Improving Energy Resilience in Deep Decarbonization of Energy Systems through Storage Coupling

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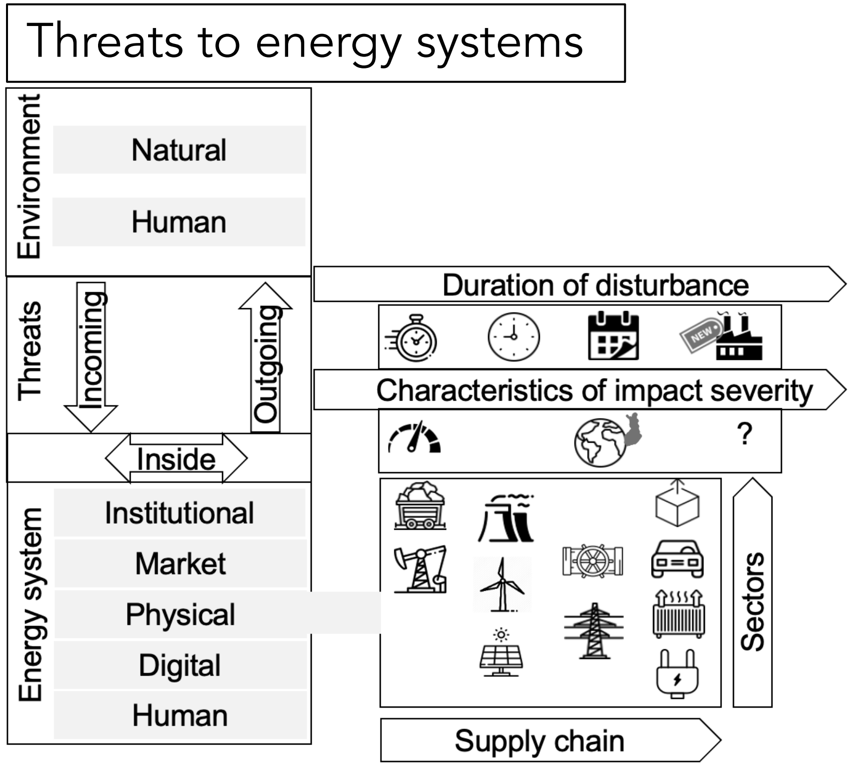
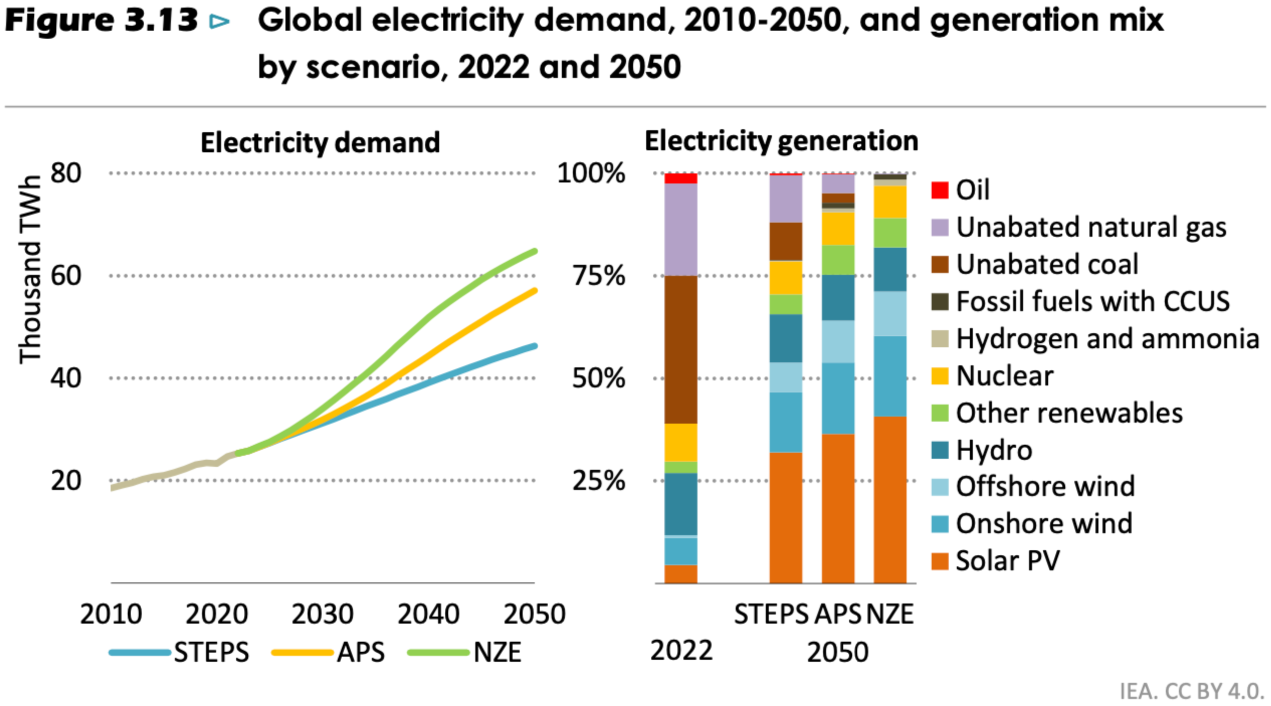
Outline of talk

- Energy transition and resilience
- Peak heat demand conditions
- Importance of energy efficiency
- Dual thermal storage with peak unit
- Integrated RE concepts with high resilence

Increasing importance of energy system resilience





Electricity demand rises over 80% to more than 150% by 2050 across scenarios and is met increasingly by low-emissions sources at the expense of unabated coal and natural gas

