Importance of multi-use of thermal storage coupled with P2H for deep decarbonization in northern cities

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5. Herbstworkshop Energiespeichersysteme

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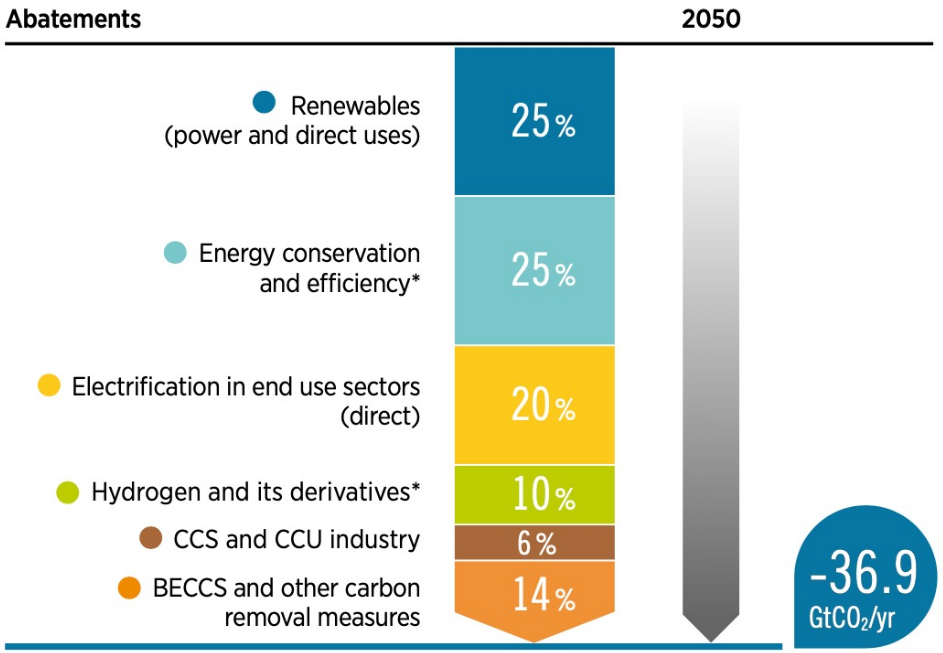
Approaching carbon neutrality through breakthrough through electrifiction and RES

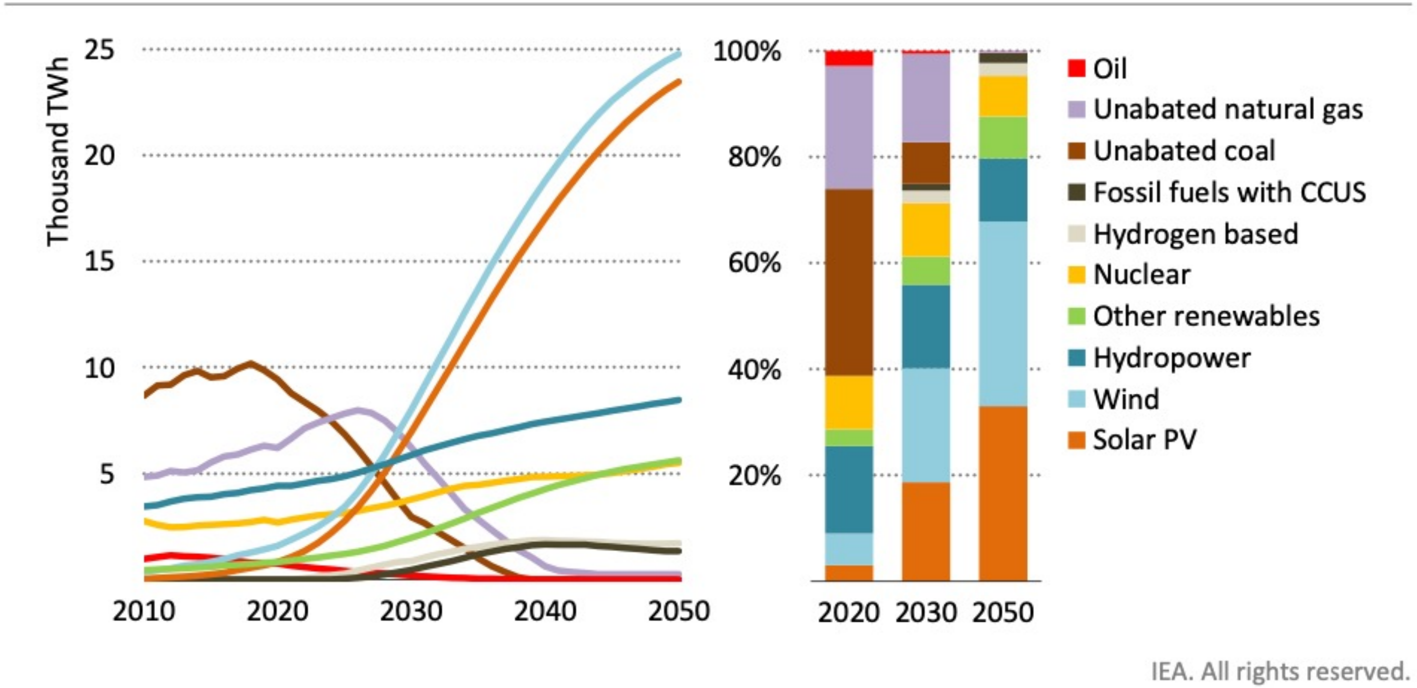
Solar and wind 70% of world electricity by 2050

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

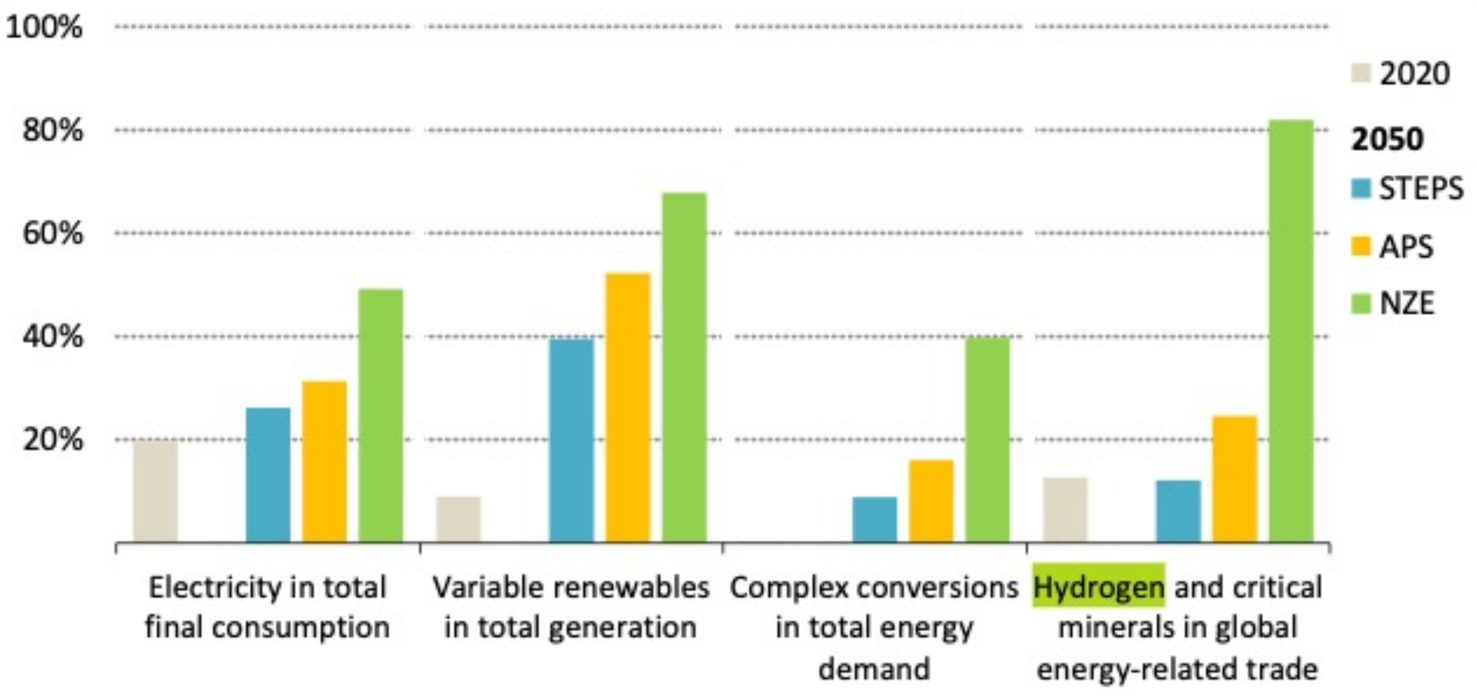


Solar and wind power race ahead, raising the share of renewables in total generation from 29% in 2020 to nearly 90% in 2050, complemented by nuclear, hydrogen and CCUS

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

Complexity of the energy transition

Figure 1.23 ▷ Key indicators of energy system change by scenario



New energy security challenges arise in systems increasingly reliant on electricity, low-carbon technologies, higher levels of supply variability and more complex conversions

Note: Complex conversions are a primary energy source that has undergone two or more conversions before being delivered to end-users. It includes roundtrip battery storage.

Source: IEA World Energy Outlook 2021

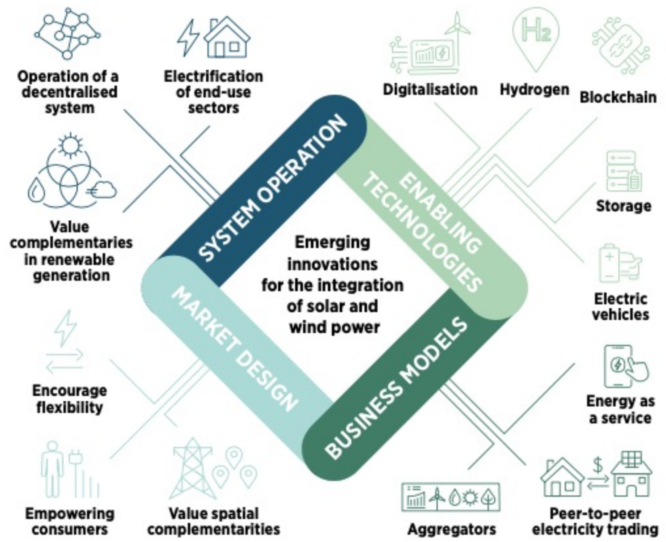
Changes in energy systems

Present

Fuel-based centralized system

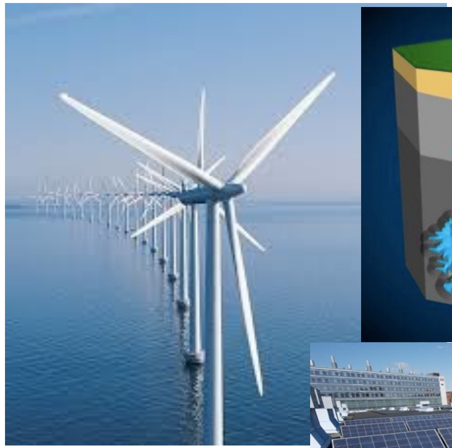
Integration

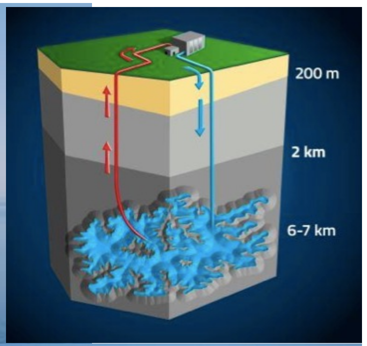
FIGURE 2.6 Emerging innovations that support the integration of VRE



Based on IRENA (2019a).

