Importance of peaking conditions and storage functionalities in the energy transition – a systems analysis

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6. Herbstworkshop Energiespeichersysteme

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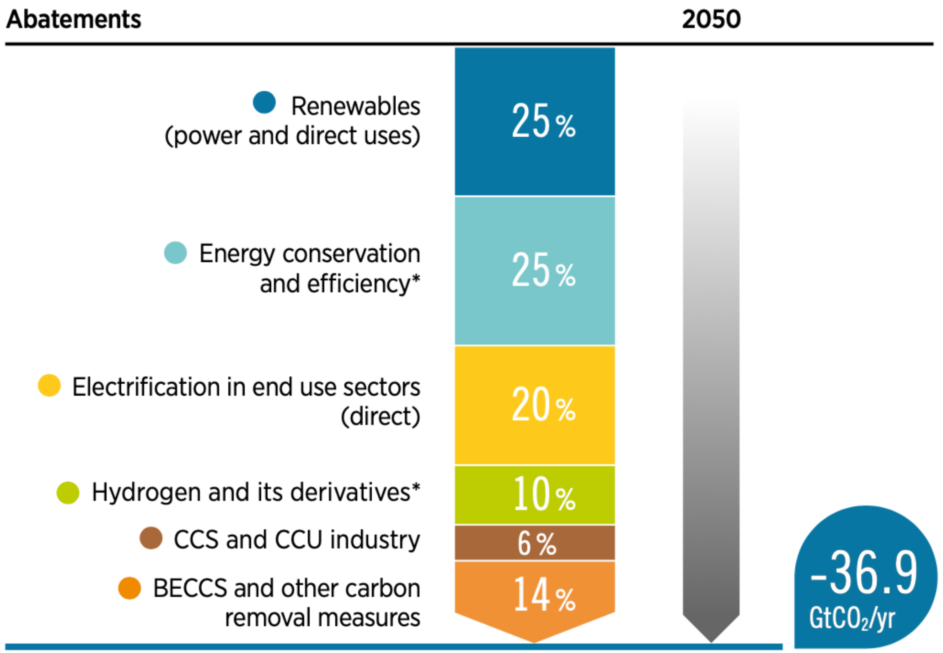
Outline

- The changing role of peak power and its solutions in the energy transition
- Energy system resilience
- Effect of weather
- Measures to mitigate peak conditions and peak power demand

Approaching carbon neutrality through breakthroughs

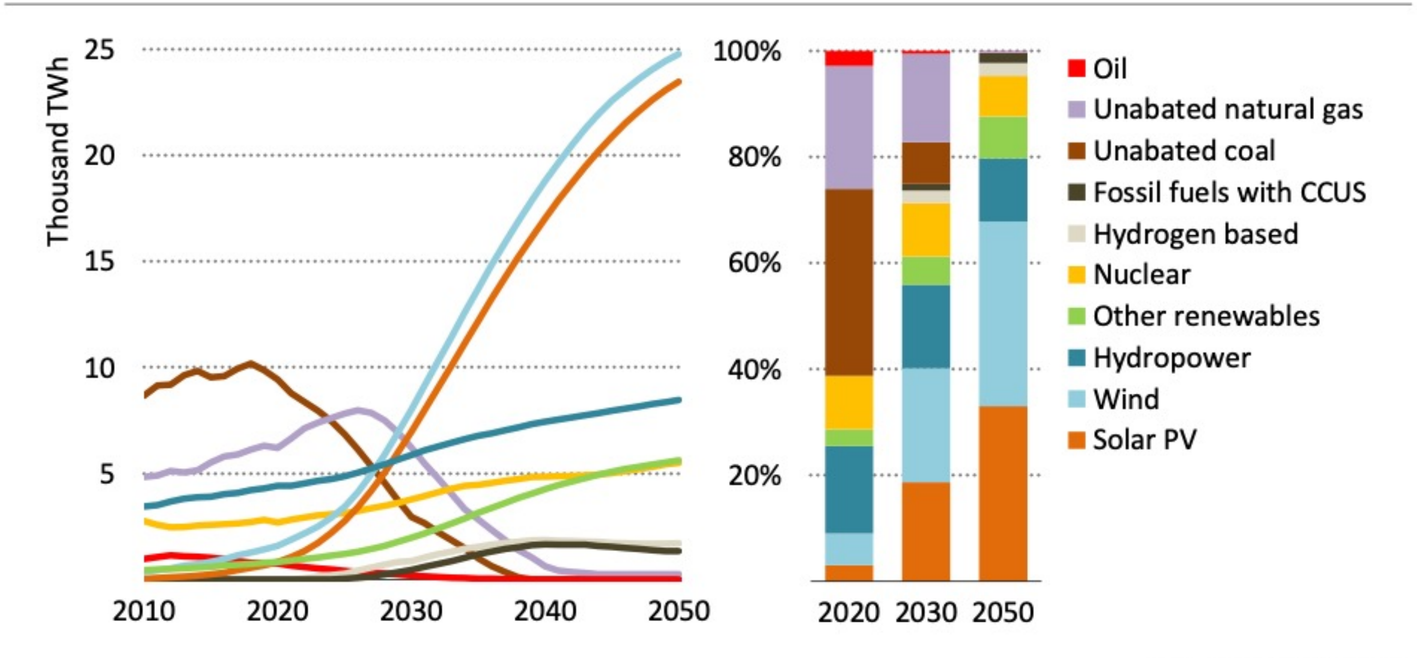
Solar and wind 70% of world electricity by 2050

FIGURE S.4 **Carbon emissions abatements under the 1.5°C Scenario (%)**



Source: IRENA, 2021

Figure 3.10 ⊳ Global electricity generation by source in the NZE



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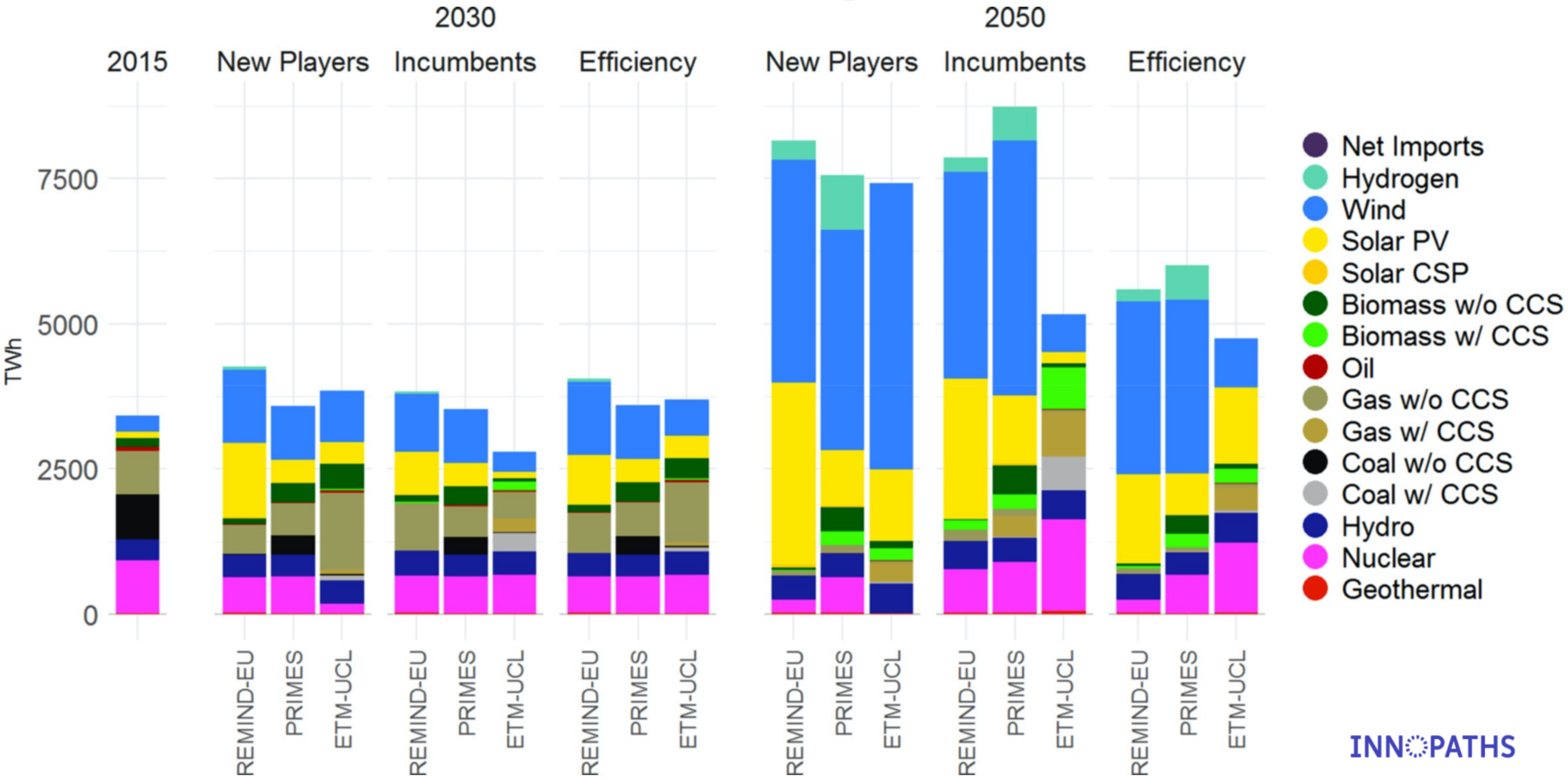
Solar and wind power race ahead, raising the share of renewables in total generation from 29% in 2020 to nearly 90% in 2050, complemented by nuclear, hydrogen and CCUS

