"Energy sector integration in light of the energy transition of cities"

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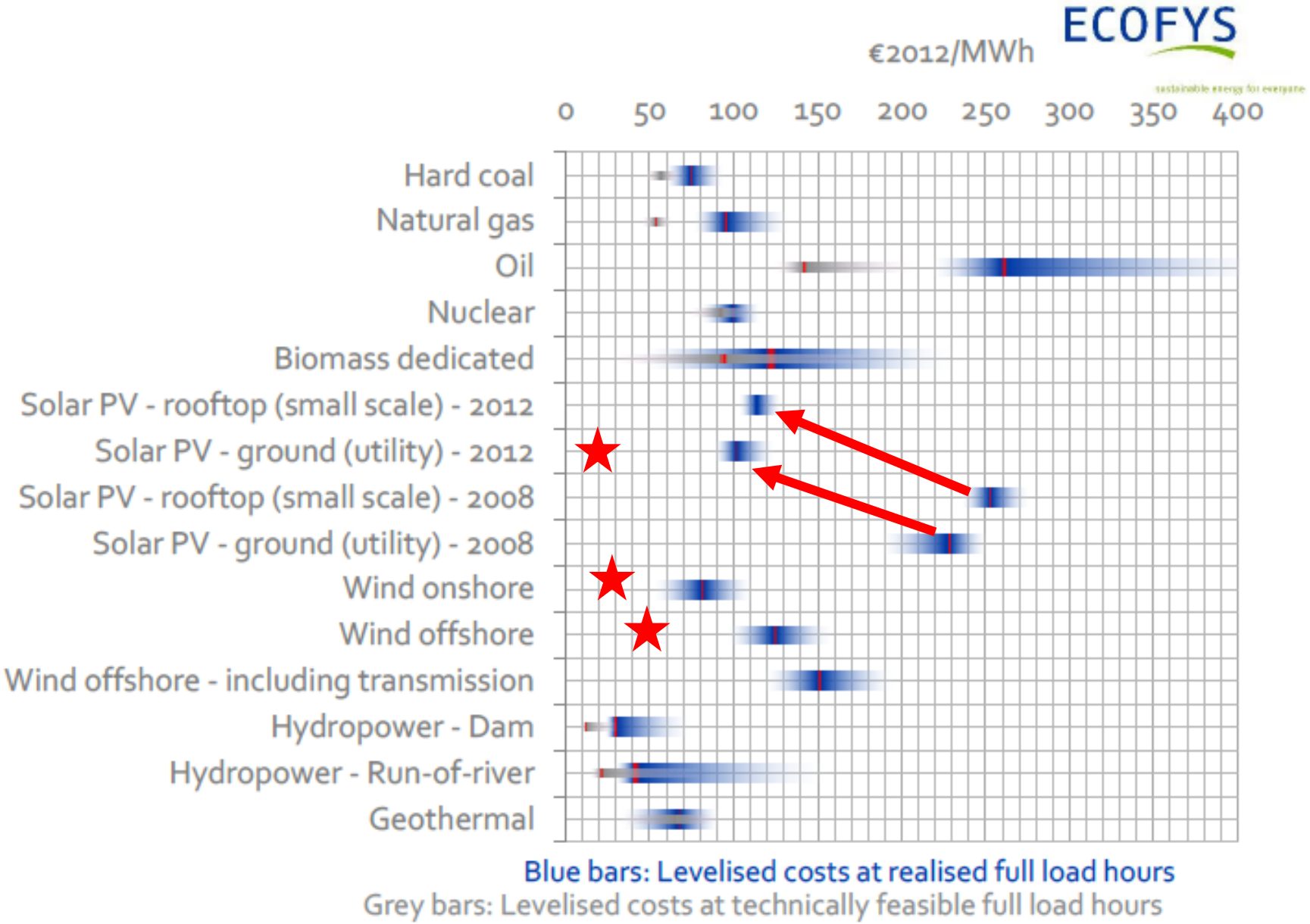