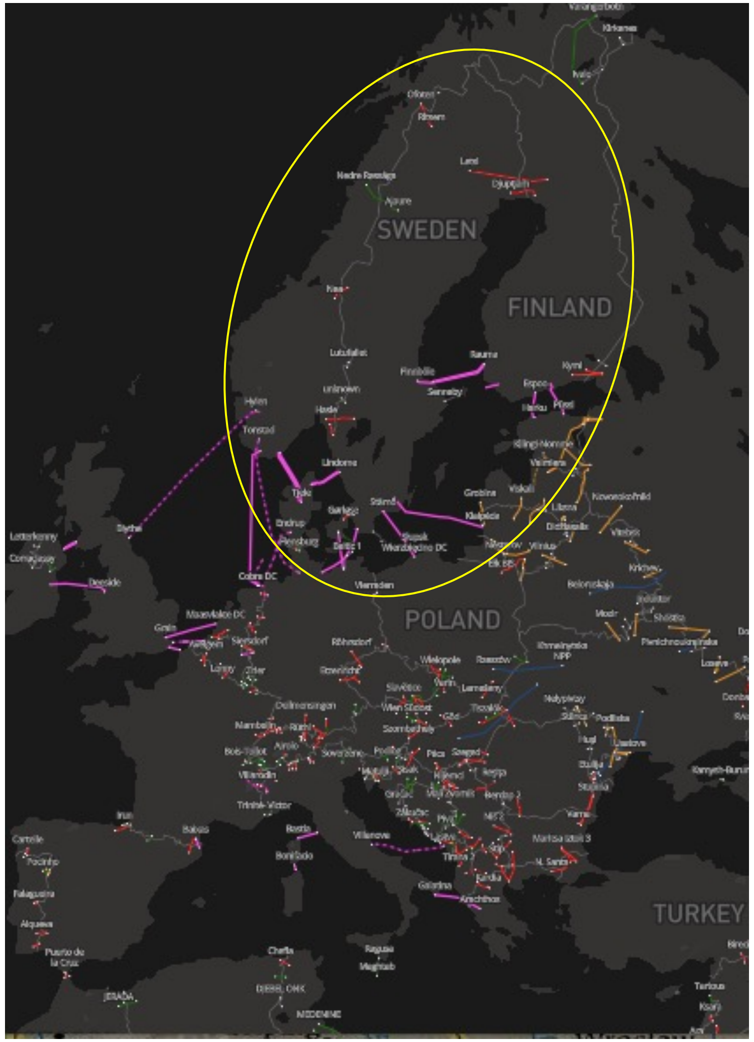
Future





Weather-based distributed energy system

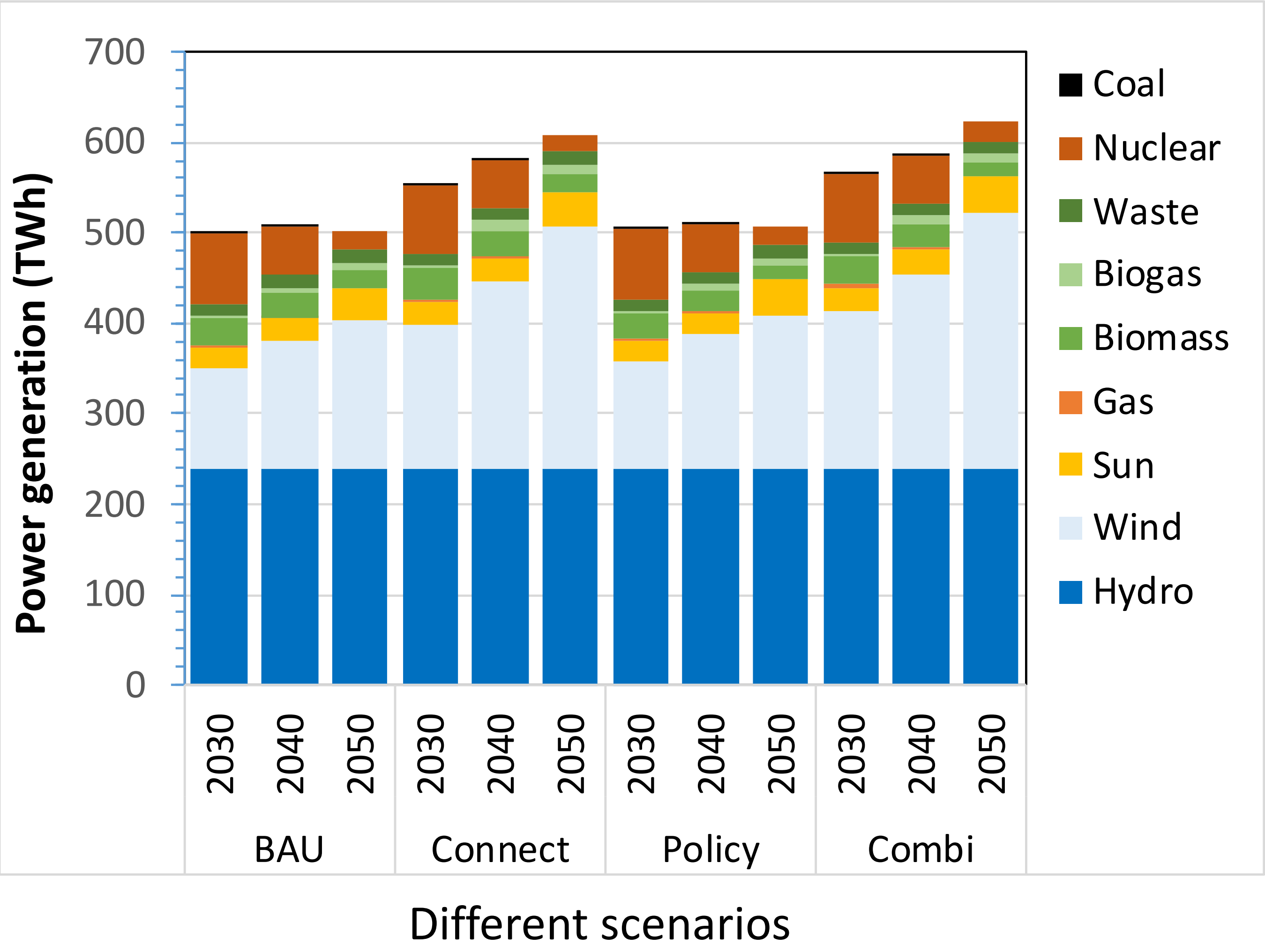
Integrated Nordic electricity market



- Strong transboundary interconnections
- Hydropower >1/2 of all power
- Wind power replacing thermal power plants
- Emission-free power (> 90% of all, in EU=50%) will help other sectors in their decarbonization efforts

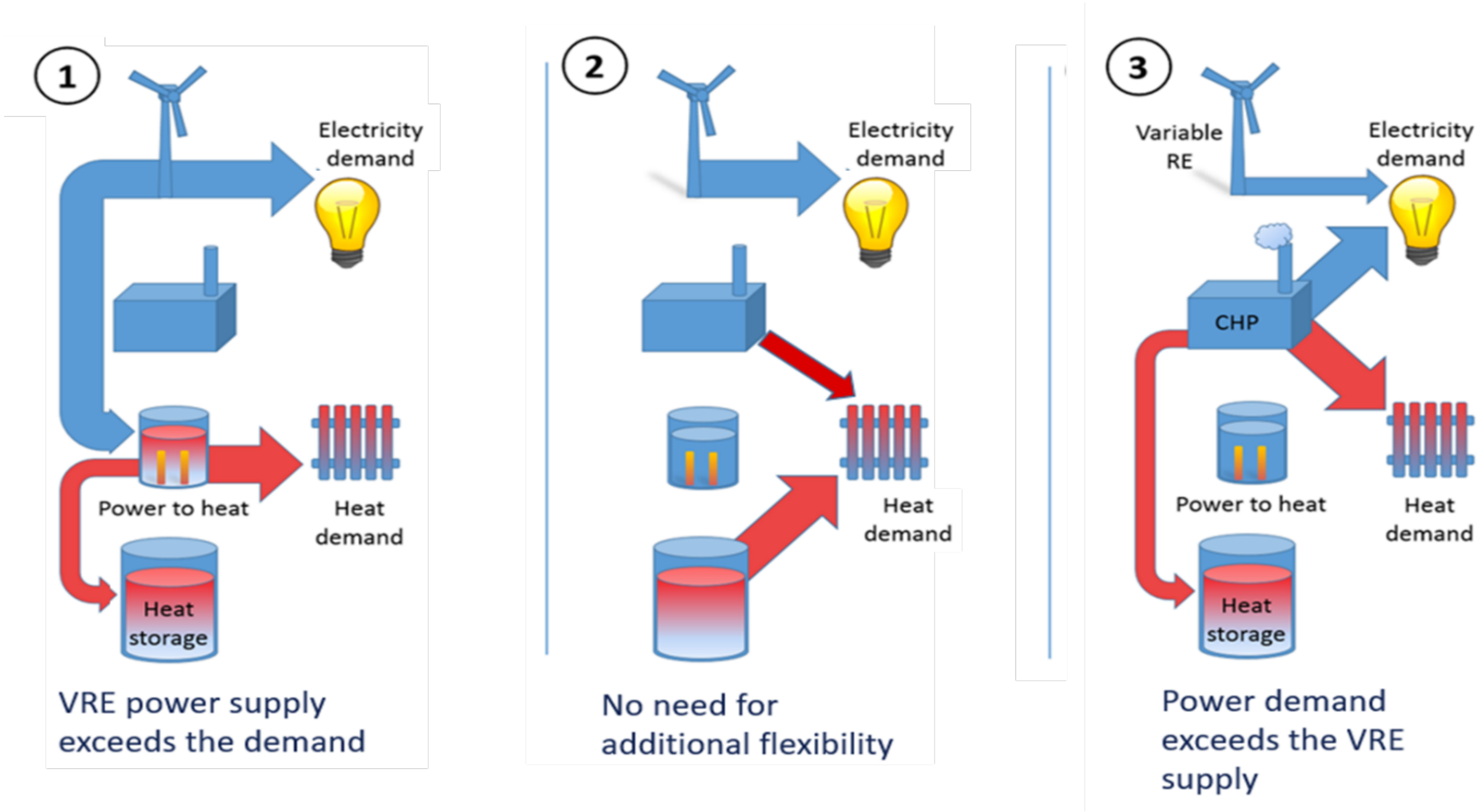
Nordic zero-emission energy transition

Electricity generation (TWh)