Source: World Energy Outlook, International Energy Agency, Oct 2023

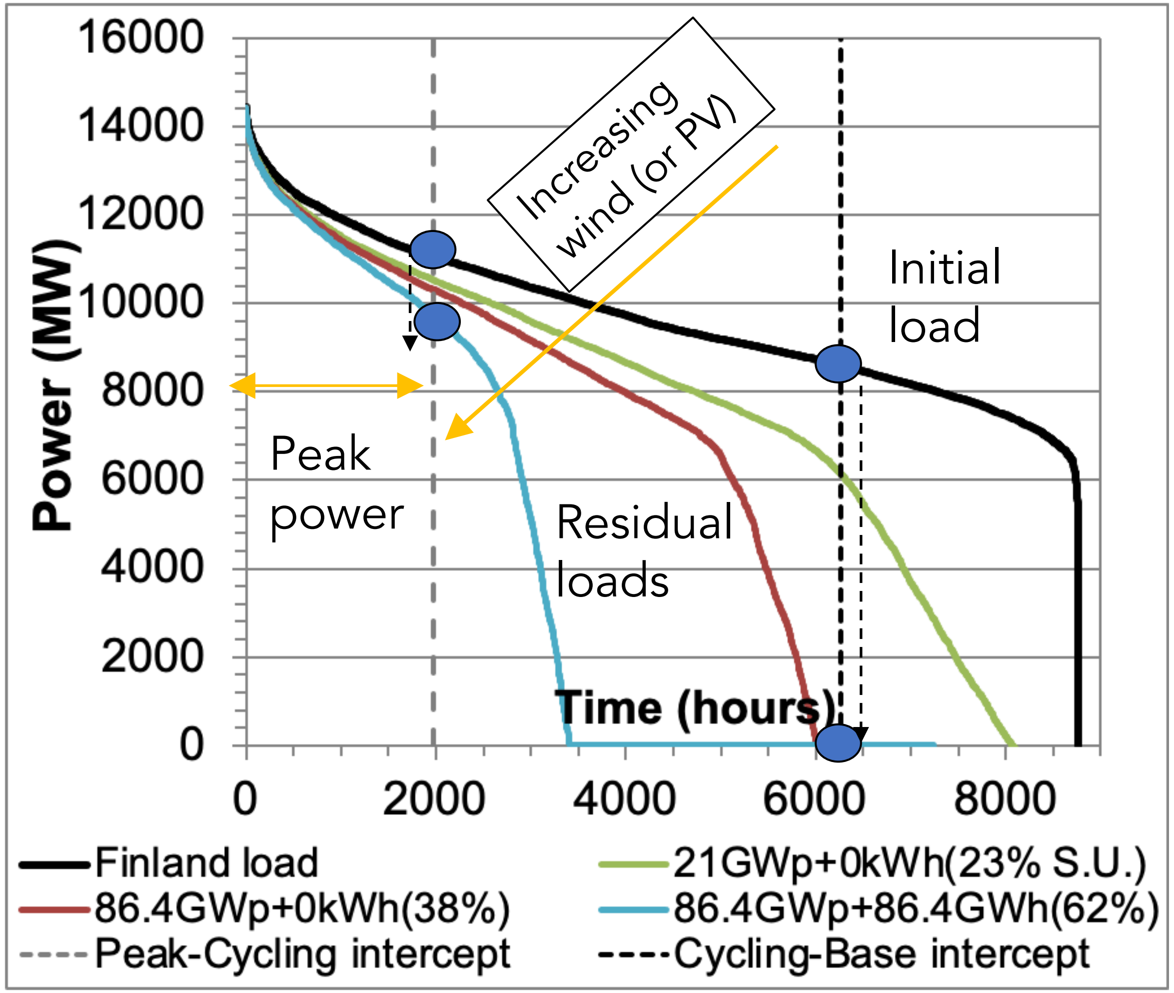
- Resilience describes the ability to survive and quickly recover from extreme and unexpected disruptions

- Commonly used concepts for energy system resilience include reliability, robustness, risk, stability, survivability, flexibility, agility, fault tolerance, and vulnerability

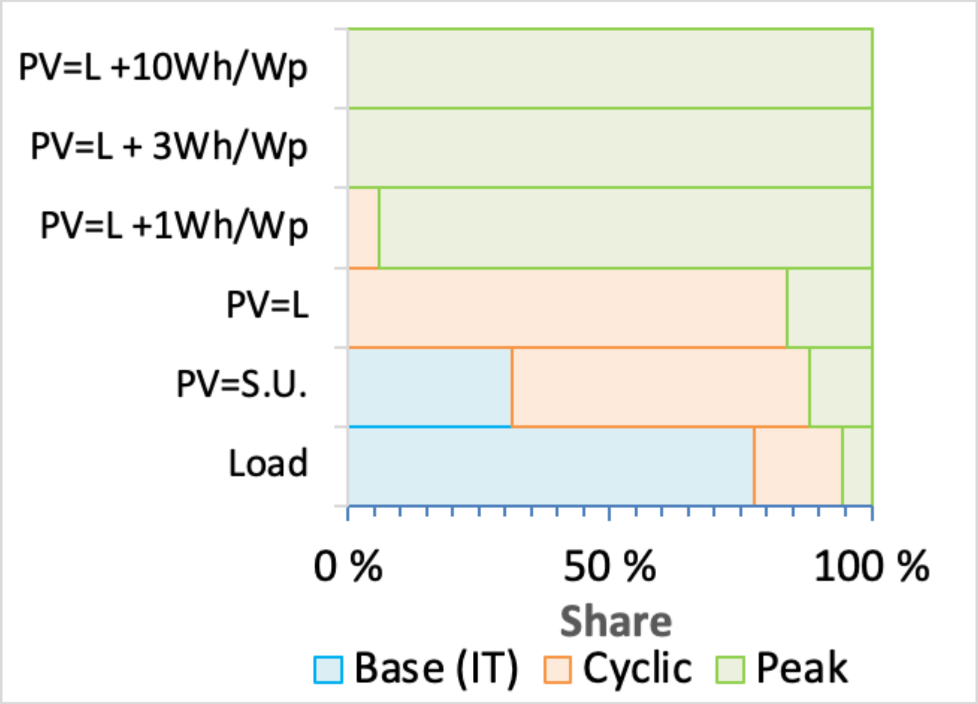
Renewable and Sustainable Energy Reviews 150 (2021) 111476

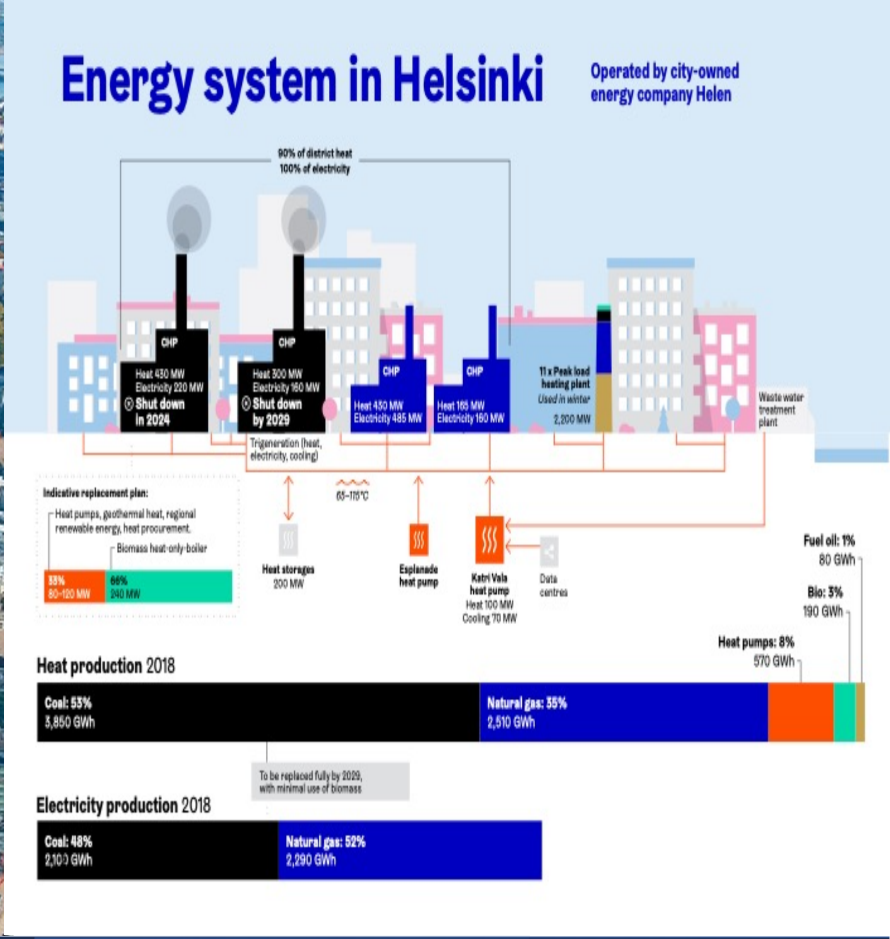
Changing residual load affects optimum power mix

Increasing variable renewable electricity shifts the residual demand towards peak power



Example: PV in Italy's power system, L=power demand, S.U.= self-use limit, storage = Wh/Wp