Source: Net Zero by 2050. International Energy Agency, May 2021

Power sector development in the EU



INNOPATHS

Ref. Energy 239 (2022) 12190
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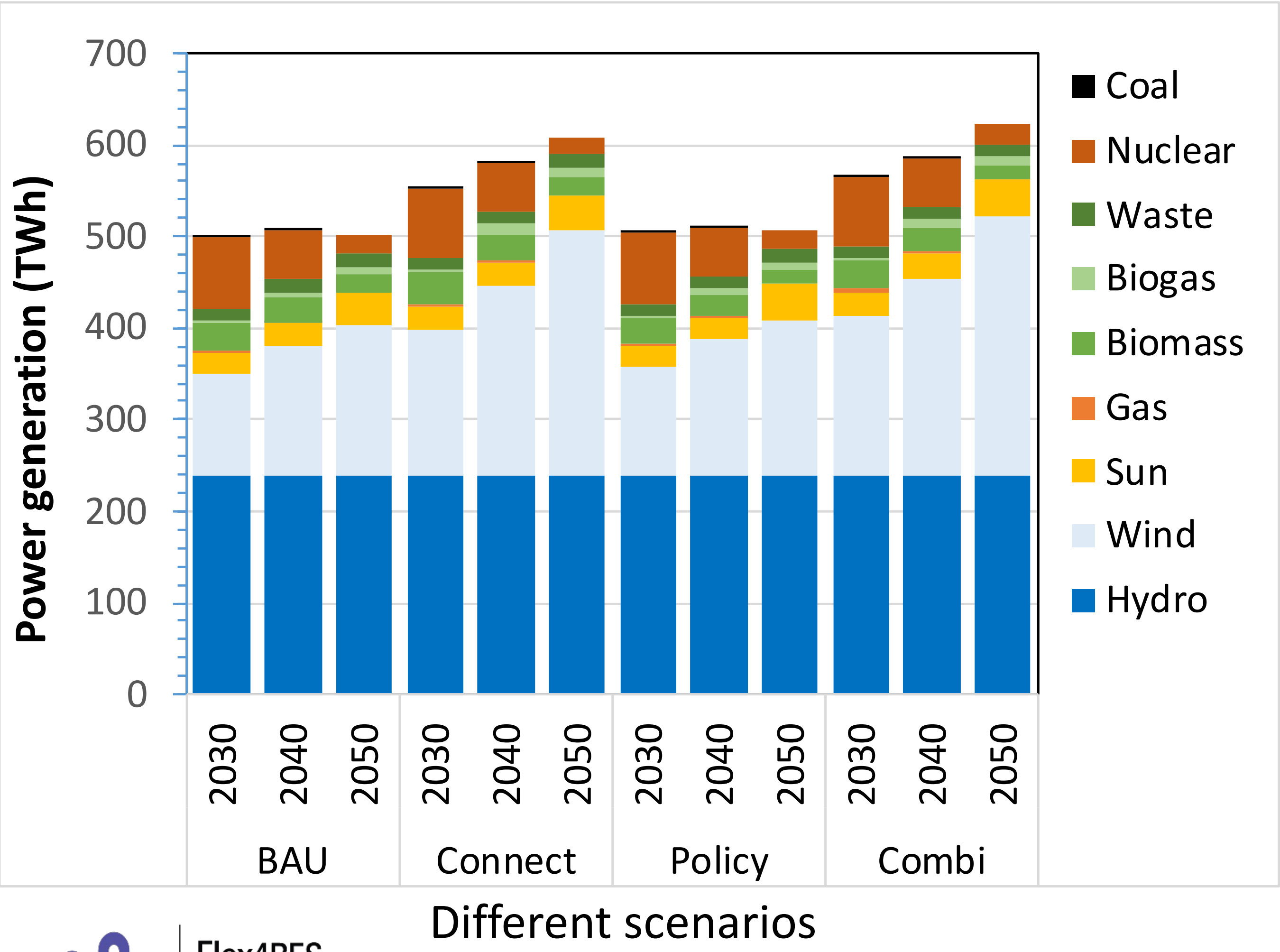
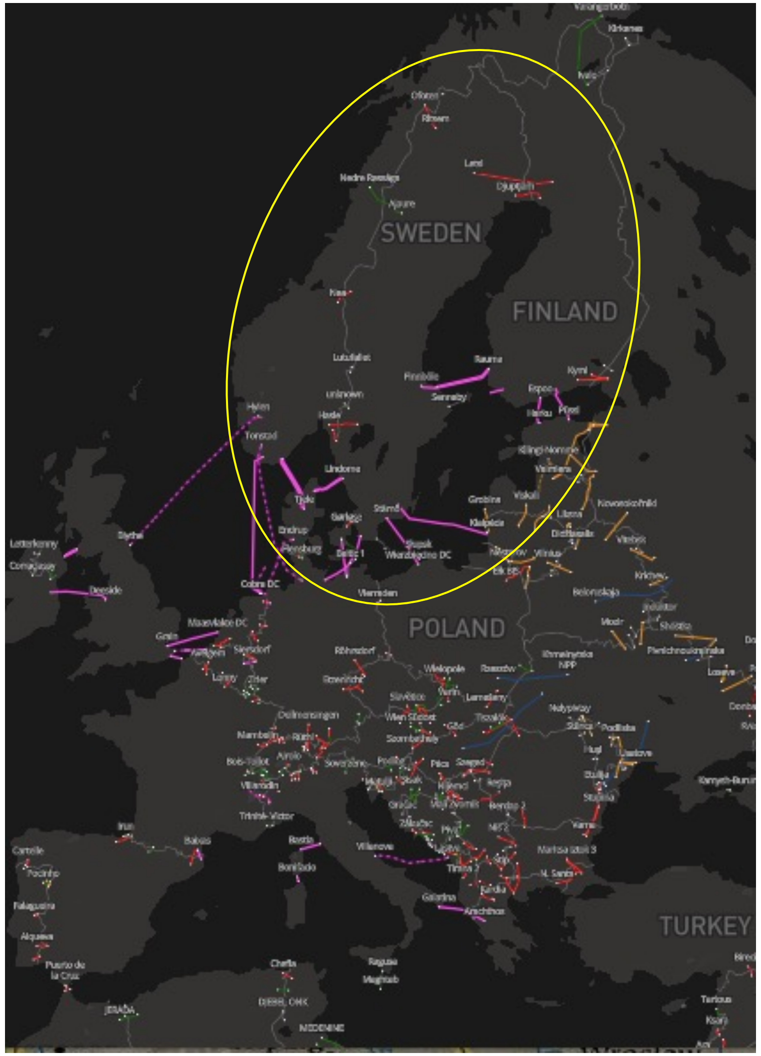
Nordic zero-emission energy transition

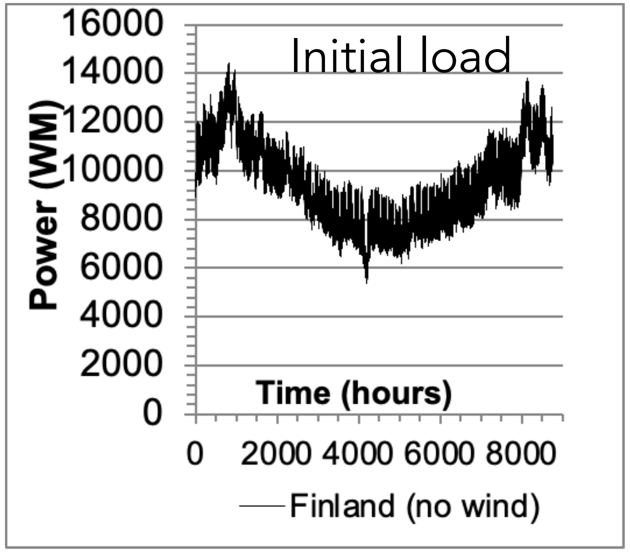
Electricity generation (TWh)

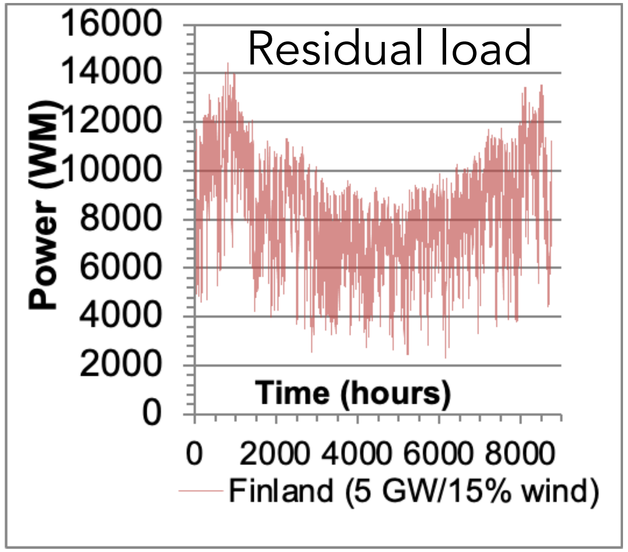


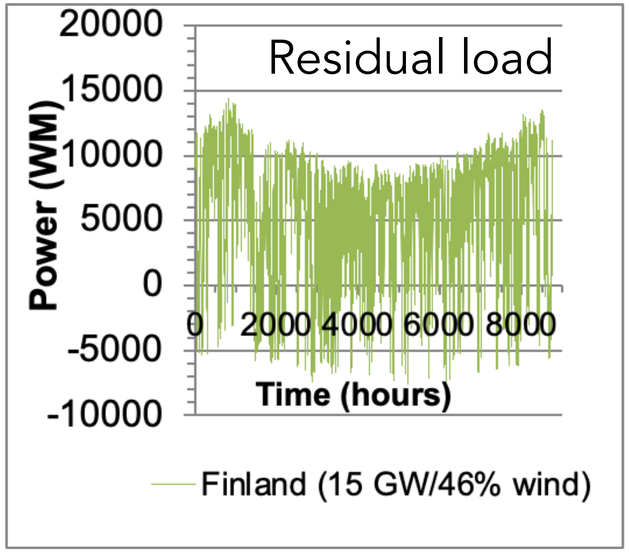


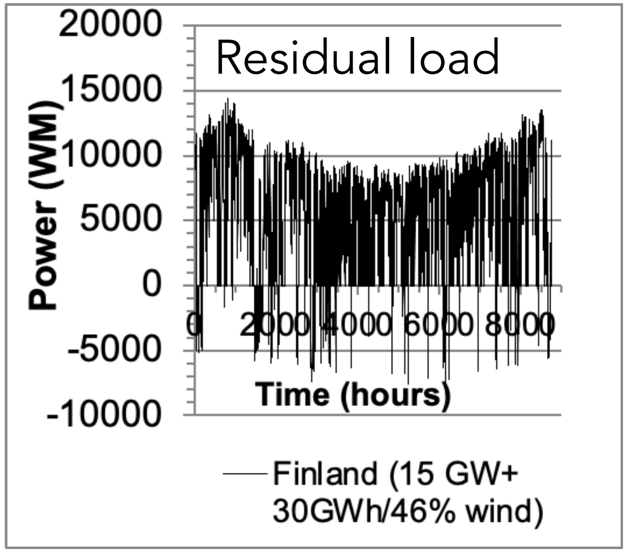
Flex4RES
Flexible Nordic Energy Systems

Impact of variable renewables on power profiles









Residual load

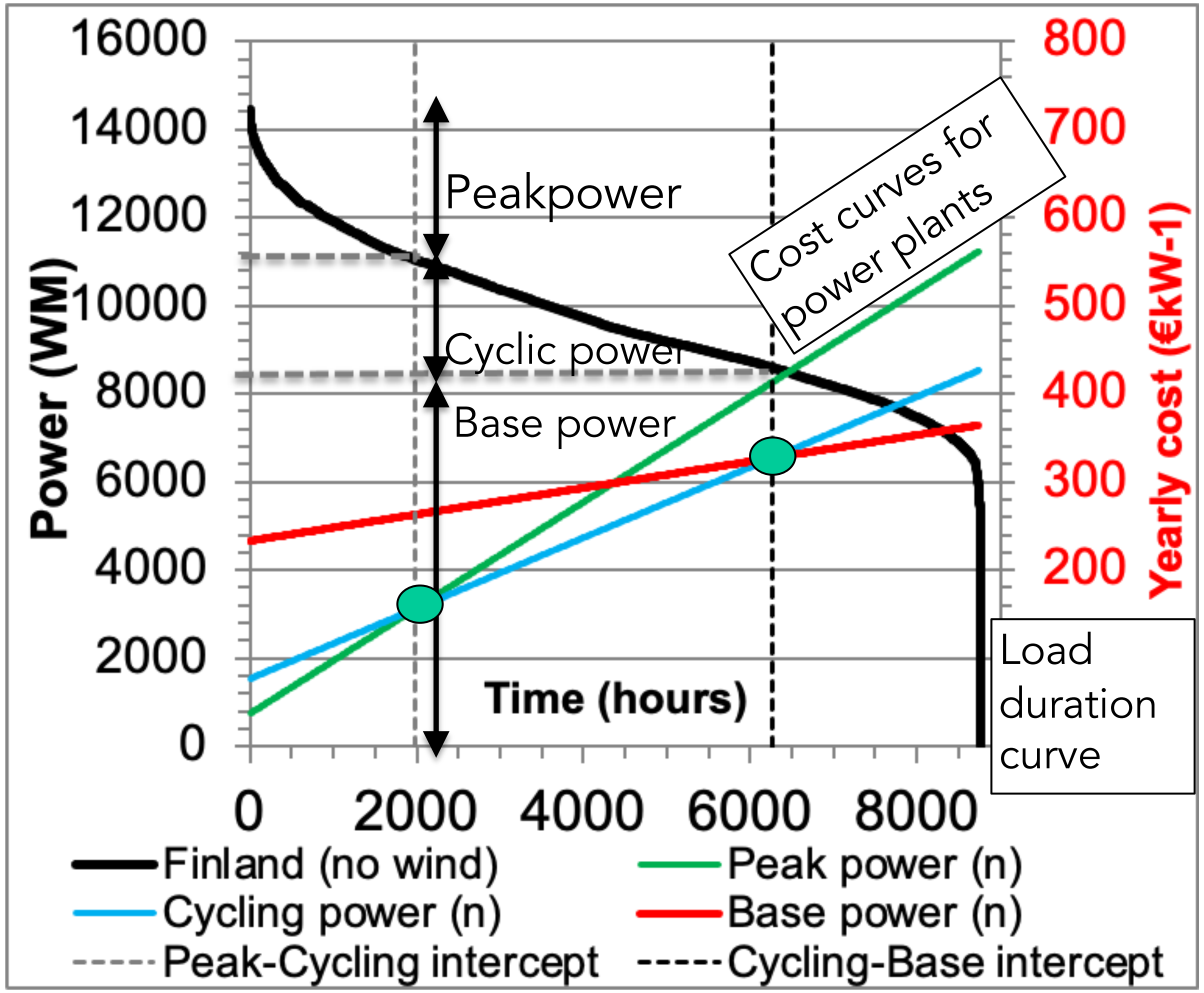
(= Initial load – wind/solar power)

- Increasing variability
- More zero and negative loads
- Less influence on peak demand

- Next step of analysis:
  - power duration curve analysis to determine the relative changes in optimal power plant mix to meet the residual loads
  - power duration curve analysis follows the marginal cost principle (power market)