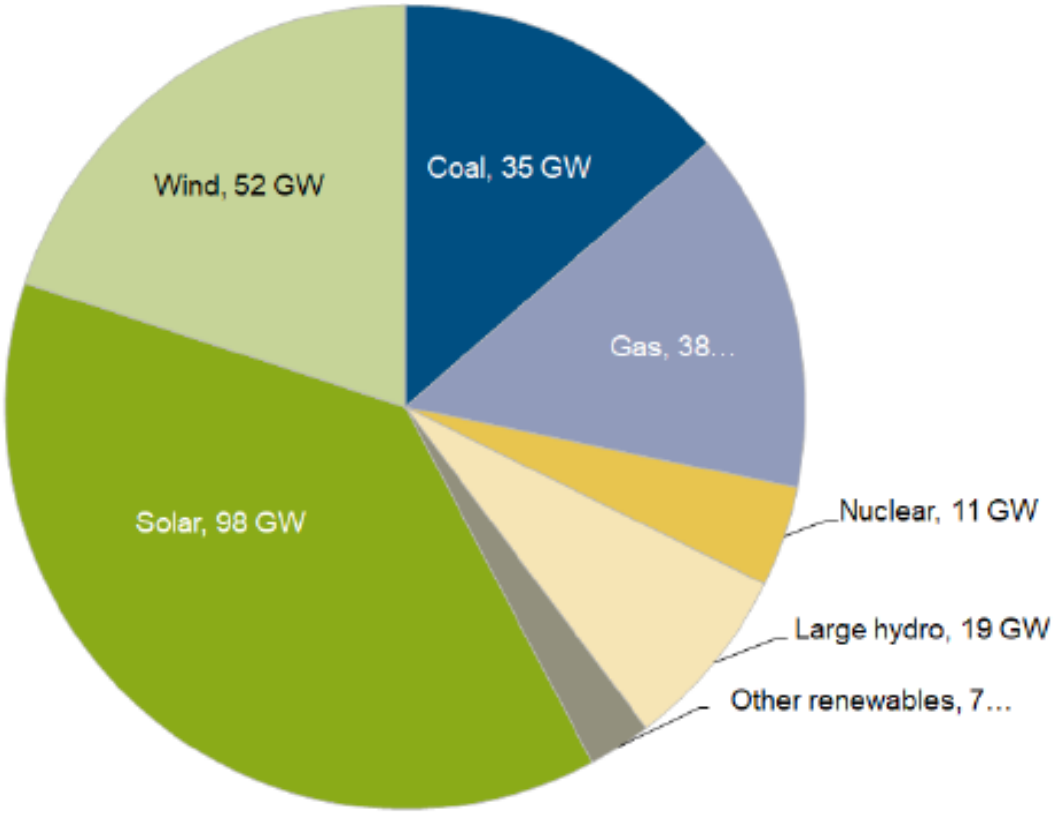
LCOE – various technologies

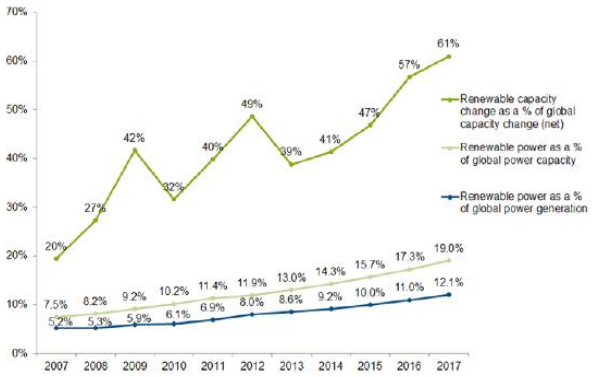
Power sector developments

Global installed generation capacity net change, 2017 [GW]