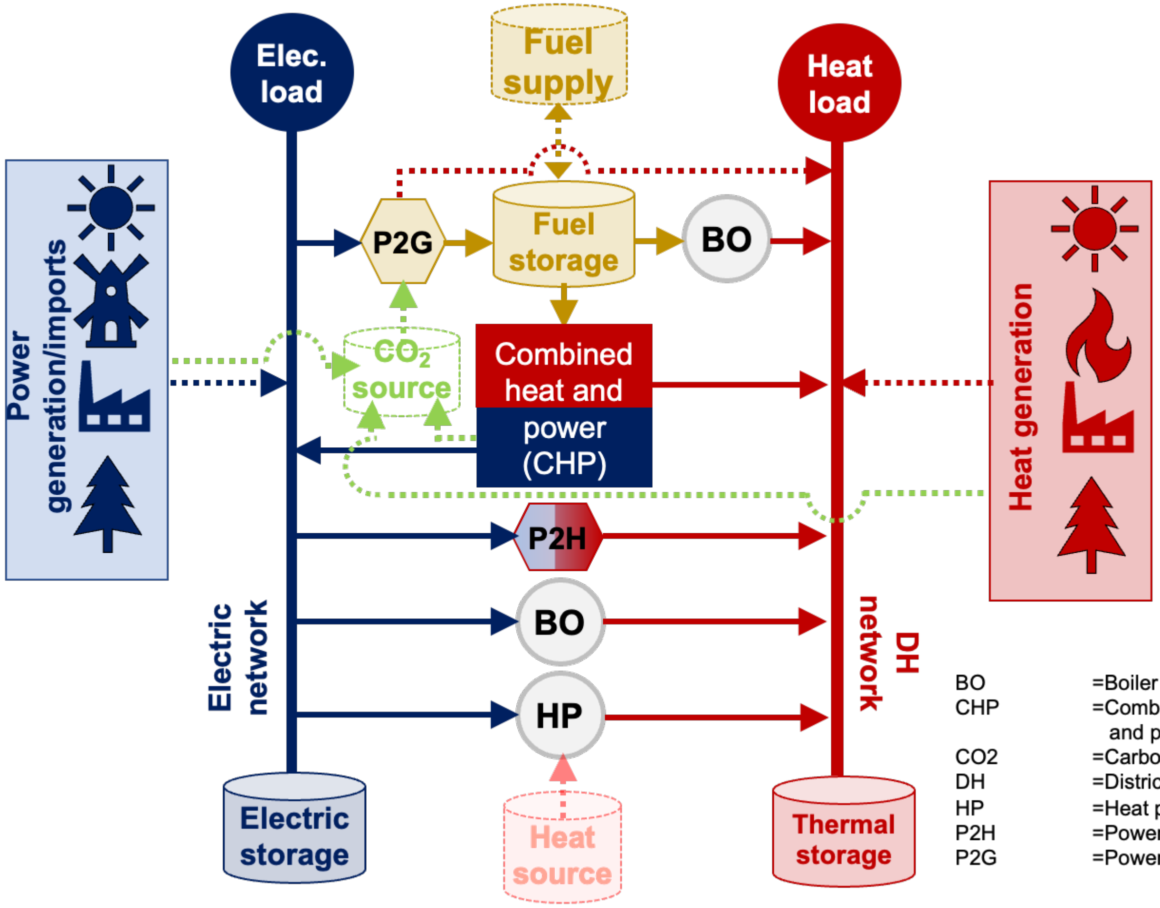


Deep decarbonization case

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

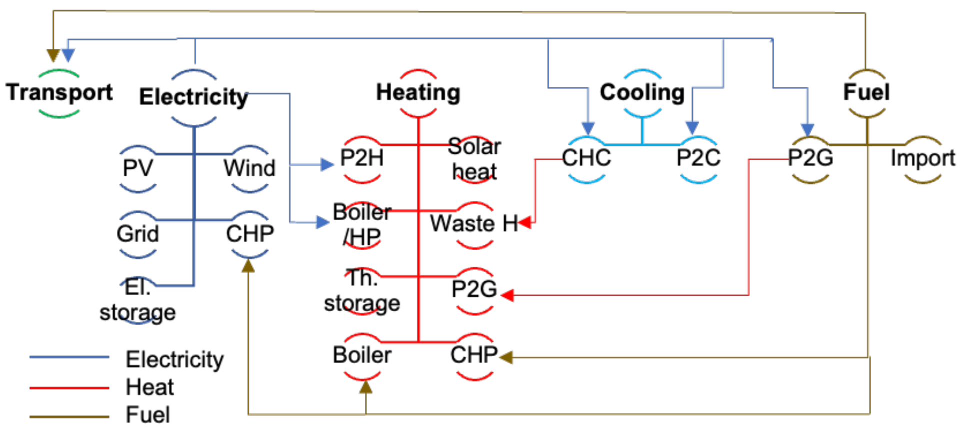
Share of fossil-fuel:	
Heating	89%
Power	65%
Transport	91%

Energy system simulation and optimization framework



BO	=Boiler
CHP	=Combined heat and power
CO2	=Carbon dioxide
DH	=District heating
HP	=Heat pump
P2H	=Power-to-heat
P2G	=Power-to-gas

