Large scale heat pumps as a link between intermittent electrical energy sources and district heating sector

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En+Eff HEATING | COOLING | CHP

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Outline

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- Methodology
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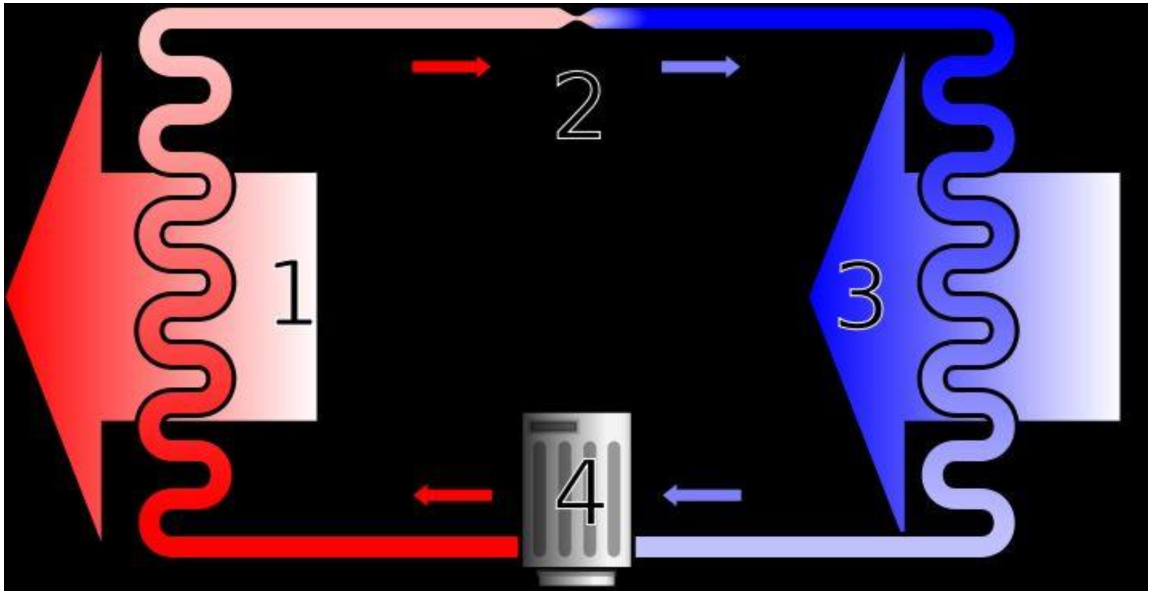
  - Optimal large-scale heat pump capacity
  - Simulated scenarios
- Conclusions

Heat pumps vs. Electric boilers

- Heat pumps:
  - High capital costs
  - Low running costs
  - Energy efficient technology

- Electric boilers
  - Low capital costs (asset-light technology)
  - High running costs
  - *Relatively* inefficient technology