Source: Source: Bloomberg New Energy Finance,

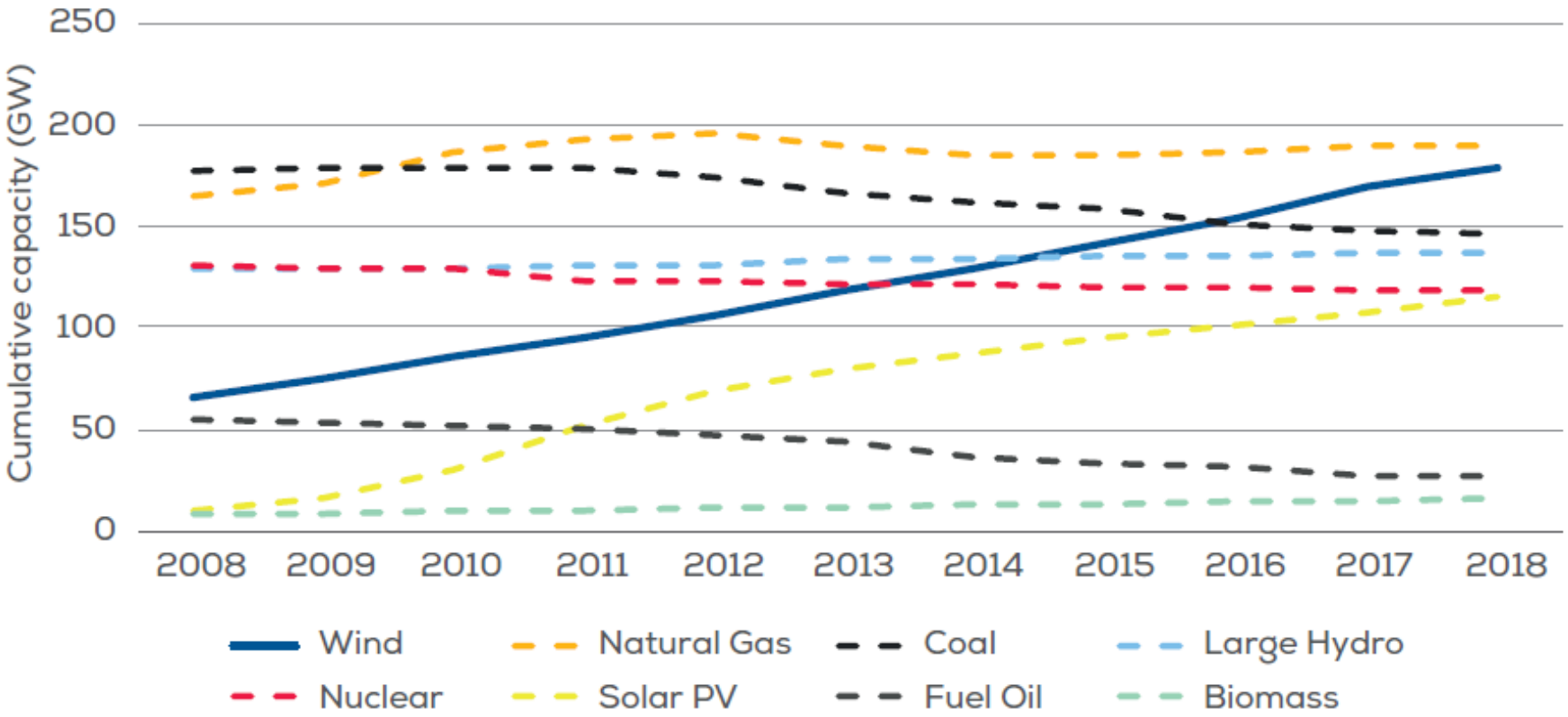
https://unfccc.int/news/world-added-far-more-new-solar-than-fossil-fuel-power-in-2017