Energy flowchart



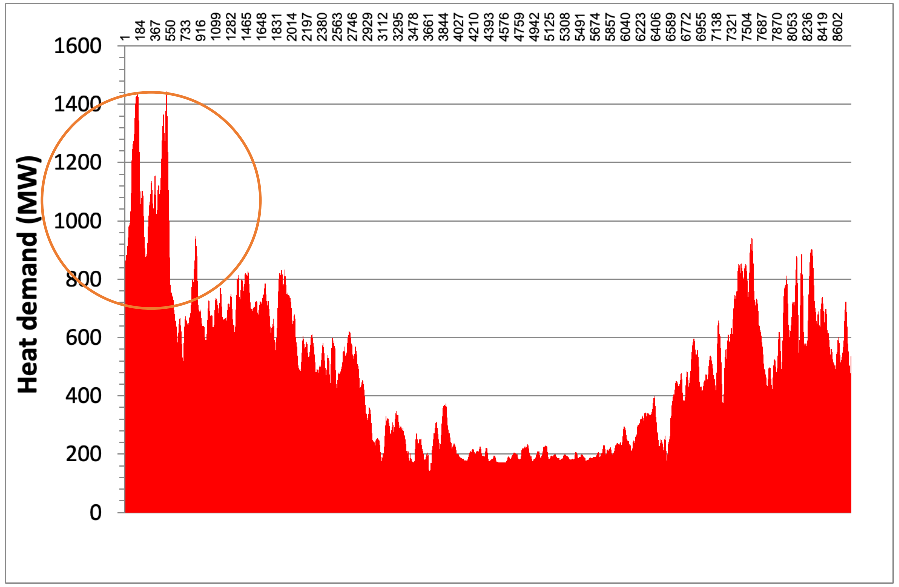
Order of merit

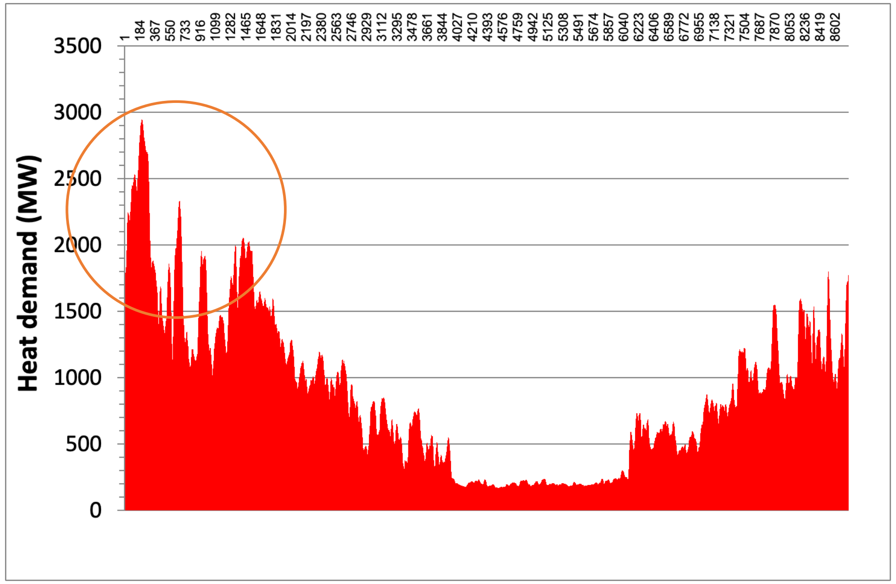
Power		Heating		Cooling		Fuel	
Wind/PV	1	Waste H	1	CHC	1	P2G	1
El. STO	2	Solar H	2	P2C	2	Import	2
P2H	3	P2H	3				
CHP	4	Th. STO	4				
P2G	5	CHP	5				
Grid	6	P2G	6				
		HP/Boiler	7				

Features:
- Excel/Visual Basic model
- Techno-economic-emission analysis
- 1-hour simulations over one year
- Date-driven load profile algorithms
- Many energy technologies
- Versatile flexibility options
- Sector coupling (PtX)
- Several energy efficiency strategies
- Storage options
- Control algorithms
- Energy analysis options
- Visualization
- Etc.

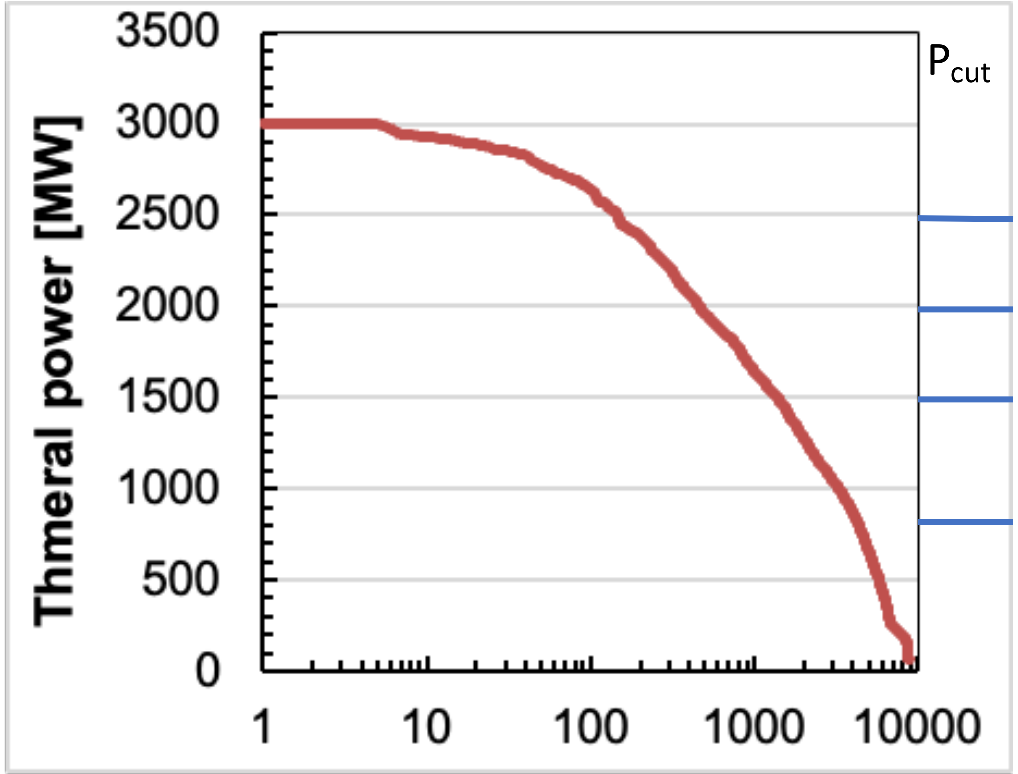
Peak heat demand conditions and shaving

Case Helsinki





- Peak heat demand is driven by the ambient temperature
  - Cold winter peak > 2 x mild winter peak
- Peak heat power demand >> Average [MW]
- Peak heat energy demand << Yearly [MWh]



$P > P_{cut}$

Share of
Peak, Energy, Time

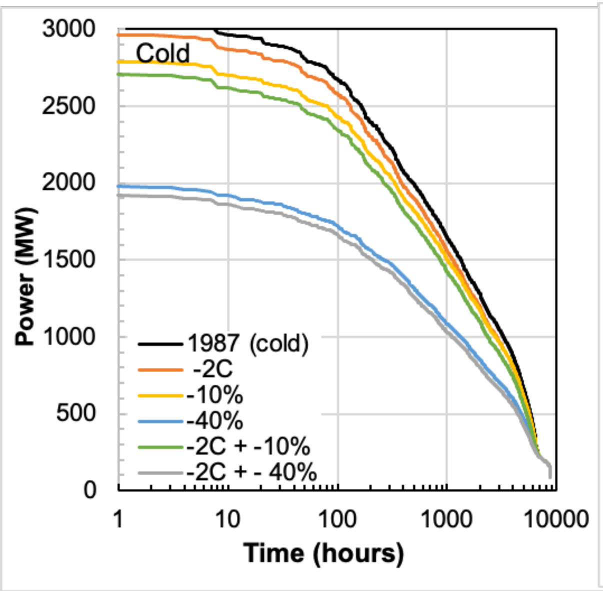
82%(18%); 5%, 2%

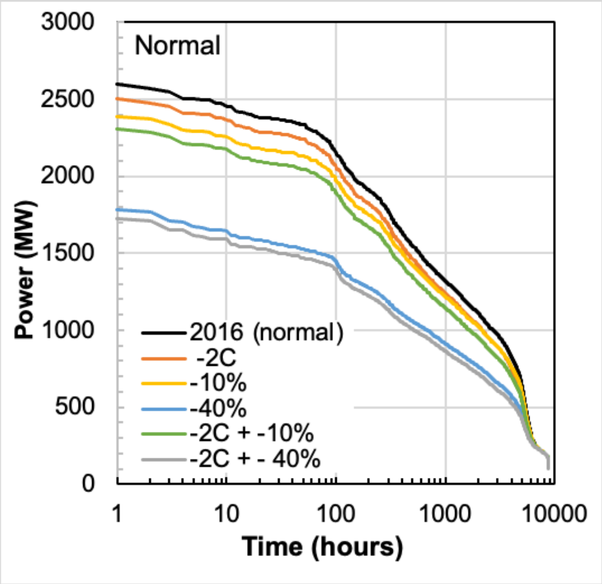
66%(34%); 14%, 5%

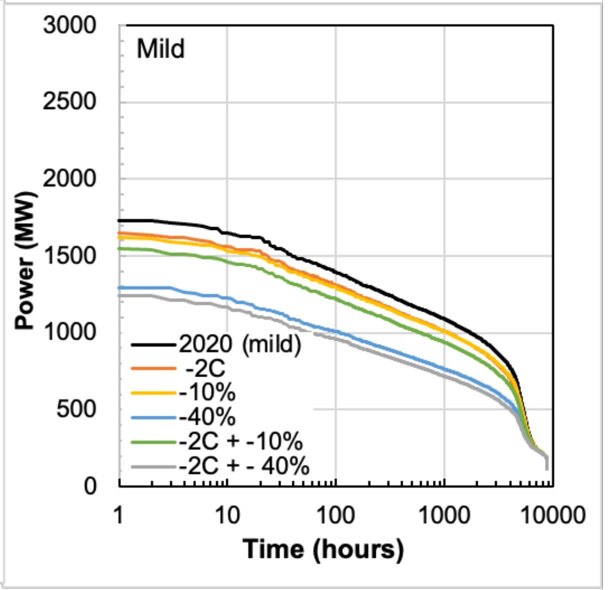
49%(51%); 35%, 16%

29%(71%); 73%, 45%
(average)