Heat pump – a refrigeration cycle

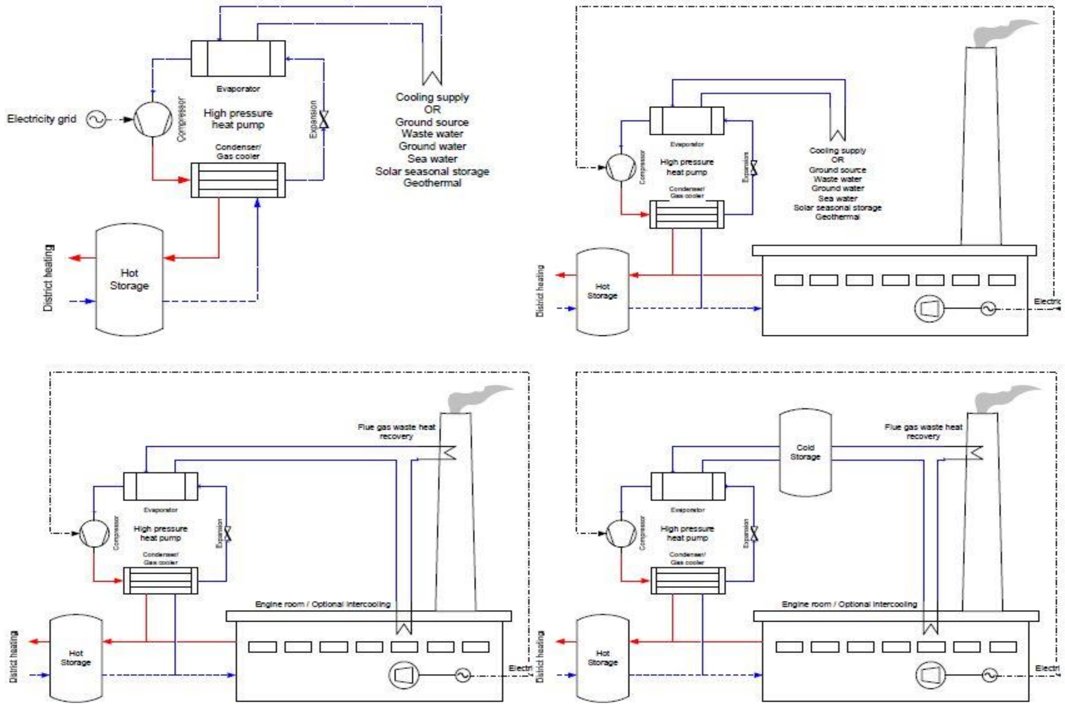


Source: http://en.wikipedia.org/wiki/Heat_pump (accessed on the 11th of January 2015)

1) condenser 2) expansion valve 3) evaporator 4) compressor

Reverse cycle → a heating cycle

Large scale HPs – basic concepts



Source: Blarke MB. Towards an intermittency-friendly energy system: Comparing electric boilers and heat pumps in distributed cogeneration. Applied Energy 2012;91:349-365.

- Large-scale heat pumps basic concepts: HP-ES (top left), HP-ES with CHP (top right), HP-FG with CHP (bottom left) and HP-FG-CS with CHP

Levelized cost of heating energy (LCOH)

- Similar method to LCOE
- Investment, fixed, variable and fuel costs presented in one number
- Comparison of different technologies
- Unit: €/*kWh* of heating energy generated

- Total annual expense (AE) in €:

$$AE = O\&M_F \cdot P + O\&M_V \cdot E_P + \frac{F}{COP} \cdot E_P + PMT_E + PMT_D + R_{M,PMT}$$

- LCOH:

$$LCOH = \frac{AE}{E_S}$$

$O\&M_F - Fixed\ operating\ and\ maintenance\ costs$
$O\&M_V$- $Variable\ operating\ and\ maintenance\ costs$
E_P- *Yearly amount of heating energy generated*
F- *Fuel (electricity) cost*
COP- *coefficient of performance*

$PMT_E\ - annuity\ of\ equity$
$PMT_D - annuity\ of\ debt$
$R_{M,PMT} - annuity\ of\ major\ revision$
E_S - heating energy delivered to the DH grid (E_S=E_P)
P – capacity of unit

LCOH – economic data

	Heat Pump	Electric Boiler
Specific investment [€/kW$_t$]	840	90
Technical lifetime [years]	20	20
Equity [%]	20	20
Debt [%]	80	80
Equity discount rate [%]	10	10
Debt discount rate [%]	3	3
Major revision [% of investment]	10	10
Major revision frequency [years]	10	10
Revision interest rate [%]	10	10
Fixed O&M [(€/kW)/year]	5.5	1.1
Variable O&M [€/kWh]	0.0005	0.0005