Power sector developments

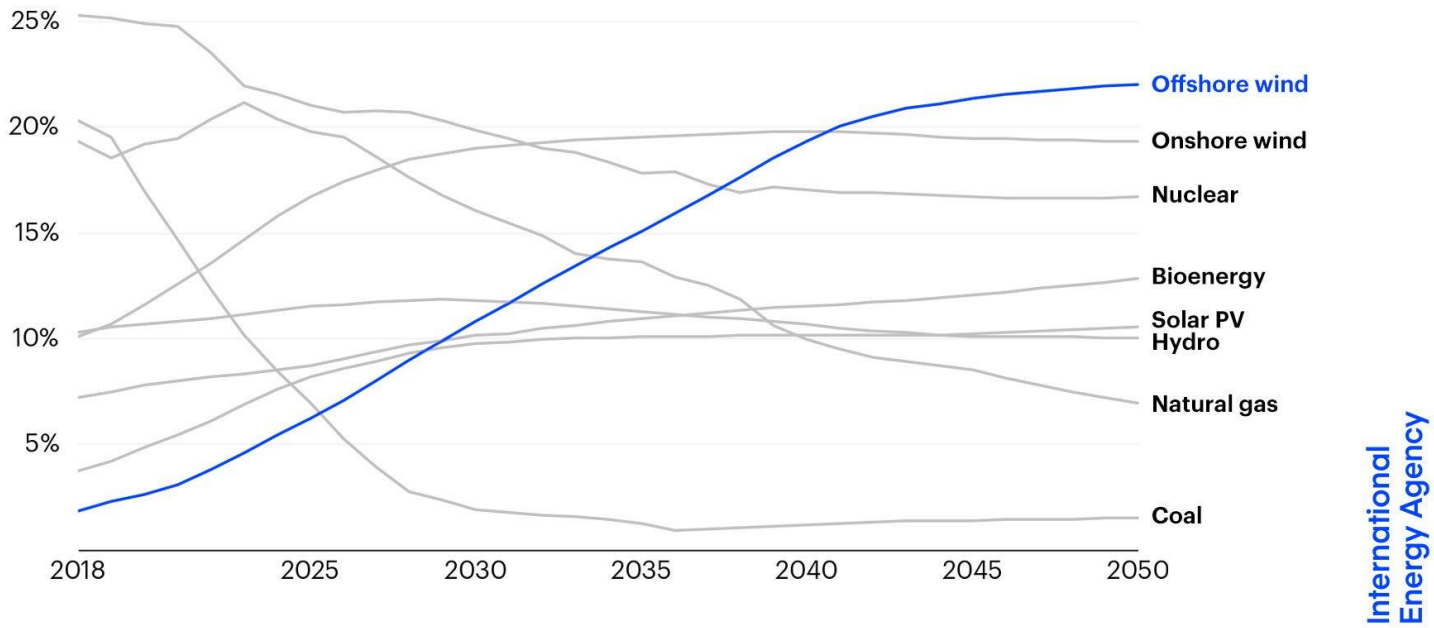
EU power generation capacity, 2008-2018 [GW]



Source: WindEurope

IEA Outlook

Shares of electricity generation by technology in the EU, Sustainable Development Scenario
Offshore Wind Outlook 2019



Wind share in electricity demand 2016/17/18

Denmark[17] – 44% South Australia[18] – 40% Iowa[17] – 37%
Kansas[17] – 36% Oklahoma[17] – 32% S.Dakota[17] – 30%
Prince Edward Island[17], Ireland[18] – 28% N.Dakota[17] – 37%
Curaçao, Portugal – 25% Uruguay – 23%
Germany[18] – 21% C. Verde, Maine[17], Spain – 20%
Nicaragua – 19% Colorado[17], Minn.[17], UK[18] – 18%
Aruba – 16% ID[17], NE[17], TX[17] – 15%
EU[18], NM[17] – 14% C. Rica, Romania, VT[17] – 13%
Sweden[18], NS[17] – 12% Austria[17], Lith.[17], OR[17] – 11%
Netherlands[17] – 10% Est.[17], Greece[18], Poland[17] – 9%
Morocco – 8% Belgium[18], Brazil, Turkey – 7%
Canada, Finland[18], France[18], Honduras, Italy[18], Panama, US – 6%
Australia[17], Croatia, Jamaica, N. Zealand – 5%
Bulgaria, China, Mexico, Tunisia, World – 4%
Chile, India – 3%
Dom. R, Hungary[17], Latvia[17], Macedonia[17], Norway[18] – 2%
Czechia[17], Egypt, Japan, Lux., South Africa, Ukraine – 1%

