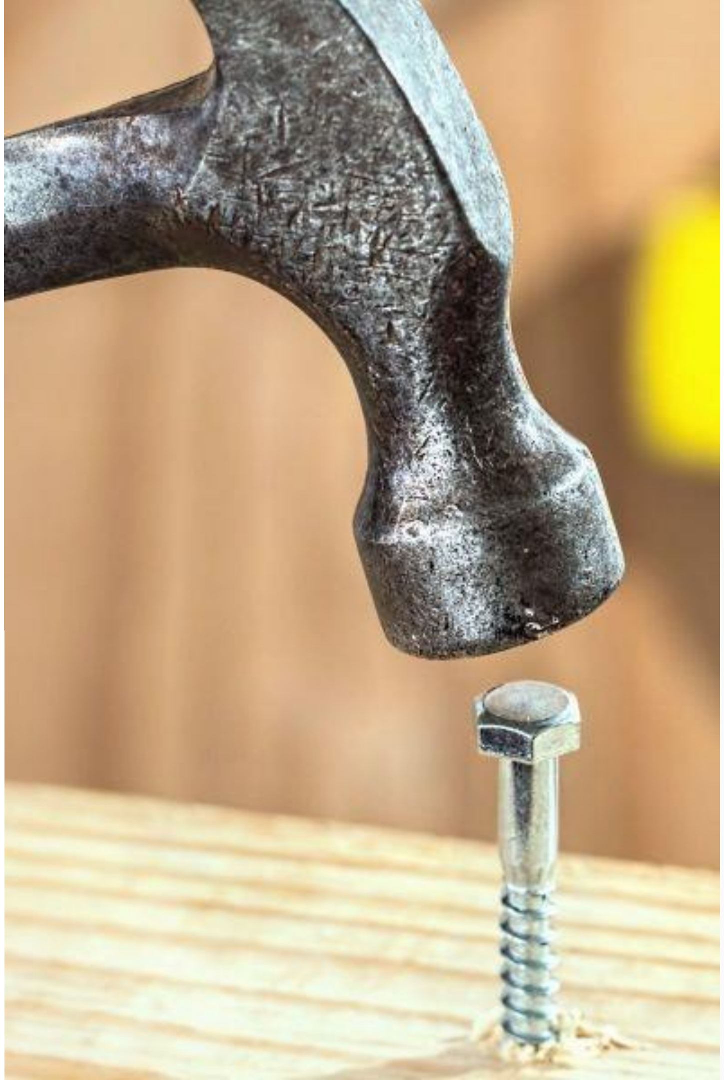


Note: The global weighted average LCOE data by technology and the fossil fuel LCOE data used to derive this chart is presented in detail in Chapter 1; RE = renewable energy.

Source: IRENA


60
50
40
30
20
10
0
[GWh/h]
Peak generation
Base load generation
Demand
t0001
t0061
t0121
t0181
t0241
t0301


