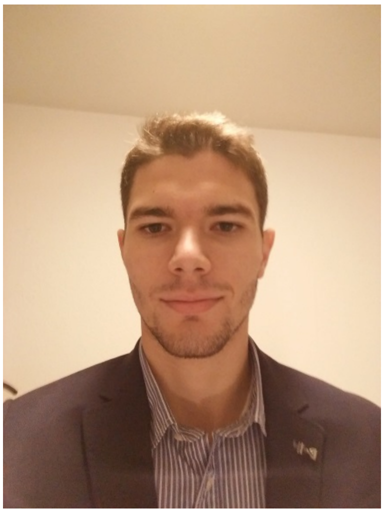

Vita

Dominik Franjo DOMINKOVIĆ

PhD Student

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Dominik Franjo Dominković started his PhD at DTU in November 2015. His main focus areas are energy supply of future smart cities, integration of energy systems, district heating and cooling, large scale heat pumps and biomass resource utilization. He has graduted with honors at University of Zagreb in January 2015. He has studied in Croatia, Denmark and Sweden. He is actively cooperating on different topics with many different stakeholders: universities, associations and industry. He received many awards and scholarships during his education and was actively involved in promotion of sustainable development as a part of Croatian campaign towards COP21, held in Paris. So far, he has published two papers in international scientific journals and six conference papers. His areas of expertise are energy systems and markets of Scandinavia and South-east Europe.

Dominik has a consulting experience in the field of renewable energy as well as managing experience which he obtained by carrying out different student jobs during his education.

His long-term carrer goals are closely connected with consultancy, focusing on the renewable energy systems.

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

Dominik Franjo Dominković

20 April 2016, Frankfurt

En+Eff - 22nd International Trade Fair and Congress

DTU Energy
Department of Energy Conversion and Storage

HEATING | COOLING | CHP

TECHNOLOGY PLATFORM

Outline

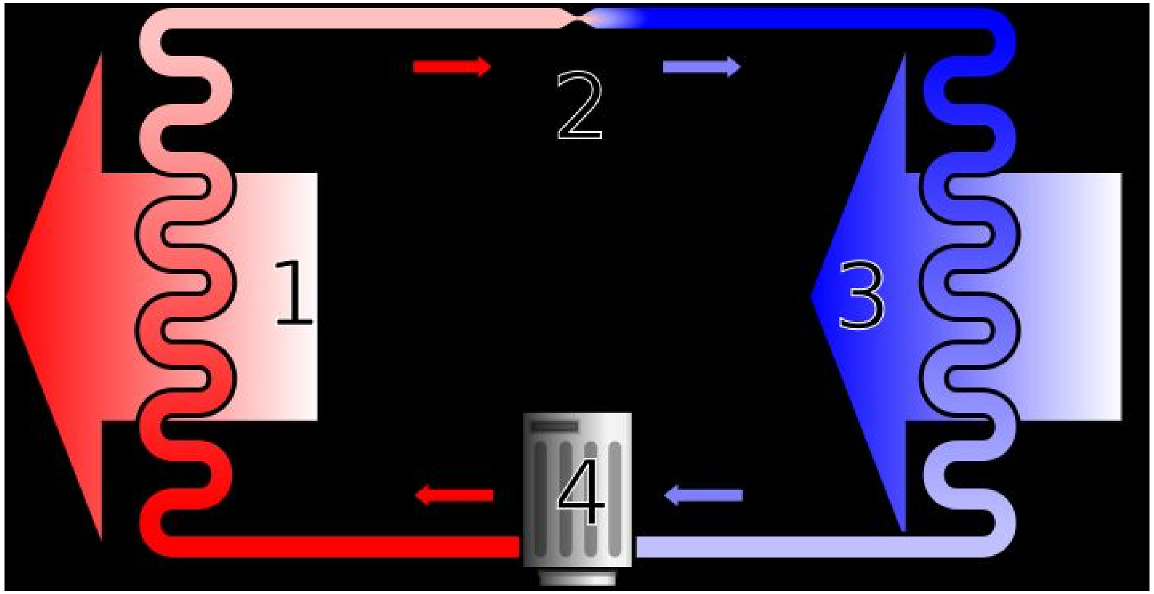
- Large scale heat pumps – concepts
- Methodology
  - Levelized cost of heating energy
  - EnergyPLAN
  - Scenarios
  - Optimal large scale HPs capacity
- Results
  - Large scale HPs vs. Electric boilers
  - Optimal large-scale heat pump capacity
  - Simulated scenarios
- Conclusions