Solar share in electricity demand 2016

Tokelau – 100%

Honduras – 10%

Italy – 9%

Germany, Greece – 7%

Cyprus, EU, Belgium, Bulgaria – 4%

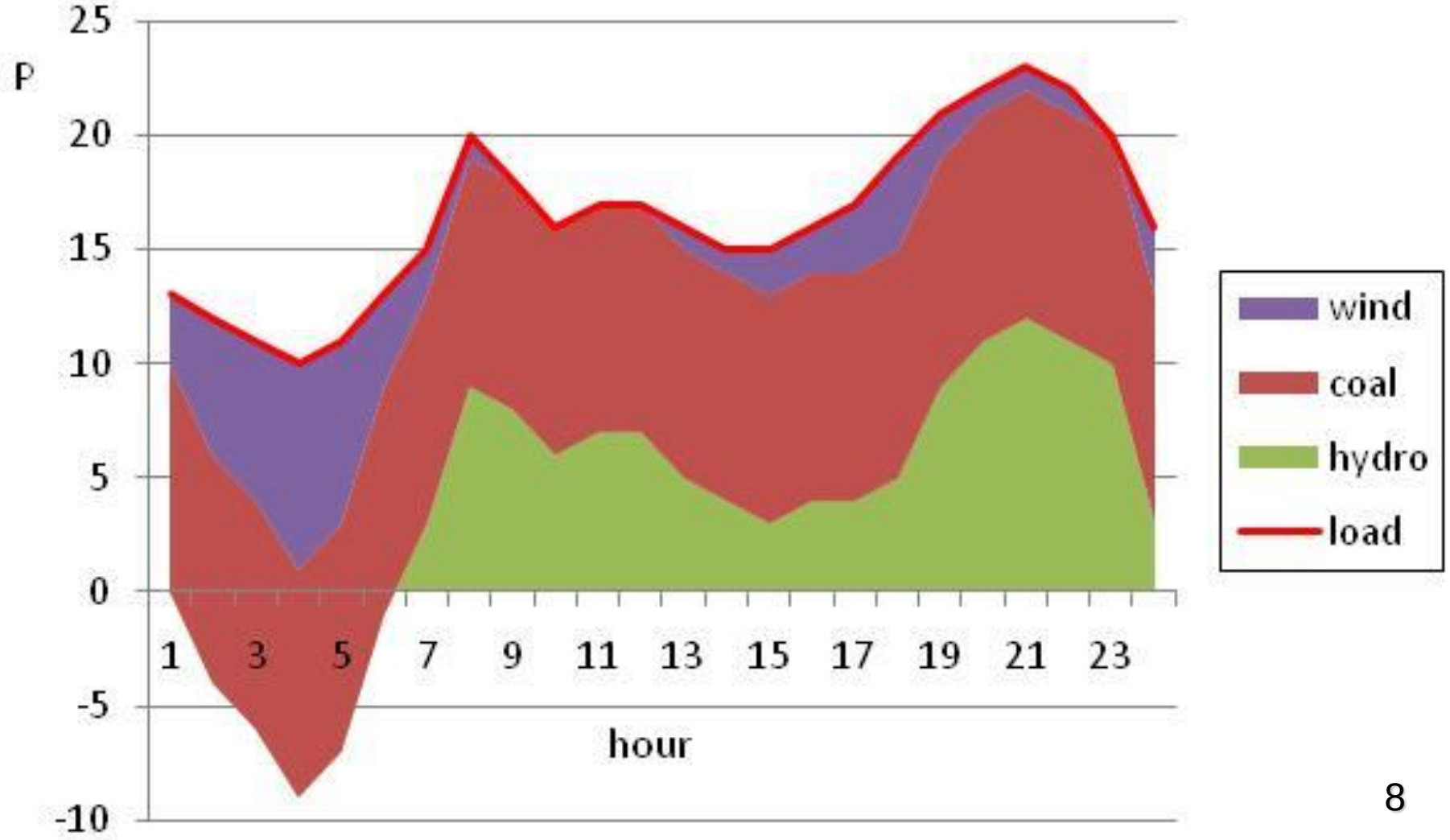
Australia[17], Czech Rep., Japan, Romania, Spain, UK – 3%

Denmark, France, Slovakia, Slovenia – 2%

World, Austria, China, Malta, Netherlands, Pakistan, Portugal, South Africa, US – 1%