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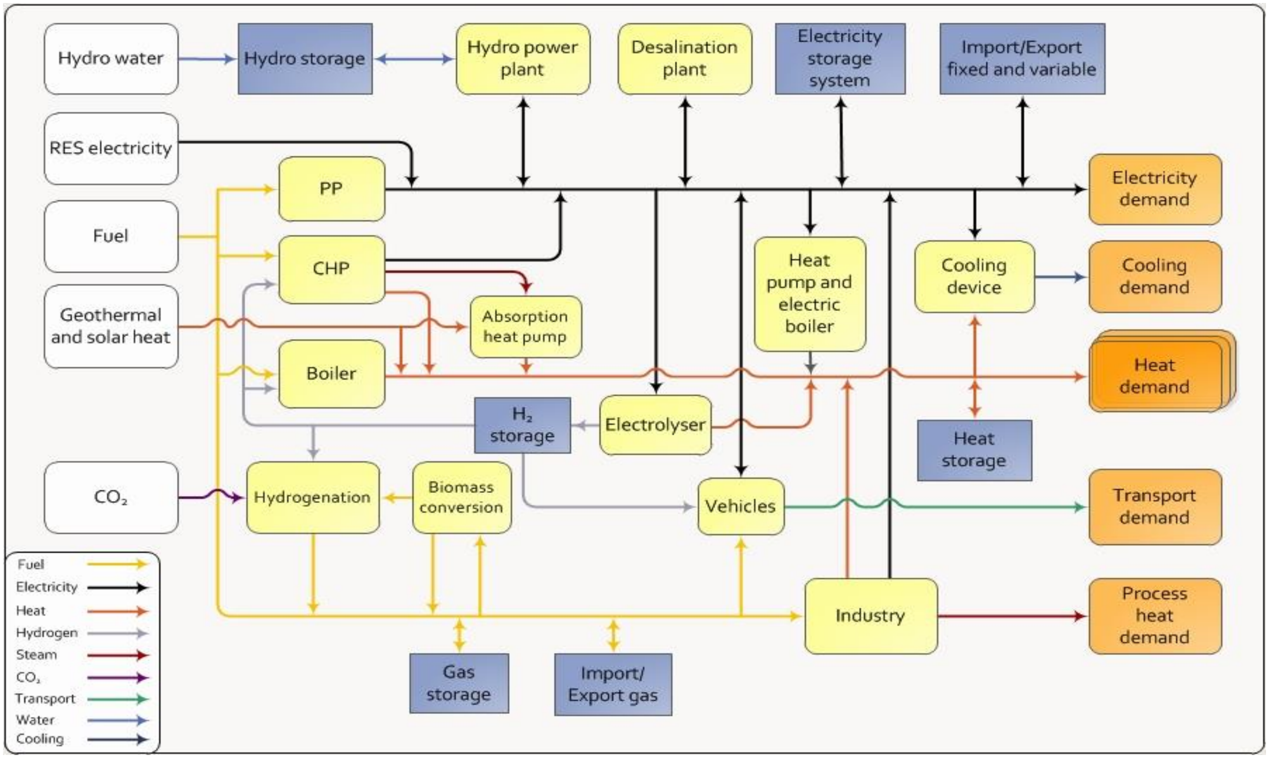
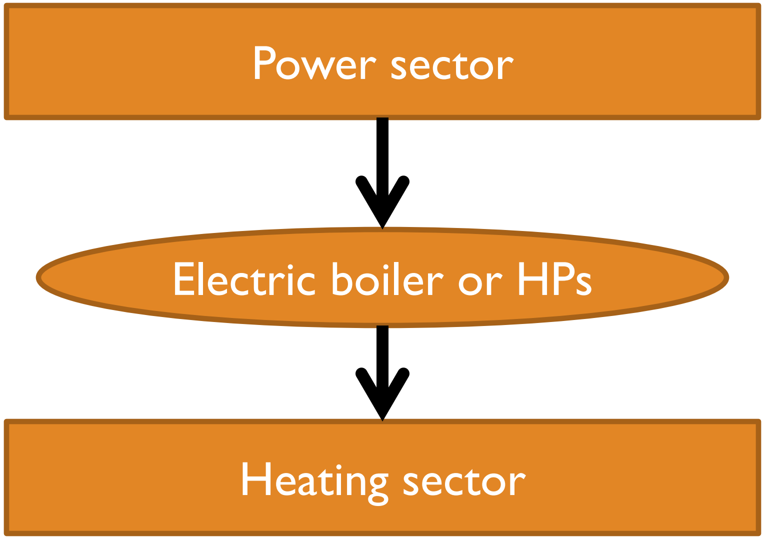
EnergyPLAN



Source: www.energyplan.eu

Smart Energy Systems

- Integration of different energy sectors
- Power, heating and gas sectors (including mobility)
- Sustainable use of biomass!



Scenarios

2020 scenarios				
BAU	HP_alternative	HP_wind1	HP_wind2	HP_storage
Implemented policy measure of minimum 50% of electricity generated by wind (no large-scale heat pumps)	BAU + optimal large scale heat pump capacity	HP_alternative + 4500 MW of onshore wind capacity	HP_alternative + 3700 MW of onshore wind capacity	HP_alternative + 600.000 m^3 of pit thermal energy storage

Optimal large scale HP capacity

EnergyPLAN:

- simulation tool
- Cannot optimize → manual iterations

Detect minimum

Iteration	HP [MW_e]	Total system costs [MDKK]
1	100	?
2	150	?
…	200	?