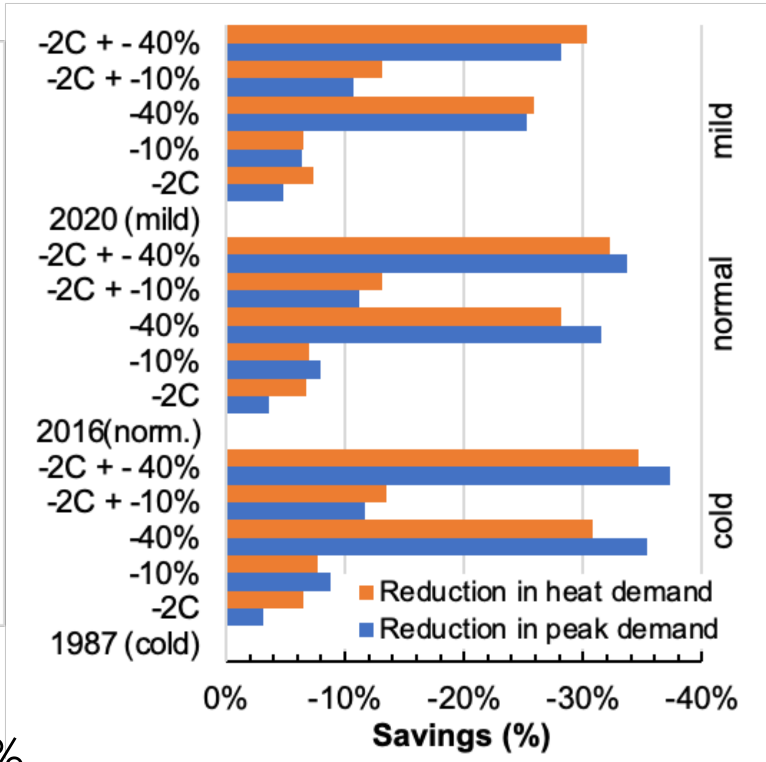
Effects of efficiency strategies on heat peak under weather uncertainty







Case Helsinki



Findings of analysis

- Weather may affect yearly heat demand by 25%, but peak demand even by 50%
- Modest building energy efficiency measures drop demand and peak up to <10%
- Strong building energy efficiency measures drop demand and peak beyond 30%
- Yields from stronger measures higher in cold weather conditions
- Yields from modest measures less dependent on weather conditions

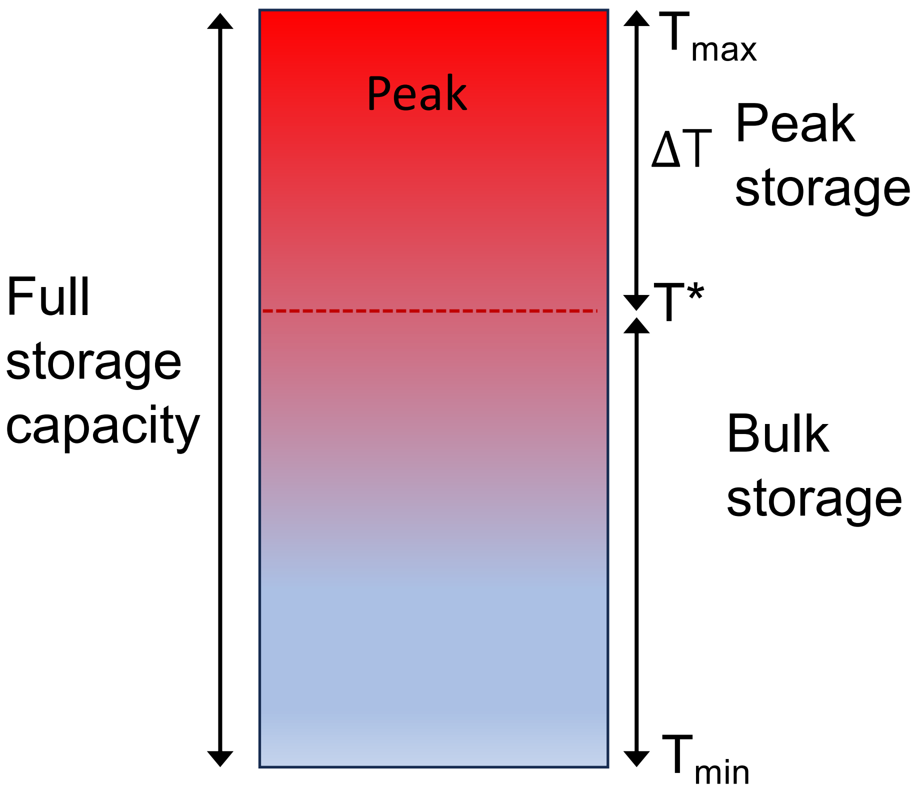
Efficiency strategies

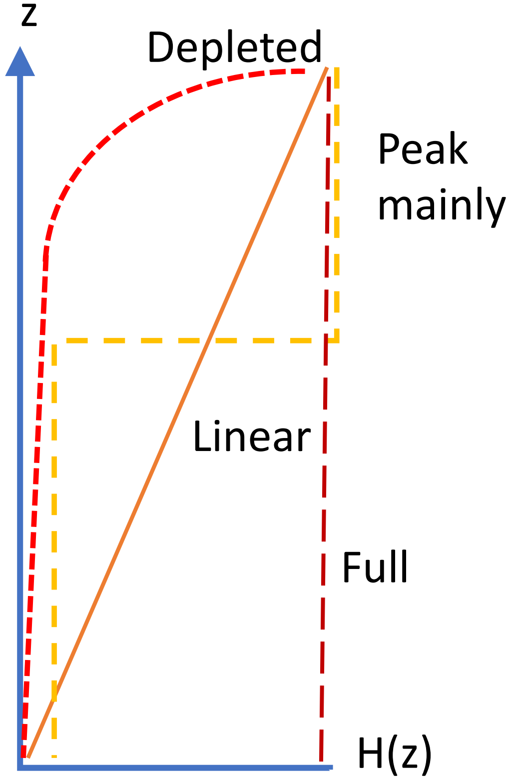
- no extra efficiency
- 10% building energy efficiency (U-value)
- 40% building energy efficiency (U-value)
- 22 °C → 20 °C indoor T