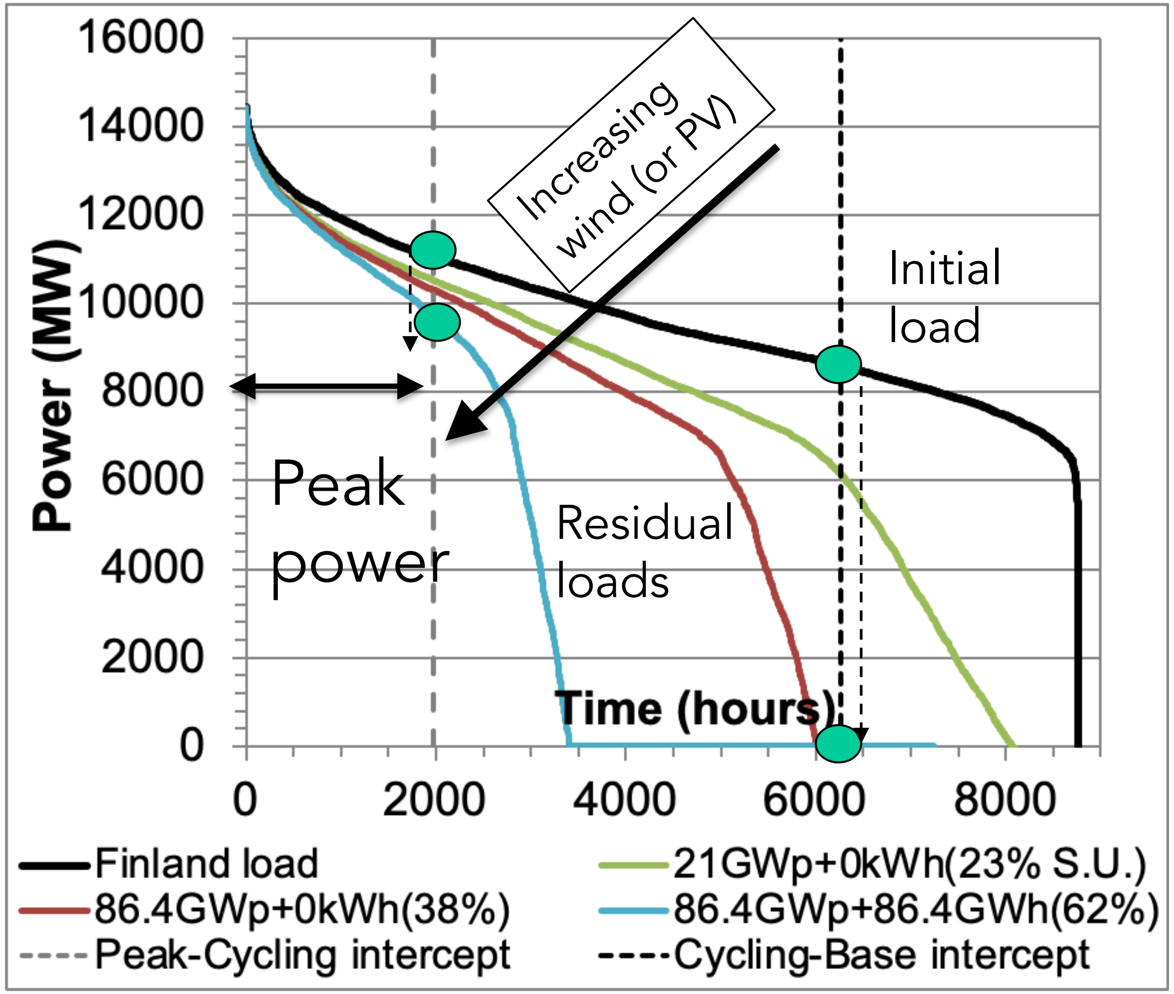
Determining the optimum power mix

Load duration curve + cost curves of power plants (Capex+Opex ✕ time) → optimum power mix



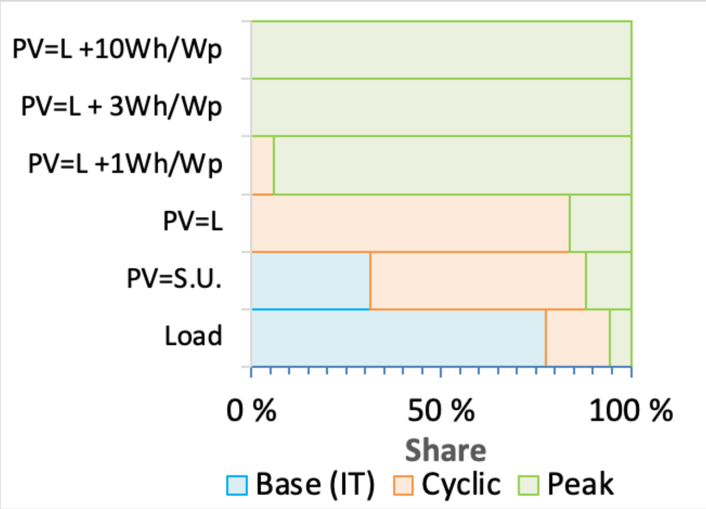
Changing residual load affects optimum power mix

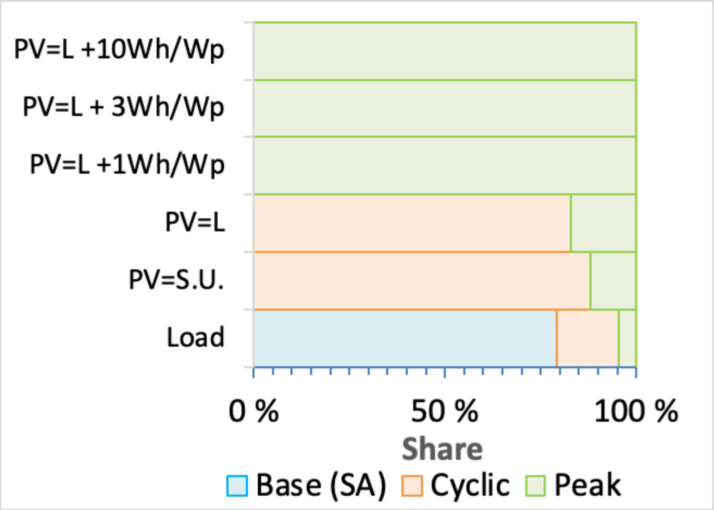
Increasing variable renewable electricity shifts the residual demand towards <u>peak power</u>

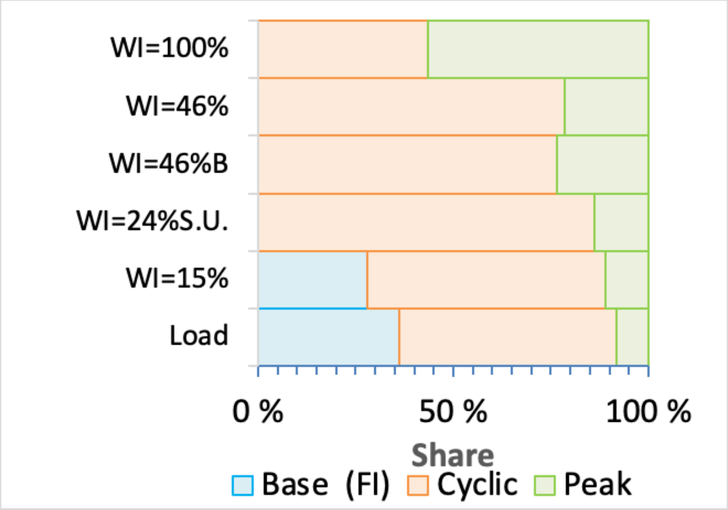


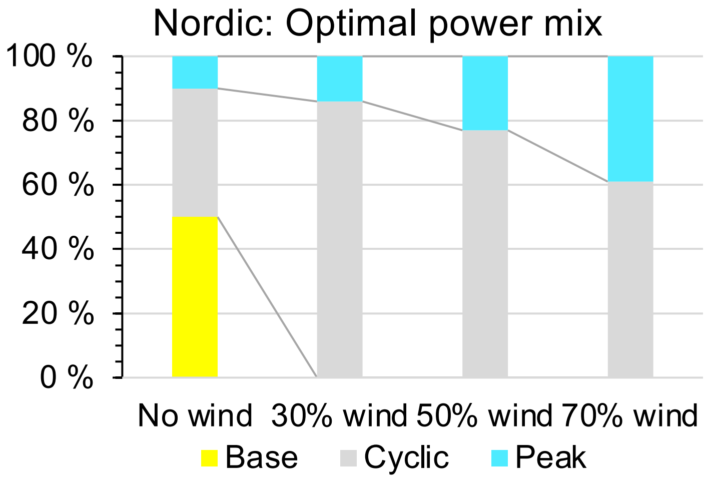
Shift towards more flexible power supply

- 4 cases: Italy/PV, Saudi-Arabia/PV, Finland/Wind, Nordic/Wind
- Sizing : PV=yearly load + 0-10 Wh/W_p storage; S.U.=self-use limit









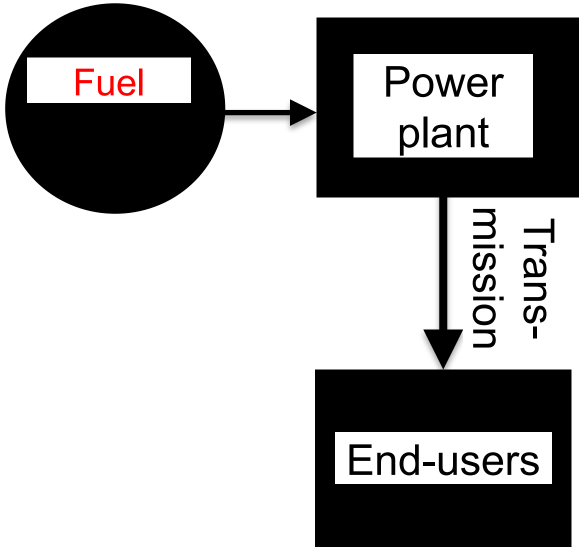
- Increasing solar and wind shifts the optimal power mix of the residual load towards cyclic& peak power plants = <u>more flexibility</u>

- Base power plants become unprofitable

- <u>Fuel-based or fuelless solutions?</u>

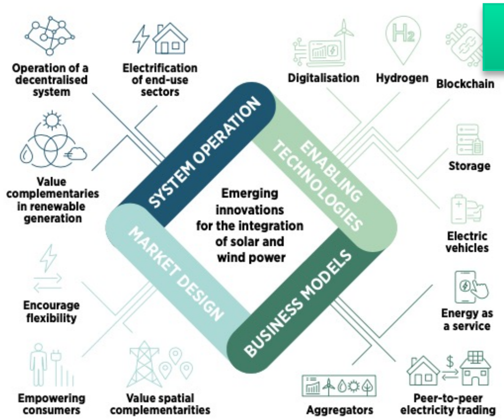
Changing ’typology’ in energy systems

Fuel-based centralized electricity systems



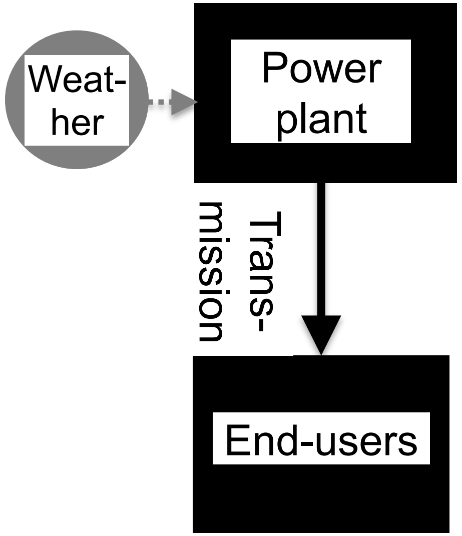
Integration

FIGURE 2.6 Emerging innovations that support the integration of VRE



Based on IRENA (2019a).

Weather-dependent, data-based decentralized electricity system



Up/down reserves
Battery storage
Hydrogen/E-Fuels
Etc.

Virtual inertia
Coordination of flex.
Data, forecasting

Sector-coupling
Energy storage
DS flexibility/DSM
Digitalisation
Prosumers, etc.