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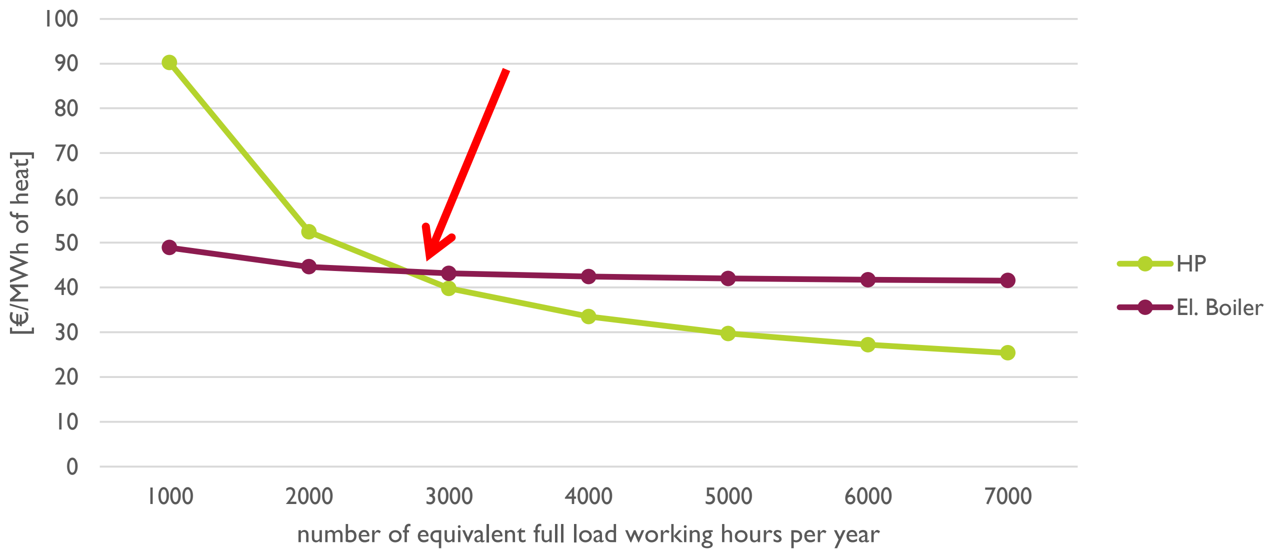
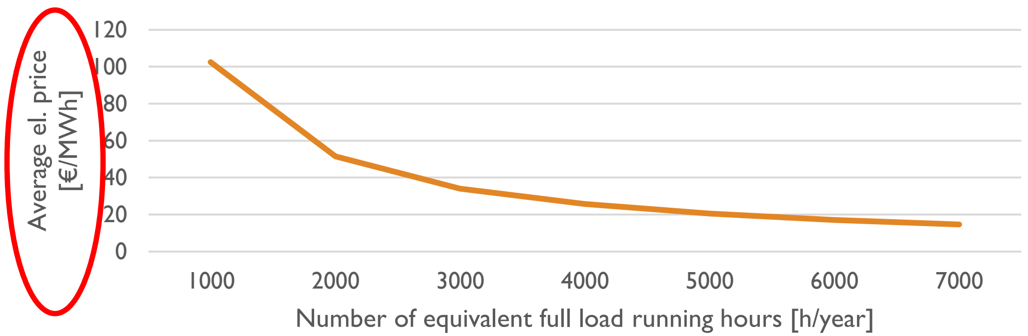
Results – large scale HPs vs. Electric boilers (I)

- average electricity price: 39.38 €/MWh (the average Noordpool el-spot price for the year 2013)



Results – large scale HPs vs. Electric boilers (II)

All intersection points in one figure:



The optimal large-scale heat pump penetration level (I)

Iteration table for the *HP_alternative* scenario:

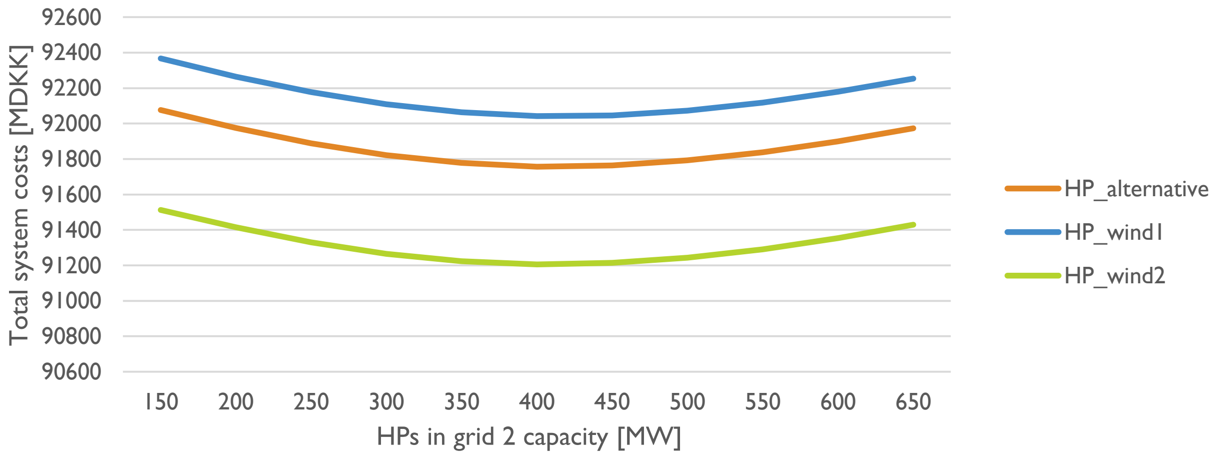
Iteration	1	2	3	4	5	6	7	8	9	10	11	12	13
HP [MWe] group 2	100	150	200	250	300	350	**400**	450	500	550	600	650	700
Total system costs [MDKK]	92,190	92,077	91,976	91,889	91,822	91,778	**91,757**	91,764	91,792	91,838	91,899	91,974	92,059

Optimal HP capacities in all scenarios:

	BAU	HP_alternative	HP_wind1	HP_wind2	HP_storage
HPs in DH group 2 [MWe]	50	400	400	400	400
HPs in DH group 3 [MWe]	0	250	250	200	250

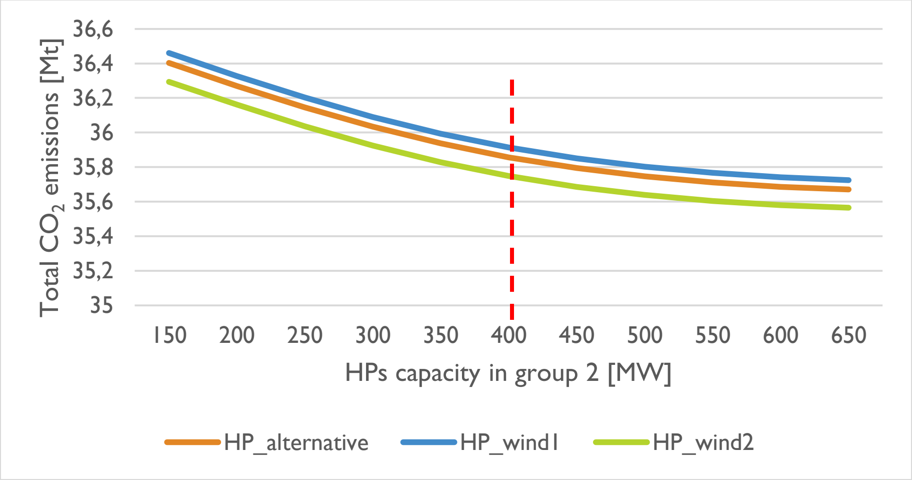
The optimal large-scale heat pump penetration level (II)

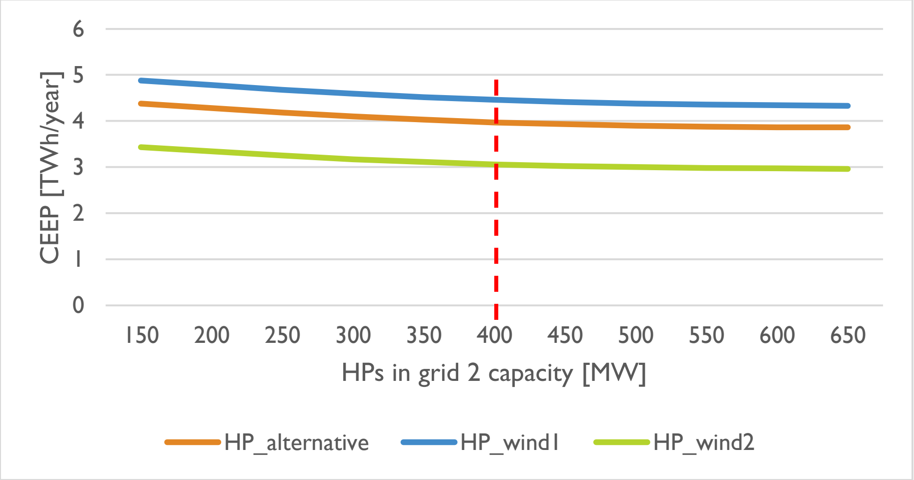
- Optimal values can be seen graphically:



CO2 emissions and CEEP

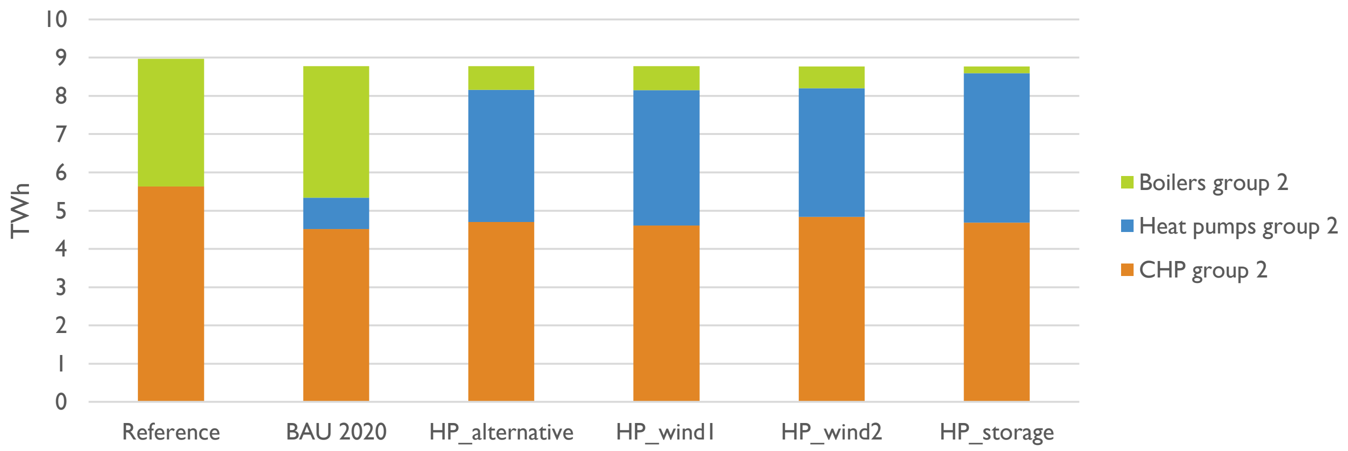
- CEEP = Critical Excess in Electricity Production





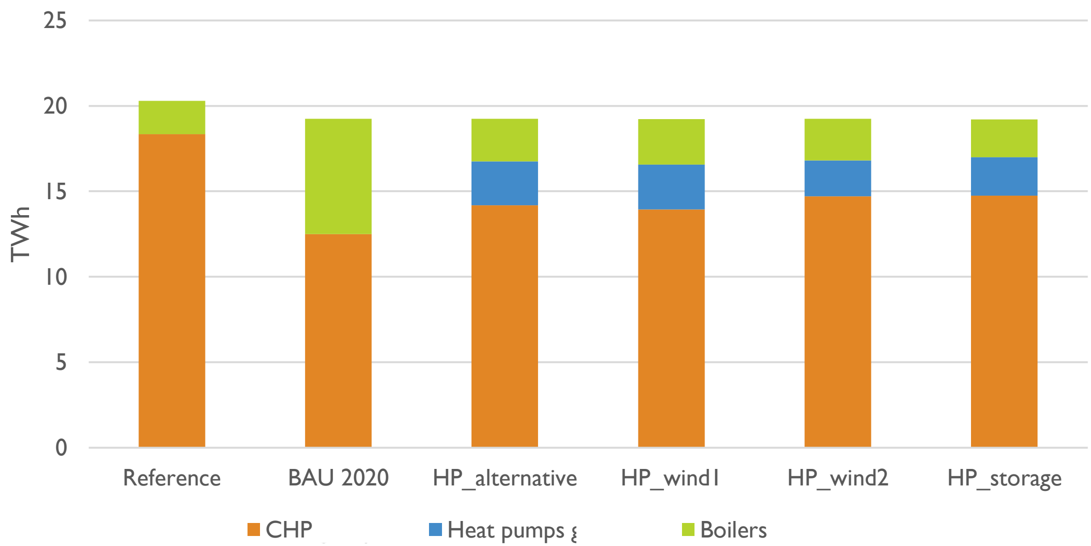
Scenario results (I)