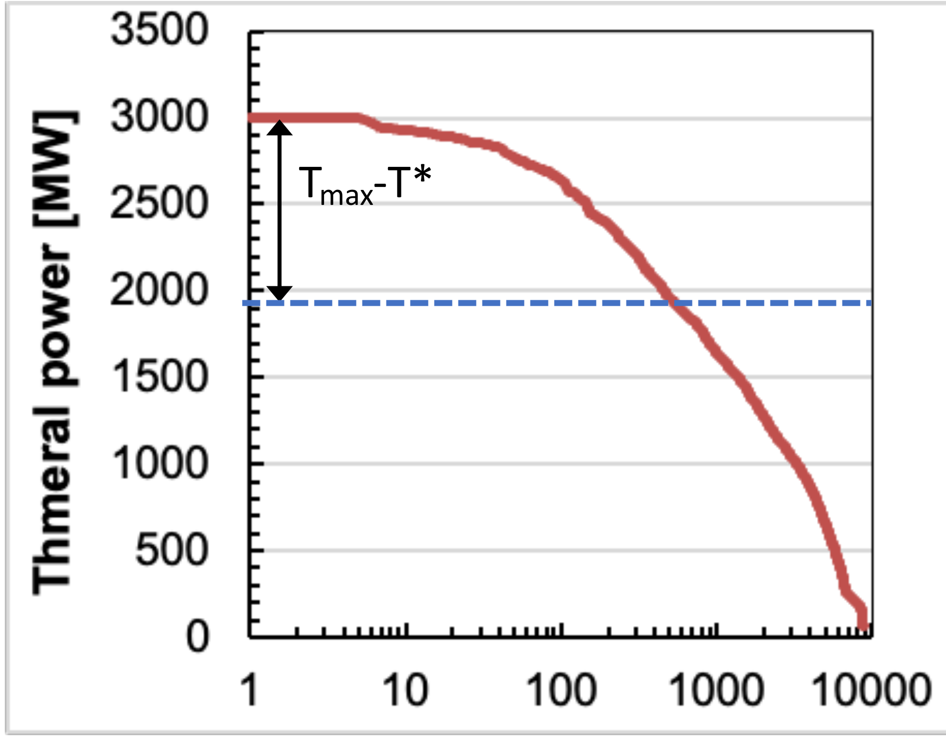
Dual/Multi-use thermal storage to cut peak heat demand

- Enthalpy H (MWh) = $m\ c_p\ \Delta T$; $\dot{H}$ (MW) = $\dot{m}\ c_p\ \Delta T$; $\Delta T = T_{max} - T^*$
- For peak conditions in dual use: $H(T^*)=0$, $H(T_{max}) = H_{max}$

Dual storage use



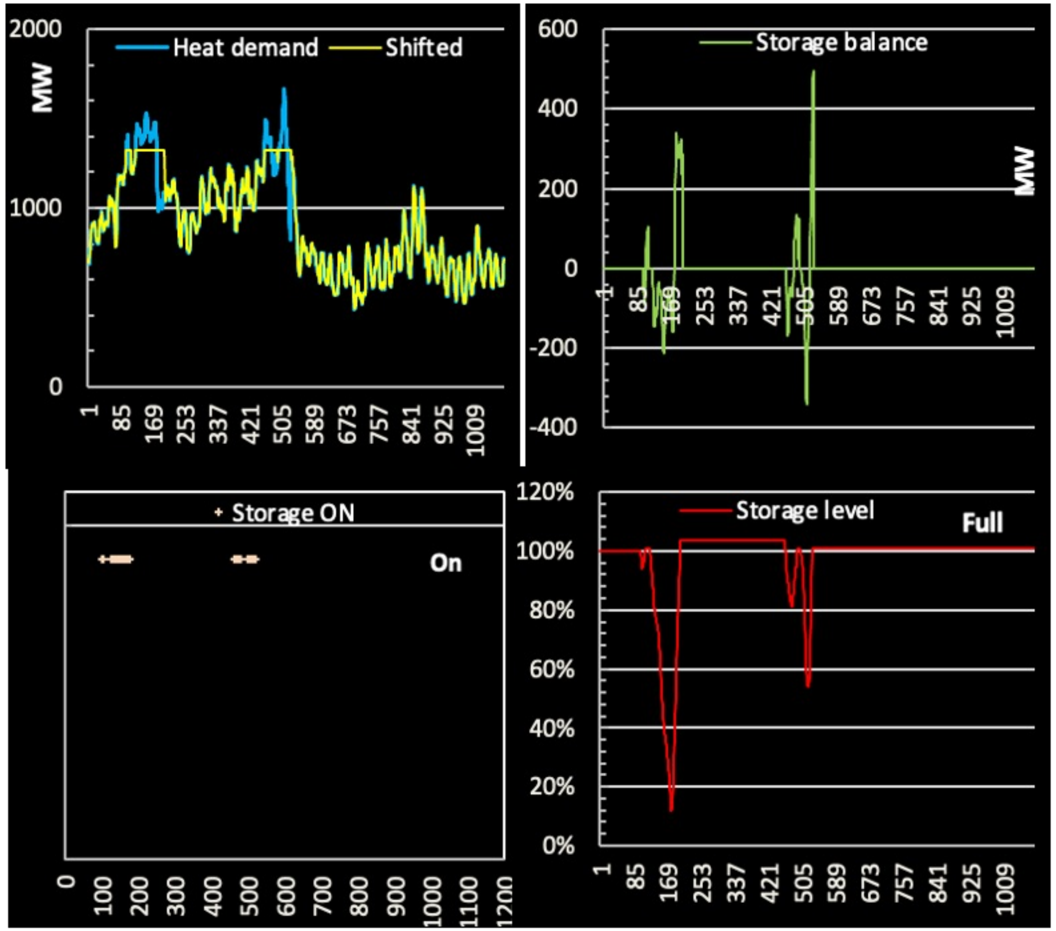


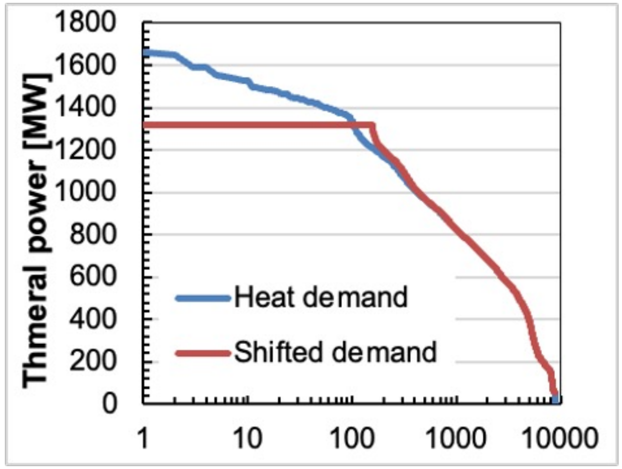


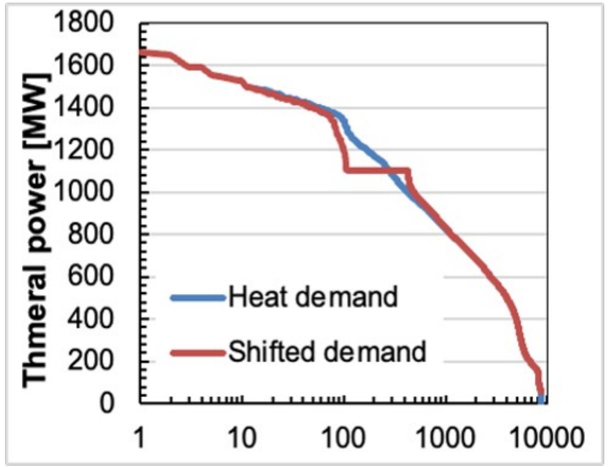
Example of dual storage for peak demand management