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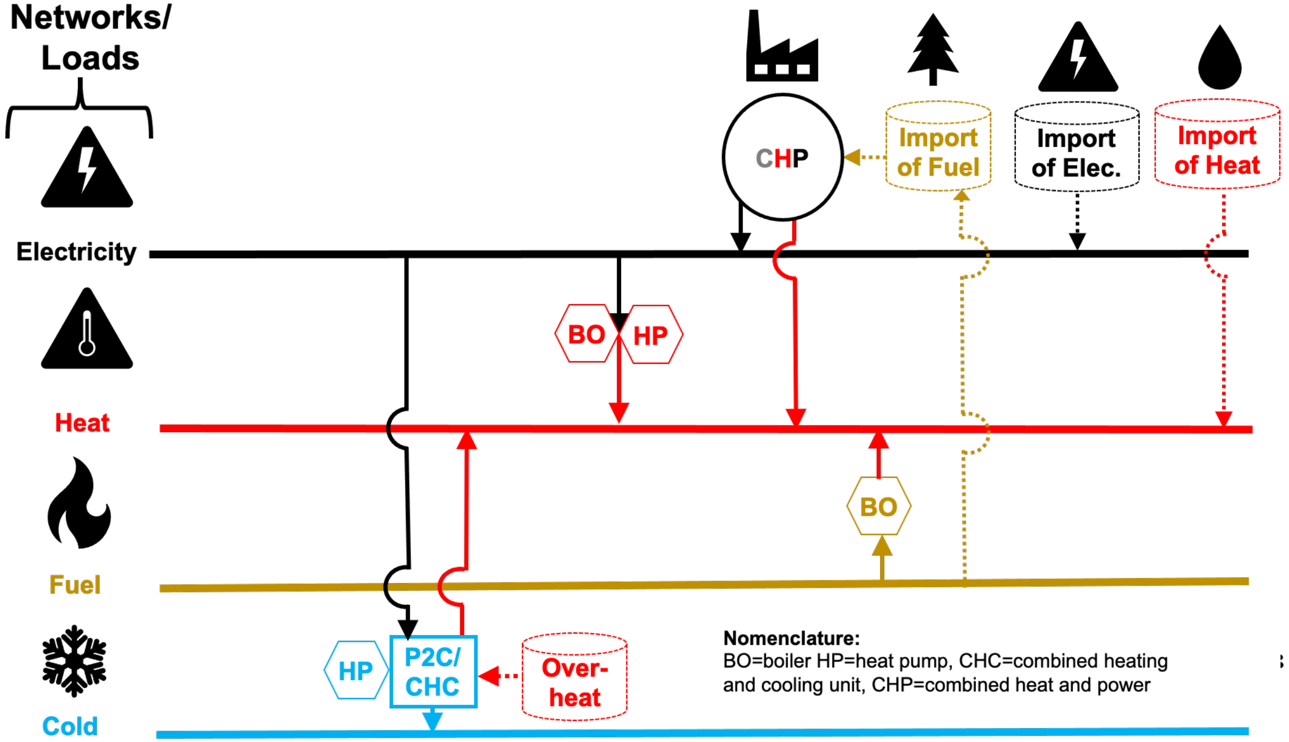
Change of energy technology architecture

Present energy system

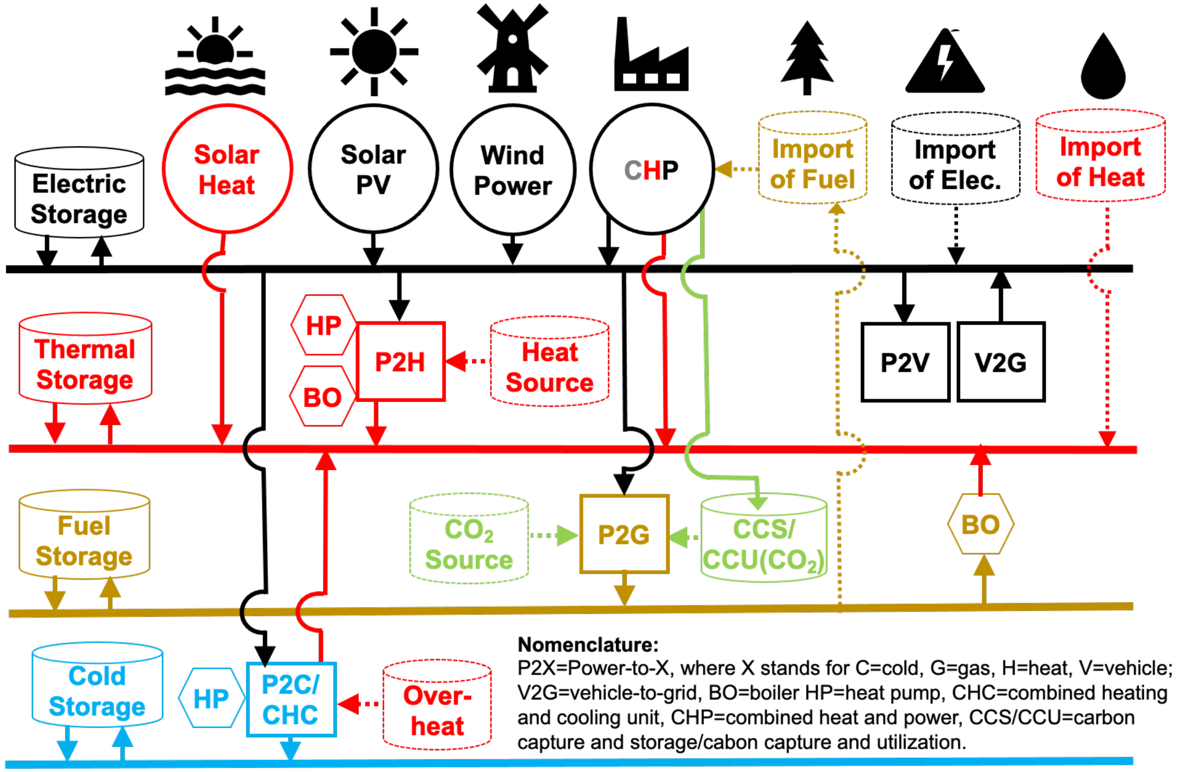
- Fuel-based energy system
- Conversion of primary energy
- Energy networks of final energy forms

Future decarbonized energy system

- Strong electrification of end-use energy
- Much renewable energy (up to 100%)
- Integration elements, e.g. PtX, storage
- Conversion of final energy



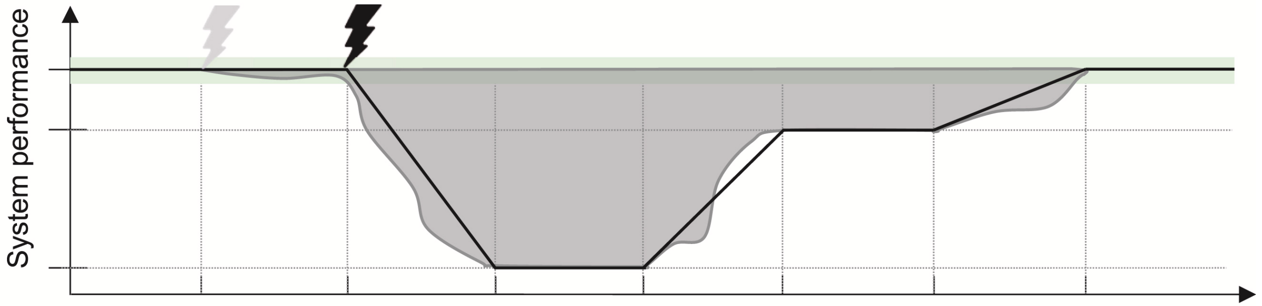
Nomenclature:
BO=boiler HP=heat pump, CHC=combined heating and cooling unit, CHP=combined heat and power



Nomenclature:
P2X=Power-to-X, where X stands for C=cold, G=gas, H=heat, V=vehicle; V2G=vehicle-to-grid, BO=boiler HP=heat pump, CHC=combined heating and cooling unit, CHP=combined heat and power, CCS/CCU=carbon capture and storage/cabon capture and utilization.

Increasing importance of energy system resilience

Resilience curve showing the system performance in time during the disruption event



Time sequence		Disruption starts	Degradation starts	Disruption ends	Restoration starts	Restoration ends	Infrastructure recovery starts	Return to normal state
Phase	0	1	2	3	4	5	6	7
Resilience type	Operational					Infrastructural		
System state	Normal	Disrupted						Normal
Objectives	Notice Prepare	Avoid Resist	Retreat	Recover			Adapt	
Characteristics	Reliability	Robustness	Modularity	Recover capacity			Learning capacity	
Actions	Preventive		Emergency			Preventive		

— Performance (approximation) — Performance (real) 🟩 Normal operation range ▨ Service loss

Energy system resilience – A review
Renewable and Sustainable Energy Reviews 150 (2021) 111476

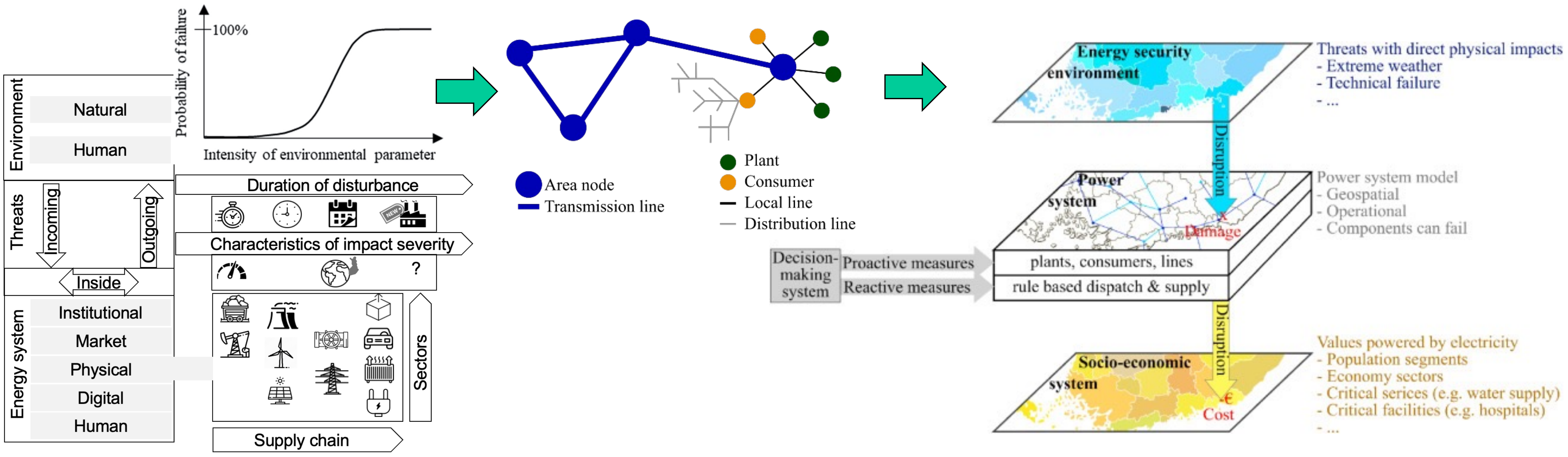
- Resilience describes the ability to survive and quickly recover from extreme and unexpected disruptions
- Energy security is defined as "uninterrupted availability of energy sources at an affordable price"
- Commonly used concepts for energy system resilience include reliability, robustness, risk, stability, survivability, flexibility, agility, fault tolerance, and vulnerability

Framework for impact assessment of resilience

Threats to energy systems

Disruption in electric system

Linking disruptions with socio-economic aspects



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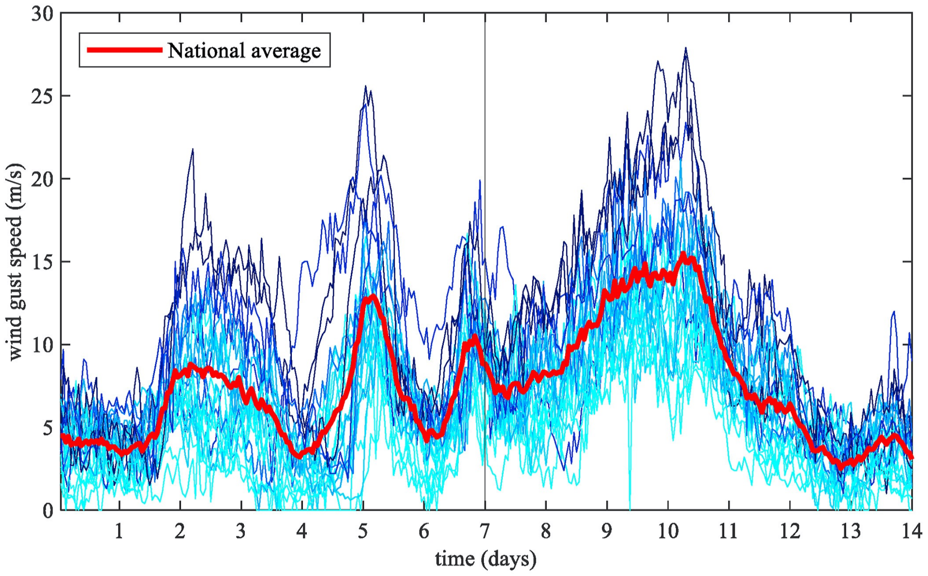
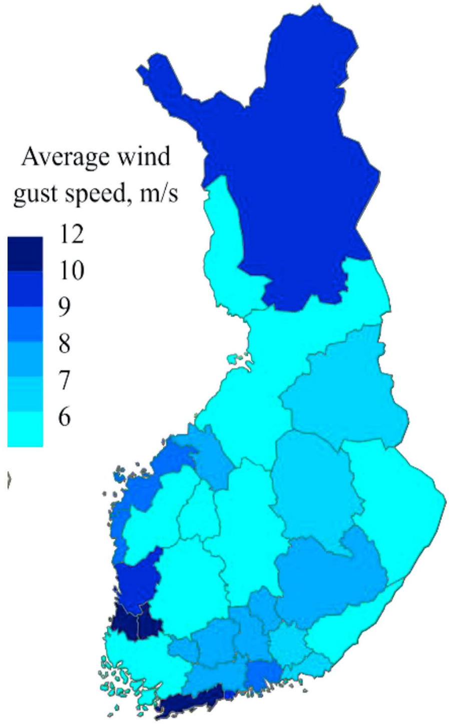
Linking socio-economic aspects to power system disruption models
Energy 222 (2021) 119928