- District heating production in *group 2:*

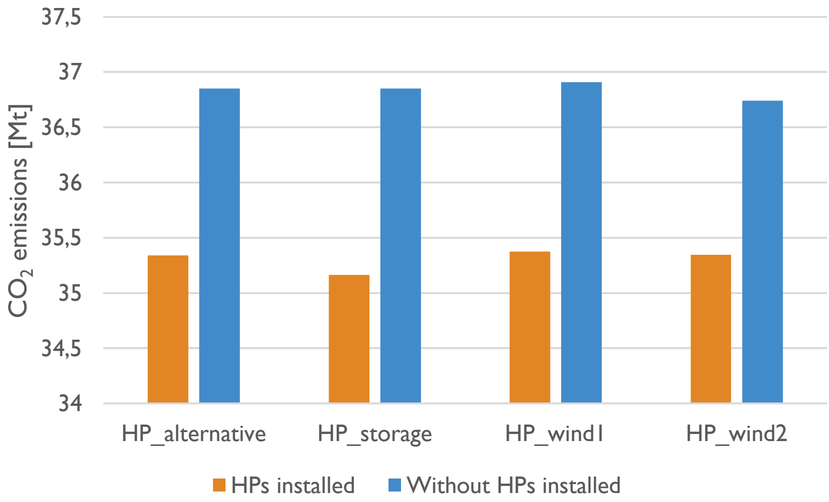


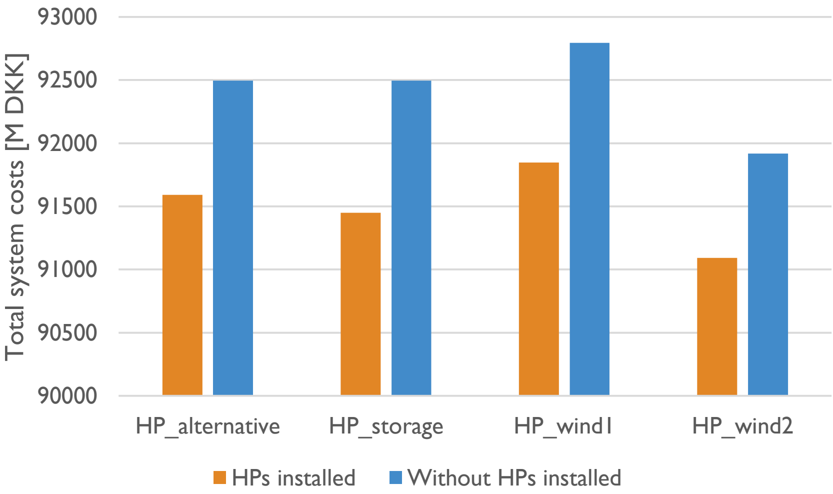
Scenario results (II)

- District heating production in *group 3:*



Scenario results (III)





	HP_alternative		HP_wind1		HP_wind2		HP_storage	
	CO_2 [Mt]	CEEP [TWh/year]	CO_2 [Mt]	CEEP [TWh/year]	CO_2 [Mt]	CEEP [TWh/year]	CO_2 [Mt]	CEEP [TWh/year]
HPs installed	35.34	3.52	35.38	3.97	35.35	2.73	35.15	3.45
No HPs installed	36.85	4.75	36.91	5.27	36.74	3.77	36.85	4.75
Reduction with HPs installed [%]	4.3%	34.9%	4.3%	32.7%	3.9%	38.1%	4.8%	37.7%

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Conclusions

- ✓ In the long run, a large scale heat pump is a more viable investment from economic point of view compared to the large electric boilers (potential for district cooling, too)
- ✓ Optimal level of heat pumps exists in every energy system. Depending on the penetration levels of intermittent energy sources and a share of district heating users, this point can move towards larger or smaller capacities.
- ✓ Implementation of large scale heat pumps lead to CO_2 emissions reduction, decrease in critical excess in electricity production and savings in total annual energy system costs
- ✓ Seasonal thermal energy storage leads to the further CO_2 emissions reduction and total system costs savings

Thank you!

Questions?