The role of power to heat

– Heat pumps, electrical heat boilers and heat storage

Lessons from Denmark

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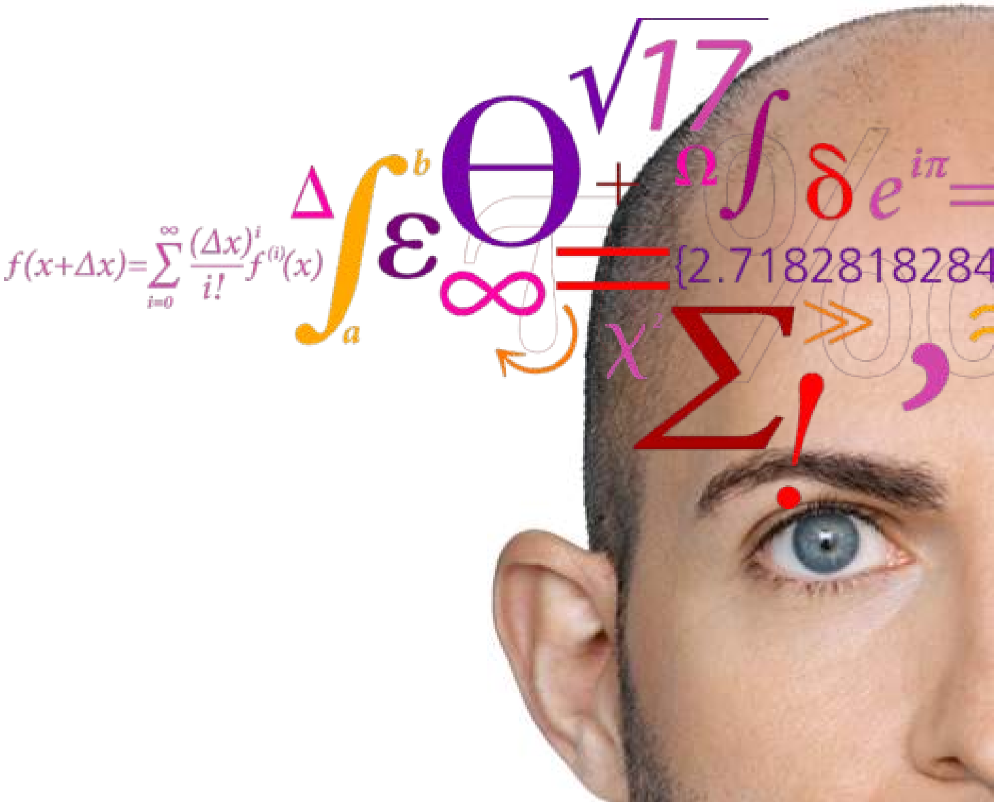
Agora, Berlin 24/9 2015



Outline

- District heating (DH) - the past and future potentials
- DH heat pumps (HP) - status and potentials
- Individual HP
- DH HP in Copenhagen
- Solar heating and DH HP
- DH research projects

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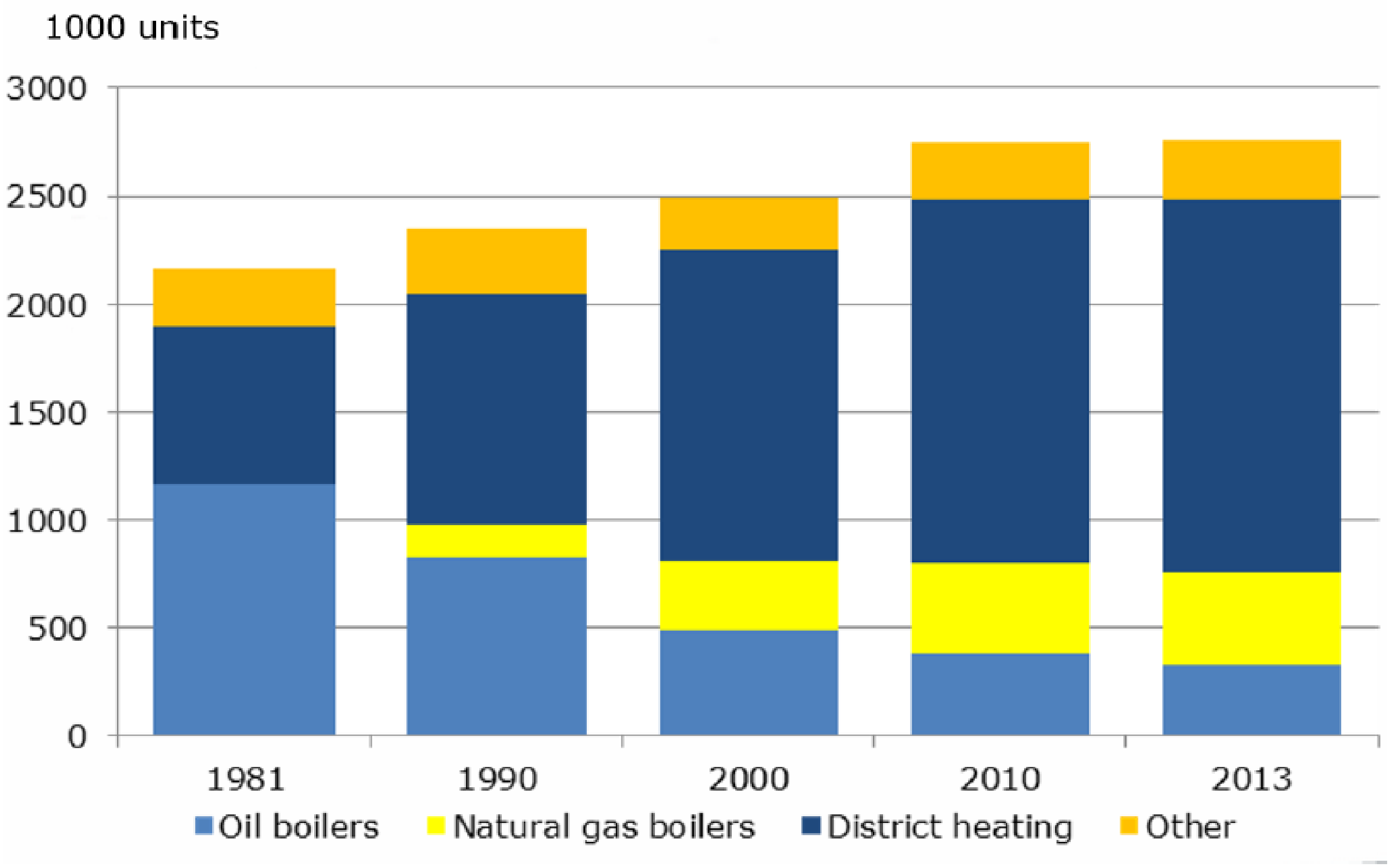
Household heating



62% DH

Figure 12: Heating installations in Danish dwellings (1000 units). In the 1980s, individual oil boilers were the dominant heat generation technology. Today, more than 62 percent of all dwellings have a district heating connection. Source: Danish Energy Agency, "Energy Statistics 2013".

(EA 2015. *The Danish Experience with Integrating Variable Renewable Energy: Lessons Learned and Options for Improvement*)

Future potentials

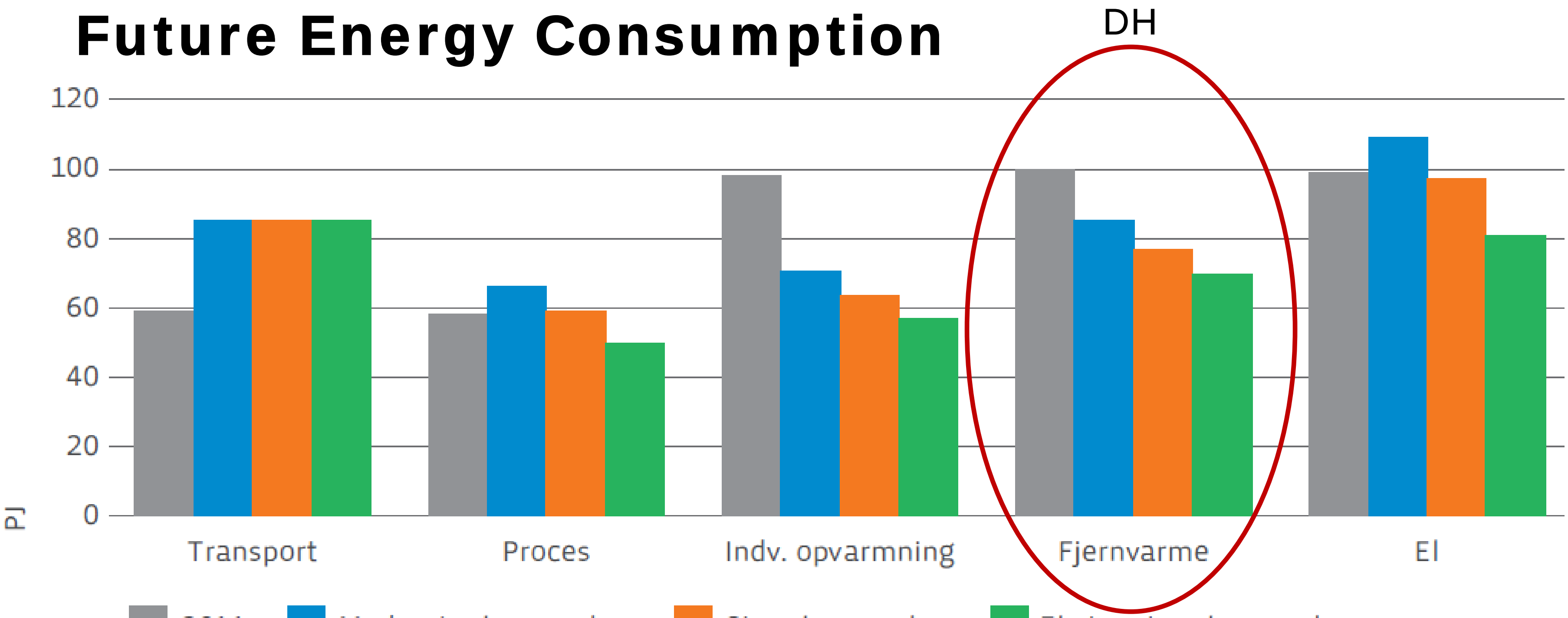
- Today covering ~**46%** of heat consumption

- In the future:

  – **between 55-57%**
  (Münster et al 2012. *The role of district heating in the future Danish energy system*)

  – **between 50-70%**
  (Lund et al. 2010 *The role of district heating in future renewable energy systems*)