Flex4RES
Flexible Nordic Energy Systems

District heat generation (DH) with PtH sector-coupling



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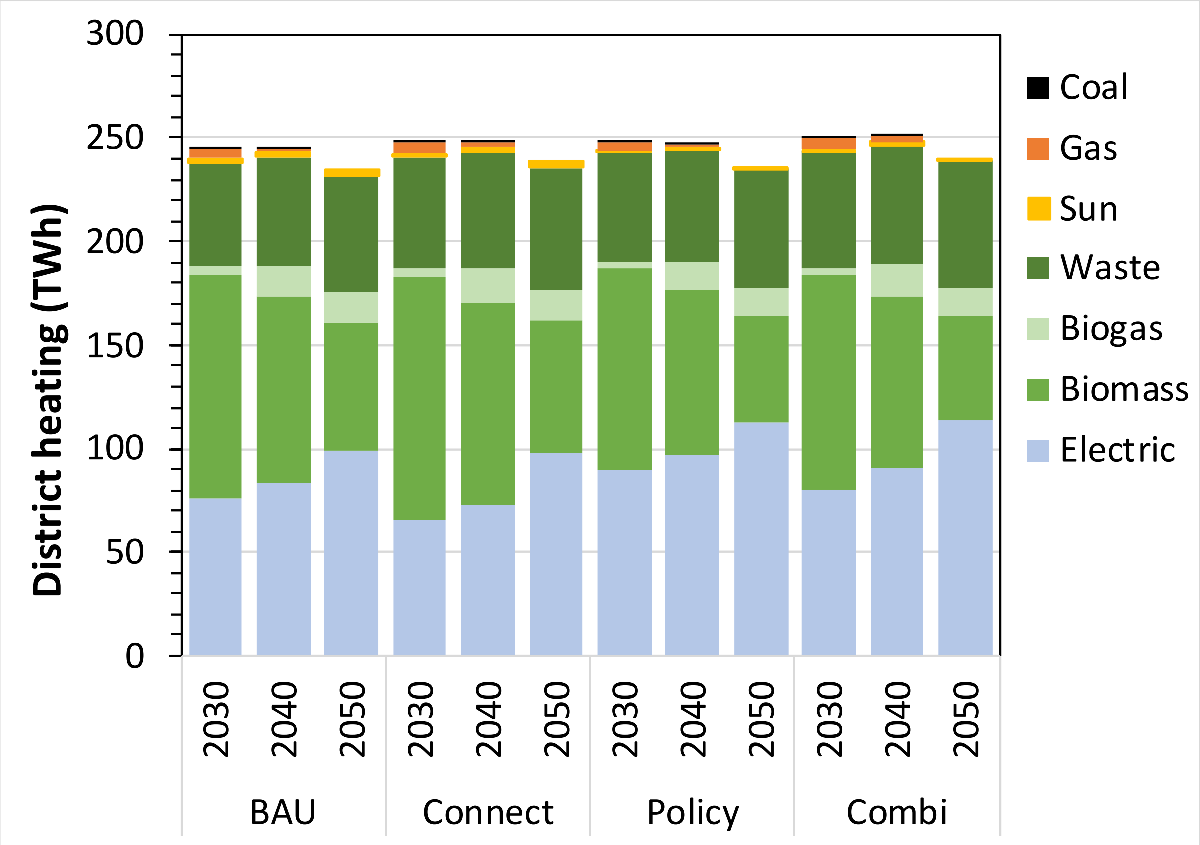
Nordic zero-emission energy transition

Heat generation (DH)



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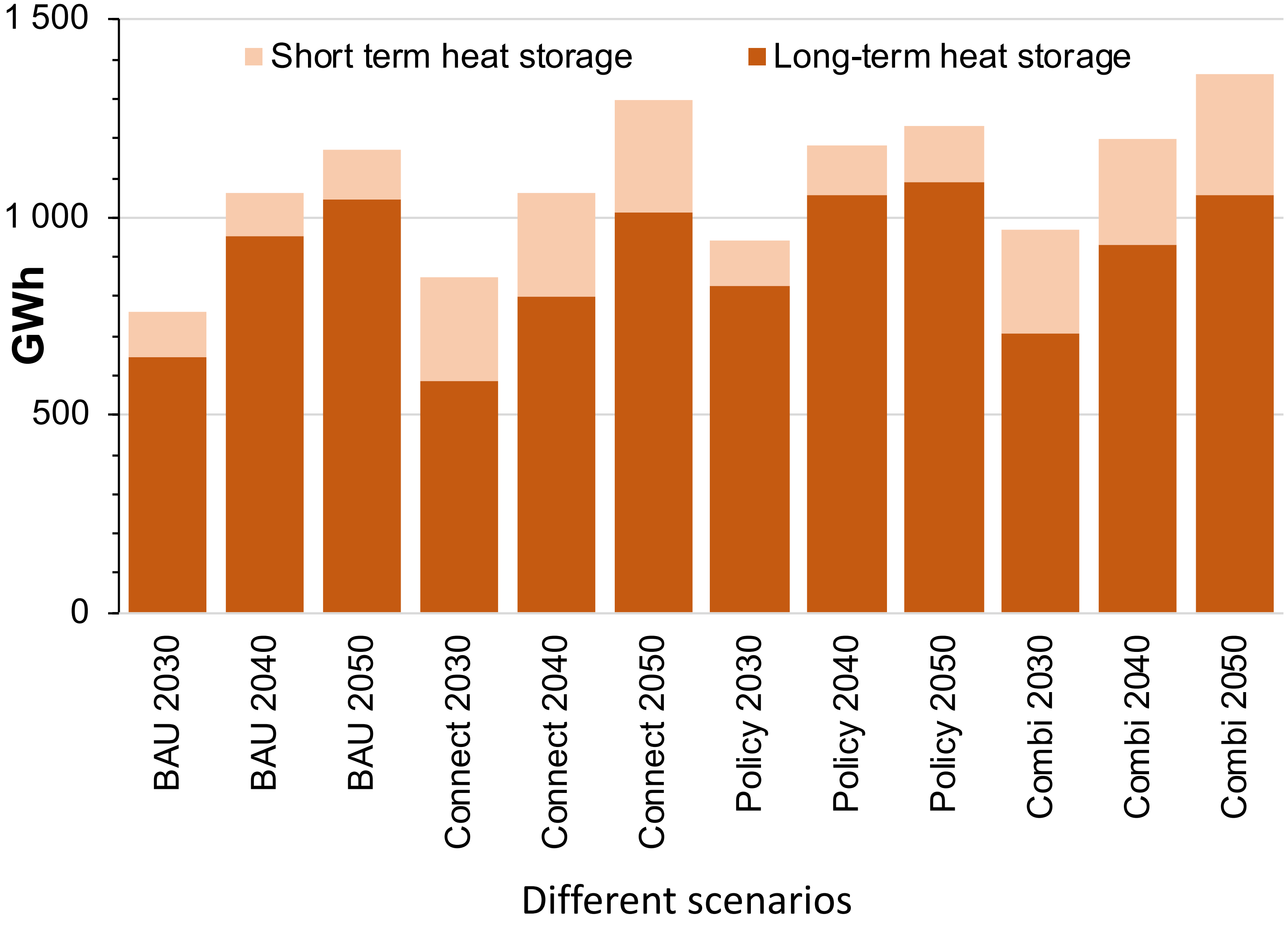
Heat storage demand



Flex4RES
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Urban context of climate & energy is important for the energy transition

Cities consume most of the resources:

- ½ of world population lives in cities (70% by 2040)
- 65% of energy is consumed in cities (80% by 2040)
- Most of the environmental impacts from cities

Cities are sources for innovation and prosperity:

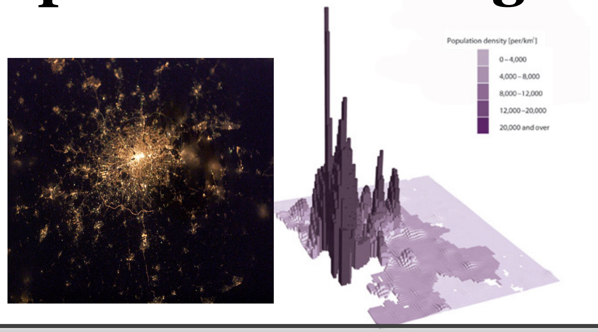
- GNP of London > GNP of Switzerland or Sweden
- Tokyo = 2% of world GNP

Enhanced energy system flexibility through cities

Share of final energy use:

① Thermal energy >50% (heat)
② Electricity 20-30%
③ Fuel 25-30% (transport)

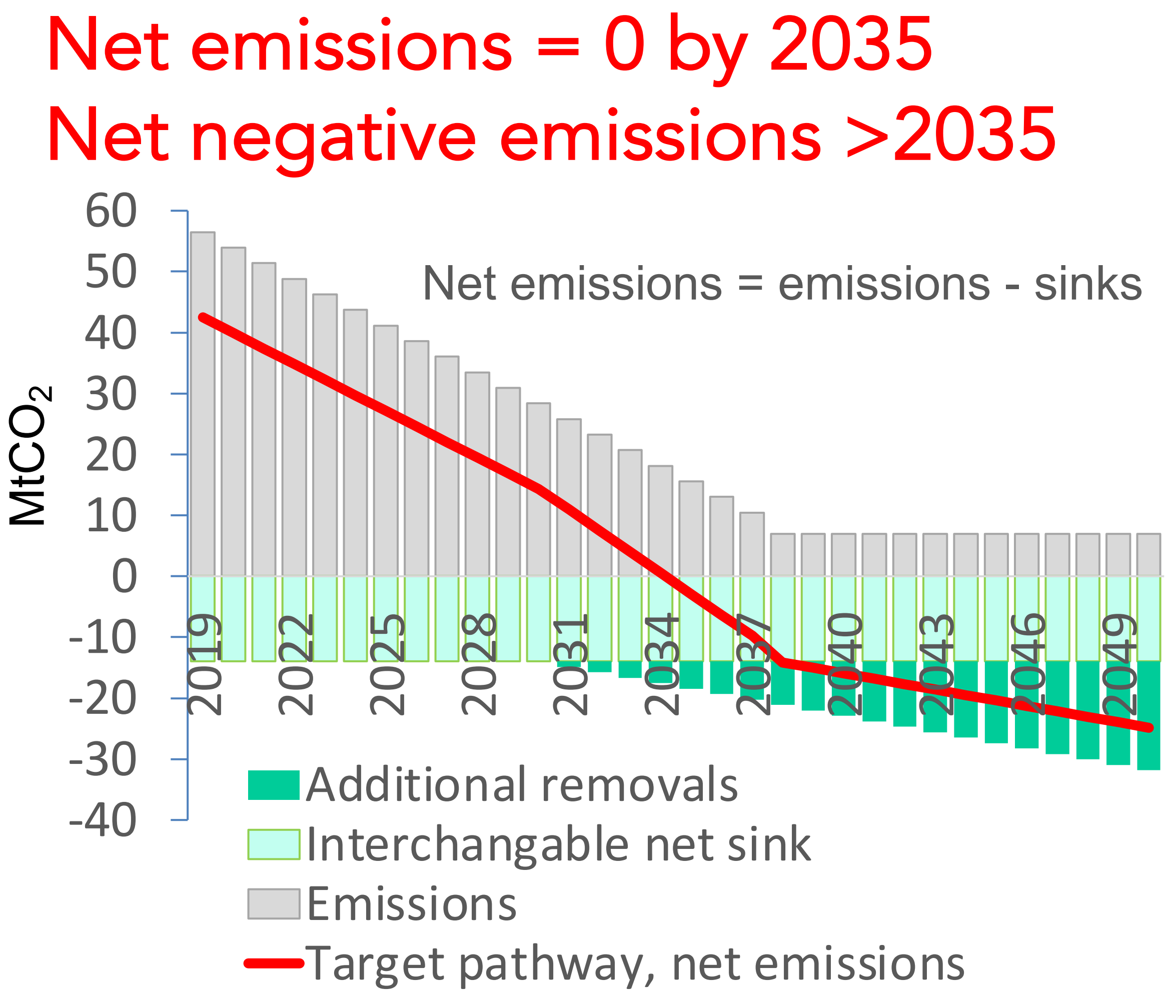
Spatial smoothing:



Sector coupling:

① Power-to-heating (PtH)
② Power-to-transport (VtG)
③ Power-to-gas (PtG)

Finland is one of the first countries aiming at carbon neutrality already by 2035



Elements of the transition:

- Strong electrification
- Biogenic carbon sinks (forests)
- Sectoral roadmaps

Deep decarbonization of urban energy systems
- Case Helsinki

District heating 92%, CHP 98%, fossil fuels dominate

Energy networks: Power, gas, heat, cold

Present energy system in Helsinki subject to profound change

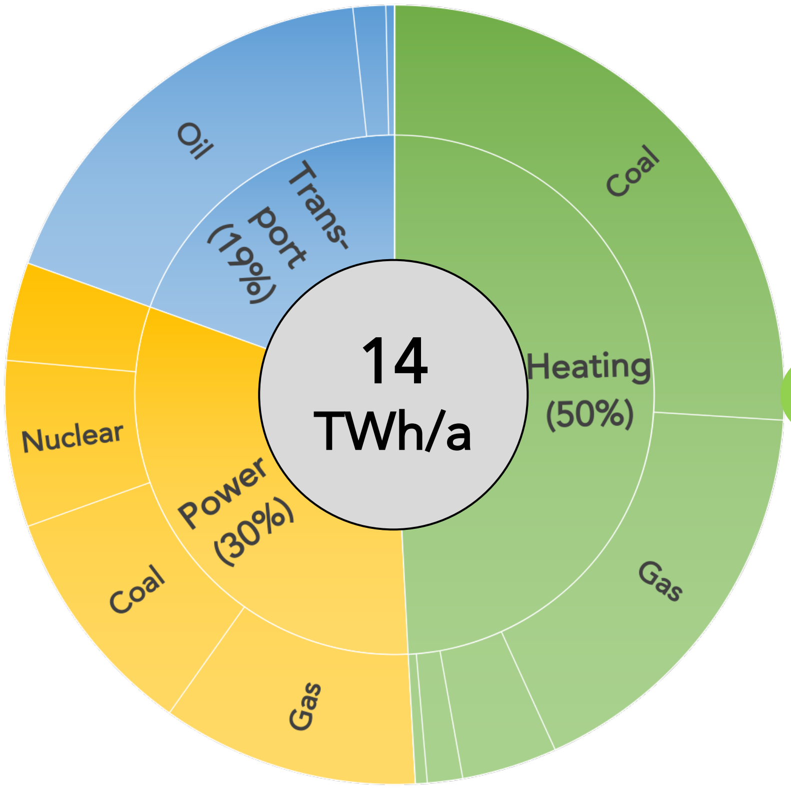
Share of fossil-fuel in Helsinki:

Heating	89%
Power	65%
Transport	91%

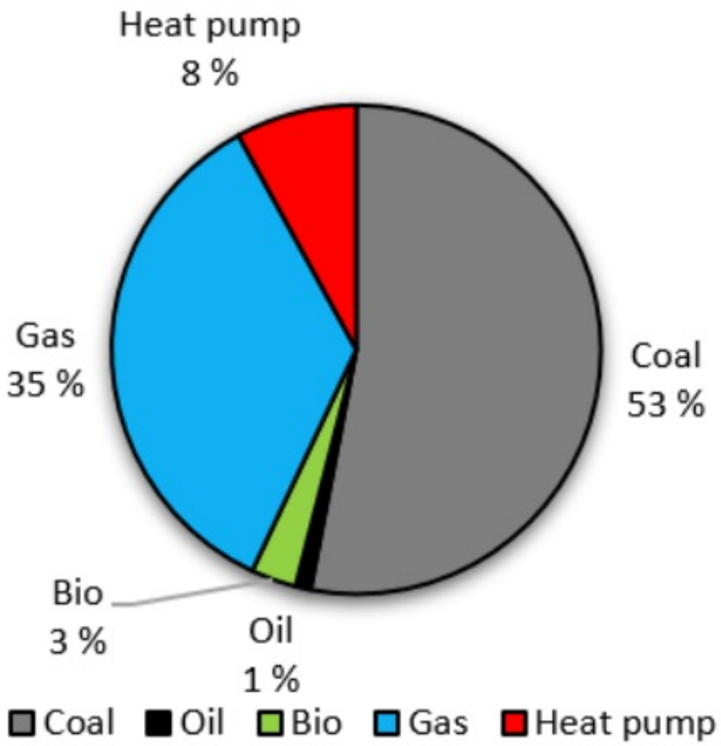
Table 1. Nominal output of plants in Helsinki (MW) for year 2018.

Year		Gas CHP	Coal CHP 1	Coal CHP 2	Gas boiler	Oil boiler	Coal boiler	Bio-boiler	Heat pump	Storage MWh
(2018)	Power	630	218	160	---	---	---		---	
	Heat	587	429	300	912	1010	190	92	127	5000

All Energy



Heat

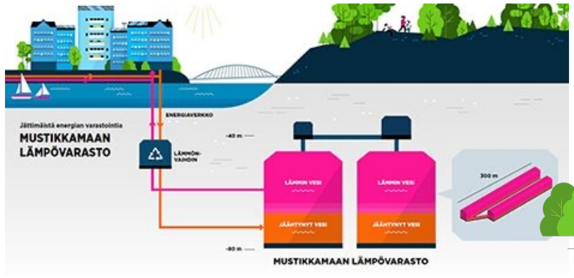


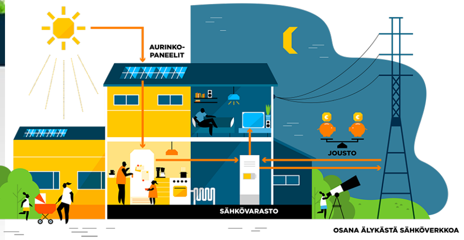
Deep decarbonization elements for Helsinki

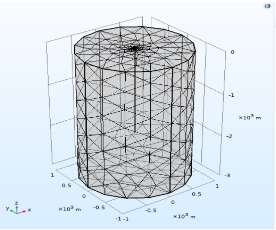
Targeting carbon neutrality by 2035 : 80% emission reductions + 20% carbon sinks

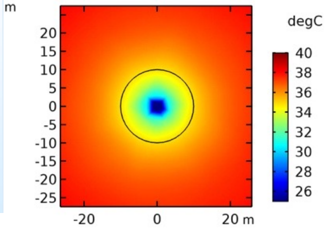
Mosaic of possible measures:

- Large-scale deep heat and sea heat pumps
- Waste heat utilization
- Large underground thermal storage
- Building energy efficiency and services
- Compact urban planning
- Off-shore wind power shares, minimize bioenergy
- Electric mobility, trams, bicycle lanes
- Helsinki Energy Challenge



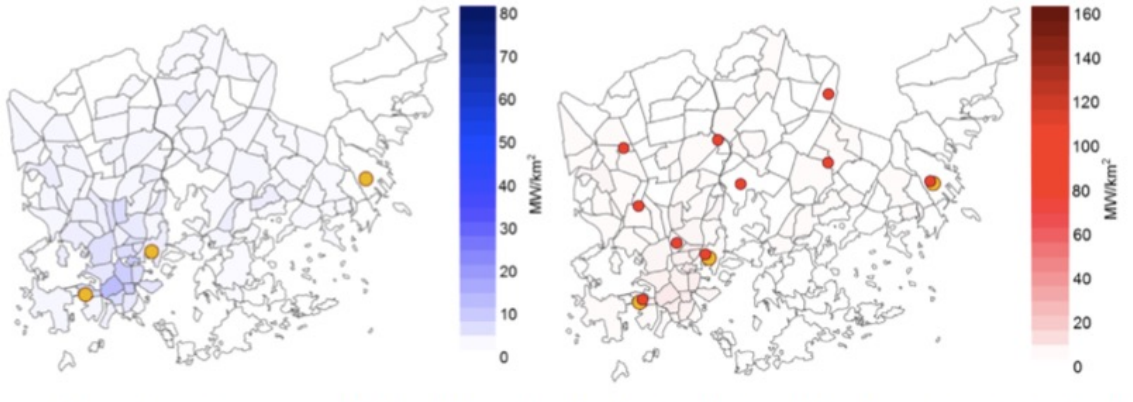


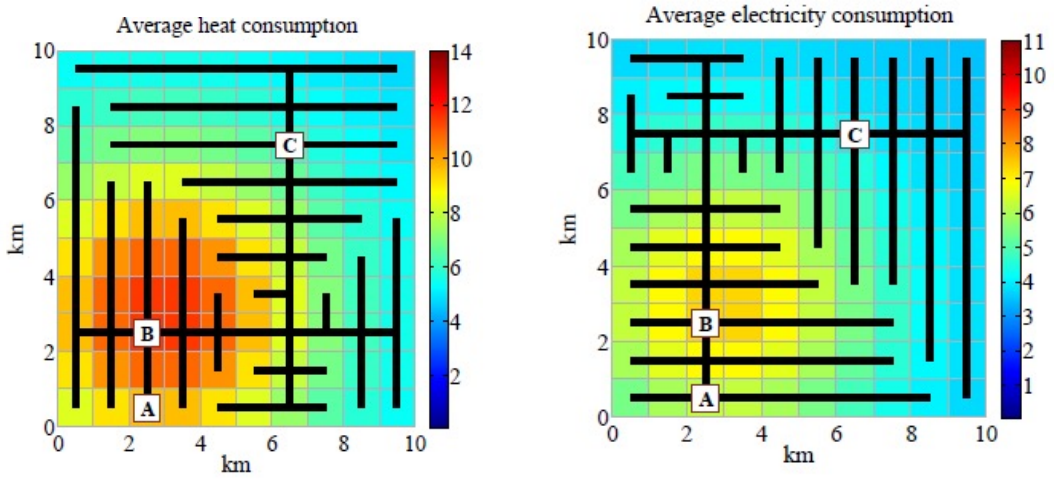




Applying VRE to urban-scale : Case Helsinki with big wind power & PV

Power and heat demand & plants in Helsinki





MW/km²

Now: 1.3$GW_{th,CHP}$; 2.0$GW_{th,peak}$
Case: Ten 10 000 m³ (a’ 642 MWh/140MW) TES units;
VRE: 0-1400 MW_p PV; 0-1650 MW wind (space limited)

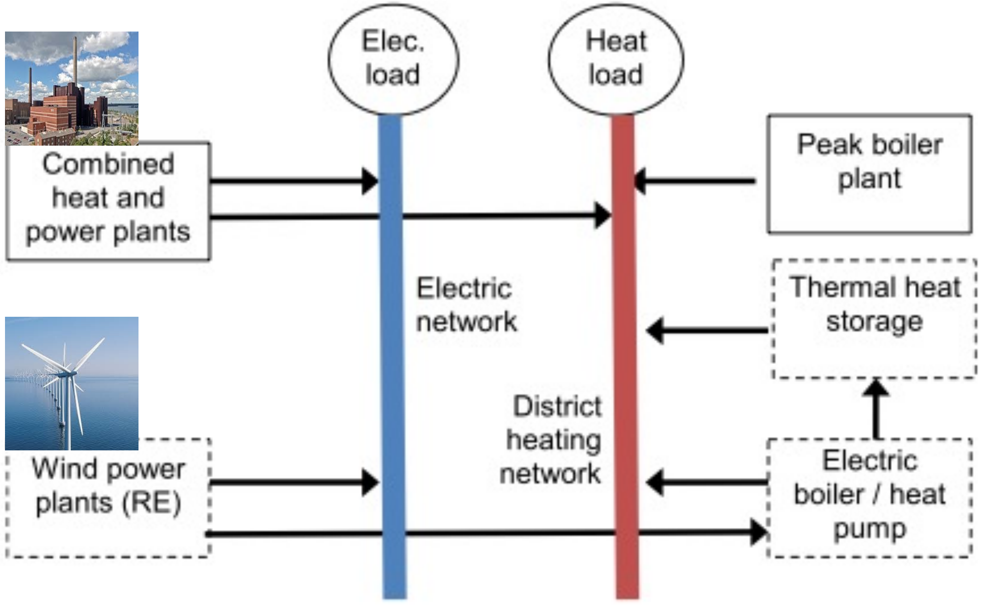
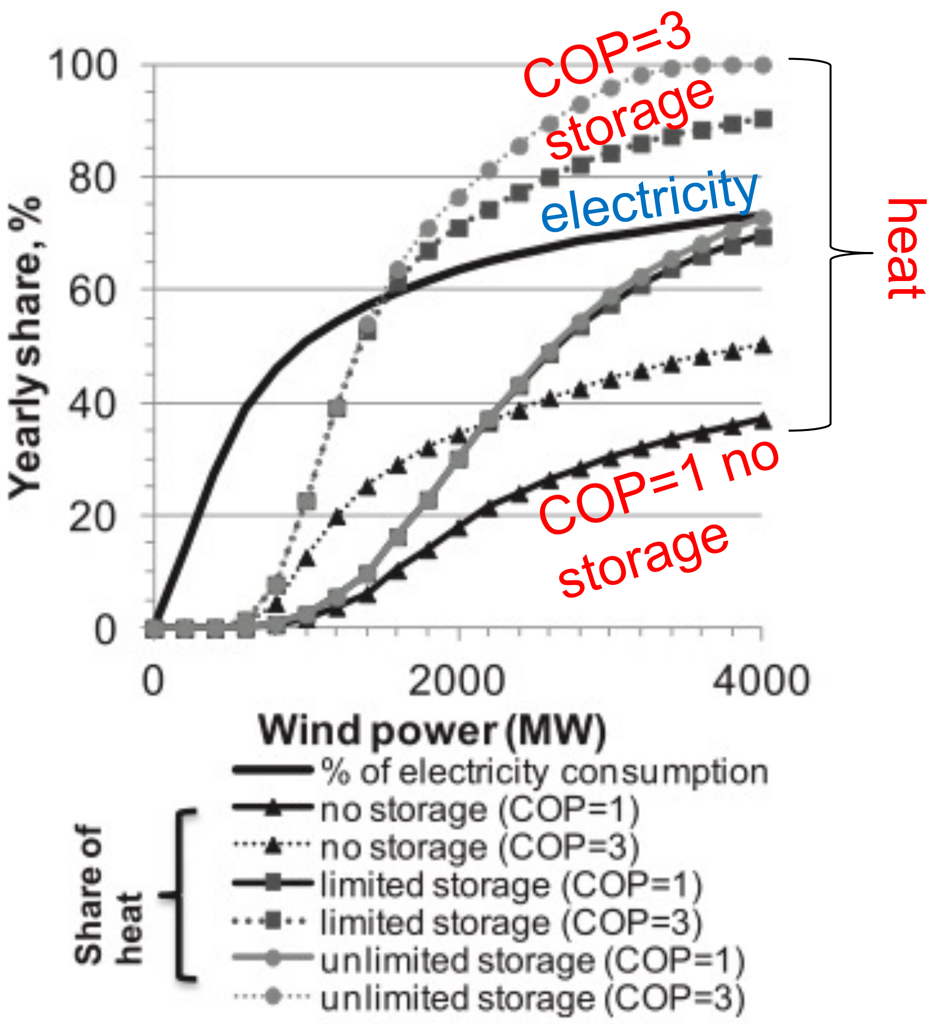