Flexible production

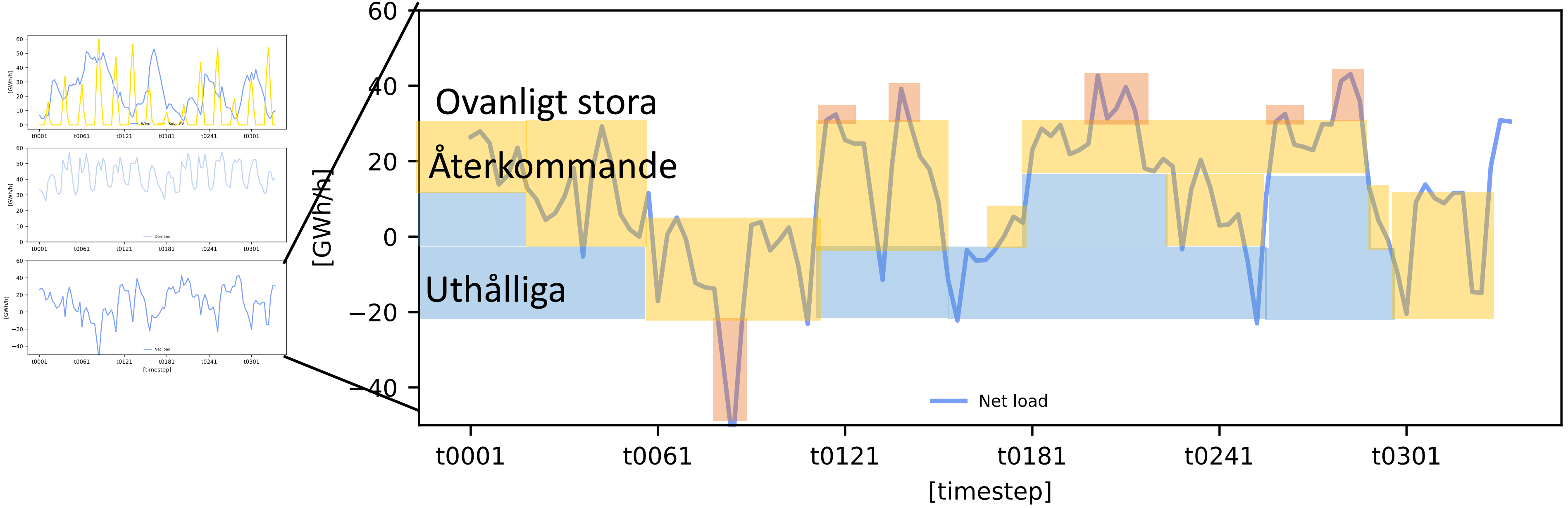



Flexible generation
Storage
Flexible production

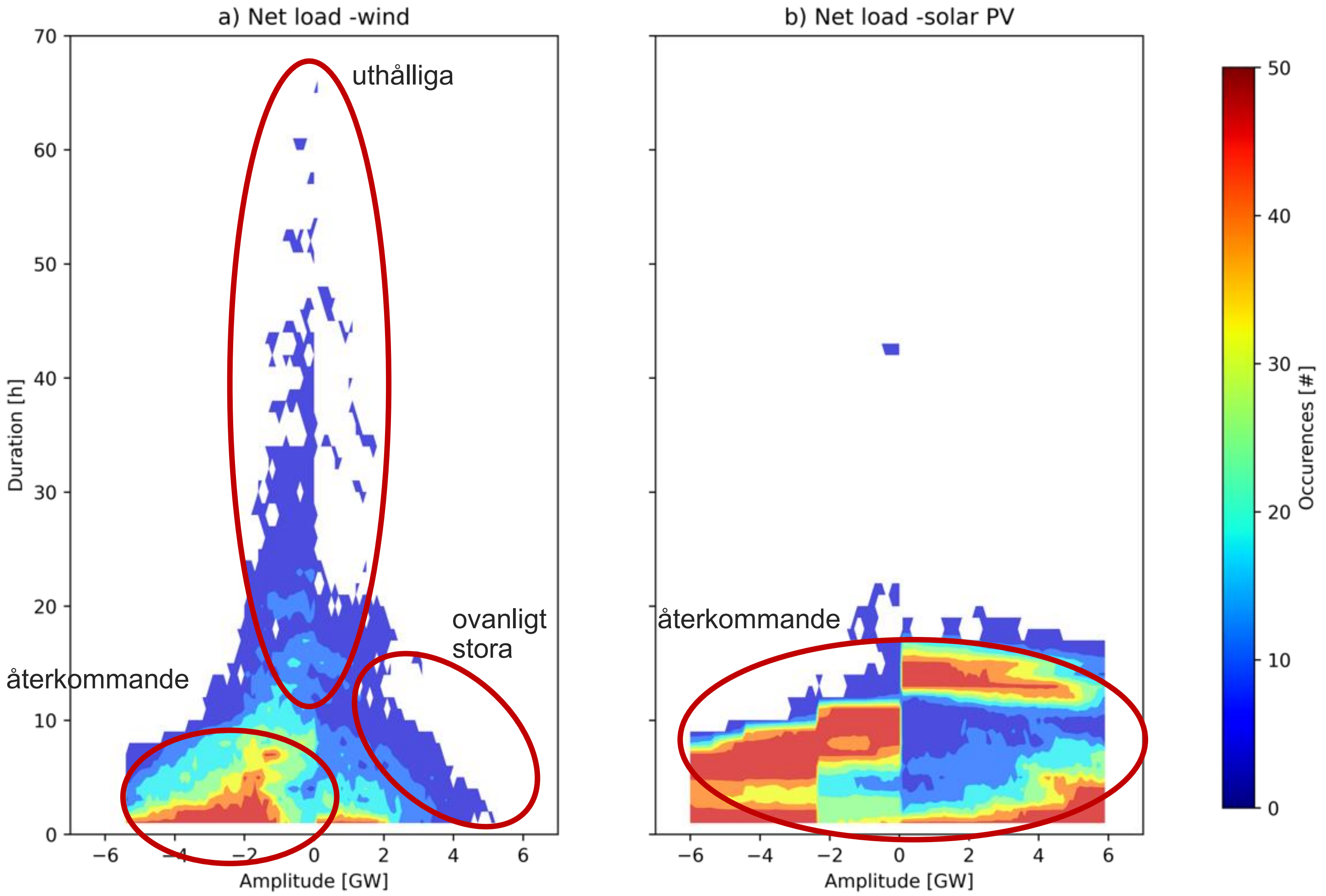
Which flexibility?