Example of extreme weather impact on power system disruption

Strong windstorm
January 2017 in Finland





Shares of the served and unserved load

Linking socio-economic aspects to power system disruption models

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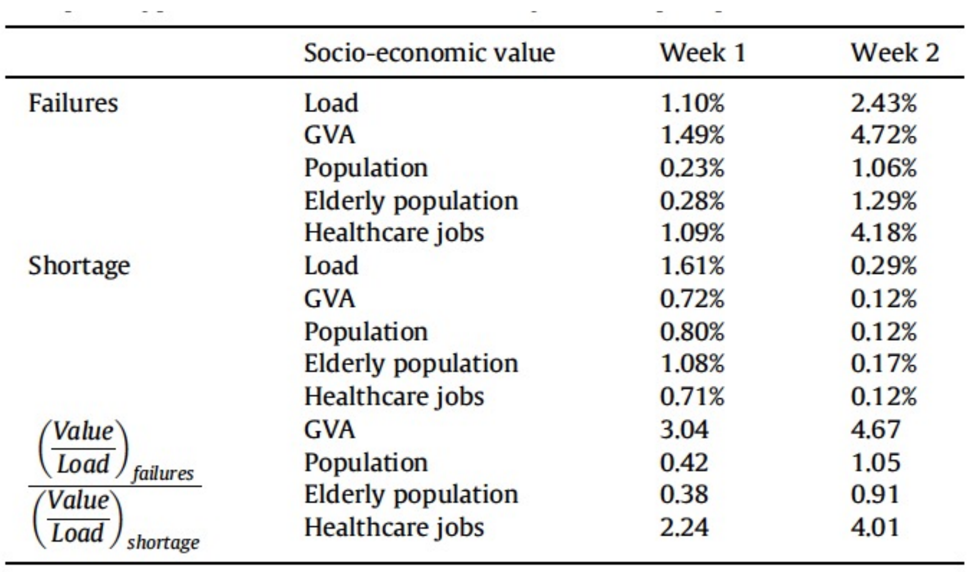
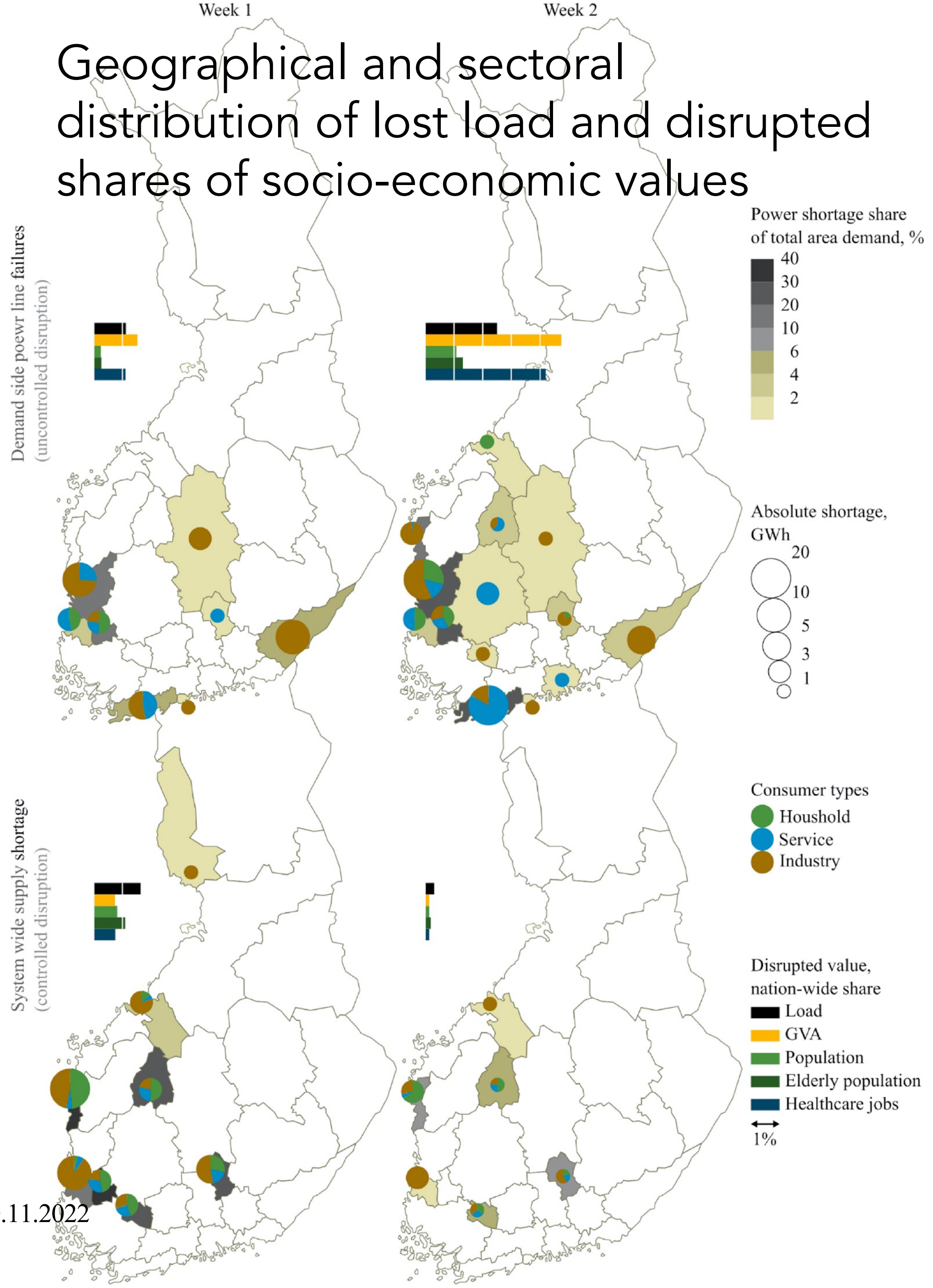
Example of socio-economic consequences from power system disruption

Nation-wide socio-economic values



	Socio-economic value	Week 1	Week 2
Failures	Load	1.10%	2.43%
	GVA	1.49%	4.72%
	Population	0.23%	1.06%
	Elderly population	0.28%	1.29%
	Healthcare jobs	1.09%	4.18%
Shortage	Load	1.61%	0.29%
	GVA	0.72%	0.12%
	Population	0.80%	0.12%
	Elderly population	1.08%	0.17%
	Healthcare jobs	0.71%	0.12%
$\dfrac{\left(\frac{Value}{Load}\right)_{failures}}{\left(\frac{Value}{Load}\right)_{shortage}}$	GVA	3.04	4.67
	Population	0.42	1.05
	Elderly population	0.38	0.91
	Healthcare jobs	2.24	4.01

Geographical and sectoral distribution of lost load and disrupted shares of socio-economic values



Linking socio-economic aspects to power system disruption models

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Deep decarbonization of urban energy systems

- Case Helsinki (60 ºN)

Targeting carbon neutrality by 2035 : 80% emission reductions + 20% carbon sinks

Share of fossil-fuel:

Heating	89%
Power	65%
Transport	91%

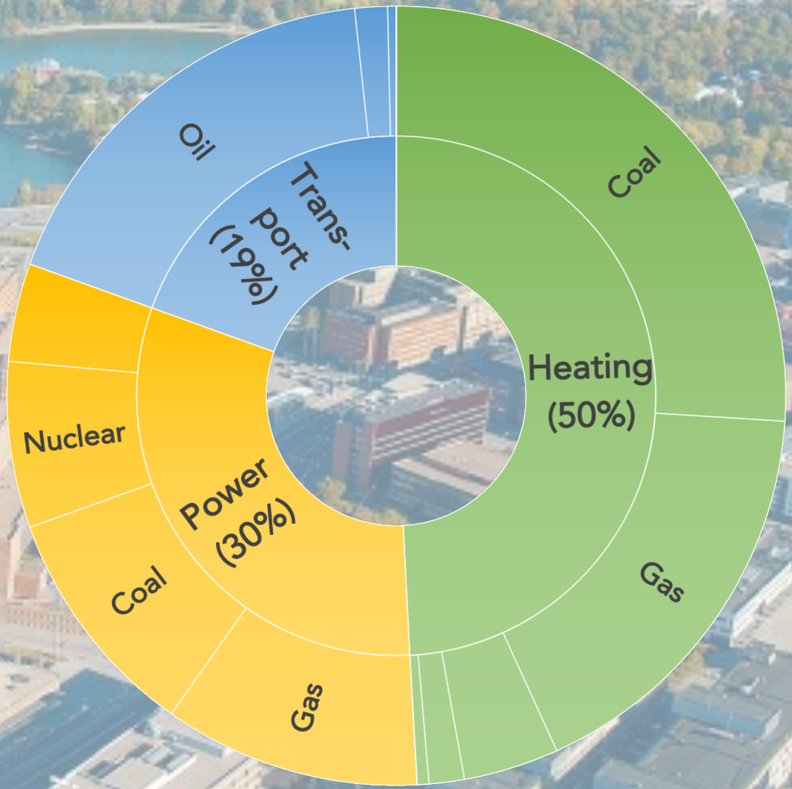
Heat and power:

CHP 98%

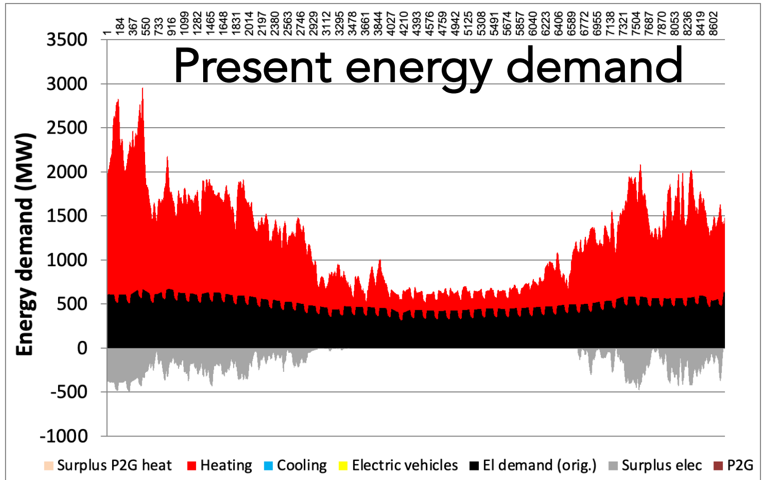
District heating 92%

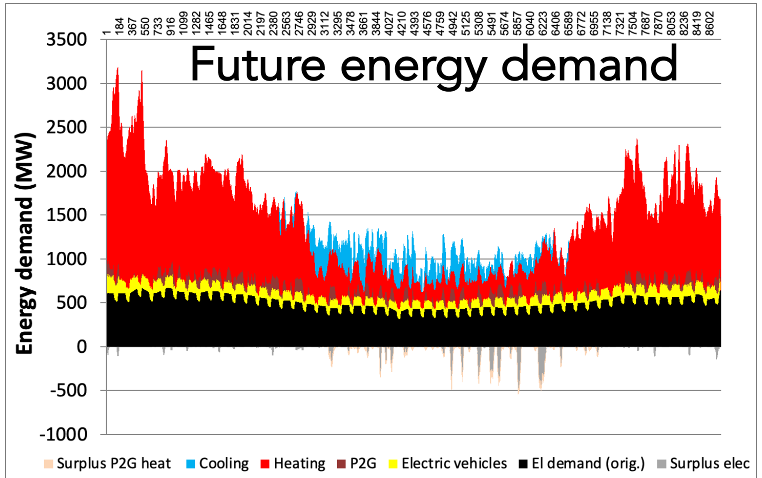
Energy networks: Power, gas, heat, cold

Shares of power outside the city



Addressing new type of challenges



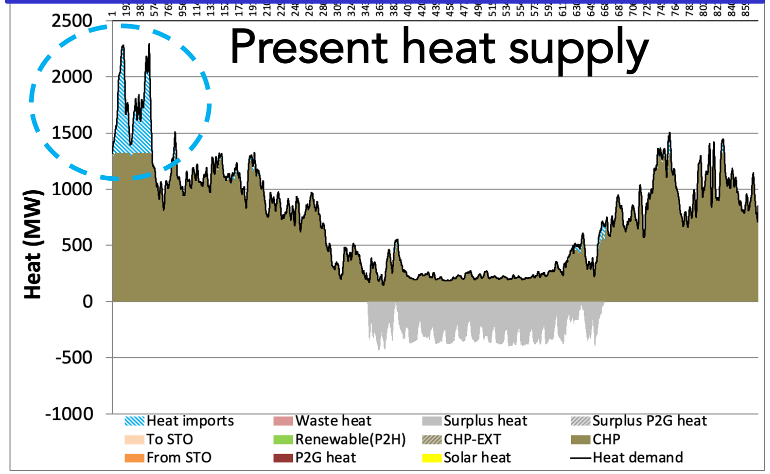


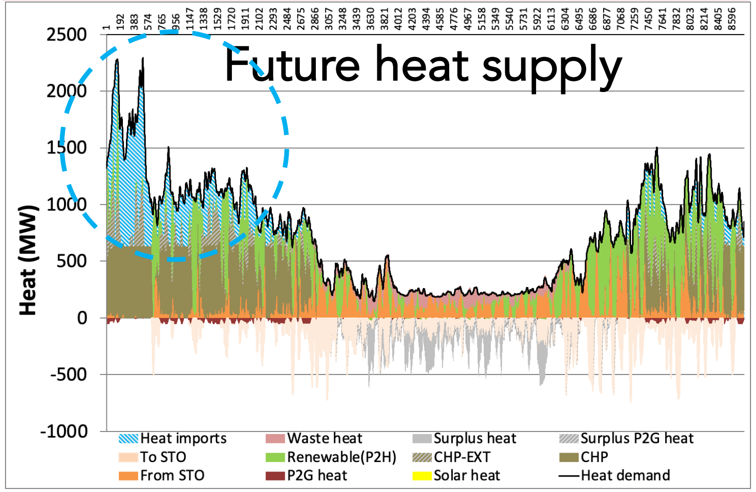
Traditional scheme

- Heat demand covered by CHP (coal+gas) + peak boilers
- Surplus of electricity (winter)
- Surplus of heat (summer)