Fig. 4. Schematic of the energy system configuration in Helsinki (Finland). Dashed line boxes are energy system components for the wind power scheme with surplus electricity-to-thermal conversion strategy.

Helsinki with wind & PtH + District heating+CHP

(integration with heat pump and storage, COP 1= elec. boiler; COP 3= heat pump)



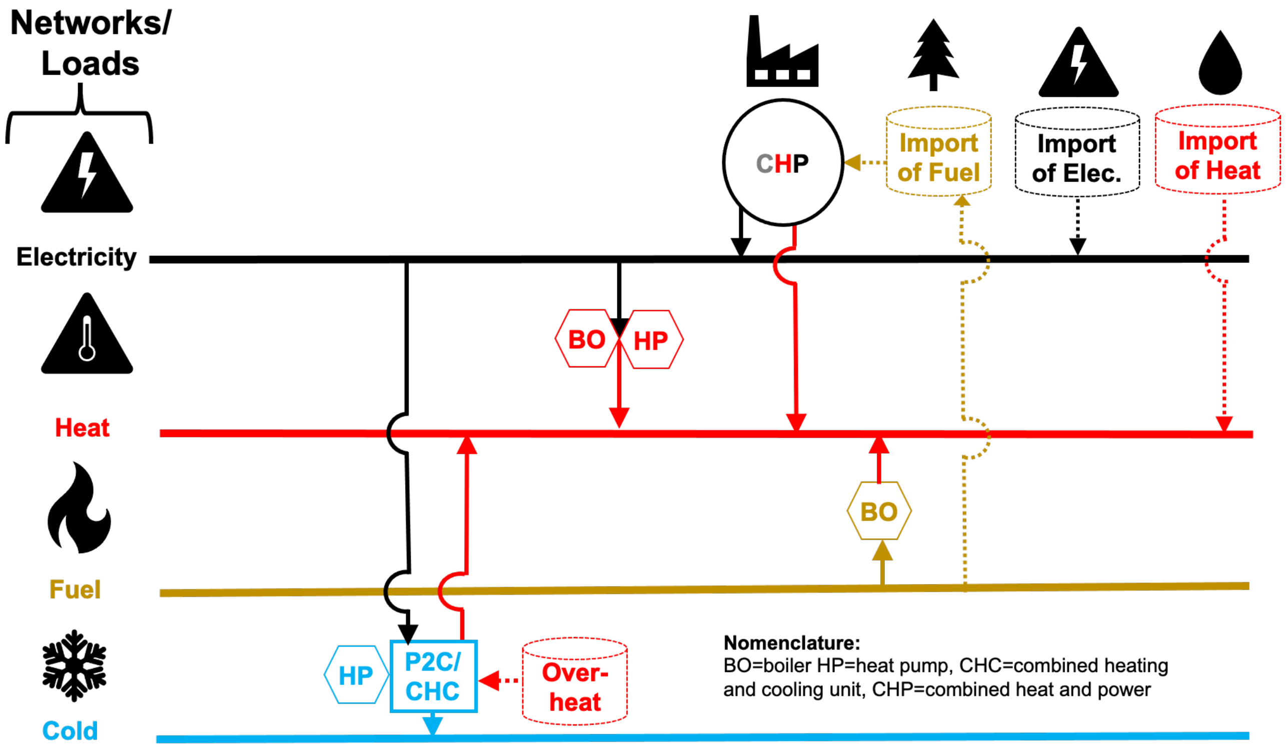
- Additional thermal components: Heat pump (COP=3); Thermal storage
- Wind share of electricity:
  - At self-use limit ≈ 25%
  - With PtH ≈60%
  - ∞-limit ≈ 70%
- Wind share of heat:
  - At self-use limit 0%
  - PtH (60%) ≈5%
  - PtH(60%)+STO≈10%
  - PtH +HP ≈25%
  - PtH +HP+STO ≈60%

P.D. Lund et al. / Journal of Cleaner Production 103 (2015) 437–445

Change of energy system architecture

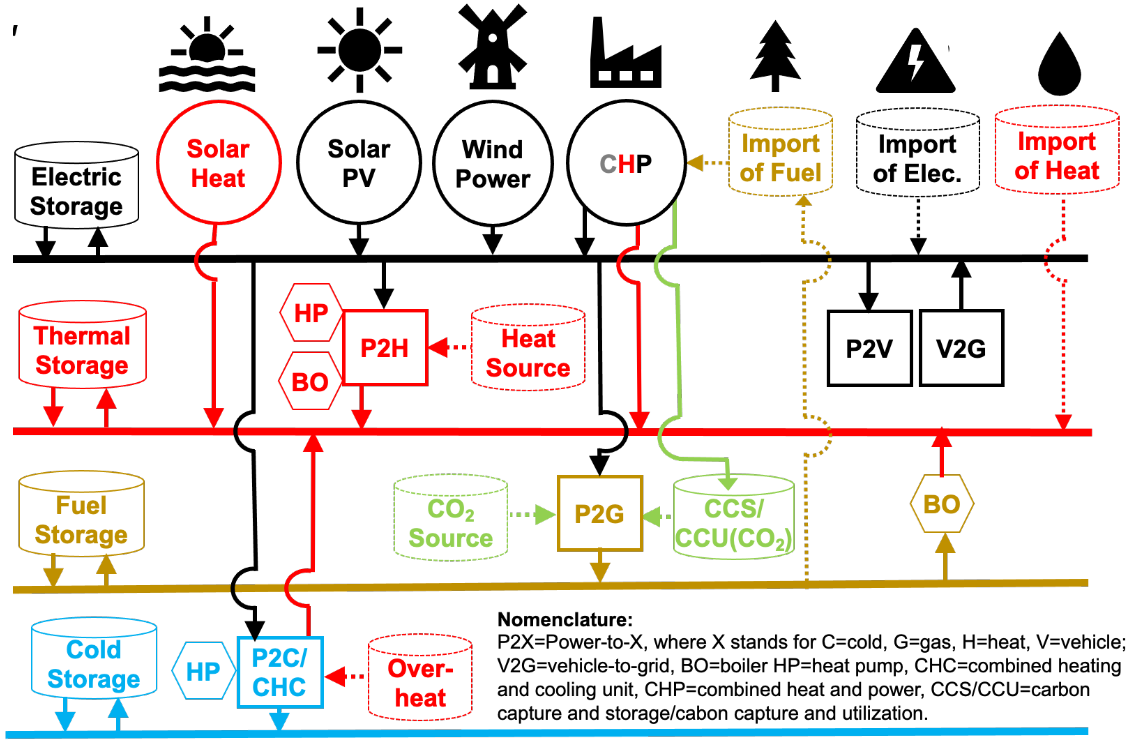
Present energy system

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



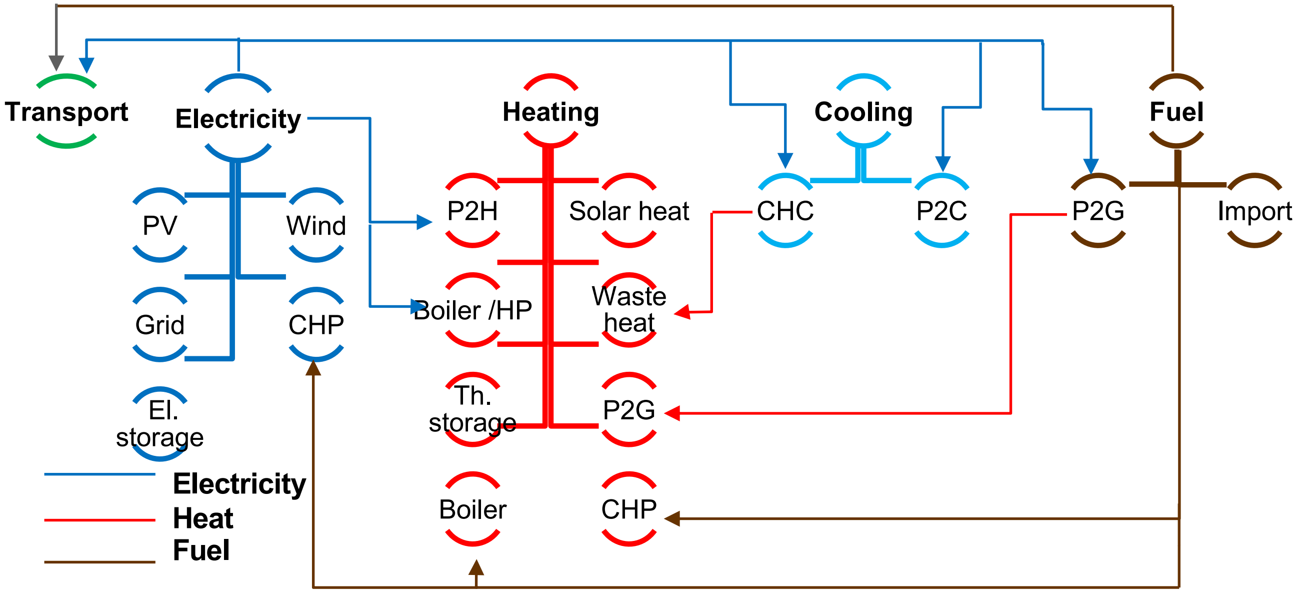
Future decarbonized energy system

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



Increasing complexity to manage the system

Energy flowchart of future energy system



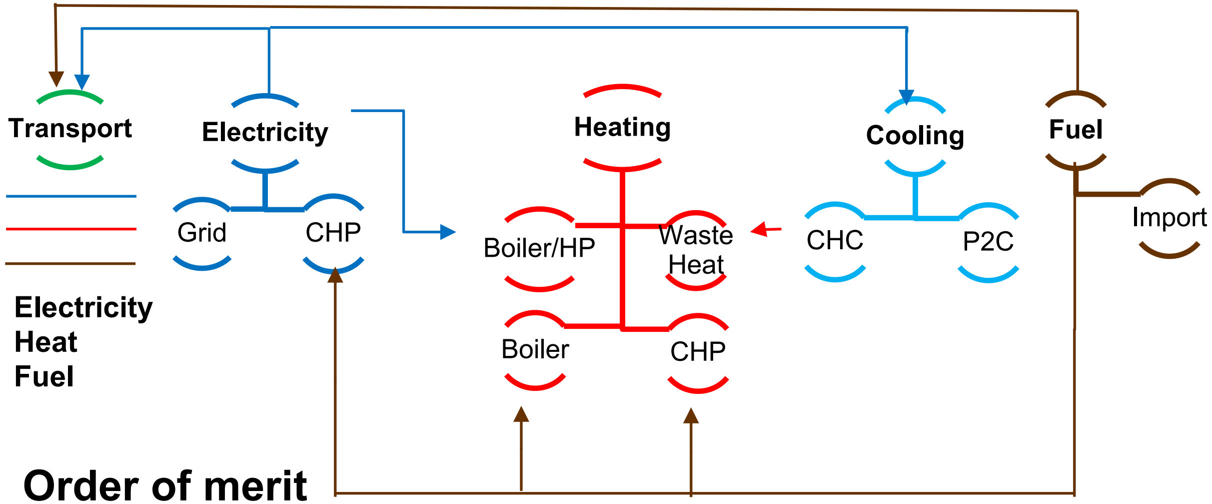
Order of merit

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				

Future decarbonized energy system

- Complex couplings & demanding matching
- Importance of system control and optimization
- From running a plant to running a system