Future Energy Consumption



Figur 6.1. Nettoenergiforbrug i 2011 og 2050 i forbrugsmodellen.

http://www.ens.dk/sites/ens.dk/files/undergrund-forsyning/el-naturgas-varmeforsyning/Energianalyser/nyeste/energiscenarier_-_analyse_2014_web.pdf

DH supply - historical development

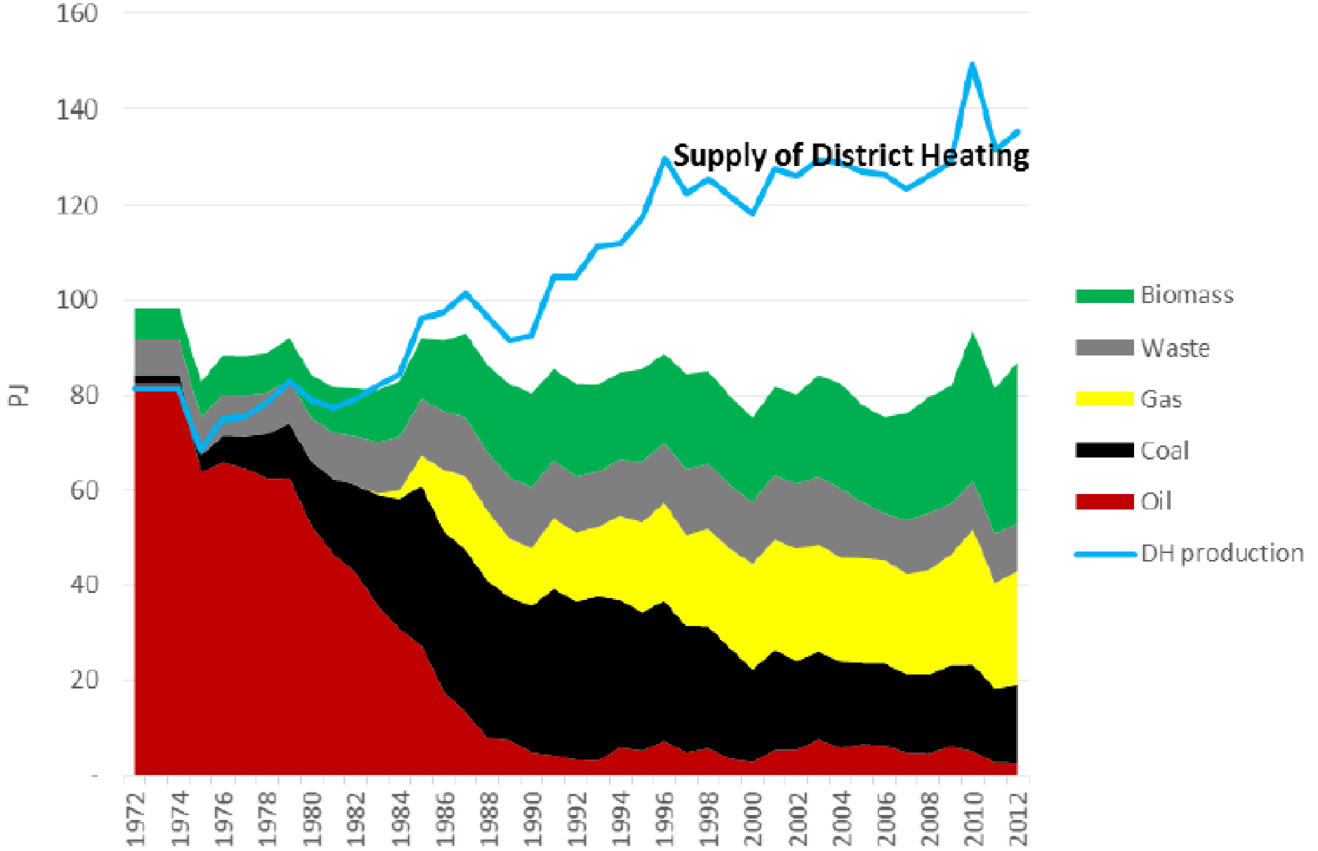


Figure 11: The supply of district heating increased from 80 PJ (Petajoule) in 1972 to 140 PJ in 2012. Due to the energy efficiency of combined heat and power (CHP) production, fuel consumption decreased from 100 PJ to 80 PJ over the same period. Source: Own elaboration, based on data from the Danish Energy Agency.

(EA 2015. *The Danish Experience with Integrating Variable Renewable Energy: Lessons Learned and Options for Improvement*)

Short run marginal heat production cost

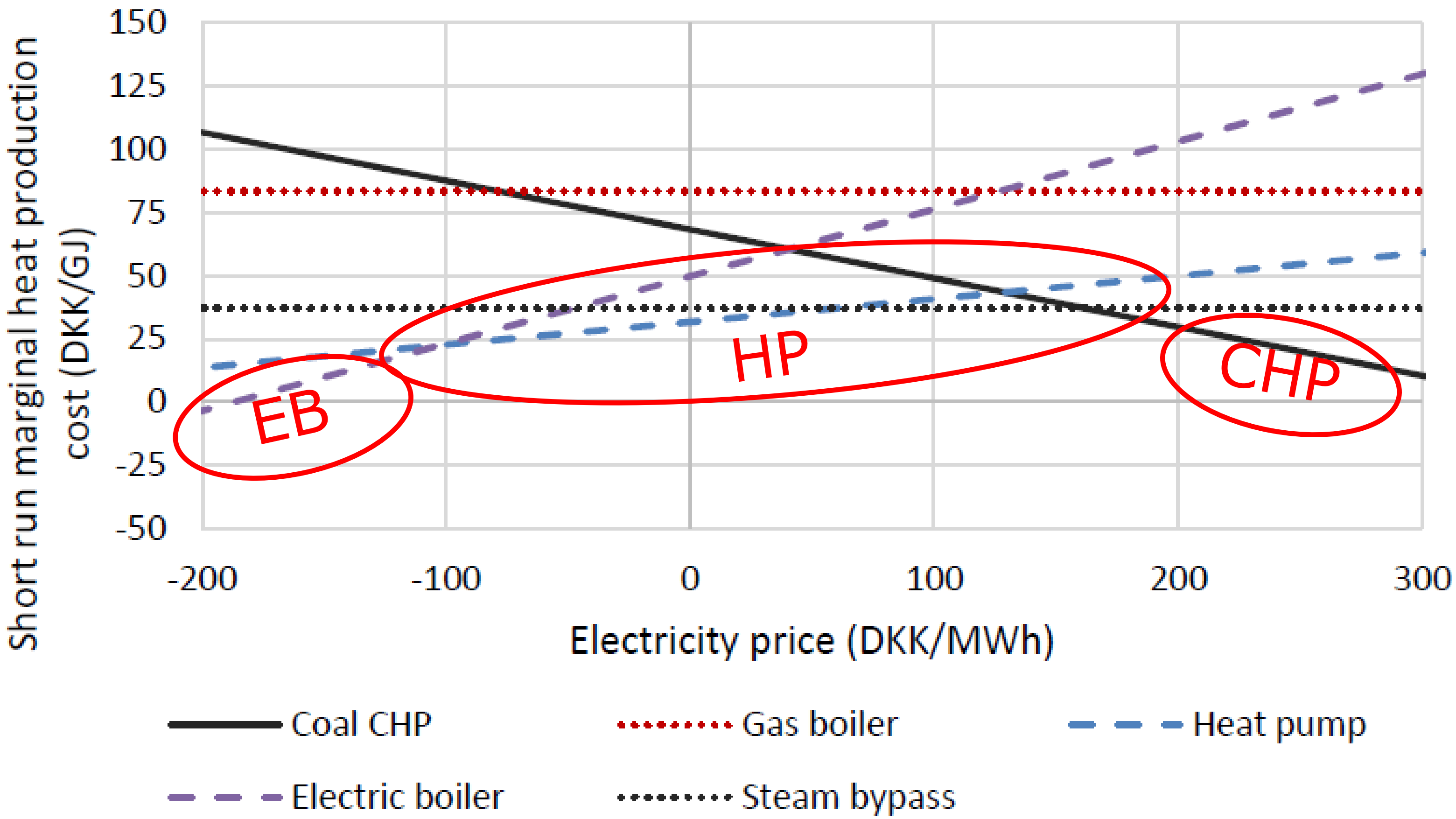


Figure 28: Short run marginal heat production cost for different units depending on the electricity price. Illustrative example. Actual costs will depend on fuel prices, emission prices, taxes and subsidies. Source: Own figure.

(EA 2015. *The Danish Experience with Integrating Variable Renewable Energy: Lessons Learned and Options for Improvement*)

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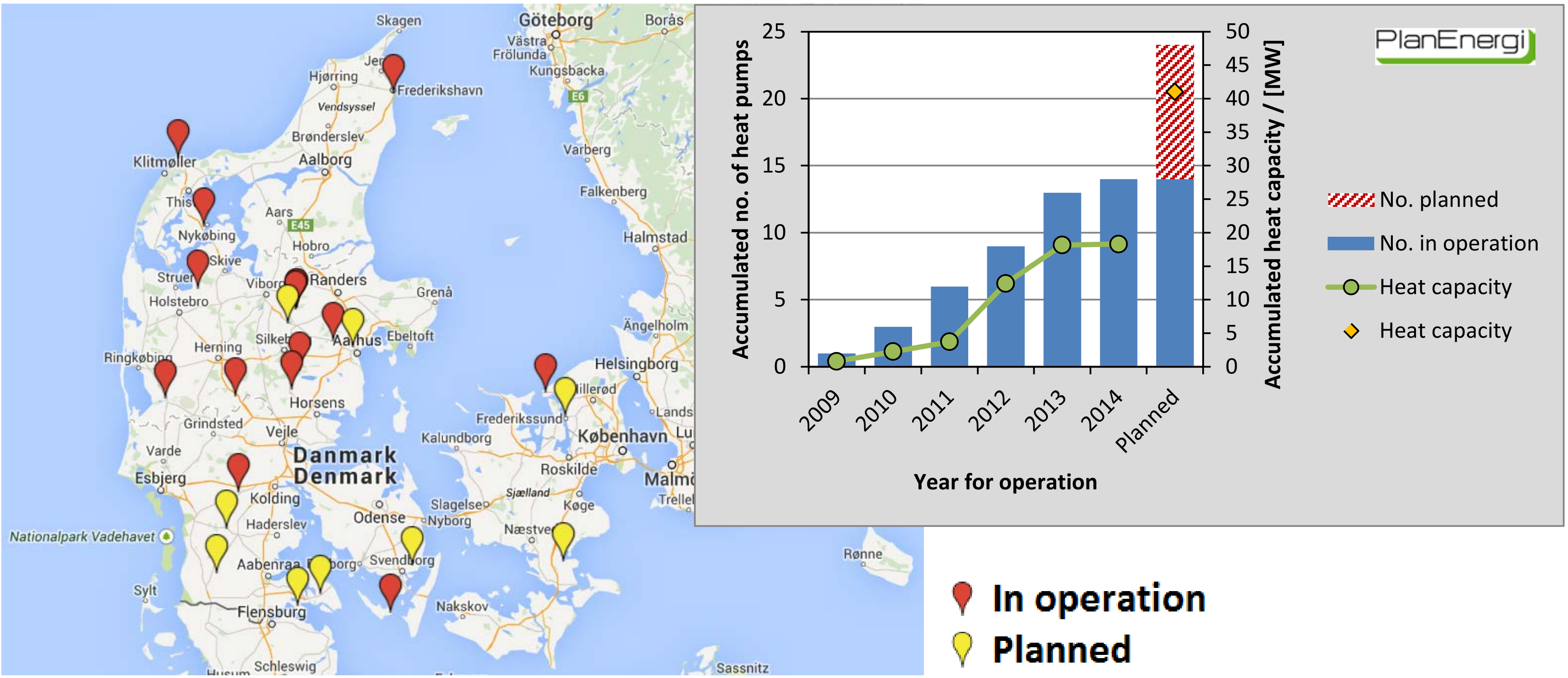
DH HP status
Electrical driven DH heat pumps in DK