This one solves it!

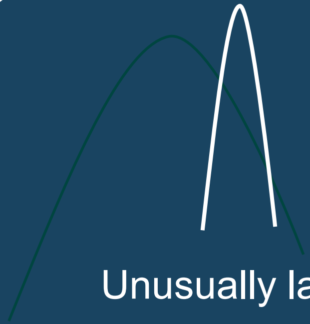
We need all!



Ovanligt stora
Återkommande
Uthålliga
60
40
20
0
−20
−40
[GWh/h]
t0001
t0061
t0121
t0181
t0241
t0301
[timestep]
Net load

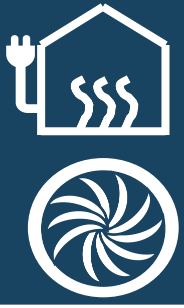

a) Net load -wind
b) Net load -solar PV
uthålliga
ovanligt
stora
återkommande
återkommande
Duration [h]
Amplitude [GW]
Amplitude [GW]
Occurences [#]

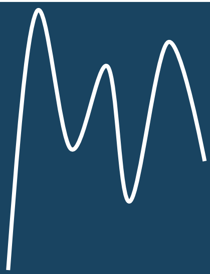
Matching need with strategy



Unusually large

Low inv. cost of charging/discharging



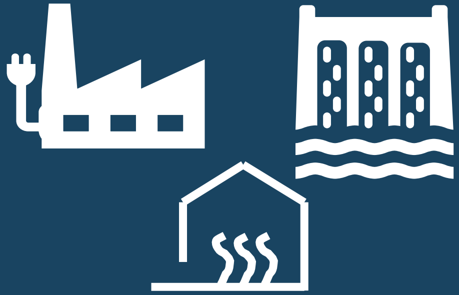


High recurrence

High efficiency

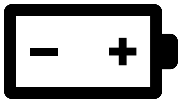
Long duration

Low cost of energy storage

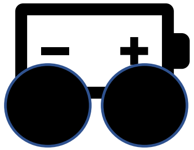


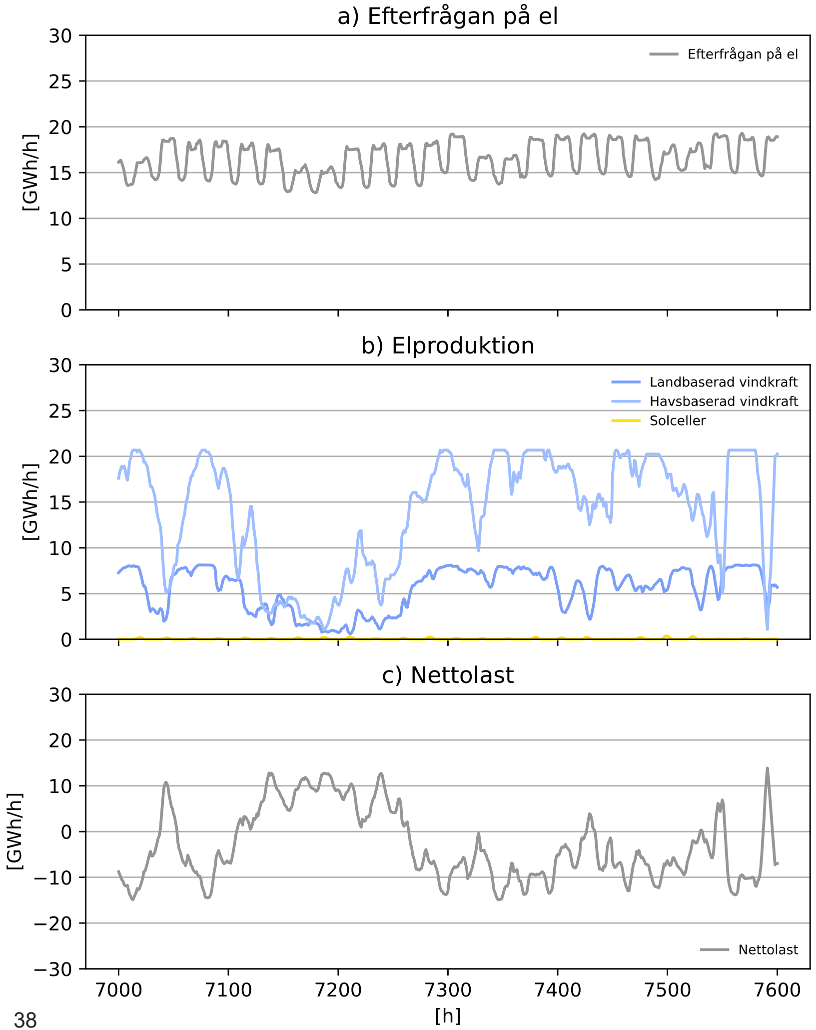
Is flexibility the purpose of the investment?

- Flexibility as primary purpose
  - **Cost structure and technical properties determine which variations can be managed**
  - E.g. stationary batteries, gas turbines



- Flexibility as extra opportunity
  - Investment made for different purpose
  - **Main purpose limits which variations can be managed**
  - E.g. strategic charging of EV and home heating appliances