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

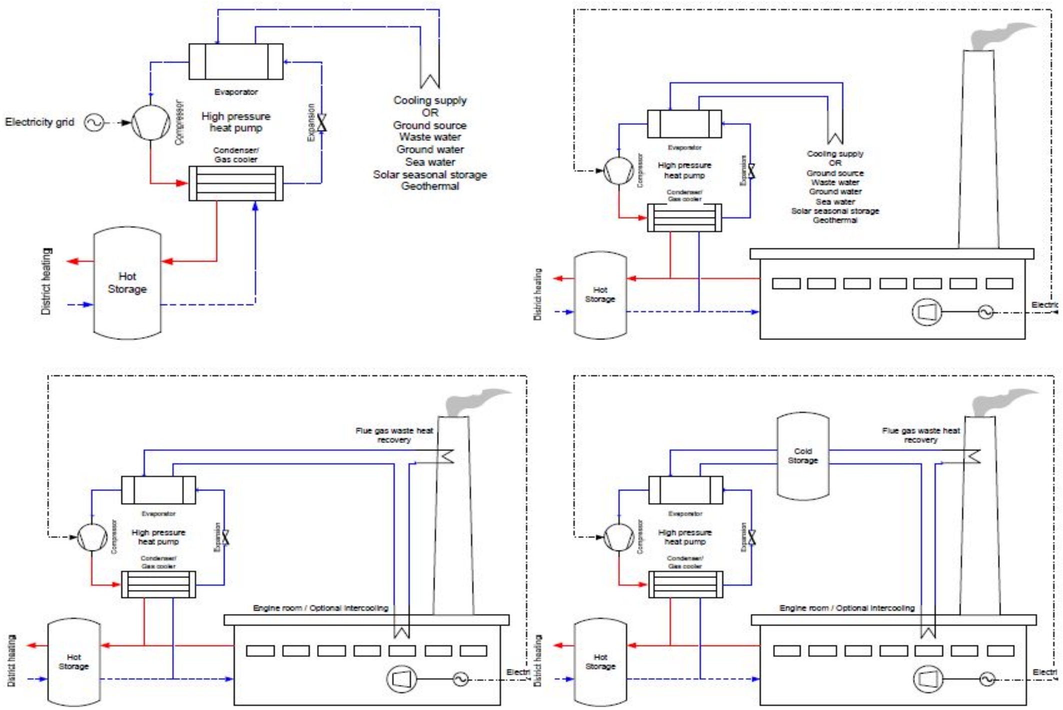


Source: http://en.wikipedia.org/wiki/Heat_pump (accessed on the 11th of January 2015)

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:

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

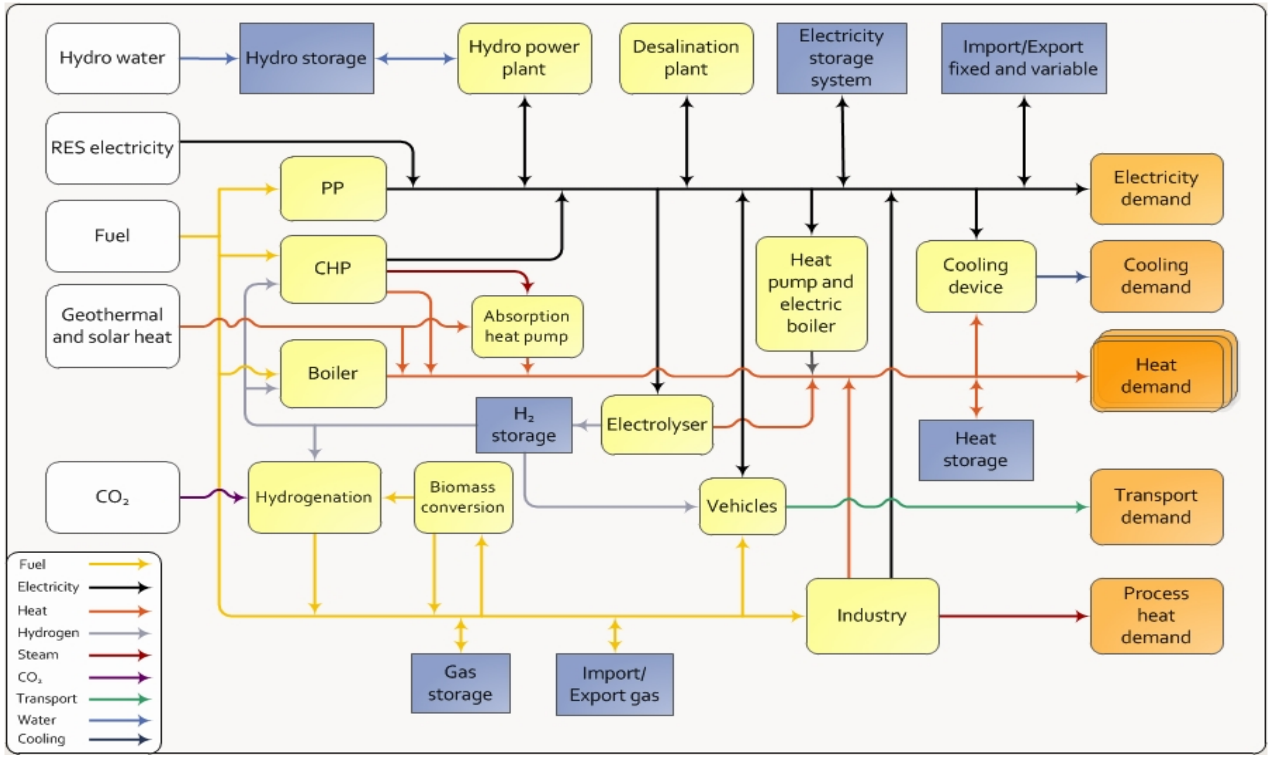
$O\&M_F$ – *Fixed operating and maintenance costs*
$O\&M_V$- *Variable operating and maintenance costs*
E_P- *Yearly amount of heating energy generated*
F- *Fuel (electricity) cost*
COP- *coefficient of performance*

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

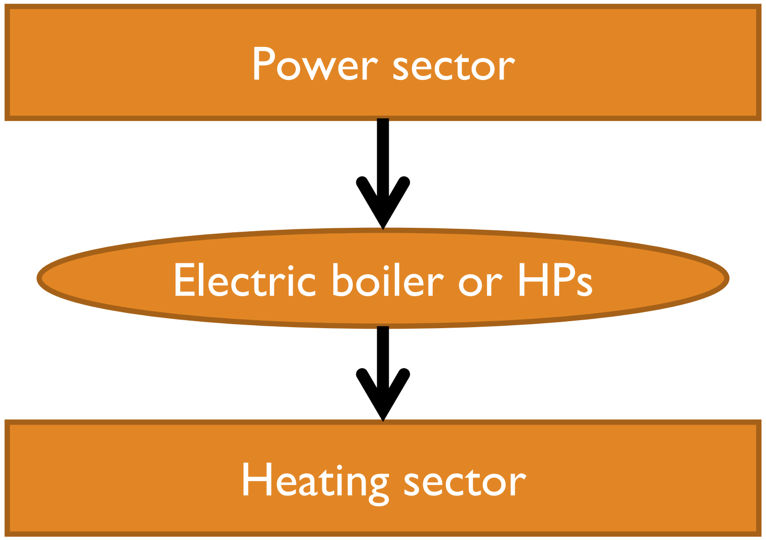
EnergyPLAN



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:

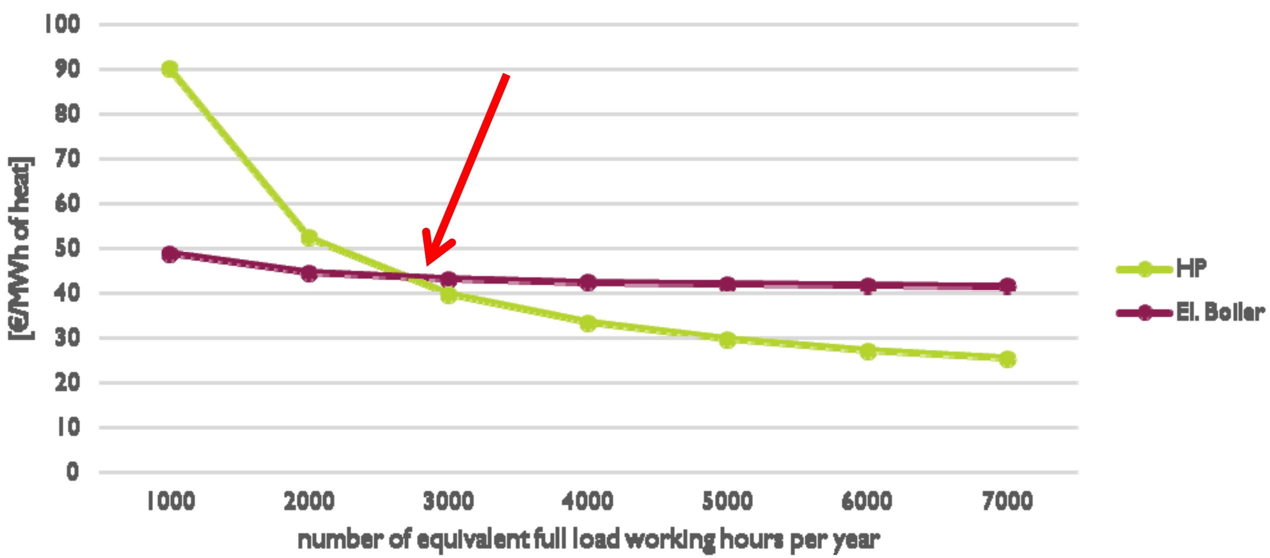
- simulation tool
- Cannot optimize → manual iterations

Detect minimum

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

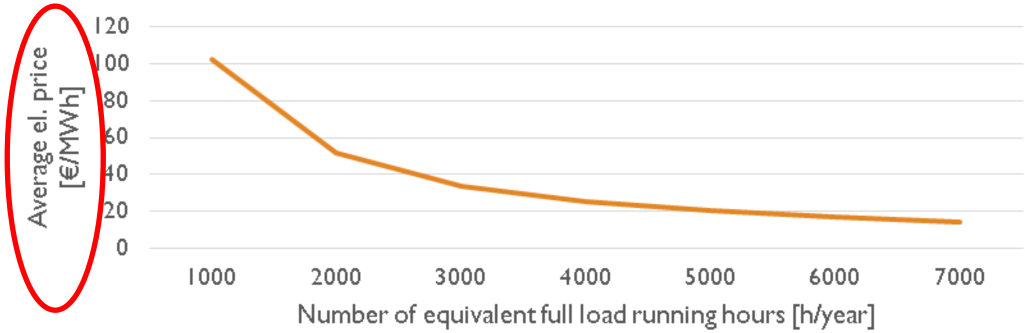
Results – large scale HPs vs. Electric boilers (I)

- 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:

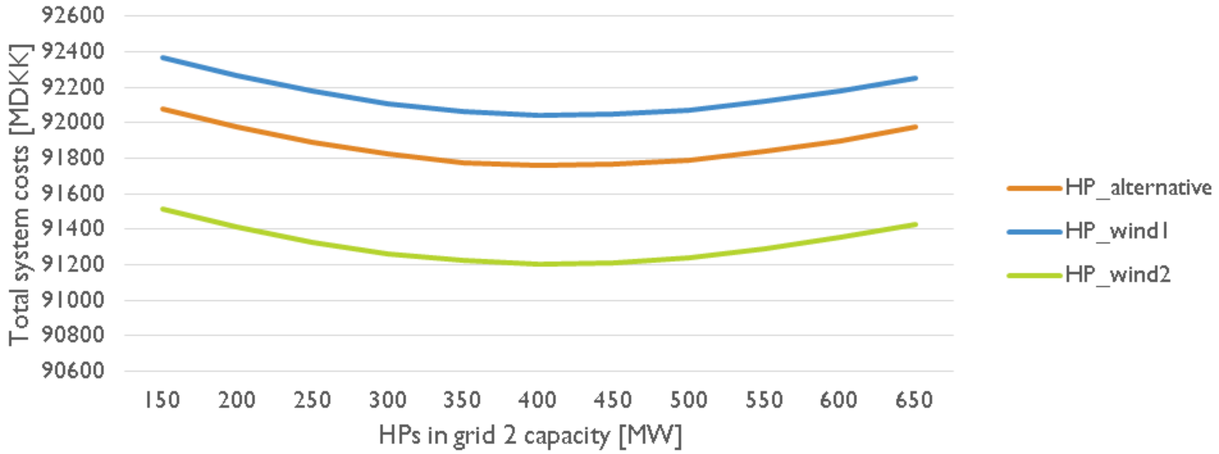
Iteration	1	2	3	4	5	6	7	8	9	10	11	12	13
HP [MWe] group 2	100	150	200	250	300	350	**400**	450	500	550	600	650	700
Total system costs [MDKK]	92,190	92,077	91,976	91,889	91,822	91,778	**91,757**	91,764	91,792	91,838	91,899	91,974	92,059

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)

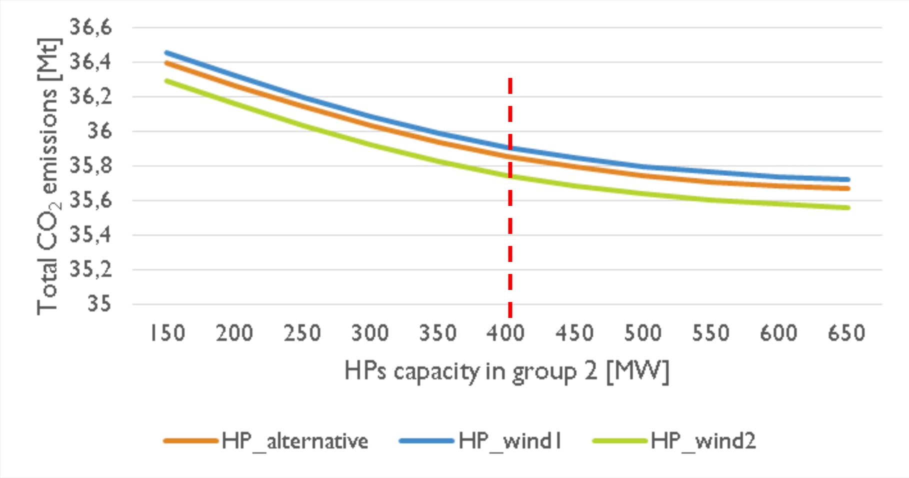
- Optimal values can be seen graphically:

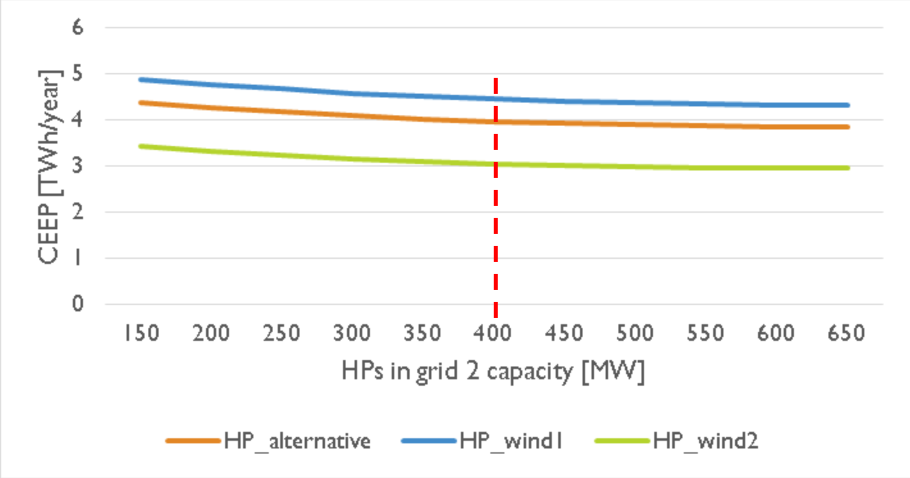


DHC+ TECHNOLOGY PLATFORM

CO2 emissions and CEEP

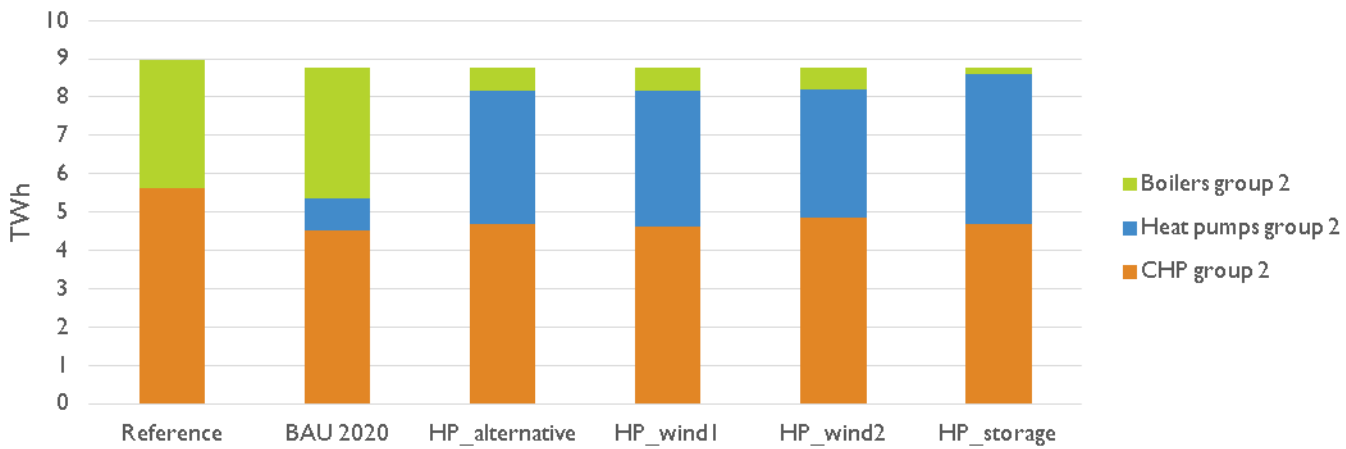
- CEEP = Critical Excess in Electricity Production





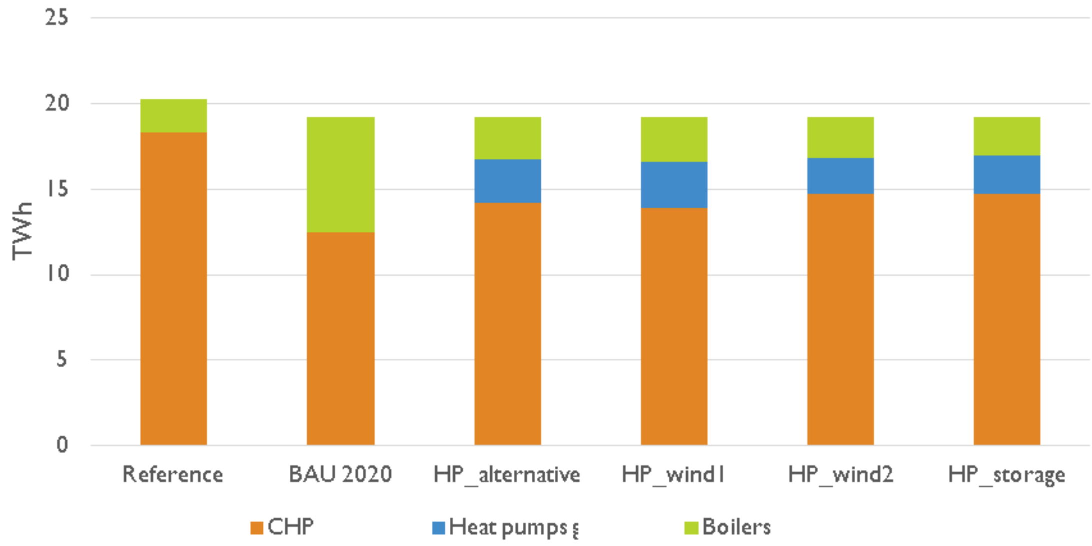
Scenario results (I)