Thermal driven heat pumps in DK

Termisk drevne varmepumper i danske fjernvarmesystemer, 2013						
Ejer	**Installeret år**	**Systemløsning**	**Varmekilde**	**Drivtemp.**	**Temp. kilde**	**Køleydelse (genvundet varme)**
Thisted Varmeforsyning	1988	Halmkedel som drivkilde	Geotermi	155° C	20° C	3,2 MW
Thisted Varmeforsyning	2000	Halmkedel som drivkilde	Geotermi	155° C	43° C	4 MW
Amagerværket	2004	Damp som drivkilde	Geotermi	160° C	50° C	9 MW
Bjerringbro Varmeværk	2007	Komb. med motor	Røggas	400° C	25° C	0,95 MW
Vestforbrænding	2007	Damp som drivkilde	Røggas	180° C	60° C	13,3 MW
Strandby	2008	Komb. med gaskedel	Røggas/sol	90° C	15° C	0,28 MW
Langå Varmeværk	2009	Komb. med motor	Røggas	380° C	30° C	0,7 MW
Gråsten Varmeværk	2011	Komb. med træpillekedel	Røggas/sol	150° C	22° C	0,7 MW
Hillerød	2011	Komb. med fliskedel	Røggas	105° C	30° C	0,5 MW
Vojens varmeværk	2011	Gaskedel	Røggas/sol	100° C	45° C	0,65 MW
Galten Varmeværk	2012	Komb. med fliskedel	Røggas	100° C	50° C	0,5 MW
Hurup Fjernvarme	2012	Komb. med fliskedel	Røggas	105° C	35° C	0,45 MW
Skagen Varmeværk	2012	Komb. med motor	Røggas	350° C	30° C	4 MW
Dronninglund	2013	Oliekedel som drivkilde	Damvarmelager	150° C	45-10° C	2 MW
Sønderborg	2013	Fliskedel som drivkilde	Geotermi	150° C	48° C	12,5 MW
Tarm Varmeværk	2013	Komb. med fliskedel	Røggas/sol	110° C	35° C	1 MW
Toftlund	2013	Komb. med motor	Røggas/sol	150° C	45-20° C	1,9 MW
Tørring	2013	Komb. med træpillekedel	Røggas/sol	150° C	50-20° C	0,7 MW

~56 MW

Heat storages and heat pumps in DK

- Report made for the Danish Energy Agency

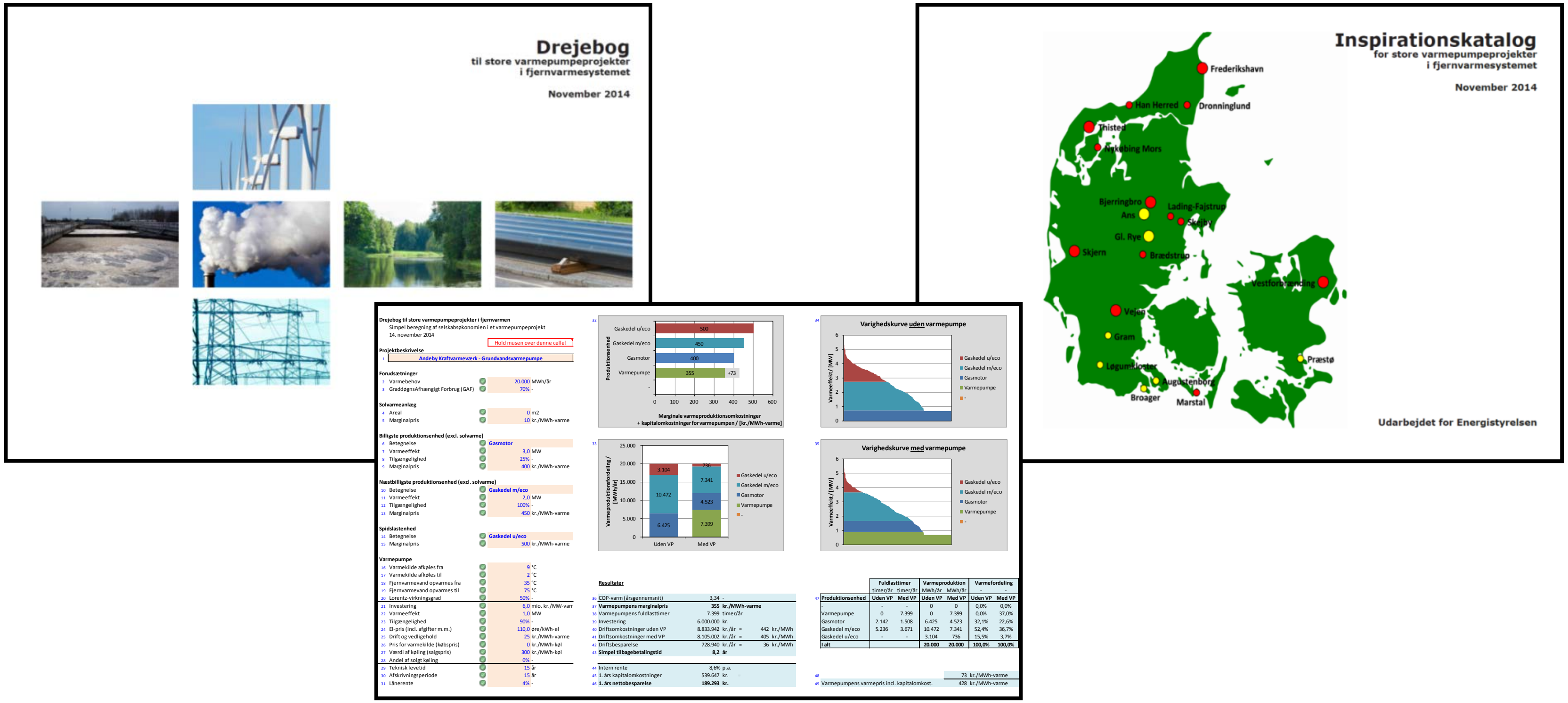
- Report made by
  - PlanEnergi
  - Teknologisk Institut
  - GEO
  - Grøn Energi

- http://www.ens.dk/undergrund-forsyning/el-naturgas-varmeforsyning/forsyning-varme/fjernvarme/analyse-fremtidens


Udredning vedrørende varmelagringsteknologier og store varmepumper til brug i fjernvarmesystemet

November 2013

Manual for DH heat pump projects



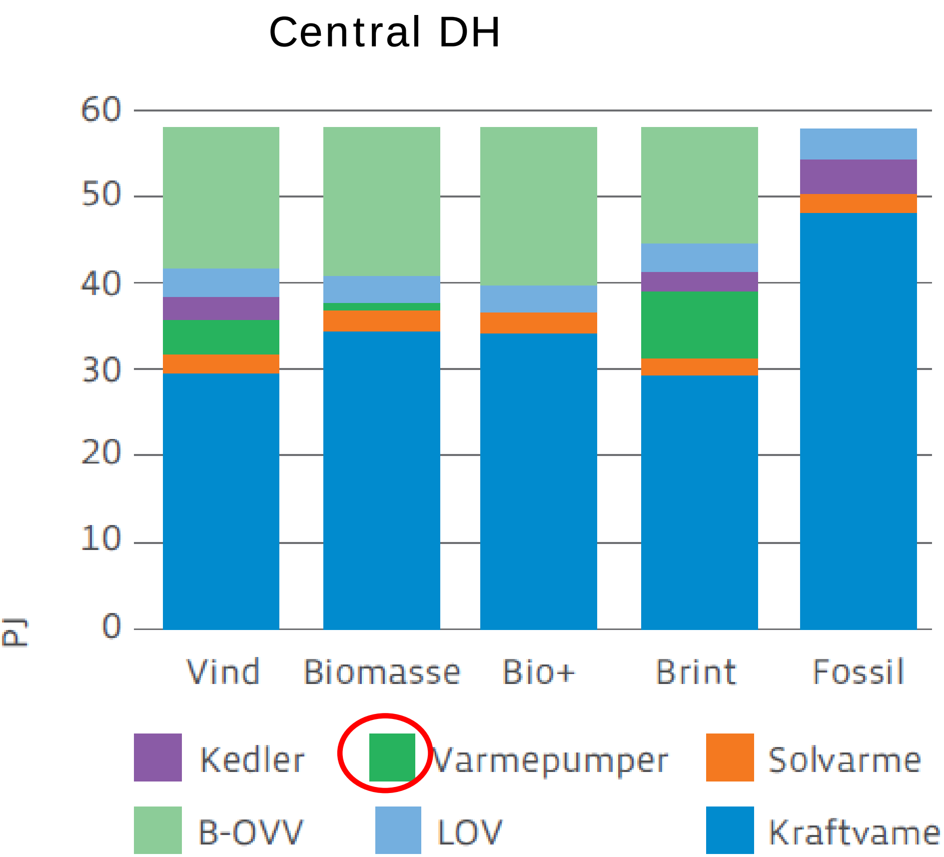
http://www.danskfjernvarme.dk/groen-energi/projekter/drejebog-om-store-varmepumper

Future role of HP's?