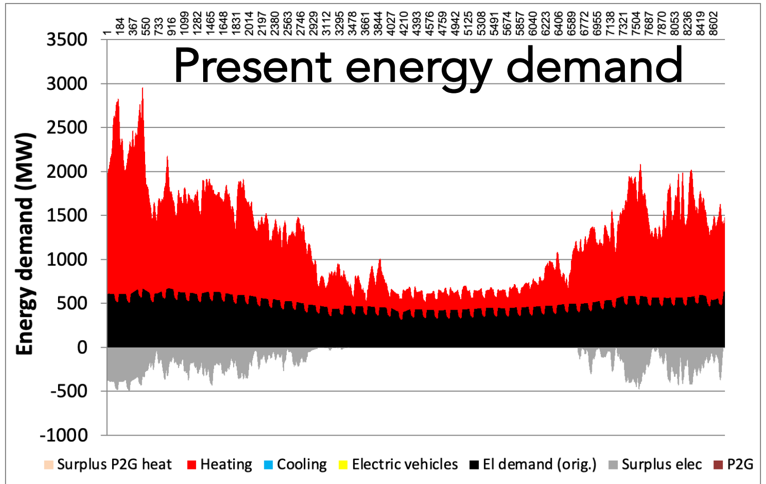
Energy flowchart of present energy system

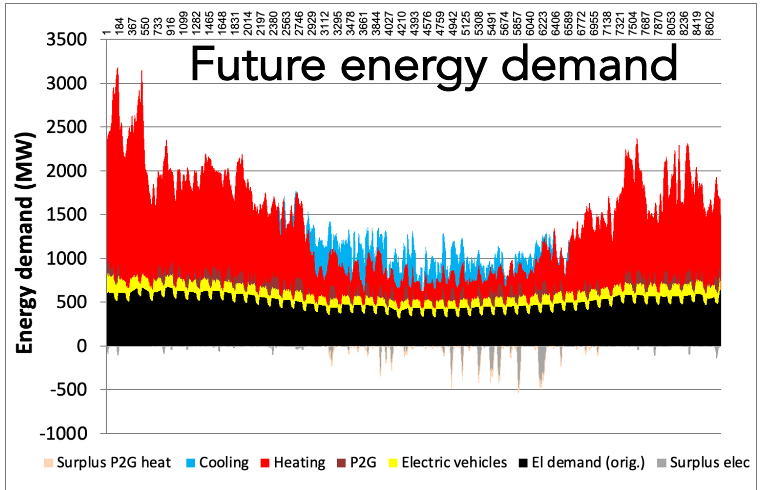


Order of merit

Power		Heating		Cooling		Fuel	
CHP	1	Waste H	1	CHC	1	Import	1
Grid	2	CHP	2	P2C	2		
		HP/Boiler	3				

Addressing new type of challenges (case Helsinki)



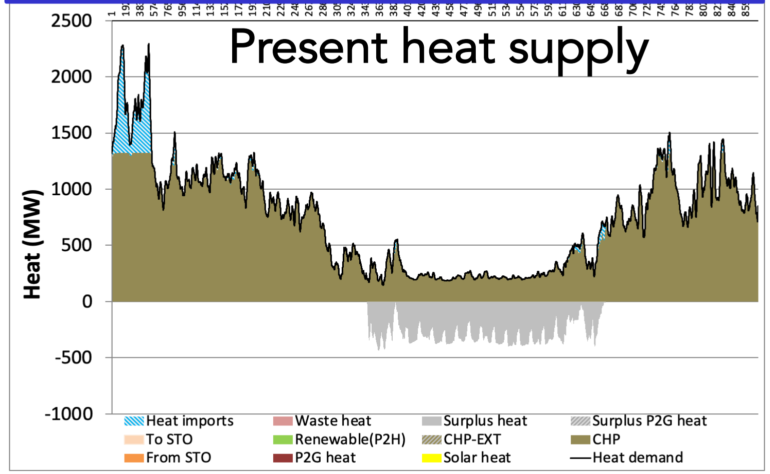


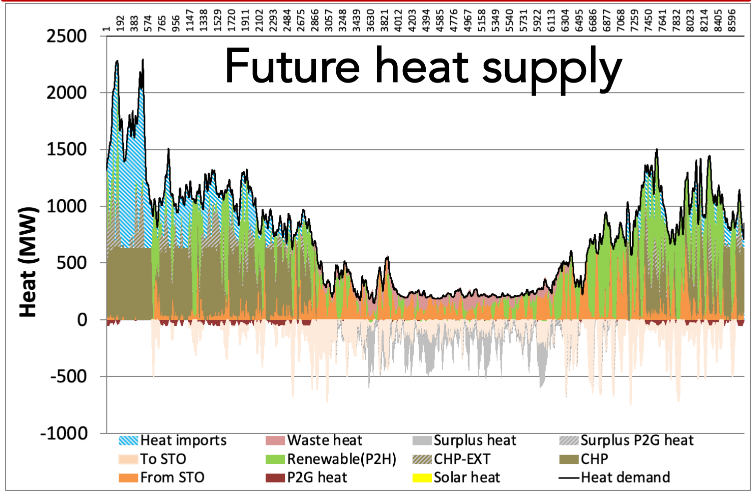
Traditional scheme

- 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, PtG, VtG

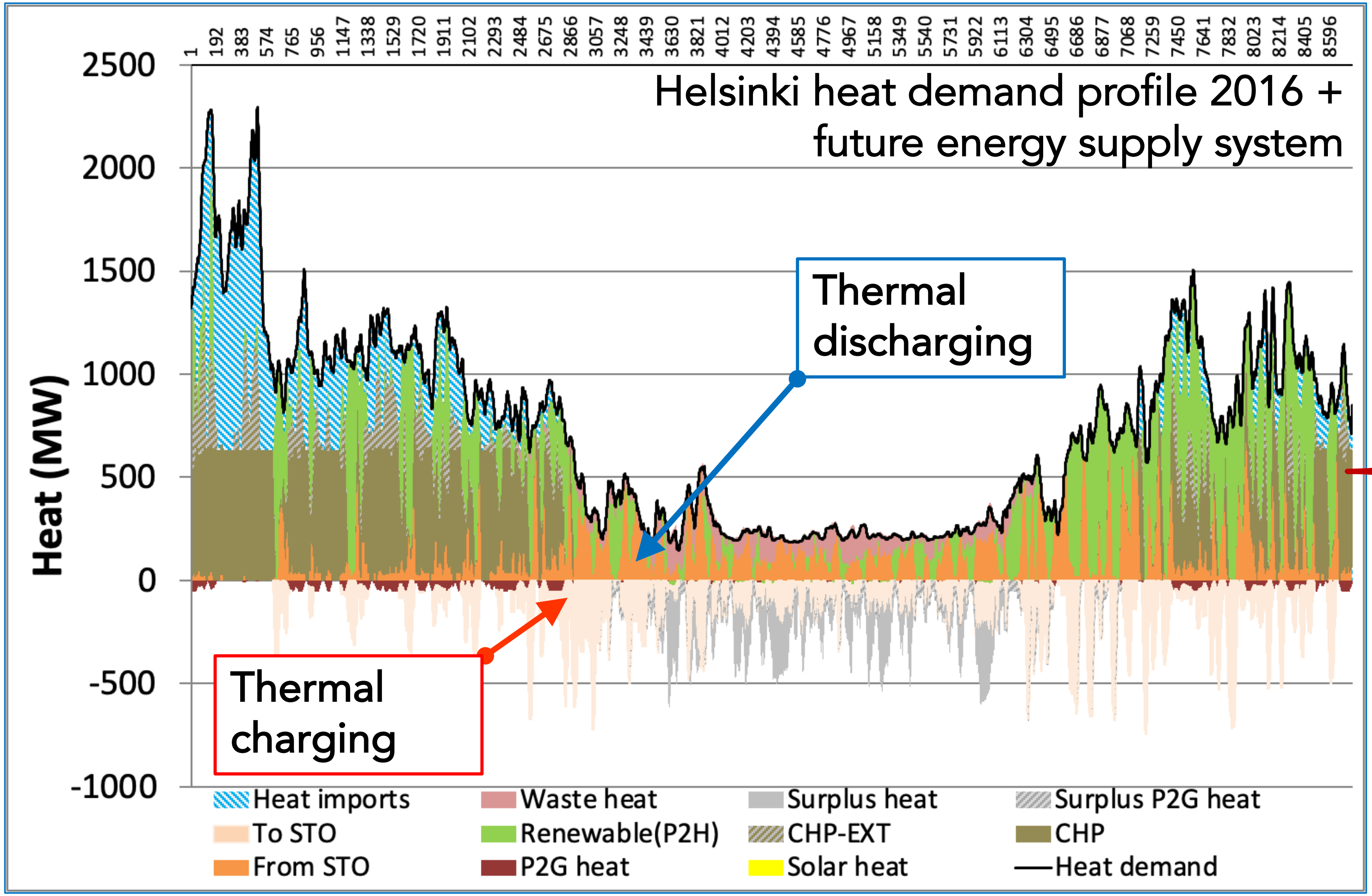
Energy control

Curtailment
Power limitations
Temp. matching
CHP modes

Resilience& Reliability

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

New roles for thermal storage



Thermal storage

New functionalities
Integrator of heat flows
'Buffer' for RE overflow
Collector of waste heat
Peaker/back-up

New control variables
Temperature matching
Priming through HPs
Power limitations (HX)
Charging/discharging

System specifics
Short/long term/seasonal?
System interfacing
Self-reliance
Multi-use
Optimal sizing

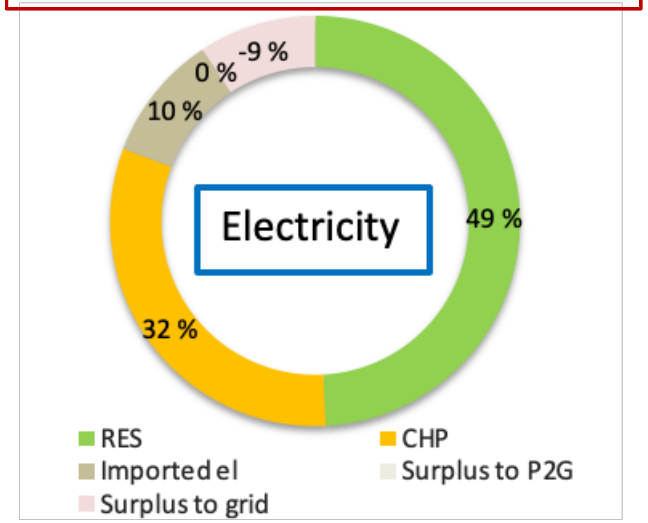
Transformation into a low-carbon energy system
(case Helsinki)