Future scheme

Changing load/matching profiles
Full electrification= 2x present el
Need of back-up? (grid, sto, fuel)
Interaction with grids (exp/imp)





New demands

Cooling
Electrical vehicles
Power-to-Gas

New system elements

Wind power, solar
CHP_{gas} (old)
Waste heat flows
Heat pumps
Storage (El/Th/Gas)
PtH, PtH_2/Gas, VtG

Energy control

Curtailment
Power limitations
Temp. matching
CHP modes

Resilience& Reliability

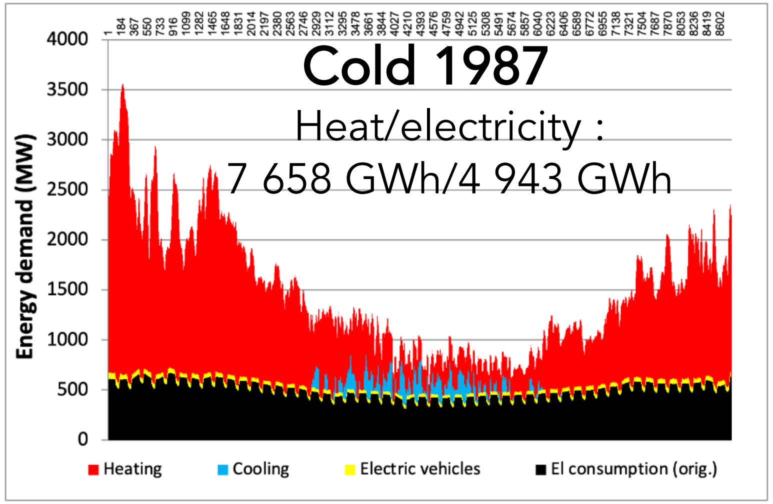
Windstills during cold
HP ouput loss in winter
RES stochastics (‘noice’)
CHP modes

Effect of weather variation on the no/low-carbon electricity-based energy system

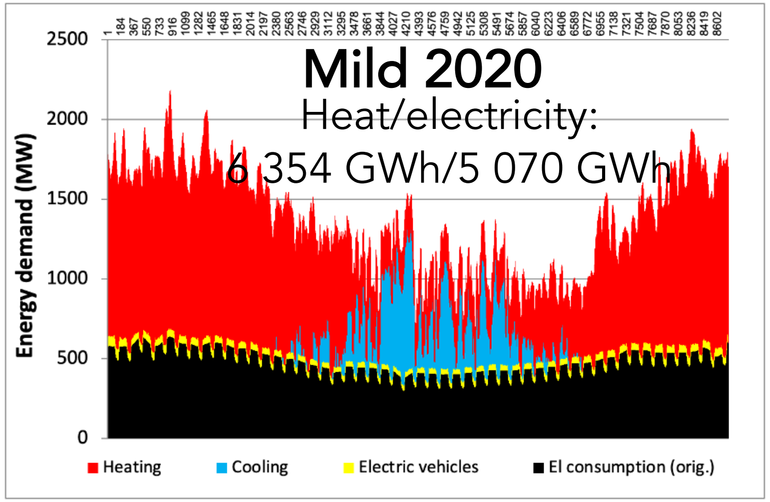
Remaining:
CHP (gas) 60%X1217 MW (tot)
Th storage 5 GWh
Heat pumps 100 MW

New clean technology:
Wind 1200 MW
PV 400 MW
Heat pump (70% of peak)
Boiler 1000 MW
Elec. sto 500 MWh
Heat sto +45 GWh
10% of EVs with V2G
P2H (RES>EL load),P2G

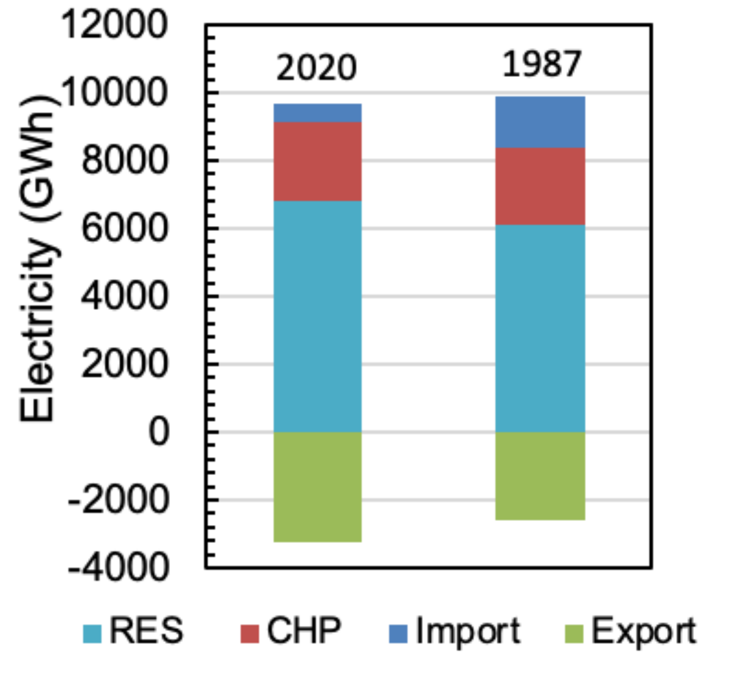
Closing:
CHP (coal) 1GW ;Fossil-boilers 2 GW



Cold 1987
Heat/electricity :
7 658 GWh/4 943 GWh



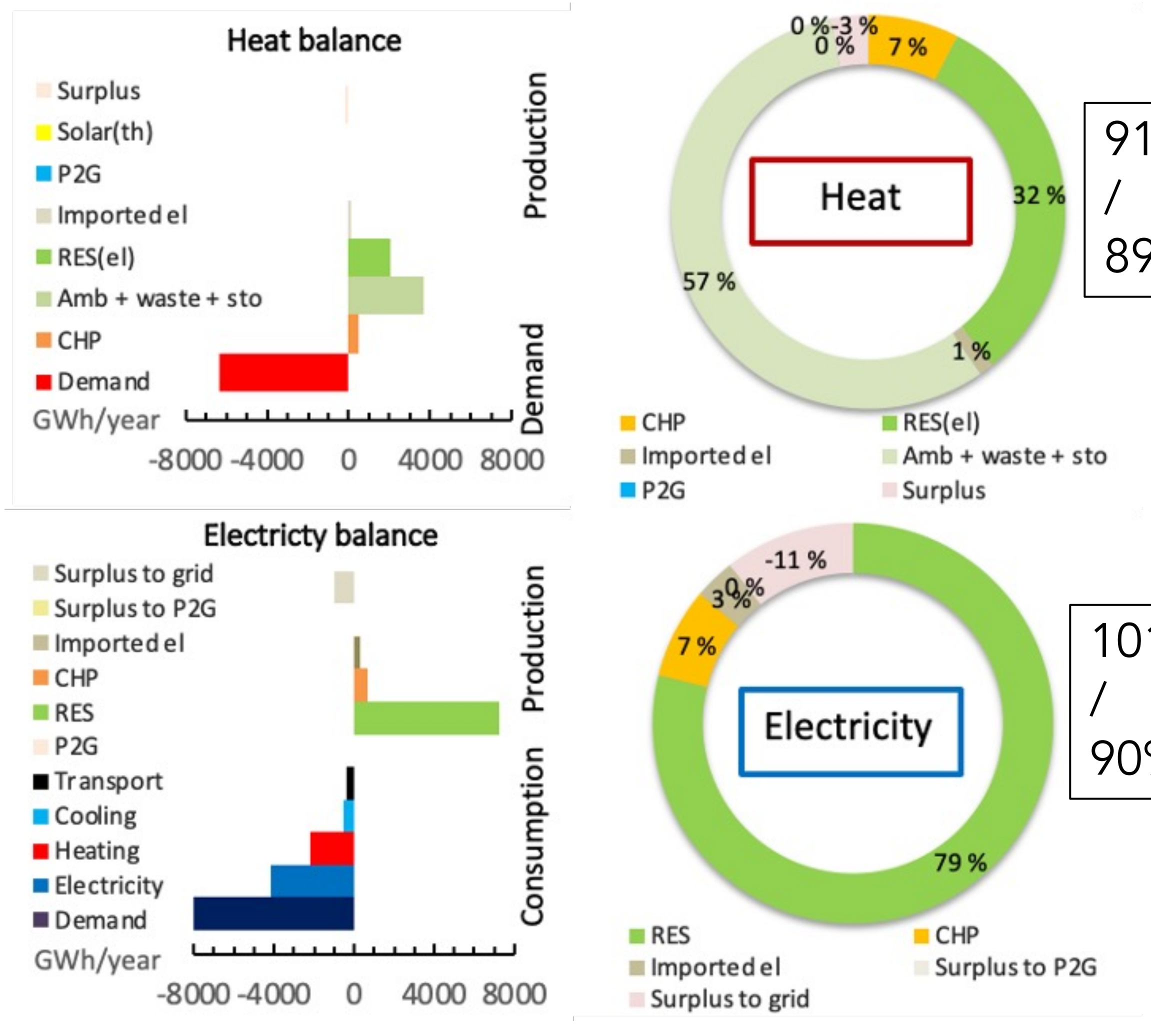
Mild 2020
Heat/electricity:
6 354 GWh/5 070 GWh



Cold versus Mild:

RES	-11%
CHP	– 1%
Imports	+187%
Exports	-20%
Peak	+70%

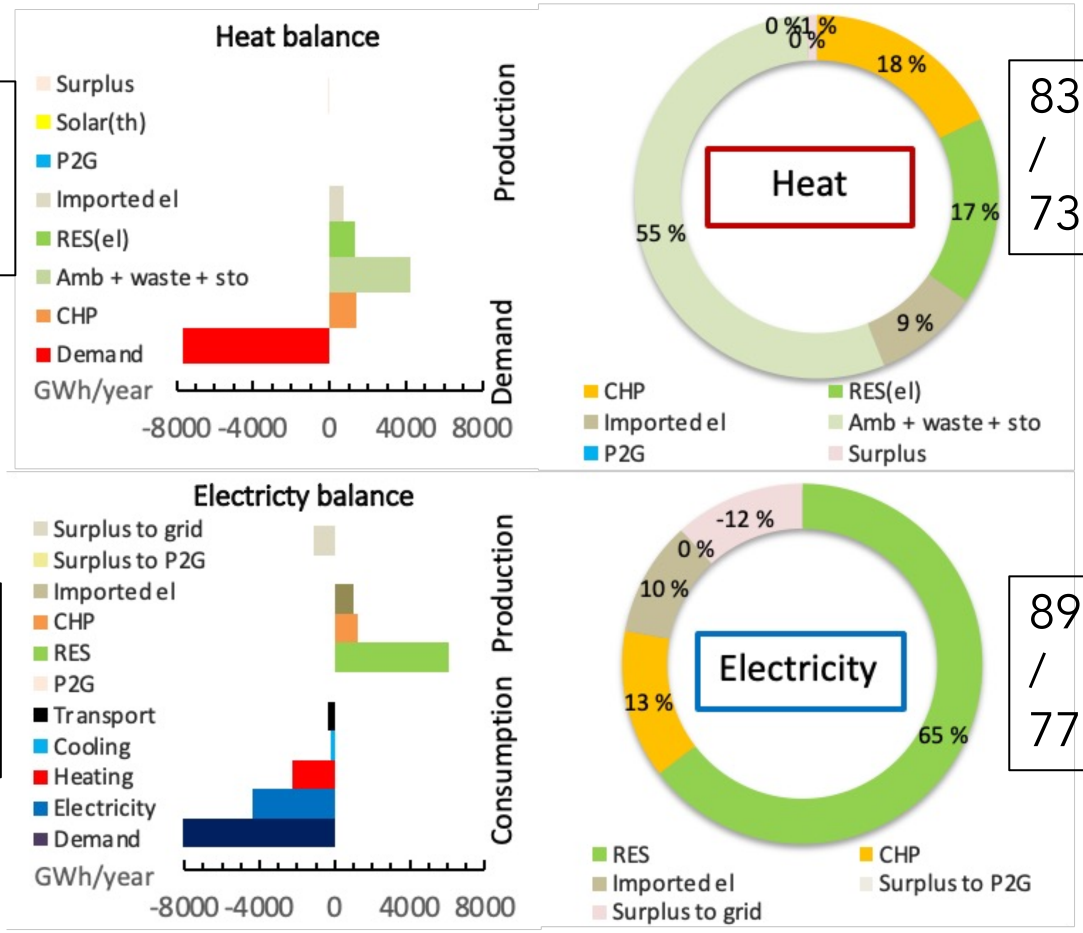
Energy balance of no/low-carbon electricity-based energy system in extreme weather (case Helsinki)