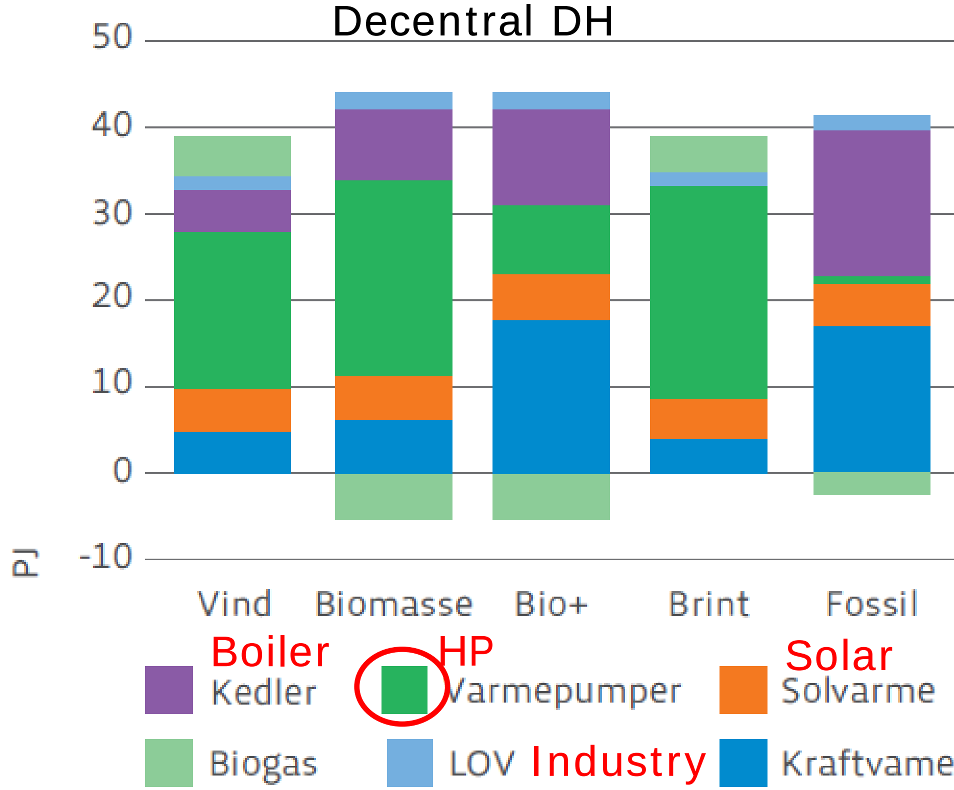
DEA 2050 scenarios

Scenario	Wind	Biomass	Bio+	Hydro-gen (Brint)	Fossil
Fuel consumption	255 PJ	443 PJ	710 PJ	192 PJ	483 PJ
Self sufficiency	104%	79%	58%	116%	(*)
Gross energy consumption	575 PJ	590 PJ	674 PJ	562 PJ	546 PJ

Future heat production



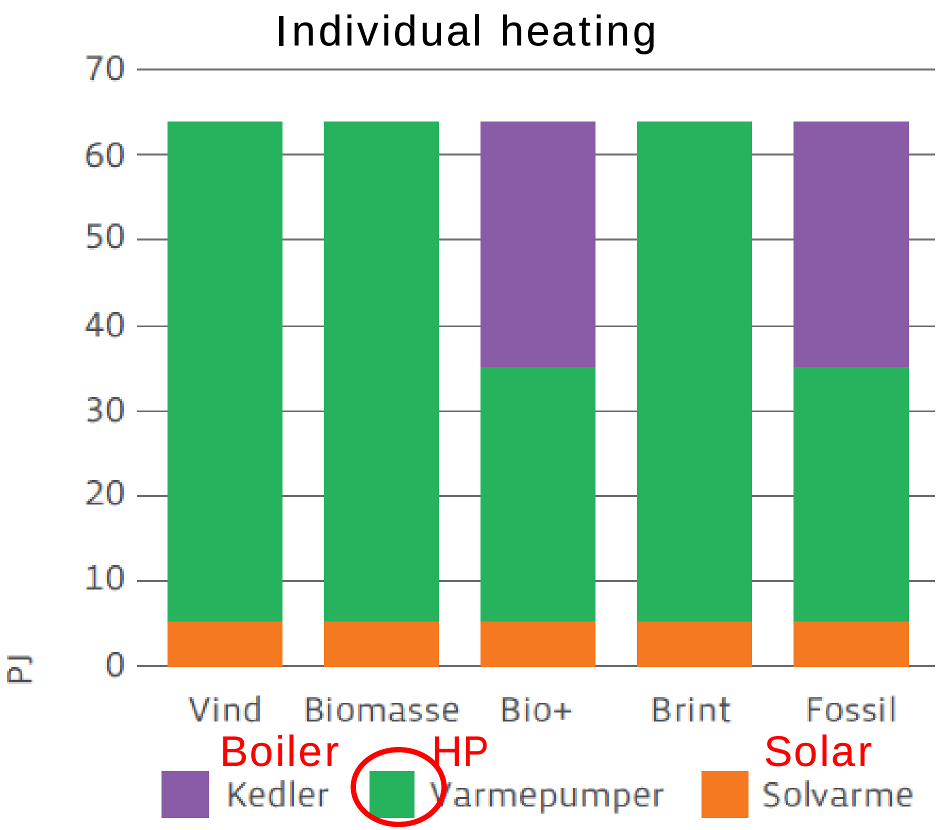
Figur 11.9. Produktion af central fjernvarme 2050. Grafisk illustration af tabel 11.3.



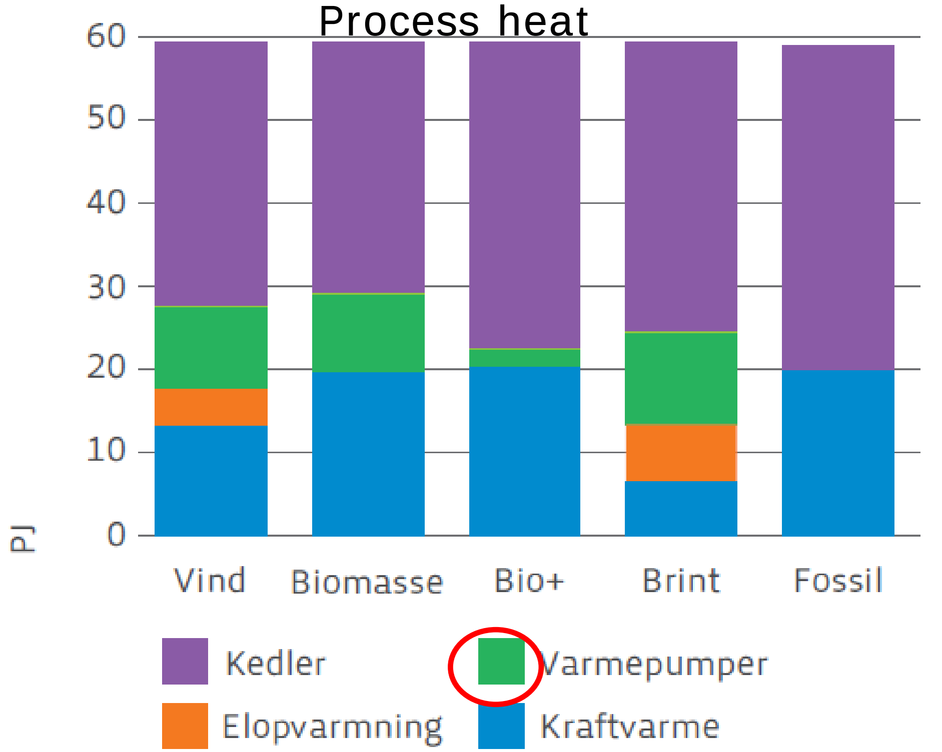
Figur 11.10. Produktion af decentral fjernvarme 2050. Grafisk illustration af tabel 11.4. Bemærk, at den negative produktion i biomasse- og bio+ scenariet skyldes procesvarmeforbrug i biogasanlæggene.

http://www.ens.dk/sites/ens.dk/files/undergrund-forsyning/el-naturgas-varmeforsyning/Energianalyser/nyeste/energiscenarier_-_analyse_2014_web.pdf

Future heat production



Figur 11.8. Individuel varmeproduktionen 2050. Grafisk illustration af tabel 11.2.



Figur 11.6. Procesvarmeproduktionen 2050 i de fem scenarier fordelt på opvarmningsformer. Grafisk illustration af tabel 11.1.

http://www.ens.dk/sites/ens.dk/files/undergrund-forsyning/el-naturgas-varmeforsyning/Energianalyser/nyeste/energiscenarier_-_analyse_2014_web.pdf

Power to heat potential

• ***Existing measures***	
• Interconnectors to Norway and Sweden	4.1 GW
• Interconnectors to Germany	2.4 GW
• Electric boilers in district heating	0.4 GW
• ***Examples of options towards 2030***	
• Heat pumps in DH	0.6 GW
• Additional electric boilers in DH schemes	1.0 GW
• Heat pumps in individual houses	0.15 GW (1.5 GW)
Total power to heat potential	**2.2-3.5 GW**

(EA 2015. *The Danish Experience with Integrating Variable Renewable Energy: Lessons Learned and Options for Improvement*)