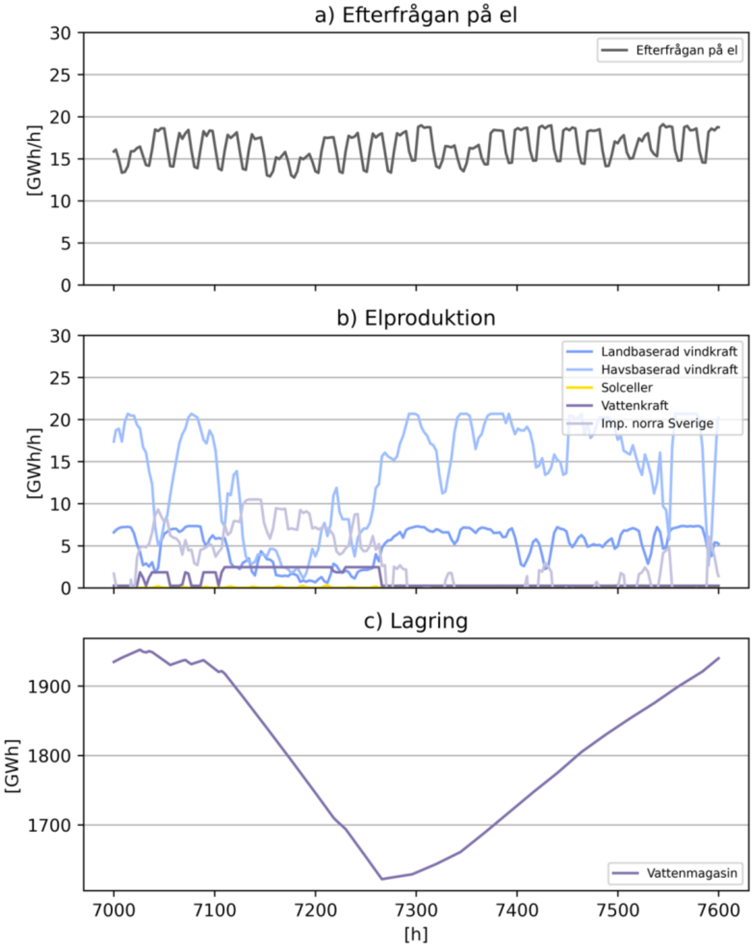




CHALMERS

Variability

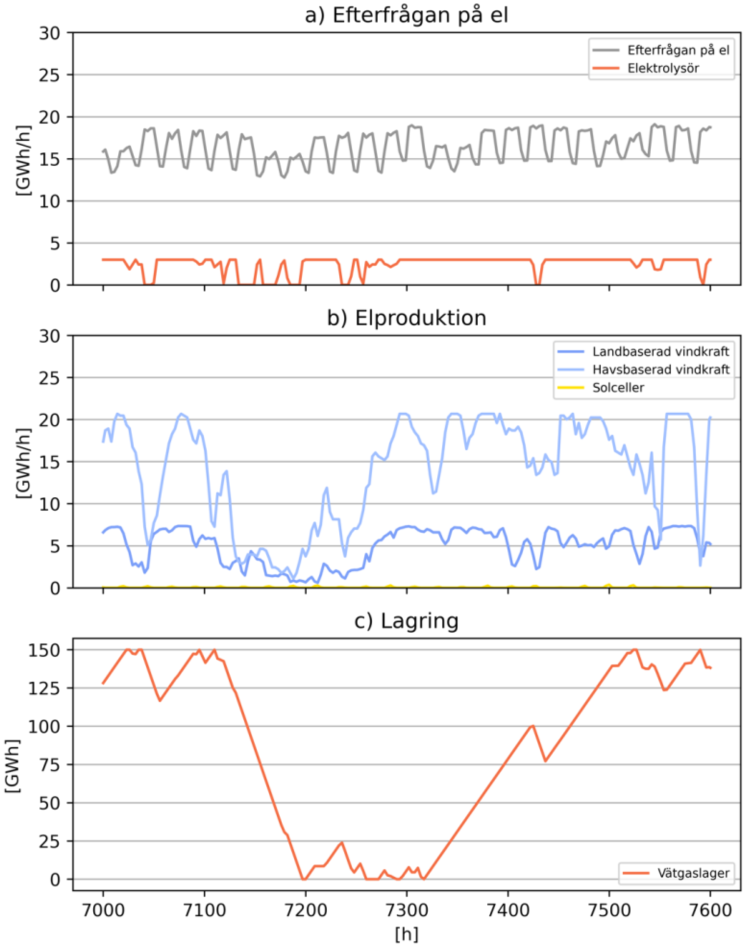
- Hydropower (30%) + wind power (70%)
- What do we do if the wind is not blowing?
- Flexibility measures
  - Trade
  - Hydropower
  - Stationary batteries and electric vehicles
  - Strategic hydrogen production
  - Strategic heat production