91% / 89%

101% / 90%

Mild 2020

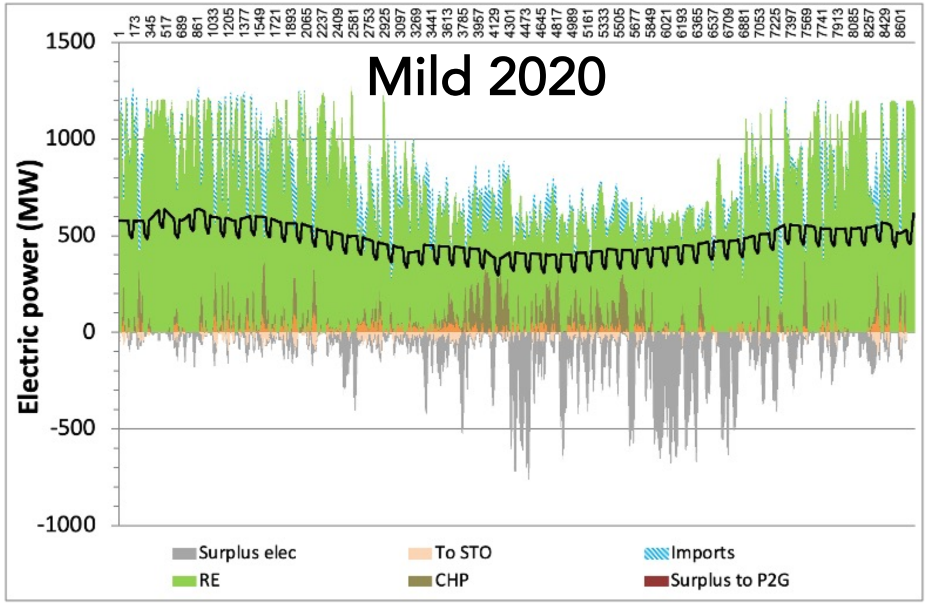


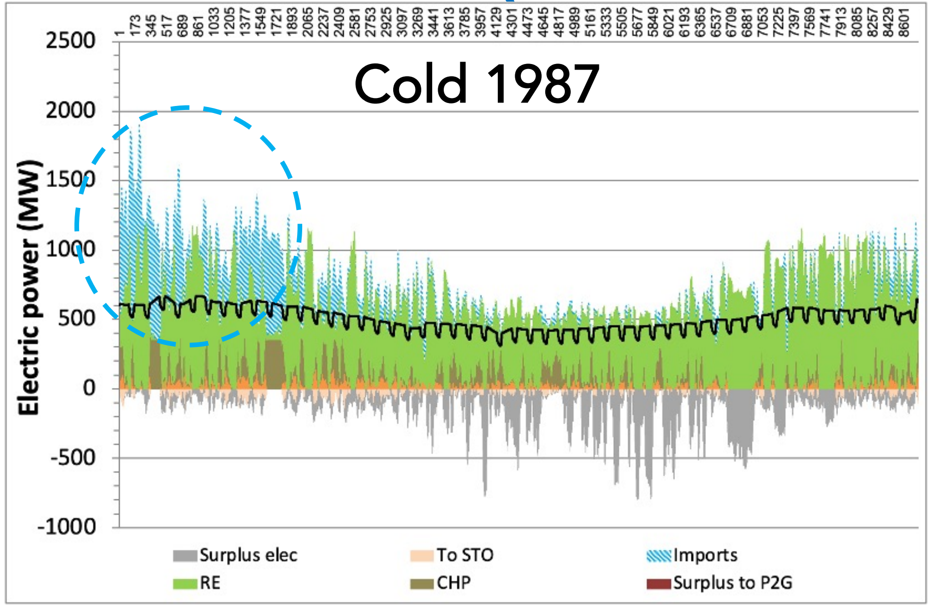
83% / 73%

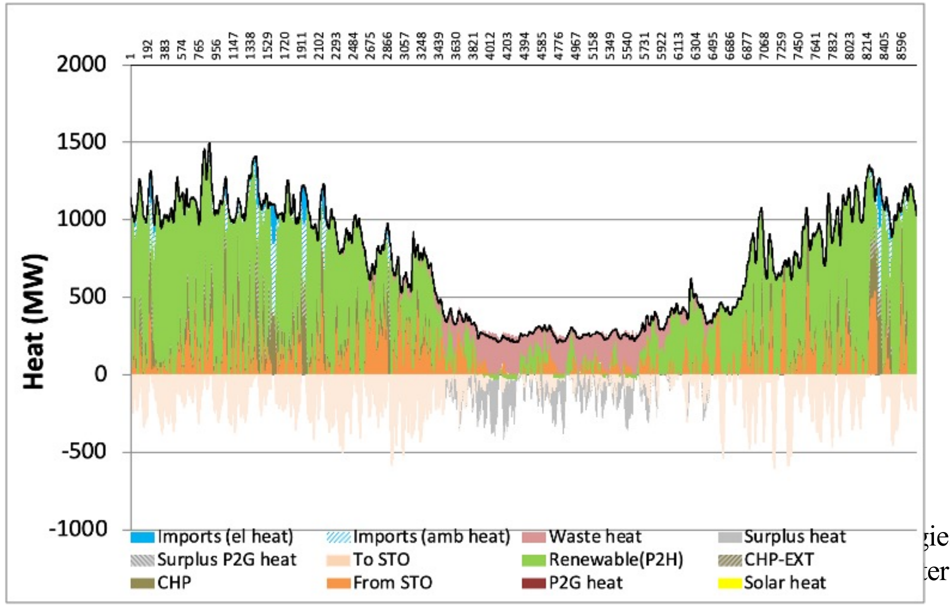
89% / 77%

Cold 1987

Power profiles of no/low-carbon electricity-based energy system in extreme weather (case Helsinki)







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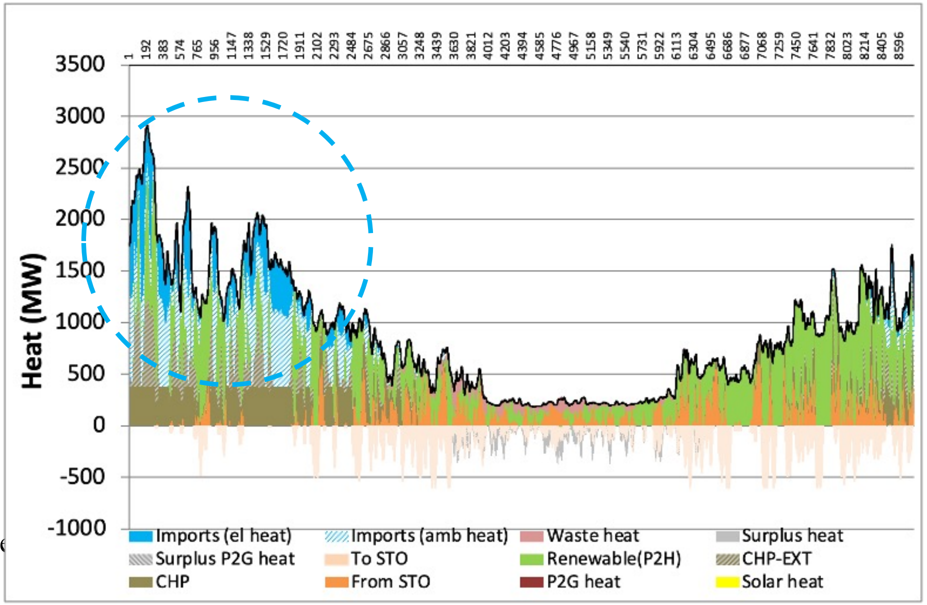
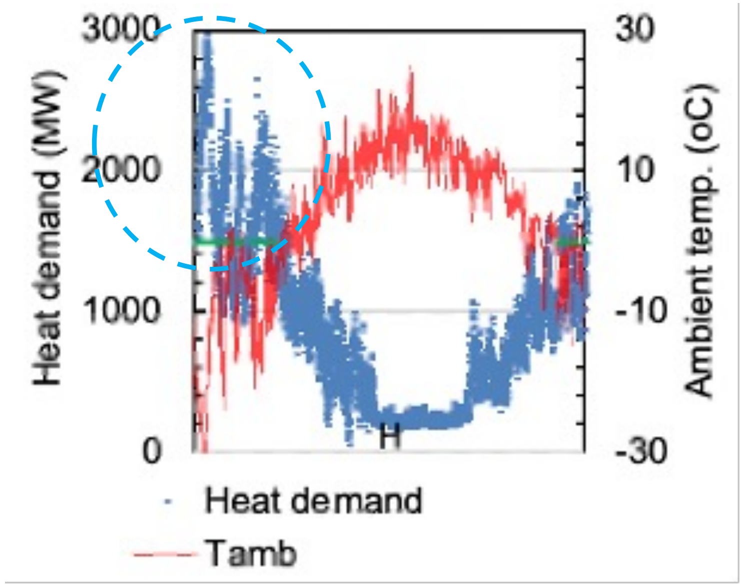


Effects of weather uncertainity on heat demand

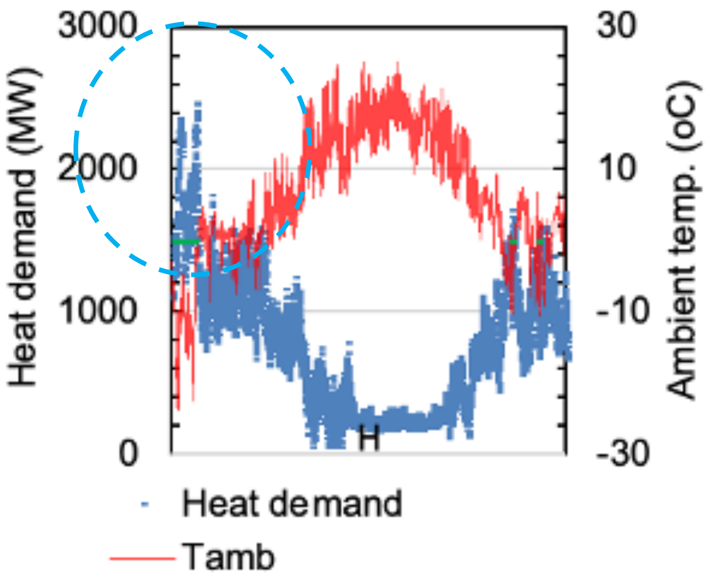
Case
Helsinki

Weather:	Cold	Norm	Mild
Year	1987	2016	2020
Avg. ambient T	3.4 °C	6.6 °C	8.7 °C
Yearly DH (heat)	+19%	+-0%	- 4%
Peak demand	+20%	+-0%	-29%