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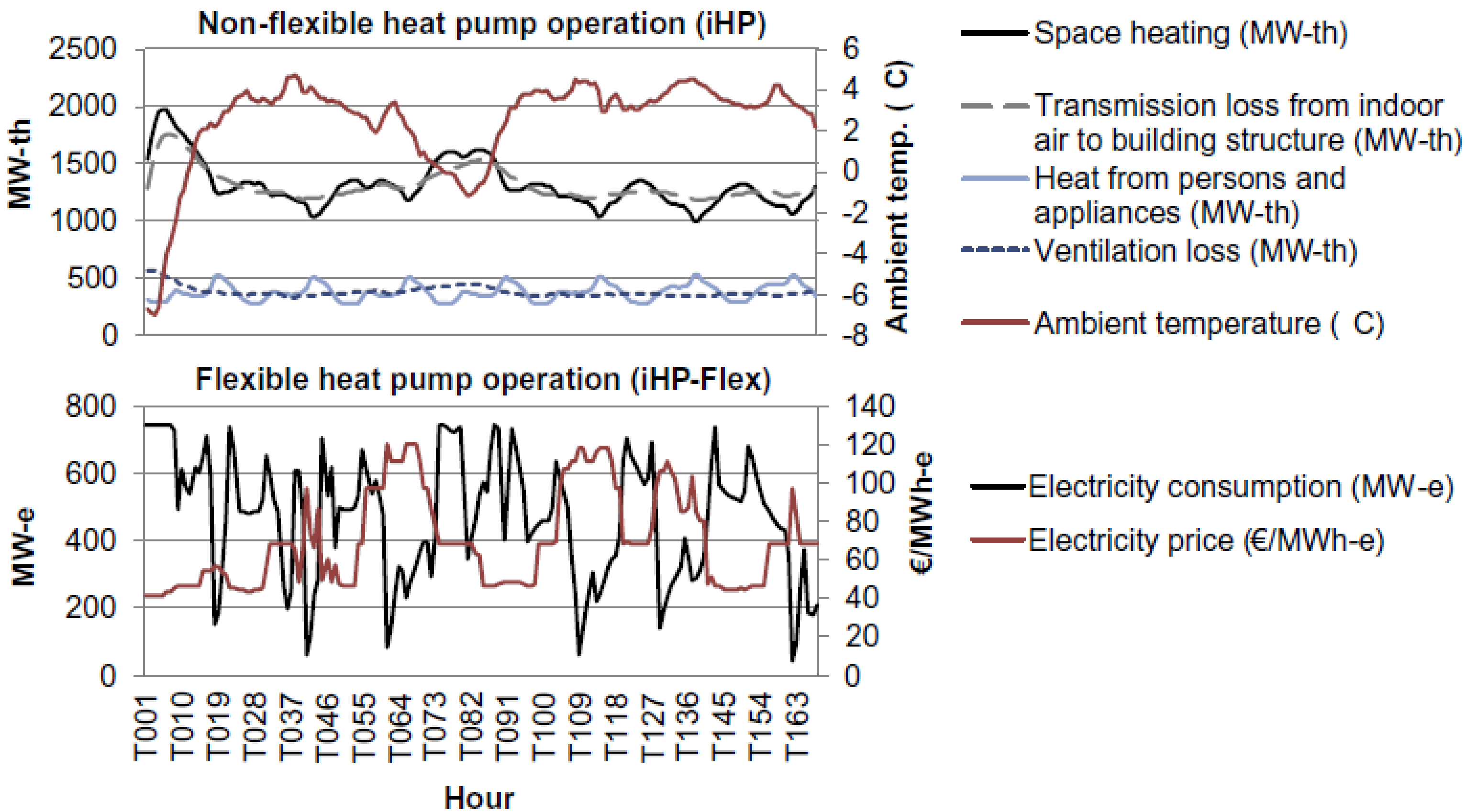
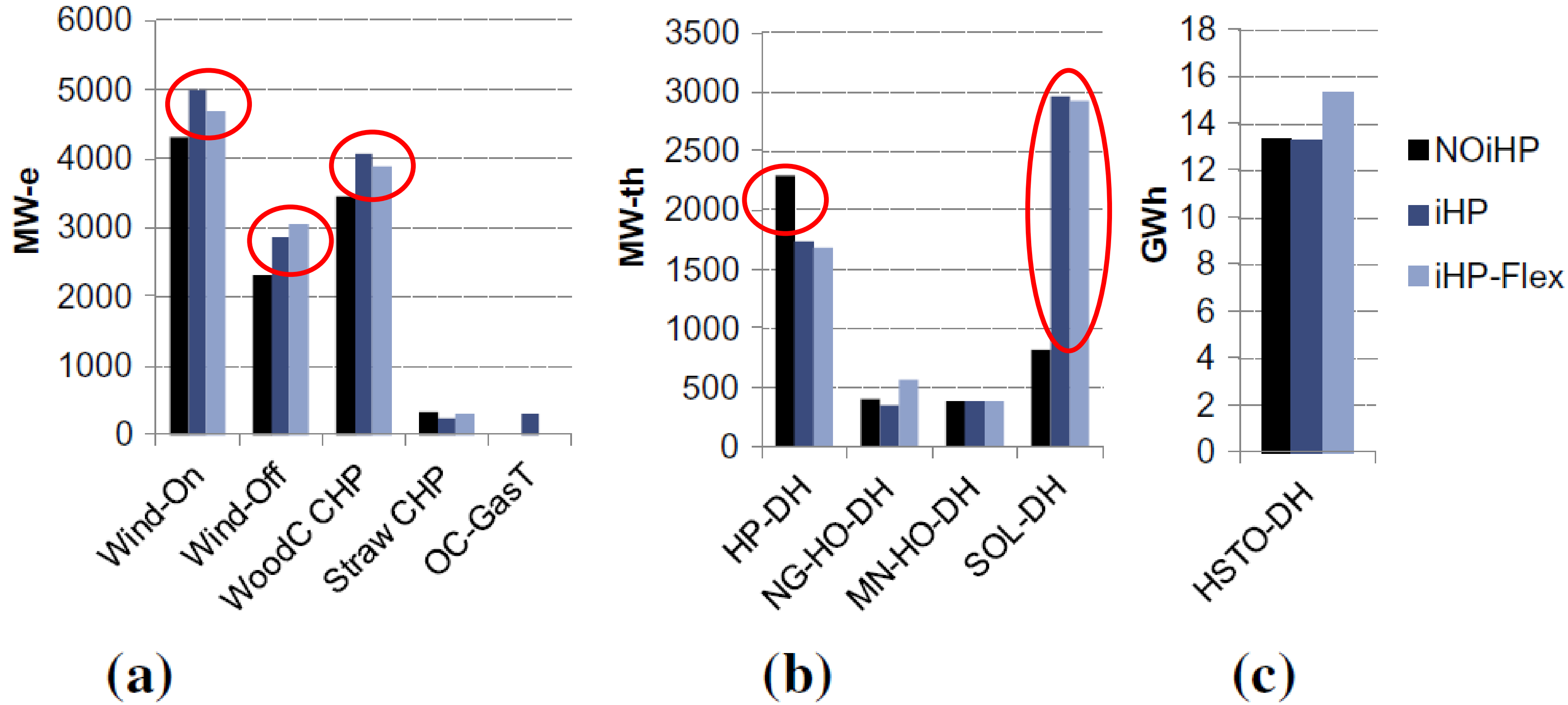
Flexible individual heat pumps 2030 scenarios



K. Hedegaard, M. Münster *Influence of individual heat pumps on wind power integration* – Energy system investments and operation / Energy Conversion and Management 75 (2013) 673–684

Optimised investment capacities



Investments in the Danish system by 2030 for different scenarios

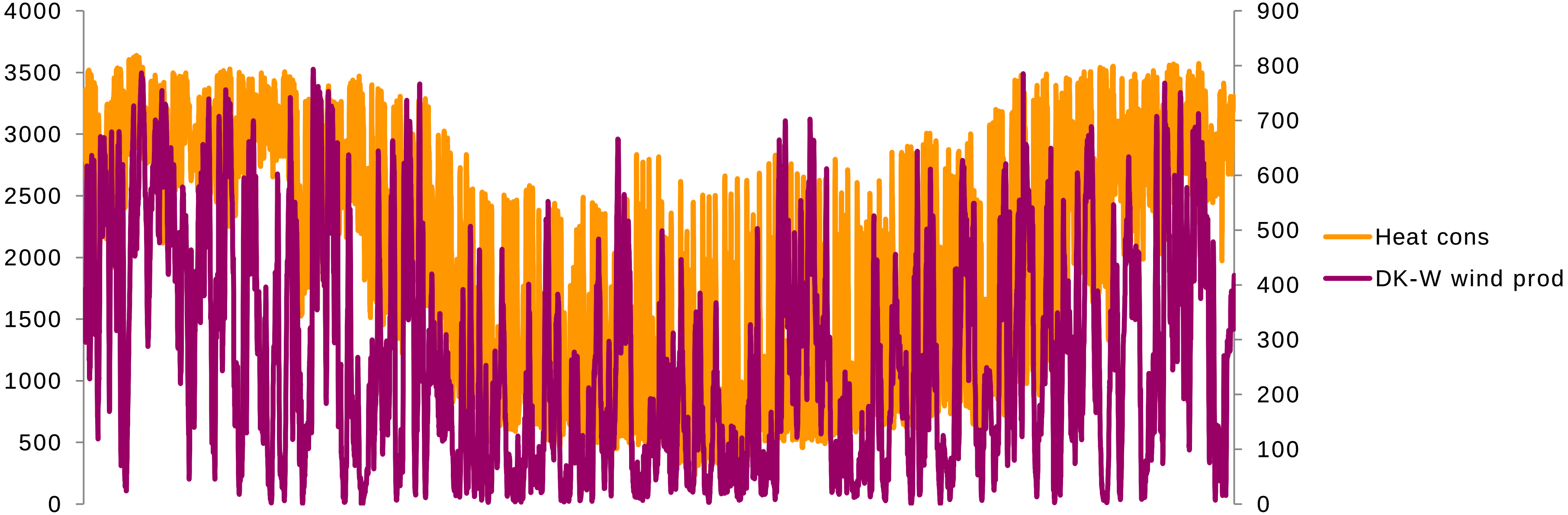
(a) investments in electricity generation capacities,

(b) investments in district heat generation capacities and

(c) Investment in thermal storages in the district heating system.

(d) On: onshore, Off: offshore. WoodC: wood chips/waste, OC-GasT: open cycle gas turbines, DH: district heating, HO: heat only, MN: municipal waste. SOL: solar thermal.

Wind production and heat consumption



 (STREAM and Energinet.dk market data)

Conclusion

- Heat pumps, even without flexible operation, can contribute significantly to **facilitating larger wind power investments and reducing system costs, fuel consumption, and CO2 emissions**.
- The main benefit of the flexible heat pump operation is a **reduced need for peak/reserve capacity**, which is also crucial for the feasibility of the heat storages.
- Socio-economic feasibility is identified for control equipment enabling **intelligent heat storage in the building structure and in existing hot water tanks**. In contrast, investments in new heat accumulation tanks are not found competitive.