Flexible hydropower

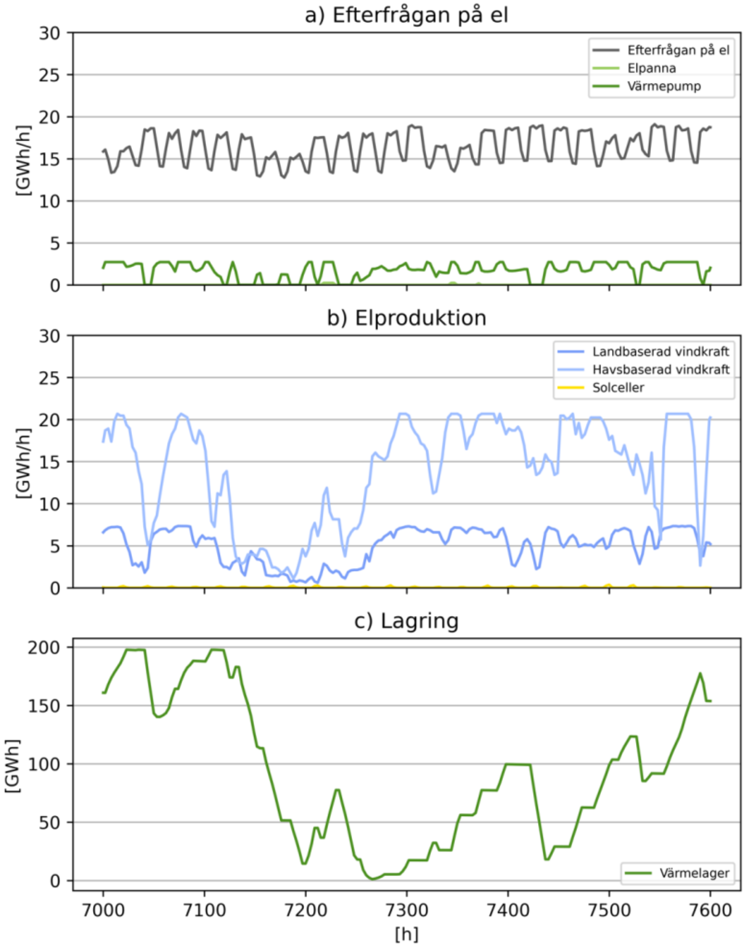
- Local production & import from northern Sweden
- Support at low wind power production. Long duration
- Increased transmission SE2->SE3: 10,4 GW

- Electricity demand in northern Sweden does not add load on critical hours (hydrogen)