- Case: Average weather conditions + some efficiency improvements; peak heat demand =1663 MW
- Large dual weekly-monthly heat storage (100 GWh)
- Peak storage: H_{max}= 6.15 GWh (mc= 205 MWh/K; ΔT=30 K), 6% of total capacity
  - -21% reduction of peak (1663→ 1310 MW)
  - If 1663 MW→ 1000MW, no effect on the peak

Case Helsinki



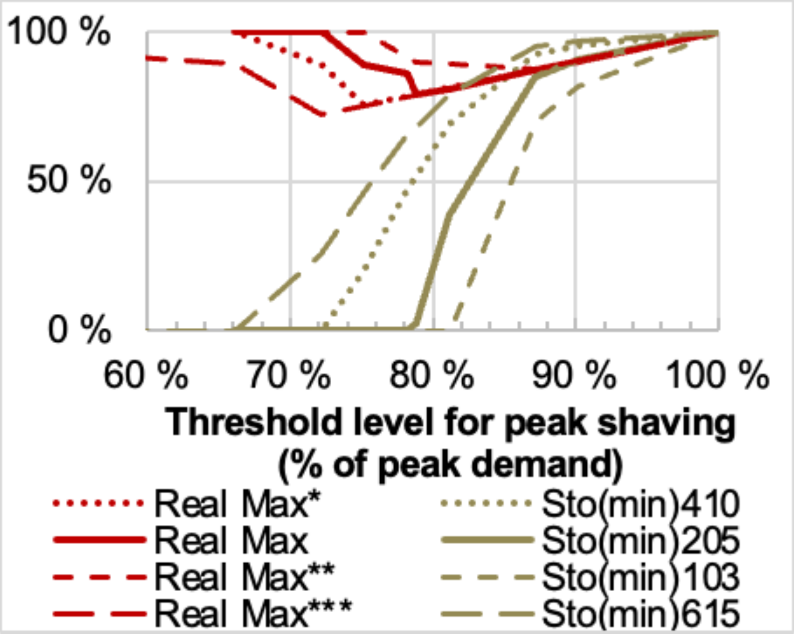


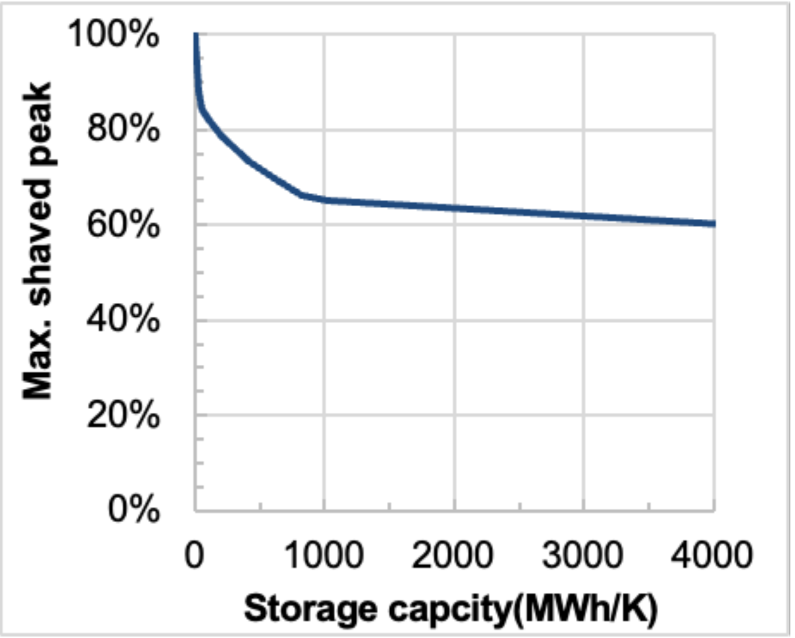


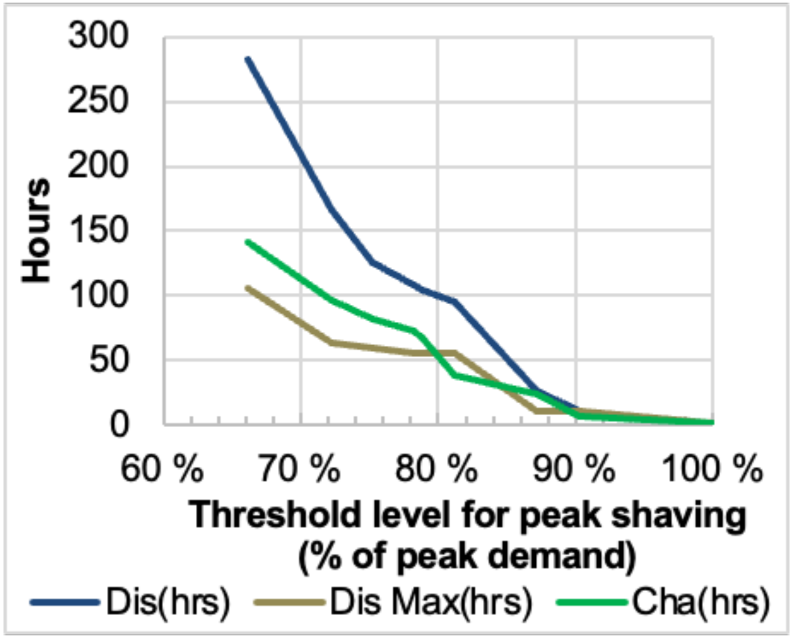
Optimum peak cut level vis-a-vis peak storage capacity

- Peak storage capacity 103-615 MWh/K
- Real Max= real peak reduction
- Sto(min) =minimum peak storage capacity
- Total discharging and charging time; max continuous discharging time (Dis, Cha, Dis Max)

- 20% peak cut possible with modest peak storage capacity < 10% of total
- Higher savings require quickly increasing peak storage capacity
  - 25% peak cut require 50% of the total storage
  - Asymptotic value ca 40%, but 100% of total





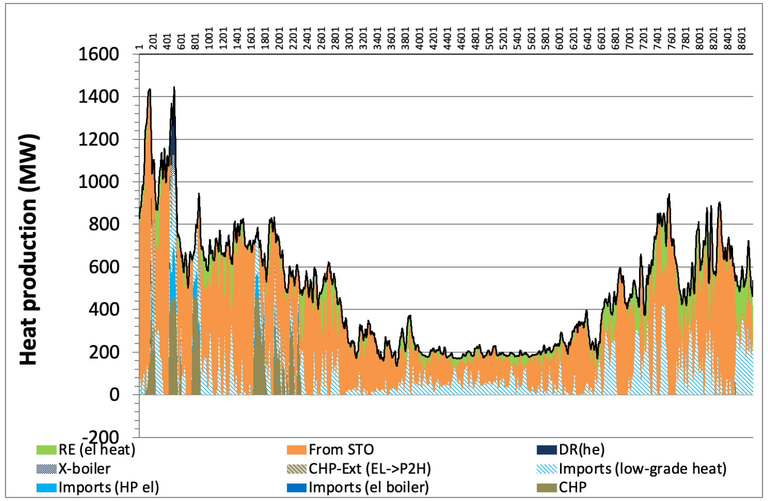


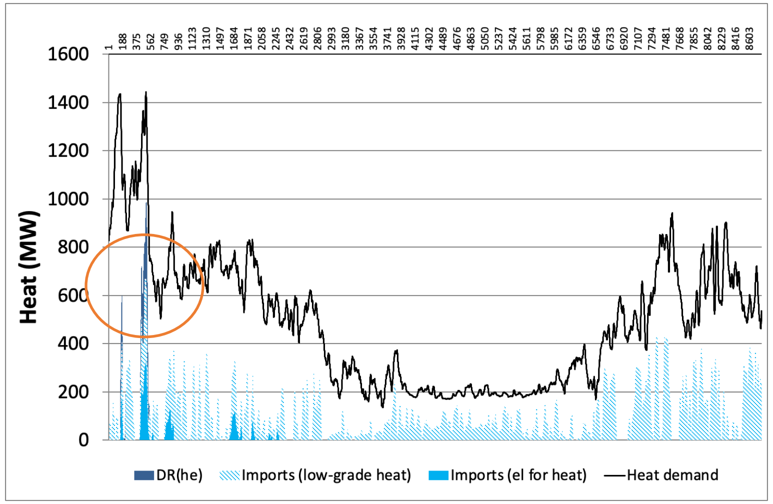
Systems effects from peak heat demand storage