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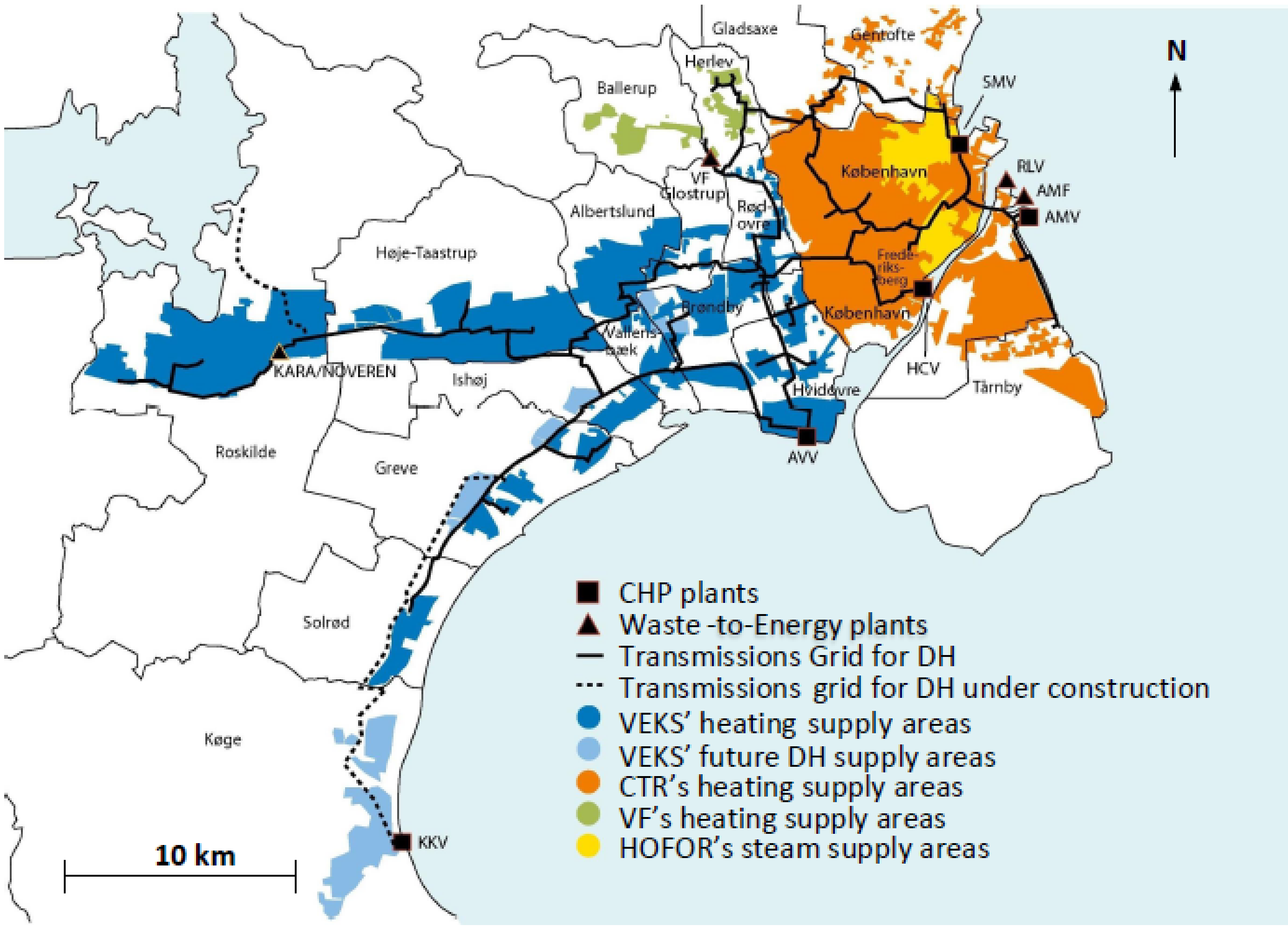
DH HP in Copenhagen



Bach et al. 2015 *Integration of Large-scale Heat Pumps in the District Heating Systems of Greater Copenhagen* (In process)

Copenhagen DH HP heat sources

- **Drinking water**: (output – assuming a COP of 3) based on the drinking water network
- **Sewage water**: available at sewage water treatment plants
- **Sea water**: when connected to the distribution grid.
- **Total**: ~10% of winter peak

Area	Heat source	Capacity [MW_{th}]
CAML	Sewage water	60.0
CVAL	Sewage water	27.0
CHUS	Drinking water	4.5
VEKV	Drinking water	4.5
VF	Drinking water	4.5
CAML	Sea water	70.0
COST	Sea water	90.0
Total		**260.5**

Conclusions

- **Limited heat sources available** in practice (~10%)
- Higher number of full load hours in distribution grid (and in a future with more wind)
- Displacement:
  - peak load production in winter time
  - some CHP plants in summer time

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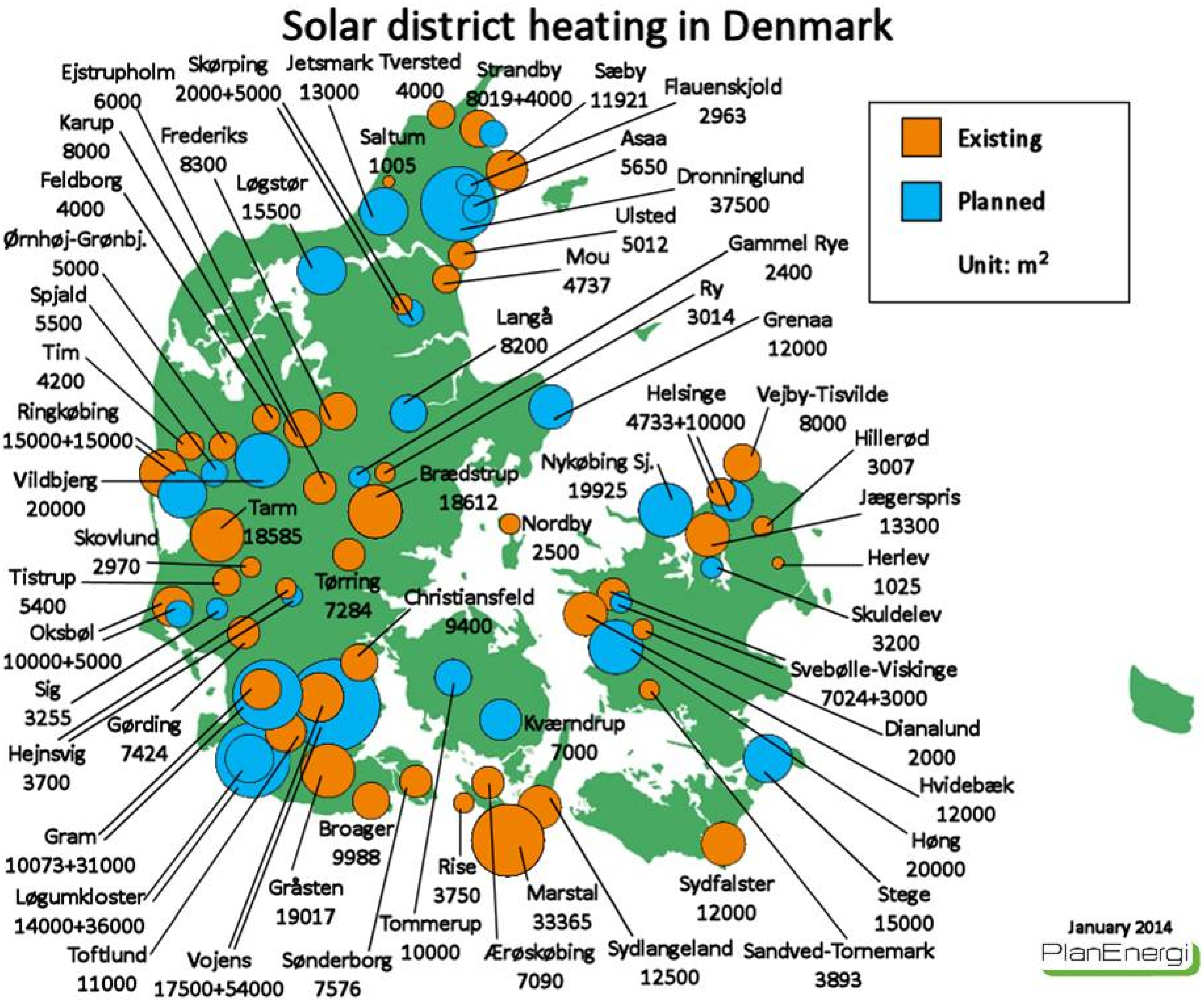
Solar heating and heat pumps

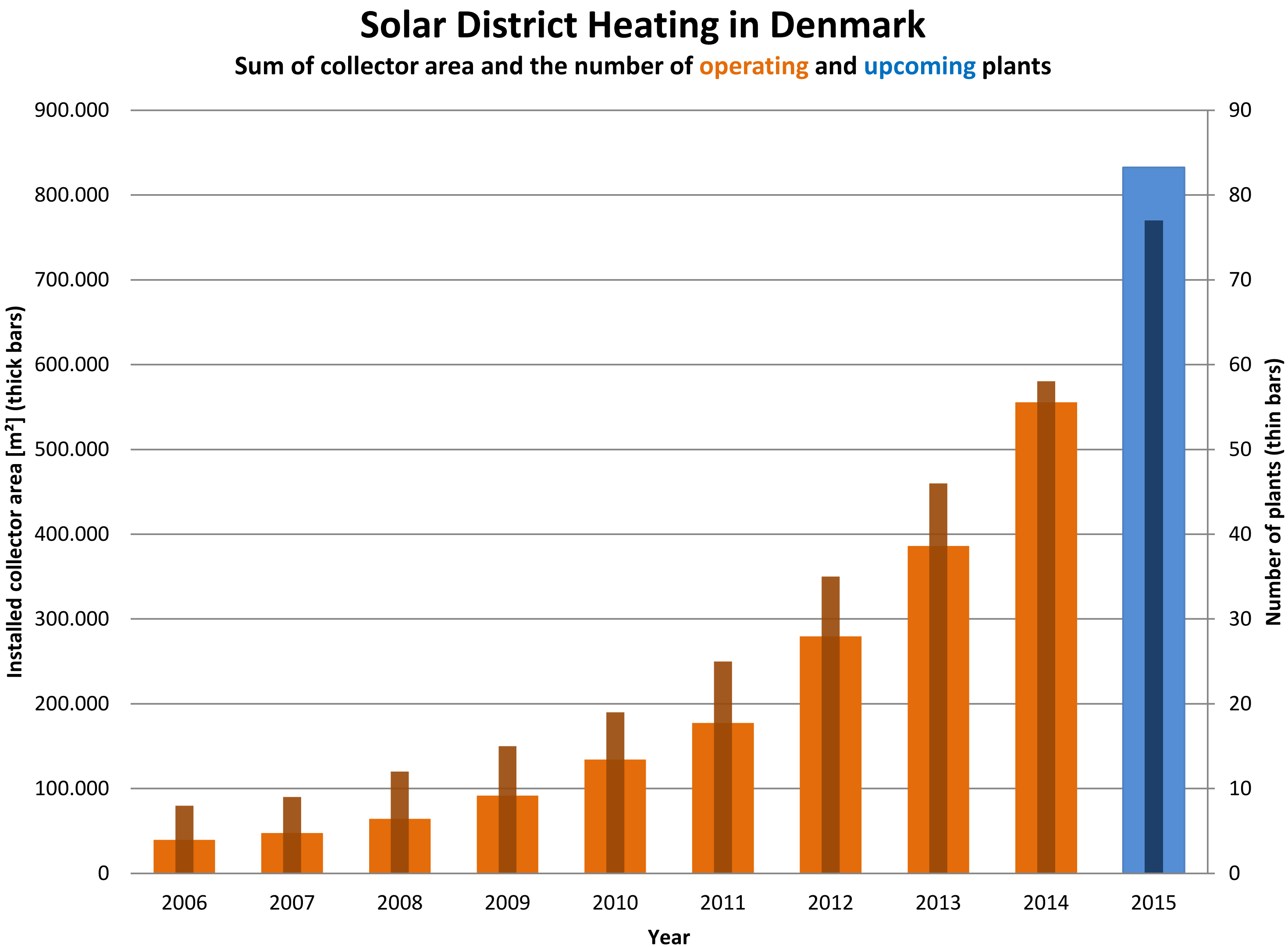
- DH can cut down the use of fuels
  by using **solar thermal**, seasonal **heat storages** and **heat pumps**