Strategic hydrogen production

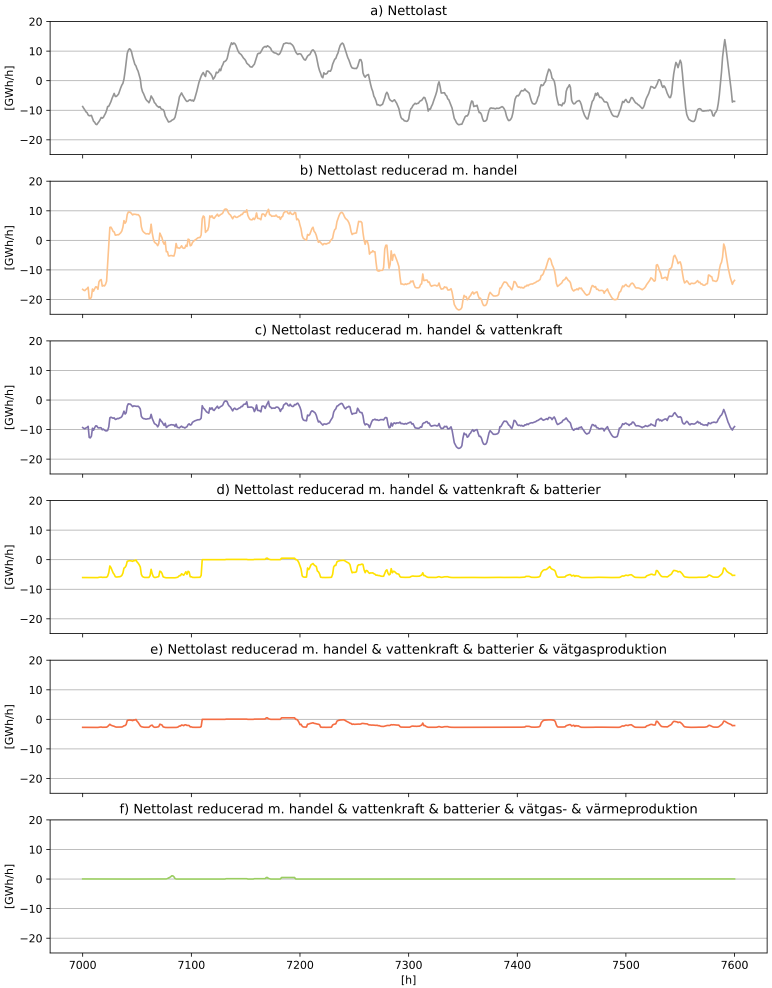
- Hydrogen production for industry
- Avoid hydrogen production during low wind events
  Low amplitude, long duration
- Stimulate wind power investments without adding load on strained hours



CHALMERS