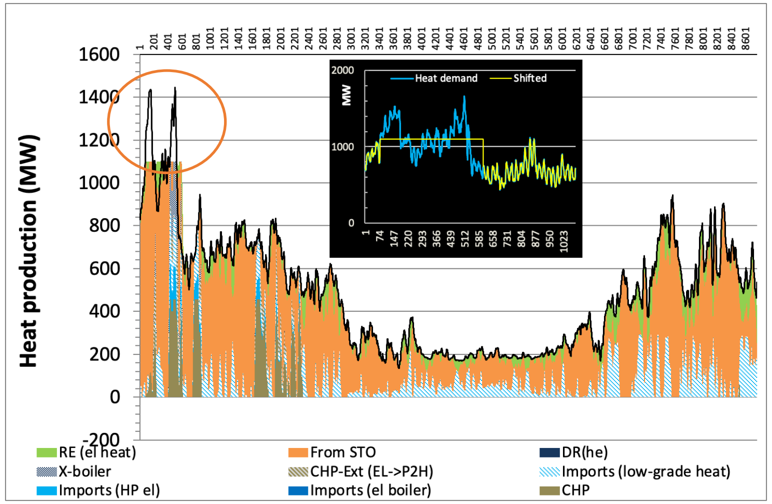
Case values:

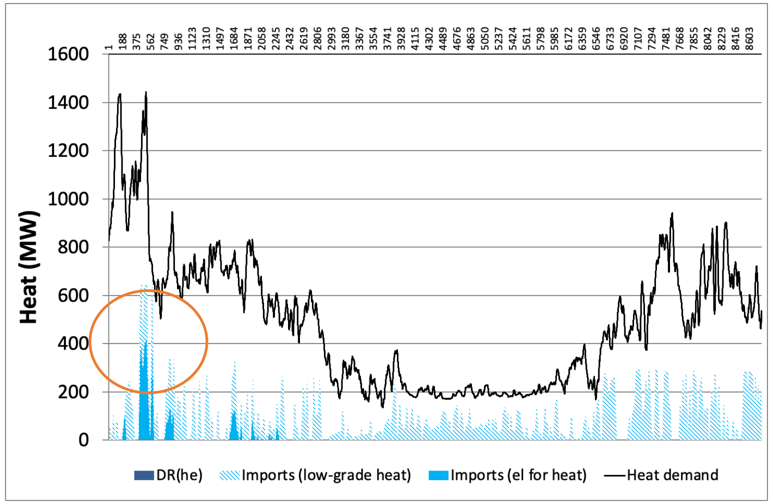
- Peak storage 25% of total storage
- 1/3 of peak demand shaved

Case Helsinki





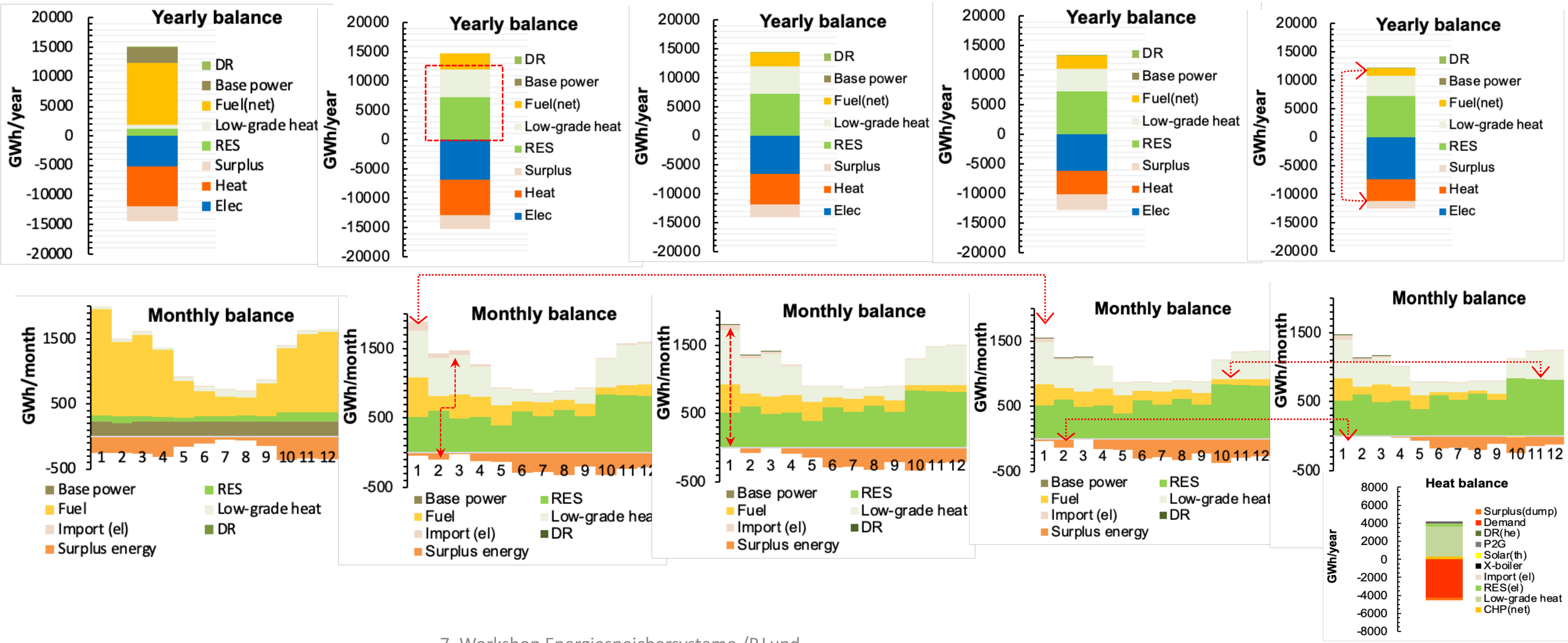




Stepwise strategy to [almost] zero-carbon energy system

1. Present Helsinki fossil energy system
2. Much RE & heat pumps, old gas CHP
3. + Thermal storage, DR + mild energy efficiency
4. +Peak th storagec+ strong energy efficiency
5. + Electric storage + V2G + P2G

~10% RE ... ~100% RE



Conclusions

Peak conditions

- Energy system resilience is linked to the peak conditions and power
- 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 5-15 % of the total load, but 80-90 % of the imported electricity or back-up fuel
- Weather causes major uncertainty in the peak power

Peak solutions (and reserves)

- Energy efficiency measures help to decrease power, energy, fuels, uncertainty in peak conditions [but are weather dependent]
- Thermal storage complements energy efficiency, but with more focuses on peak demand only
- Duel storage concept with peak storage could well reduce the peak heat load by 20%
- "Smart solutions" required to fully cover the peak demand and compensate for the uncertainty