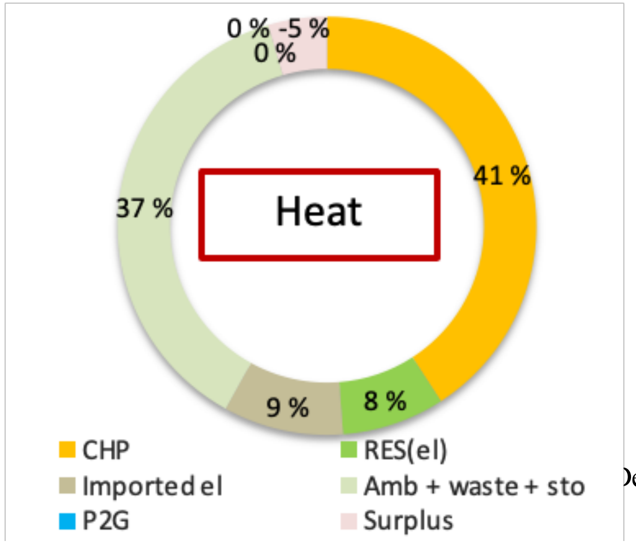
Remaining:
CHP (gas) 1217 MW (tot)
Th storage 5 GWh
Heat pumps 100 MW

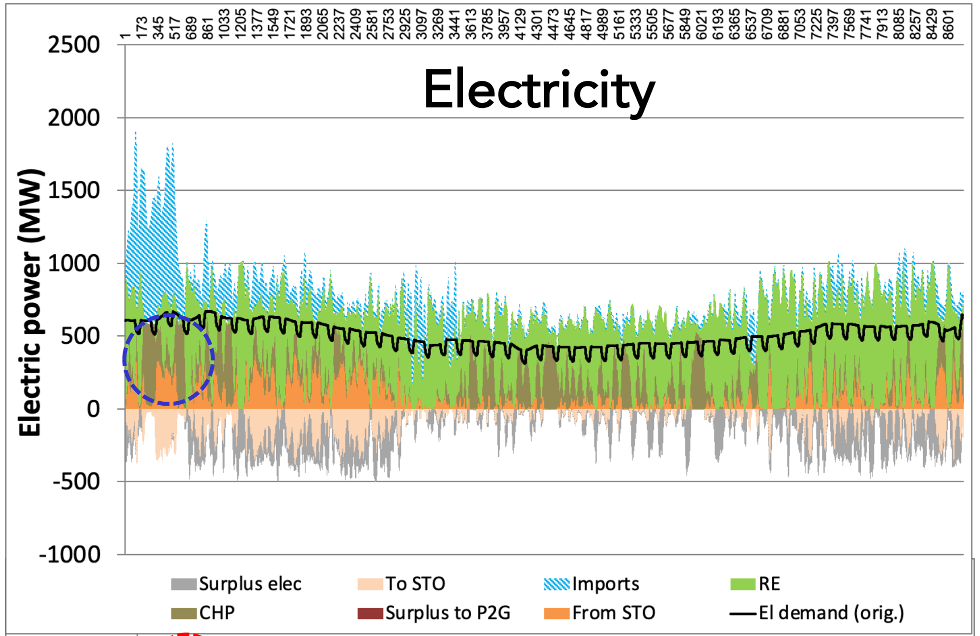
New clean technology:
Wind 1000 MW
PV 400 MW
HP 500 MW
Boiler 1000 MW
Elec. sto 500 MWh
Heat sto 45 GWh
10% of EVs with V2G
P2H (RES>EL load)

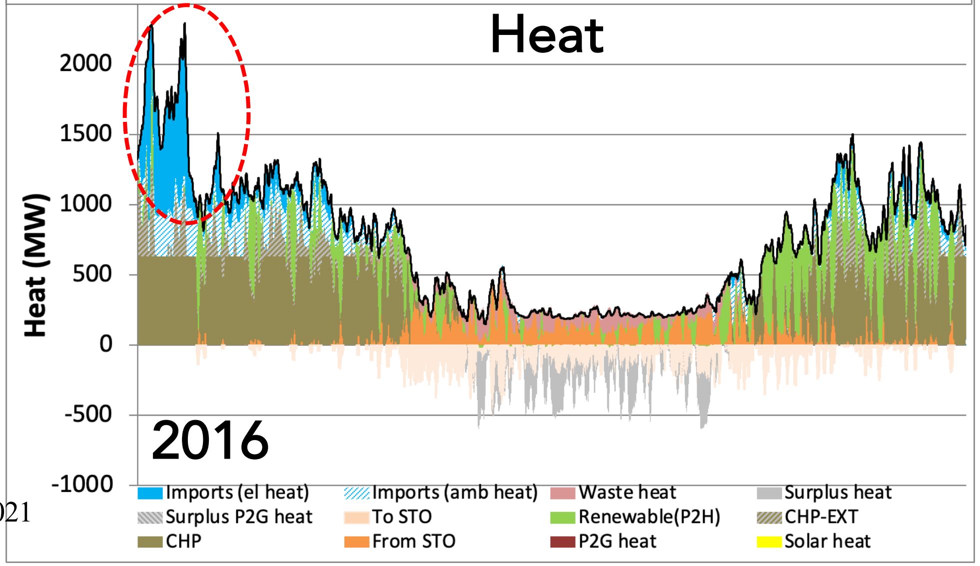
Closing:
CHP (coal) 1GW ;Fossil-boilers 2 GW

+104% electricity
- 62% CO_2 emissions





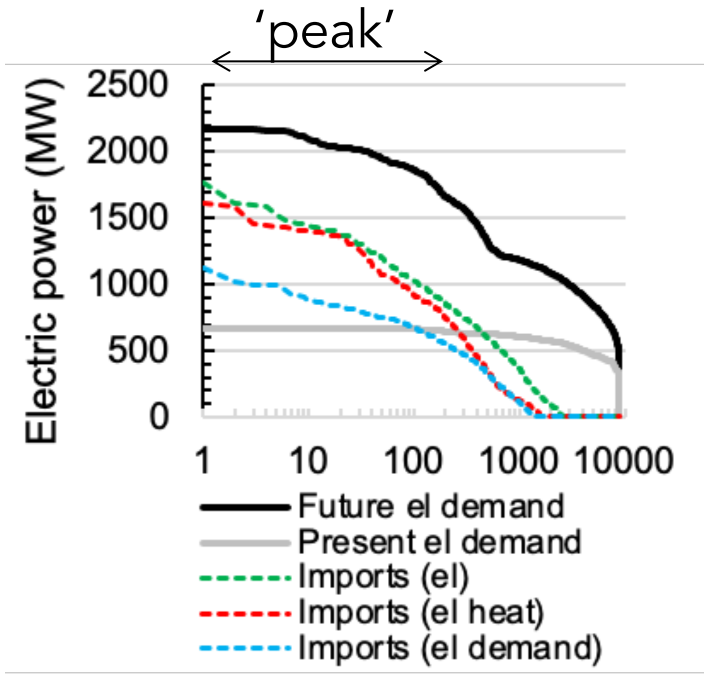




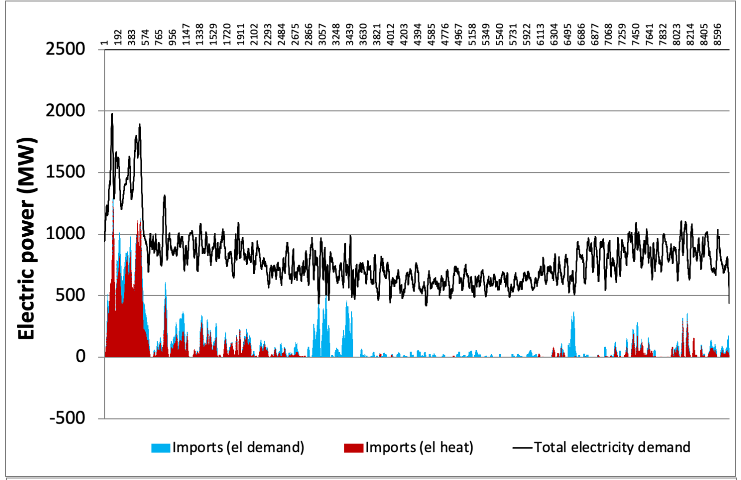
The “winter peak” in heating

Peak conditions

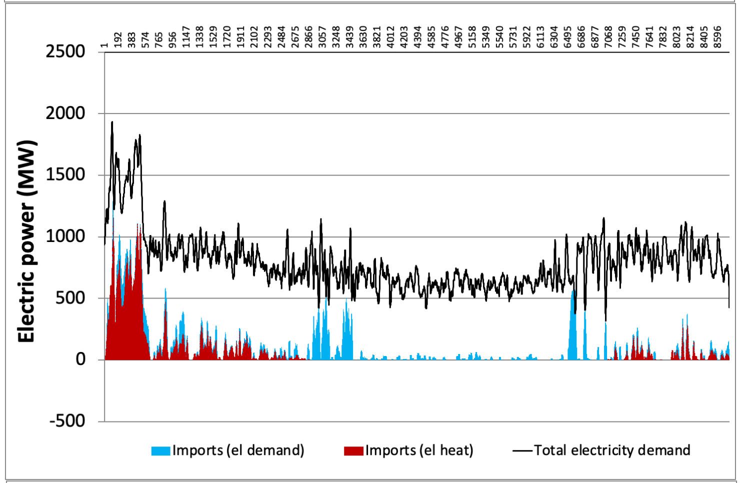
- Peak load is 5-10 % of total heat load, but 80-90 % of imported electricity (ca 300-600GWh)
- Occurs ca every 5 years
- Fuel-storage based solution ?