Strategic heat production

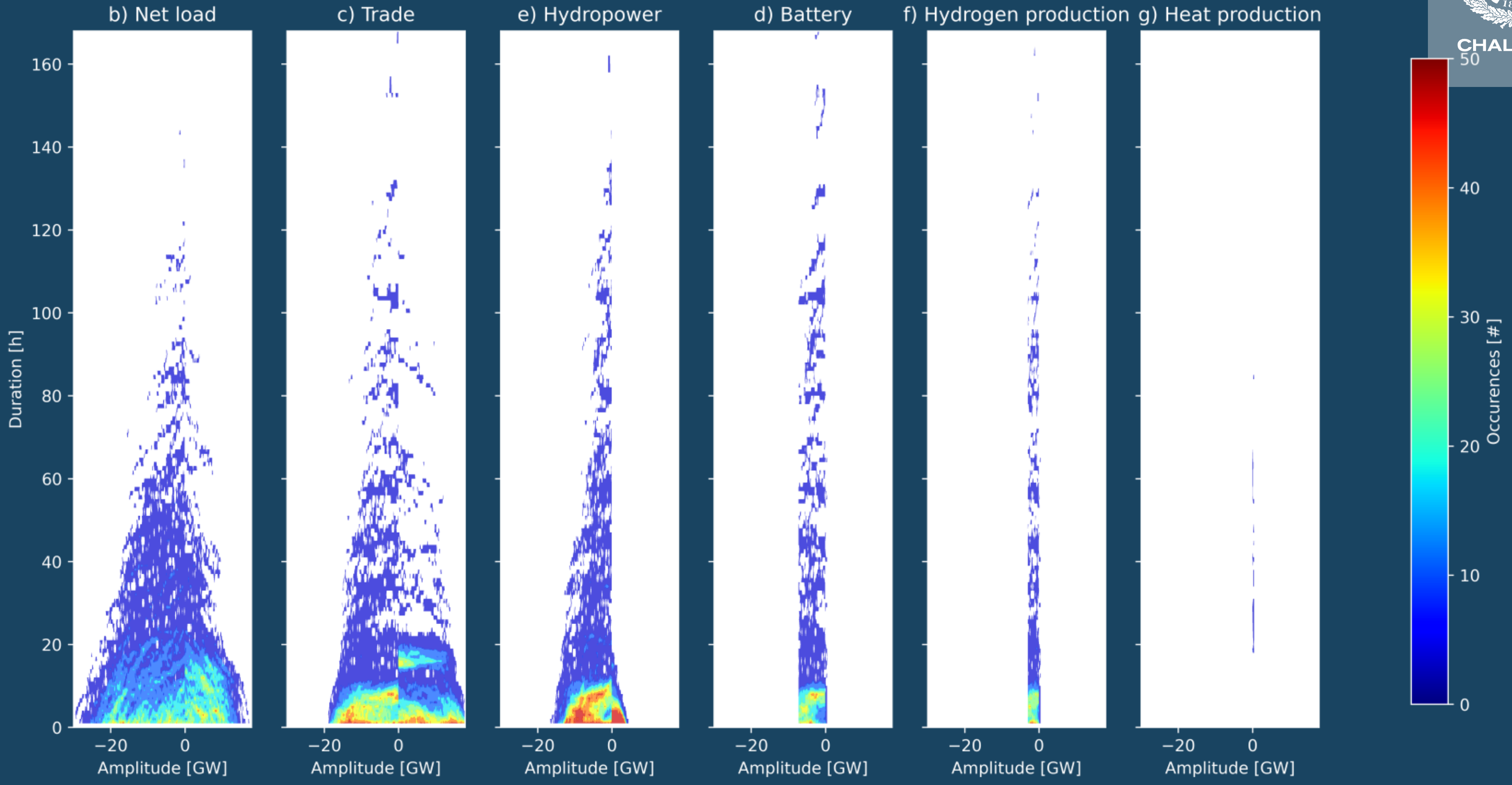
- Heat pumps in the district heating grid
- Avoid heat pump operation during low wind events
  Low amplitude, long duration
- Stimulate wind power investments without adding load on strained hours