- District heating production in *group 2:*

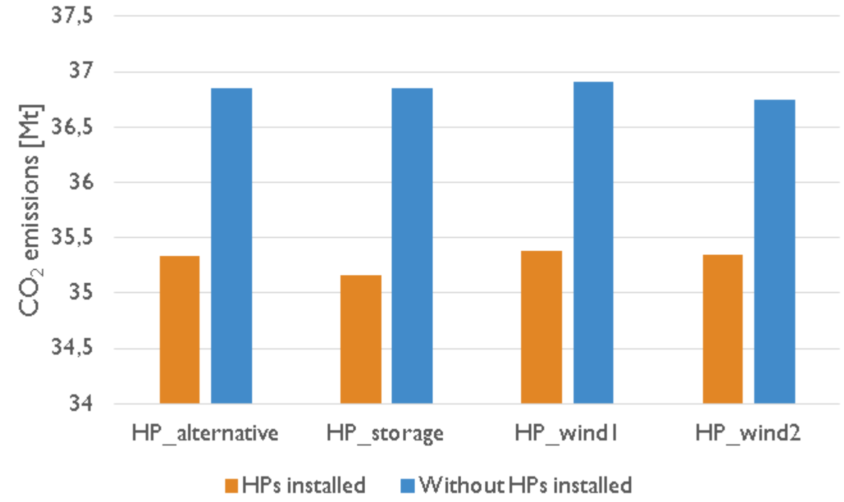


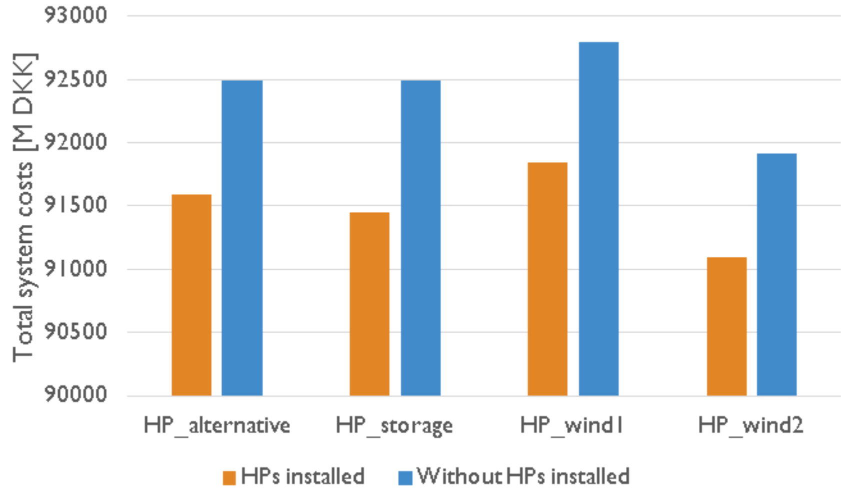
Scenario results (II)

- 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/yea	CO_2 [Mt]	CEEP [TWh/yea	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%

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

DHC+ TECHNOLOGY PLATFORM

Thank you!

Questions?