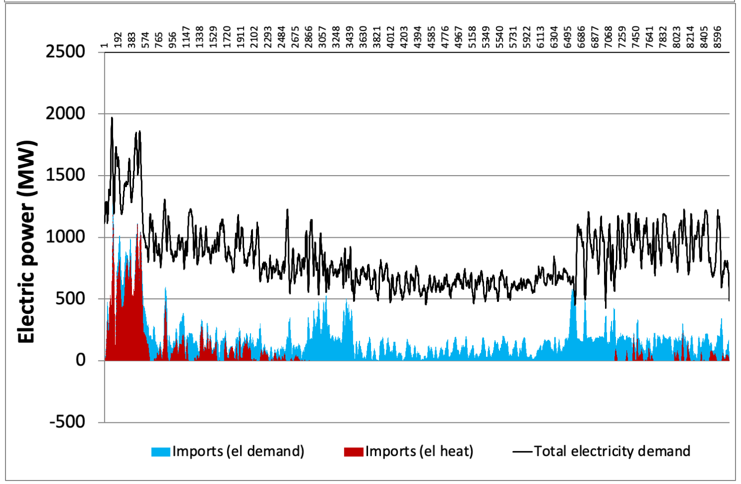
Heat storage x 1 (5GWh)
+104% electricity
-62% CO_2 emissions



Heat storage x 10 (50GWh)
+101% electricity
-63% CO_2 emissions

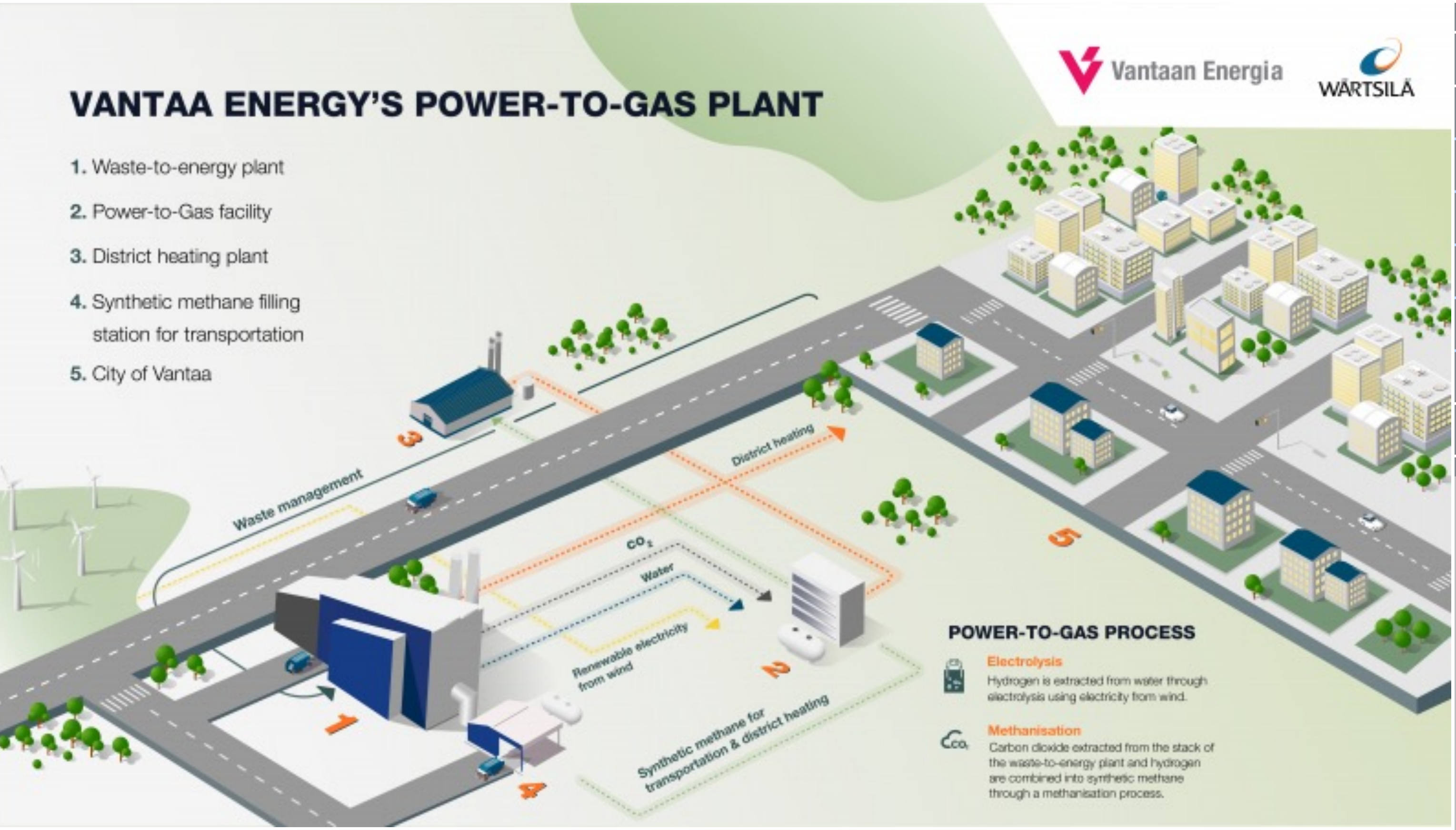


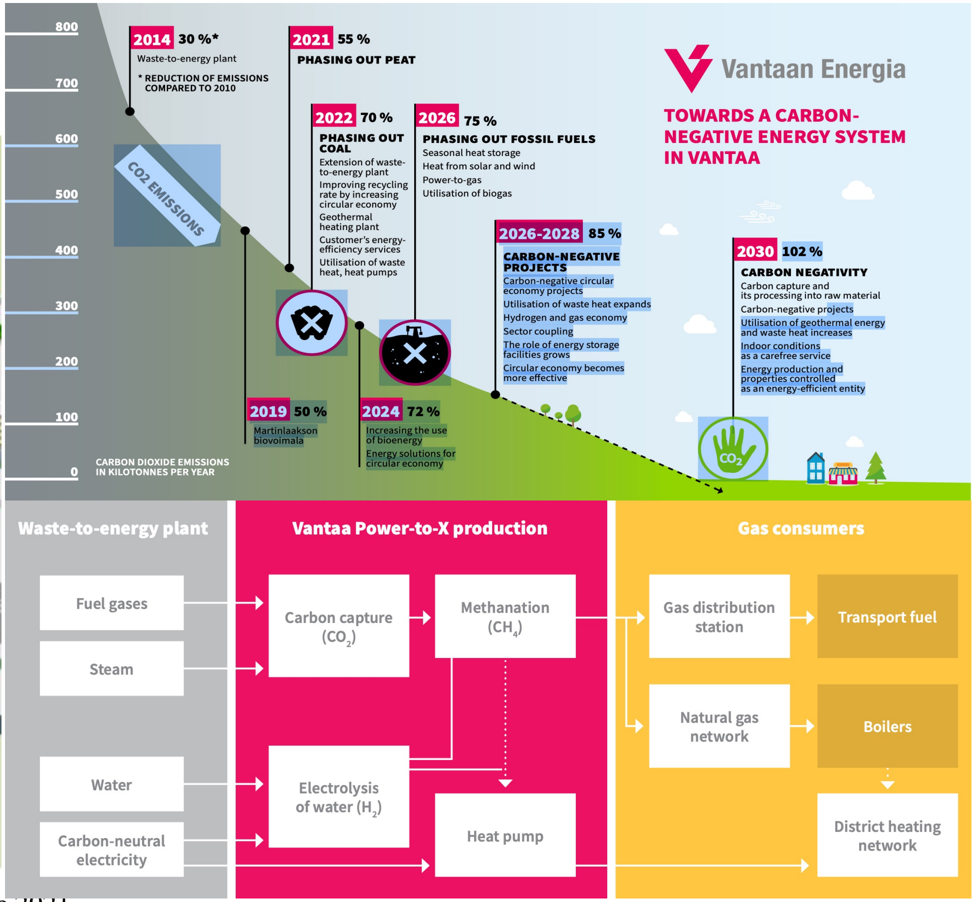
Heat storage x 10 (50GWh)
+curtailment
+85% electricity
-67% CO_2 emissions



PtG schemes – pilot-plant at Vantaa city

- Synthetic methane on a commercial scale with a fuel capacity of 10 MW and 12 MW of heat
- Linked to Vantaa (close to Helsinki Airport) waste-to-energy plant or fed into the natural gas network
- The efficiency of the production of the fuel is 46% and overall efficiency 90%
- Utilisation of waste heat is a significant facilitator for the implementation of the project

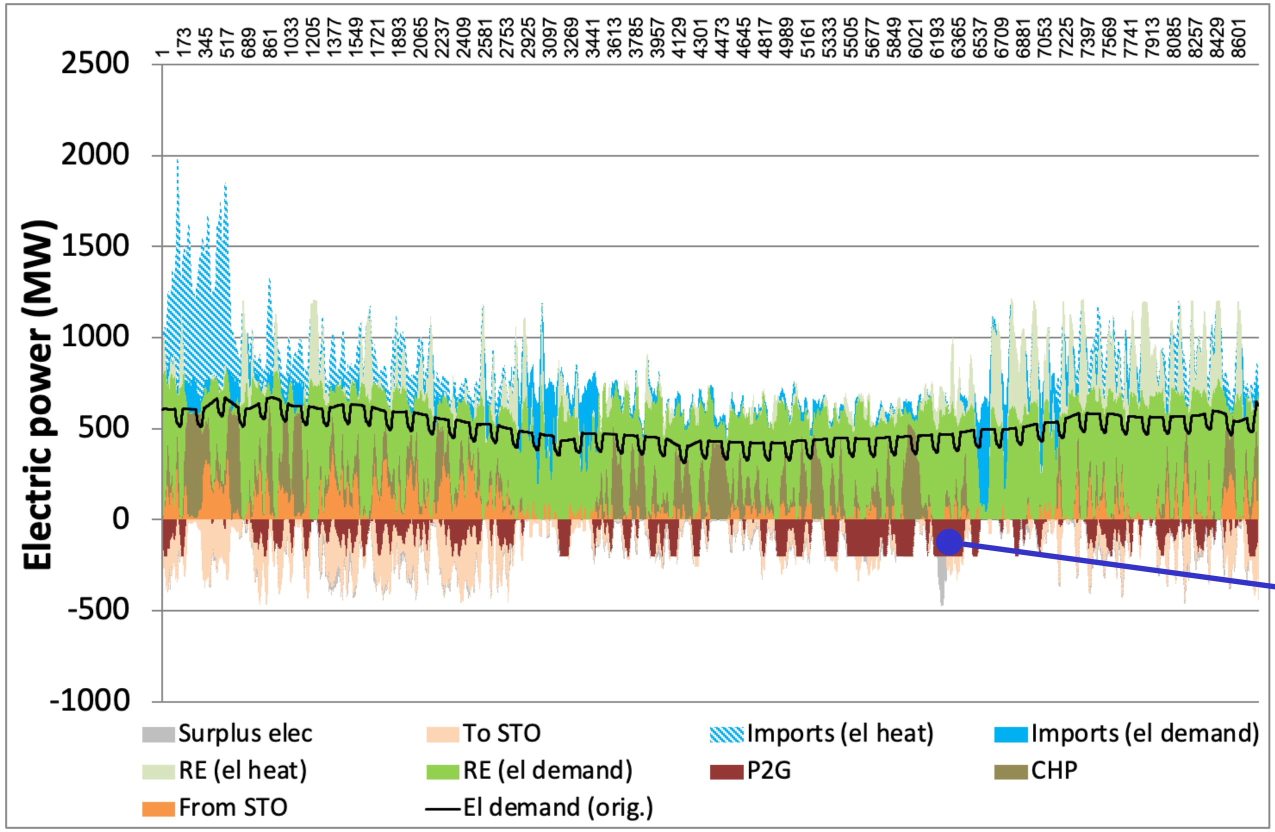




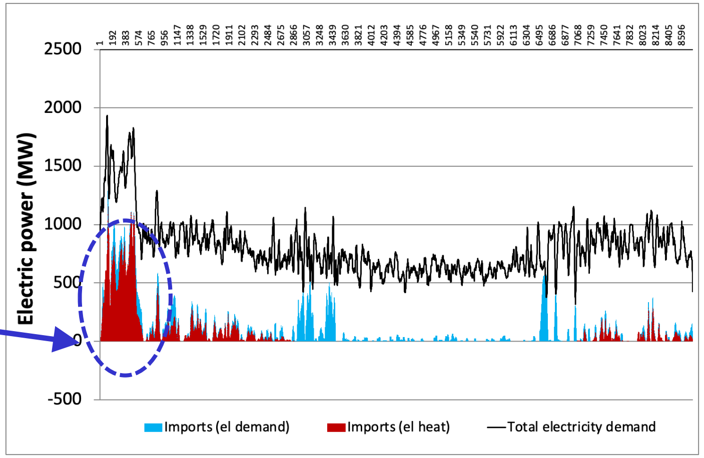
Ref. Vantaa Energy Ltd

Solution to the "winter peak" in heating

- Fuel-based solution to supply the peak heat:
  - 200MW wind+ 200MW P2G = 300-450 GWh (SNG)
  - Biogas-boilers



Fuel storage x 400 (400GWh)
+88% electricity
-71%...(-75%) CO_2 emissions



Takeaways

- Heating will be increasingly important in the energy transition
- Peaking load conditions will require special attention
- Demand for climate-neutral fuel remains (though high electrification)
- Complex system solutions based on RES+PtX+storage emerging
- Sophisticated energy management and control approaches required
- Thermal storage will be an important intergrator