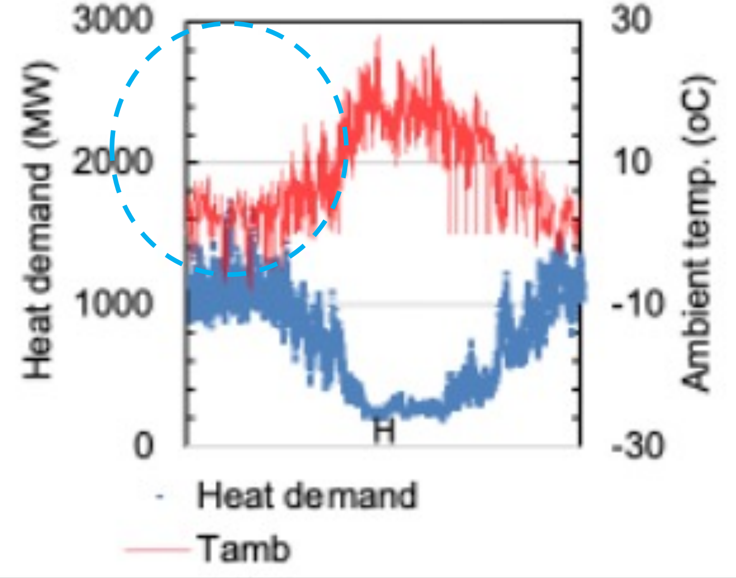
Cold



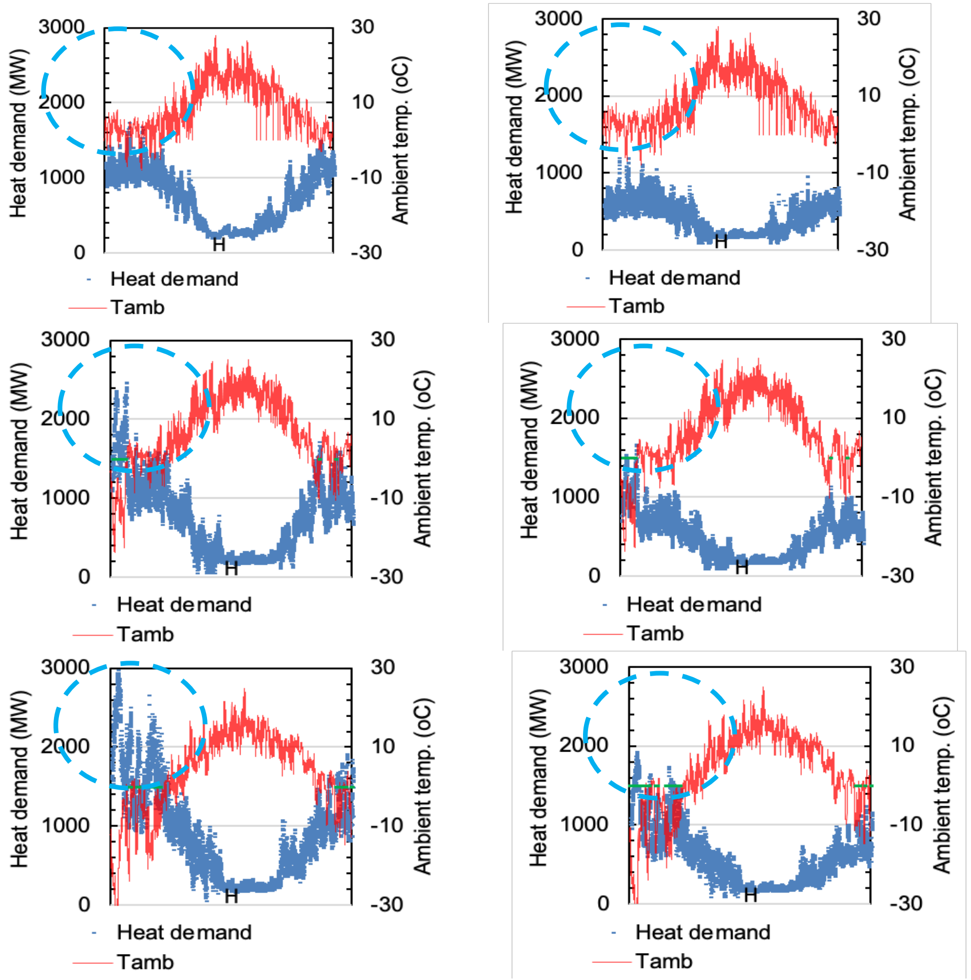
Normal



Mild



Effect of demand-side efficiency on heat demand for deep-decarbonization (case Helsinki)



Mild

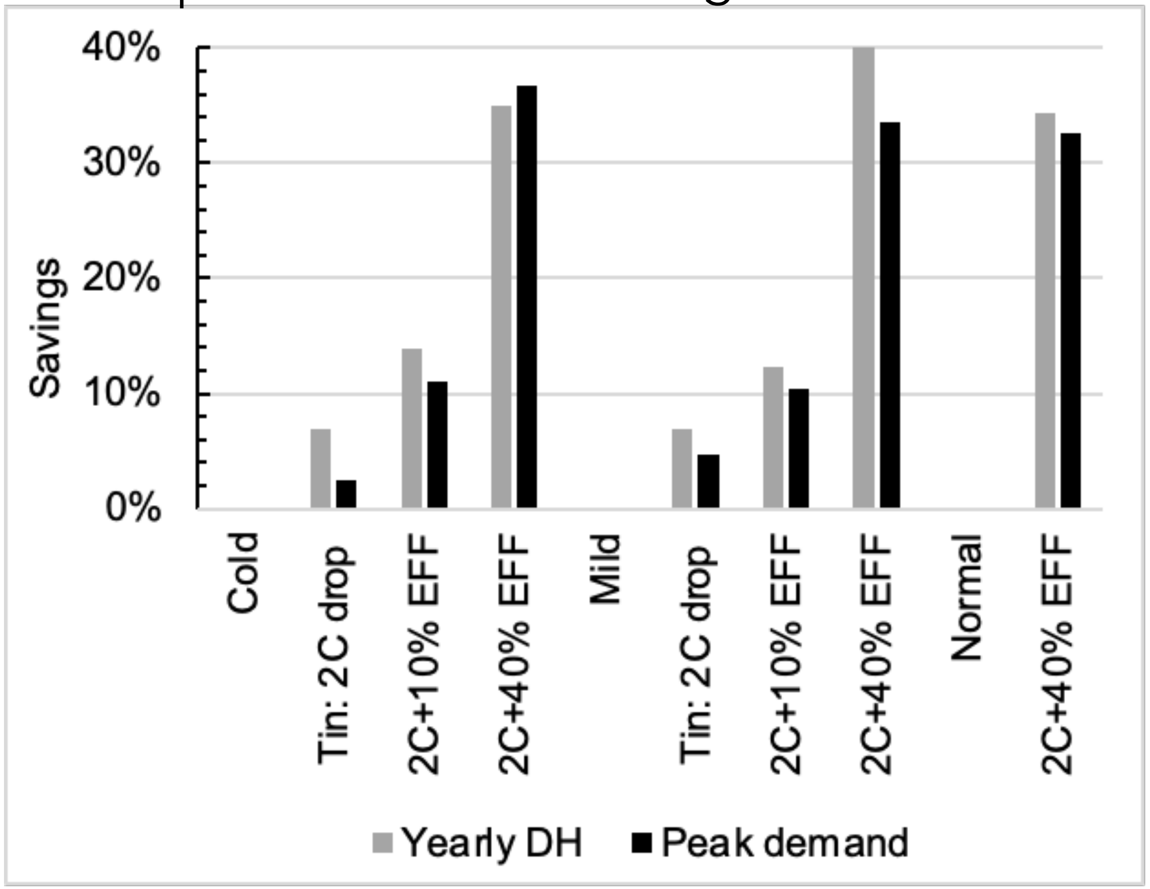
Normal

Cold

REF

2C+40% EFF

Comparison of each case against 'Normal'

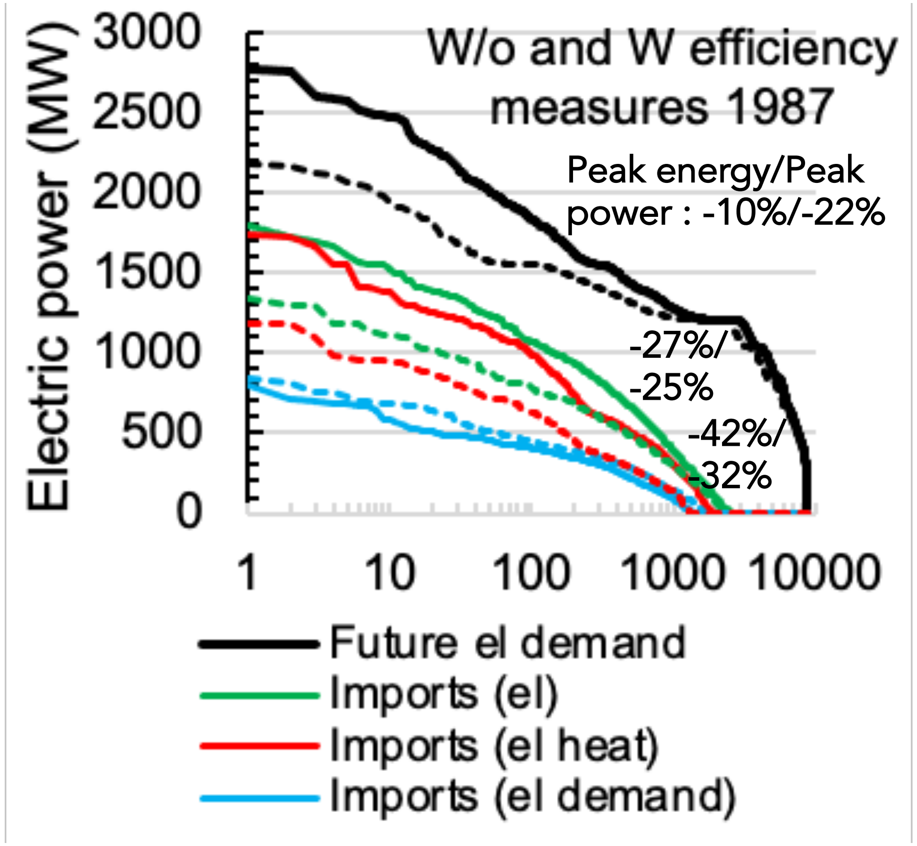


2C = indoor temperature +22 °C → +20 °C

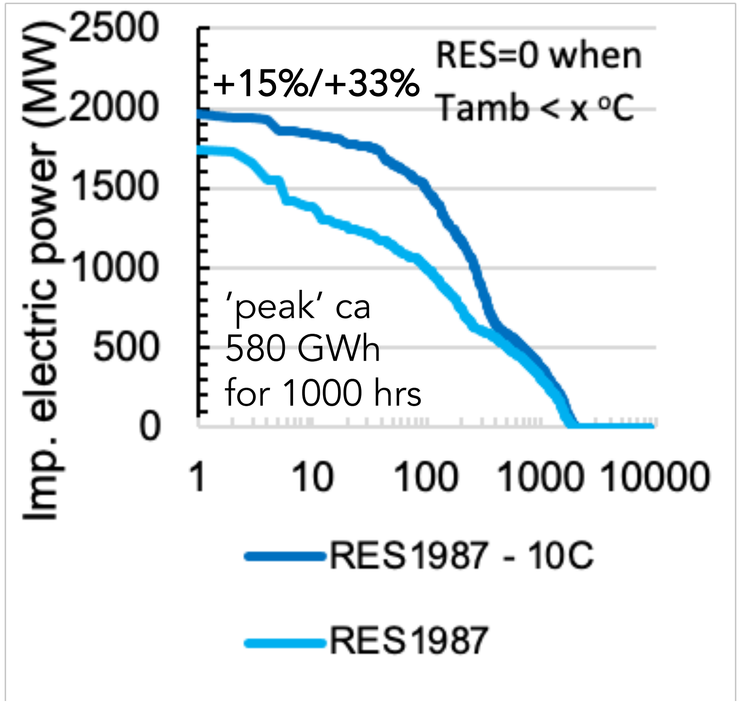
EFF% = % efficiency improvements in building stock

Summary of selected effects on peak conditions in a no/low-carbon electricity-based energy system

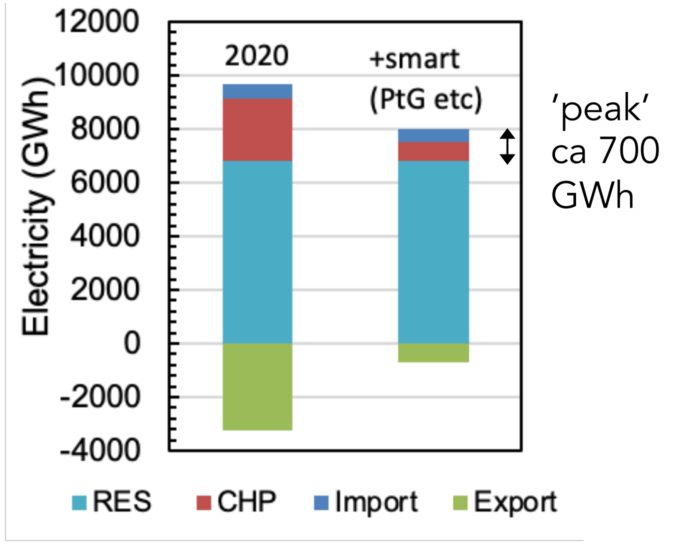
Importance of efficiency measures



A 'disruption' in the middle of the coldest period



Effect of 'smart' technologies



Takeaways

Peak conditions

- Share of peak load/power will increase in the optimal mix of power plants to meet the residual load (=more flexibility)
- In deep-decarbonized energy systems, peak load is 5-10 % of the total load, but 80-90 % of imported electricity or back-up fuel
- Weather causes uncertainty in peak power level
- Energy system resilience also linked to the peak conditions and power

Peak power solutions (and reserves)

- Energy efficiency measures help to decrease power, energy, fuels, uncertainty in peak conditions
- "Smart solutions" required to fully cover the peak demand and compensate for the uncertainty
- Sustainable fuel-based peak-power production (e.g. multi-fuel engine-CHP) could be useful