(www.planenergi.dk)

DTU

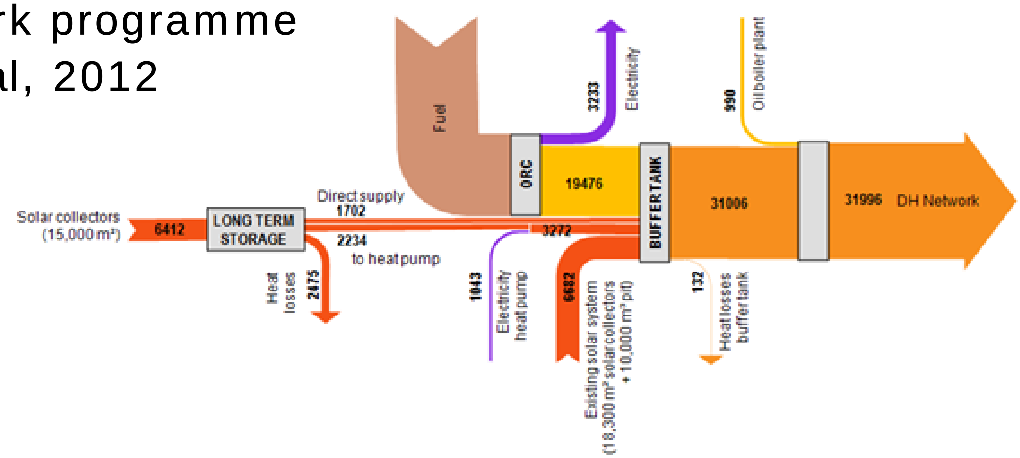
2013


Solar district heating in Denmark
Existing
Planned
Unit: m²
Ejstrupholm 6000
Skørping 2000+5000
Jetsmark 13000
Tversted 4000
Strandby 8019+4000
Sæby 11921
Flauenskjold 2963
Karup 8000
Frederiks 8300
Saltum 1005
Asaa 5650
Dronninglund 37500
Feldborg 4000
Løgstør 15500
Ulsted 5012
Ørnhøj-Grønbj. 5000
Mou 4737
Gammel Rye 2400
Spjald 5500
Ry 3014
Langå 8200
Grenaa 12000
Tim 4200
Ringkøbing 15000+15000
Helsinge 4733+10000
Vejby-Tisvilde 8000
Hillerød 3007
Vildbjerg 20000
Brædstrup 18612
Nykøbing Sj. 19925
Jægerspris 13300
Tarm 18585
Nordby 2500
Skovlund 2970
Herlev 1025
Tistrup 5400
Tørring 7284
Christiansfeld 9400
Skuldelev 3200
Oksbøl 10000+5000
Svebølle-Viskinge 7024+3000
Sig 3255
Gørding 7424
Kværndrup 7000
Dianalund 2000
Hejnsvig 3700
Hvidebæk 12000
Gram 10073+31000
Broager 9988
Høng 20000
Rise 3750
Marstal 33365
Sydfalster 12000
Stege 15000
Løgumkloster 14000+36000
Gråsten 19017
Tommerup 10000
Toftlund 11000
Vojens 17500+54000
Sønderborg 7576
Ærøskøbing 7090
Sydlangeland 12500
Sandved-Tornemark 3893
January 2014
PlanEnergi


Solar District Heating in Denmark
Sum of collector area and the number of operating and upcoming plants
Installed collector area [m²] (thick bars)
Number of plants (thin bars)
900.000
800.000
700.000
600.000
500.000
400.000
300.000
200.000
100.000
0
90
80
70
60
50
40
30
20
10
0
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Year

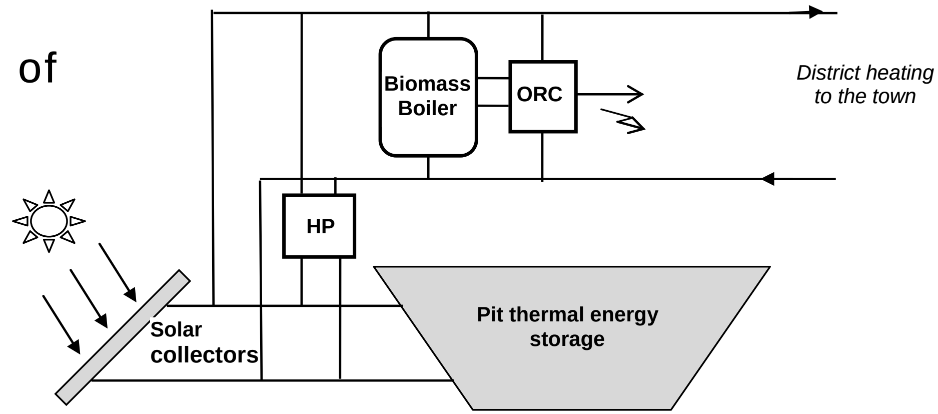
SUNSTORE 4 demonstration plant in Marstal

- The SUNSTORE 4 project
  - Supported by EC 7th framework programme
  - Demonstration plant in Marstal, 2012



- A district heating system with
  - 100% RE
  - > 50% solar thermal
  - A seasonal heat storage
  - A heat pump

- District heating system consisting of
  - 33,300 m^2 solar plant
  - 75,000 m^3 pit heat storage
  - 1.5 MW_{th} heat pump
  - 4 MW wood chip boiler
  - 750 kW_e ORC



Conclusion

- **Solar heating** can be an important ressource for district heating
- **Heat storages** even out timeshifts between heat production and heat demand
- **Heat pumps** provide flexible power consumption that utilizes low temperature heat sources
- This makes it possible to integrate more **fluctuating RE** in the energy system

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4DH - Danish research centre

4th generation district heating (4GDH)

Hypothesis:

- 4GDH systems and technologies will play a big part in future cost-effective sustainable energy systems and are likely to replace the import of fossil fuels and create jobs and economic growth in Denmark and in Europe.

- Collaboration between industry, universities and the public sector

1) District Heat Grids and Components,
2) District Heating Production and System Integration,
3) District Heating Planning and Implementation

http://www.4dh.dk/

Heat Roadmap Europe

Key Conclusions

- **Energy Efficiency:** heat savings are a key component in the decarbonisation of the EU energy system. The total heat demand in Europe should be reduced by approximately 30-50%, which is similar to the conclusion presented by the European Insulation Manufacturers Association, Eurima. However, after this point the price of sustainable heat supply is likely to be lower than the price of further heat savings.

- **District Heating:** There is currently more heat being wasted in Europe than is required to heat all of the buildings. District heating can capture this excess heat and move it into the buildings. District heating should be increased from today's level of ~10% up to ~50% in 2050. It should increase in urban areas, where the heat densities have been estimated based on the pan-EU heat atlas.

- **Individual Heat Pumps:** in rural areas, individual ground and air-sourced heat pumps should replace existing oil boilers. Heat pumps connect cheap renewable electricity production (such as wind and solar) with efficient renewable heat production (due to their COP).

- **Energy System:** heat savings, district heating, and individual heat pumps are key components in a future low-carbon EU energy system. They are fundamental to the technical and economic viability of the Smart Energy System.

http://www.heatroadmap.eu/

progRESsHEAT

http://www.progressheat.eu/

About progRESsHEAT

Goal:

- assisting local, regional, national and EU political leaders in **developing policy and strategies** to ensure a quick and efficient deployment of renewables in heating and cooling networks
- applying **model-based** quantitative impact assessment of local, regional and national policies up to 2050 (Local: EnergyPro, National: TIMES)

Running from March 2015 to October 2017. The project is supported by the Horizon 2020 programme

PARTNERS IN THE PROJECT

Institute for Energy Systems and Electric Drives, Vienna University of Technology - TU-Wien (Austria) // Fraunhofer Institute for Systems and Innovation Research ISI (Germany) // Technical University of Denmark - DTU (Denmark) // Institute for Resource Efficiency and Energy Strategies - IREES GmbH (Germany) // OÖ Energiesparverband - ESV (Austria) // ee energy engineers GmbH (Germany) // Gate 21 (Denmark) // Instituto de Engenharia Mecanica e Gestao Industrial - INEGI (Portugal) // Agentia Pentru Management ul Energiei si Protectia Mediului Brasov - ABMEE (Romania) // City of Litoměřice (Czech Republic) // Energy Cities (France)