CHALMERS

Managing variations

- South Sweden 3 winter weeks
- Trade reduce peaks above 10 GW
- Hydropower reduce positive net load up to 10 GW
- Strategic charging of EV:s even out
- Hydrogen and heat lift negative net load


b) Net load
c) Trade
e) Hydropower
d) Battery
f) Hydrogen production
g) Heat production
Duration [h]
0
20
40
60
80
100
120
140
160
−20
0
Amplitude [GW]
Occurences [#]
0
10
20
30
40
50

CHALMERS

Variations management -theory

- There are many different types of variations
  - Amplitude, endurance, recurrence
  - Solar variations have high amplitude and recurrence
  - Wind variations have high endurance
- Different strategies suit different types of variations
  - Cost structure
  - Technical characteristics
- Sector coupling offers flexibility in the electricity system of the future
  - The transport sector deals with variations with high amplitude and short endurance
  - Hydrogen production for the industrial sector handles variations with long endurance
  - Heat production handles variations with long endurance

Variation management in Sweden

- When it is a little windy in winter
  - Is wind power used for the load that cannot be moved in time
  - Hydropower meets the remaining load
- When it's not windy in the summer
  - Solar electricity is imported from the continent
  - Variations in solar power are balanced with stationary batteries
  - On cloudy days, hydropower

How do we get the flexibility in place?

- Strategies for unusually large variations need to be procured
  - Few hours and large differences between years entail high risk
  - The price of electricity during peak hours becomes unacceptably high
  - Ex. the power reserve
- The energy-only market provides insights into strategies for recurring and sustainable variations
  - Predictable electricity price variations
  - Major wind power expansion in Northern Europe
  - Good understanding of wind variations
- Flexible markets may be needed nationally during the transition period
  - Flexibility in place before variability
  - Uncertainty about the development of the electricity market
  - Three products for three types of variations: unusually large, recurrent, durable

Questions?

Lecture:

https://www.youtube.com/watch?v=VP5xoW6hQC4

CHALMERS

UNIVERSITY OF TECHNOLOGY