LTILHOHE

OKSUNEN

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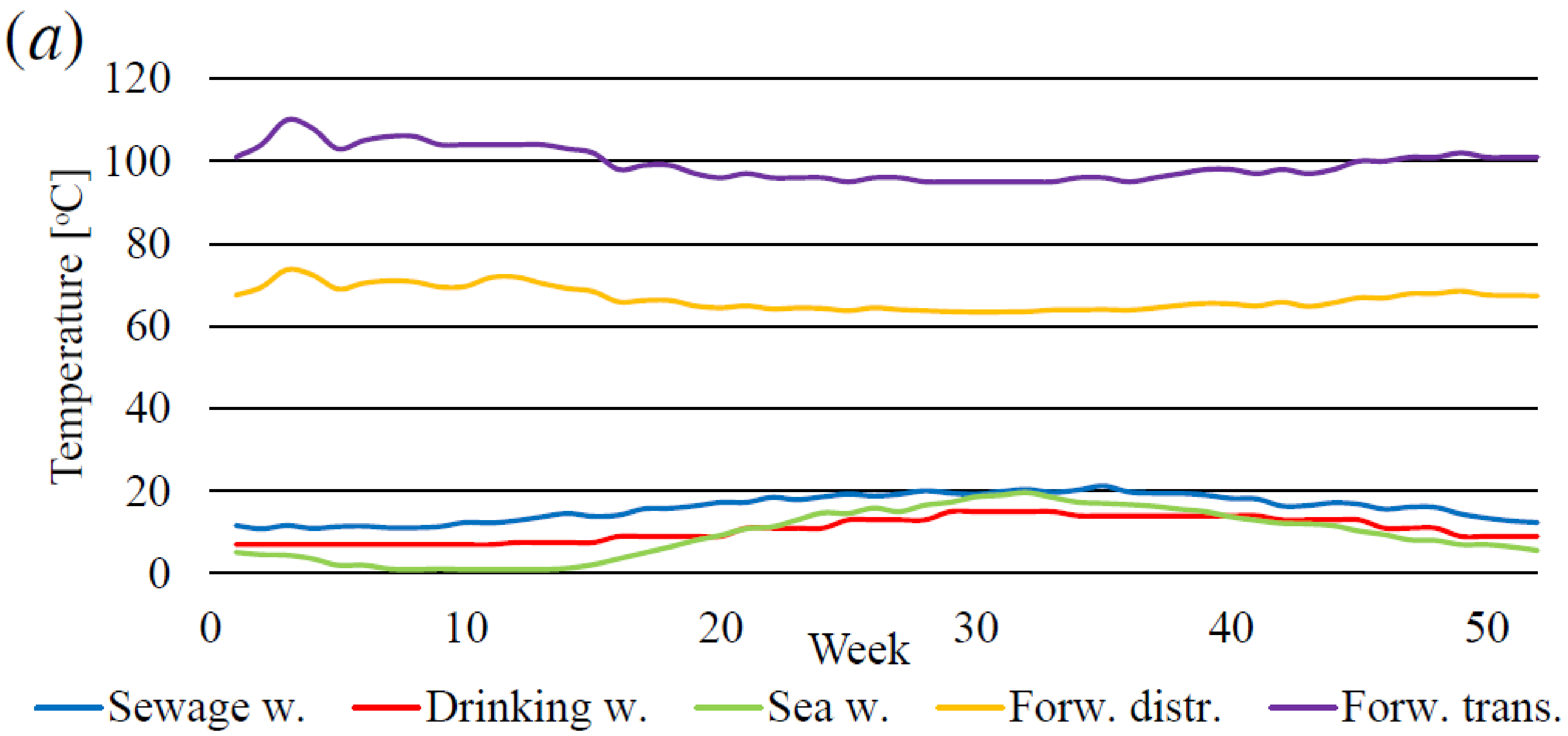
see the opportunities!

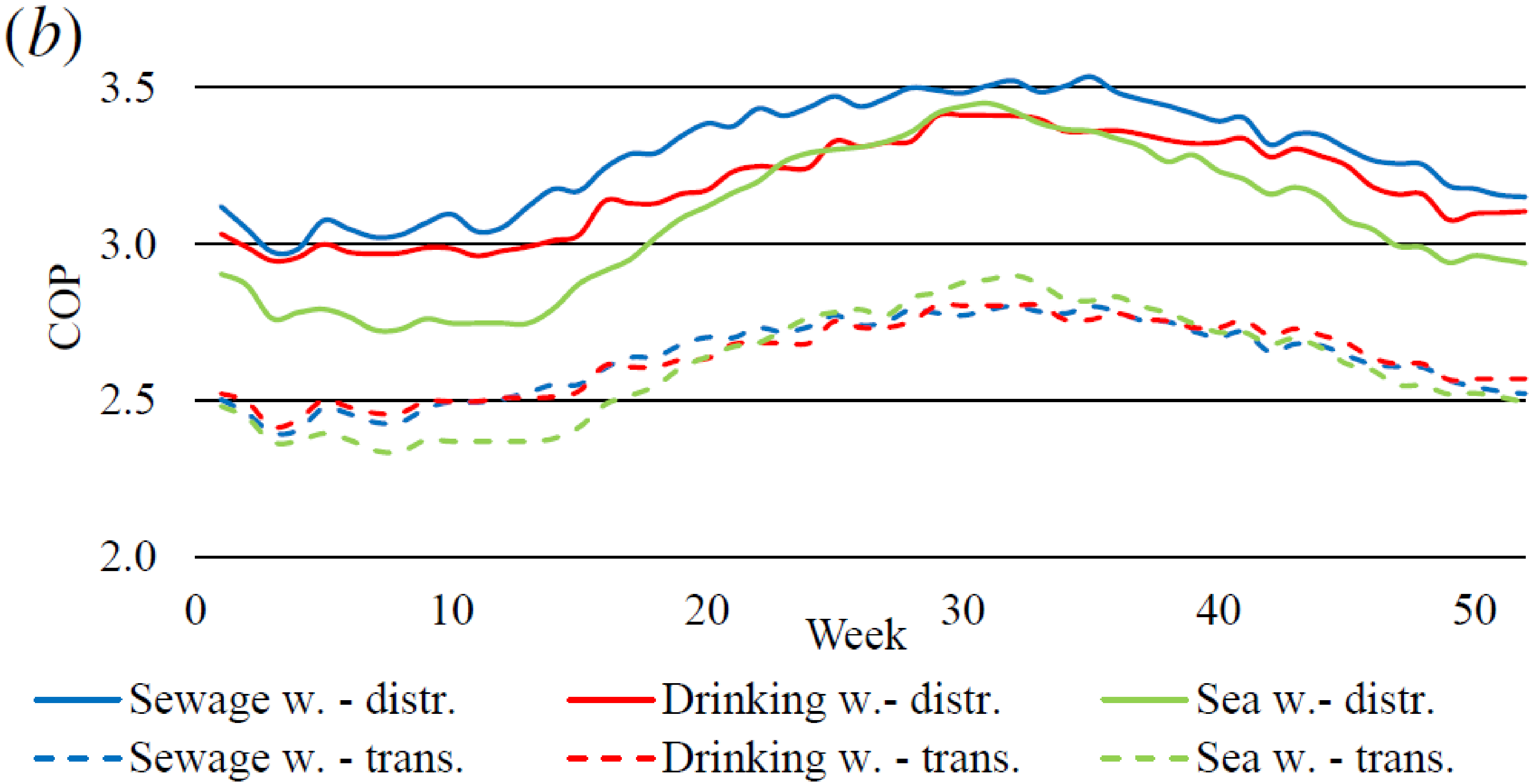
Extras

DH HP in Copenhagen
Heat source temp



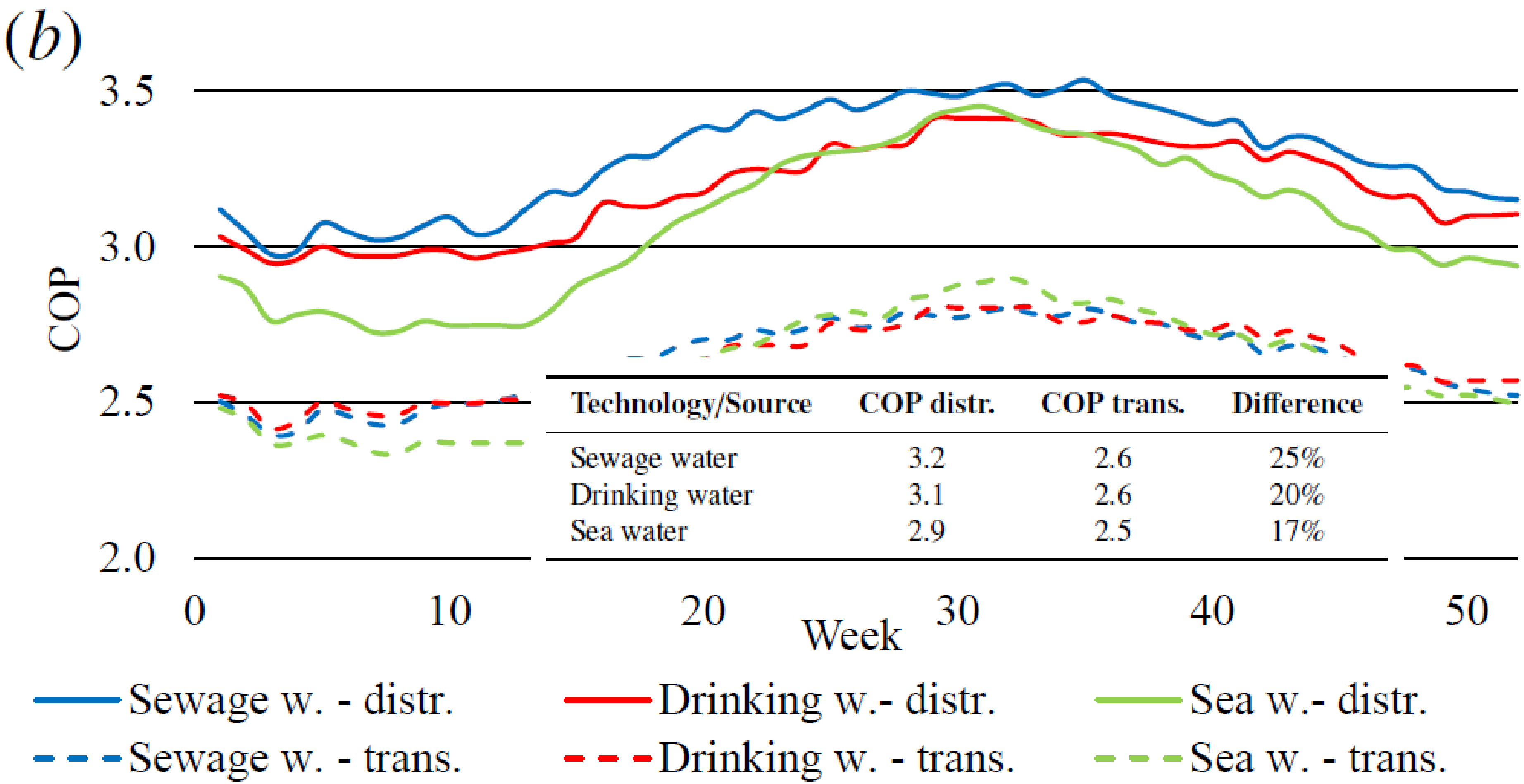
(a) Temperatures of heat sources and district heating forward temperatures of transmission and distribution

DH HP in Copenhagen Seasonal COPs



(b) Seasonal COP for the different technologies connected to distribution grid and transmission grid.

DH HP in Copenhagen
Seasonal COPs



Technology/Source	COP distr.	COP trans.	Difference
Sewage water	3.2	2.6	25%
Drinking water	3.1	2.6	20%
Sea water	2.9	2.5	17%

(b) Seasonal COP for the different technologies connected to distribution grid and transmission grid.

DH HP in CPH
Full load hours