Croatia, Hungary, India, Lux. – 0.5%

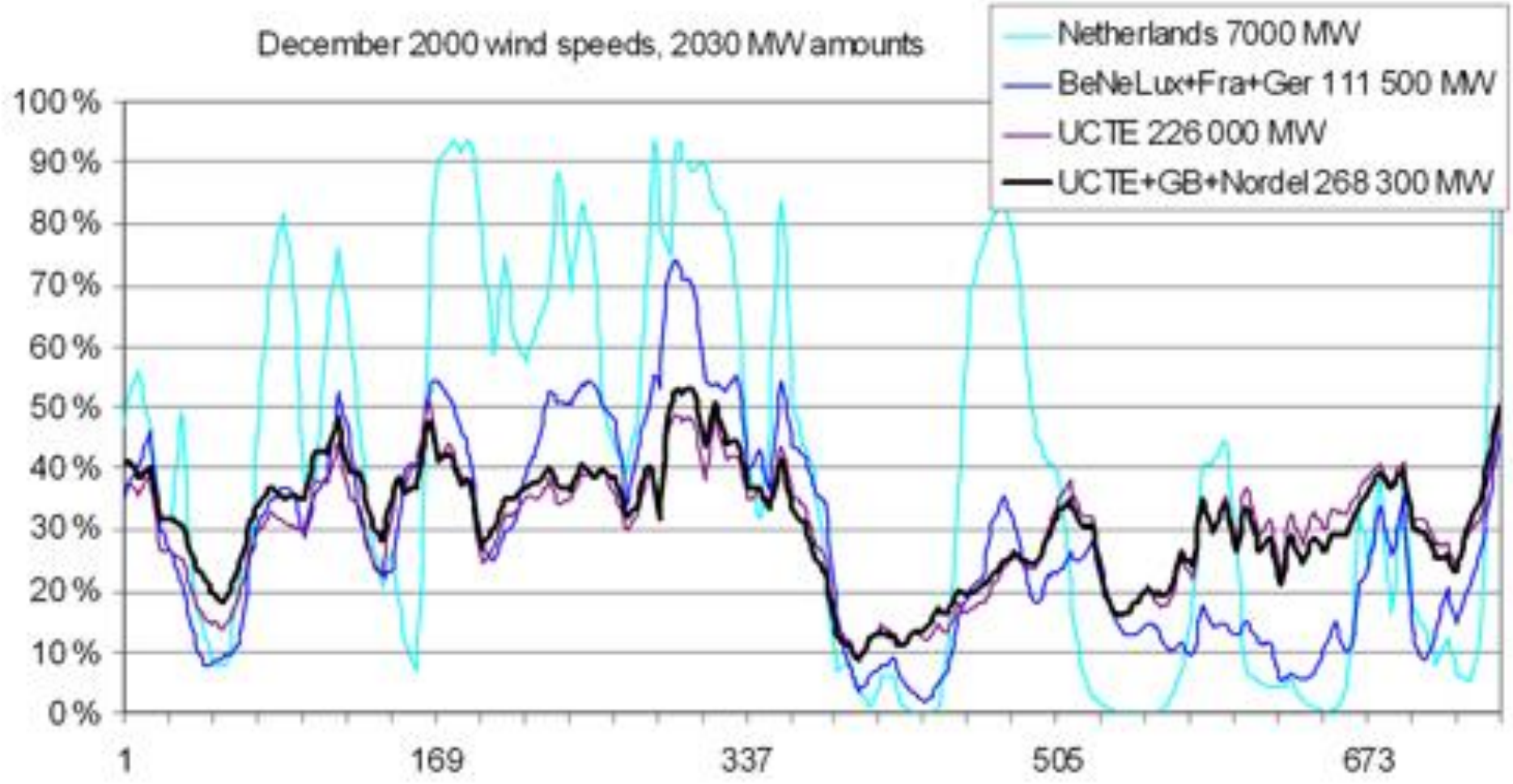
Baseload + 15% wind



How to solve renewables variability/intermittency problem?

- More grid interconnection
- Flexibilisation of thermal power plants
- Wholesale markets coupling
- Demand response and integration of power, heating, cooling, transport and water systems – power-to-X
- Dedicated electricity storage

Smoothing intermittency by geographical dispersion



Cycling of thermal power plants

ENERGY CHARTS

Publishing Notes | Data Protection | Deutsch

Home | Power | Energy | Prices | Map of power plants | Downloads | Information

Unitwise electricity production from hard coal in Germany in week 13 2017

date selection

year: 2017 << >>

month: << >>

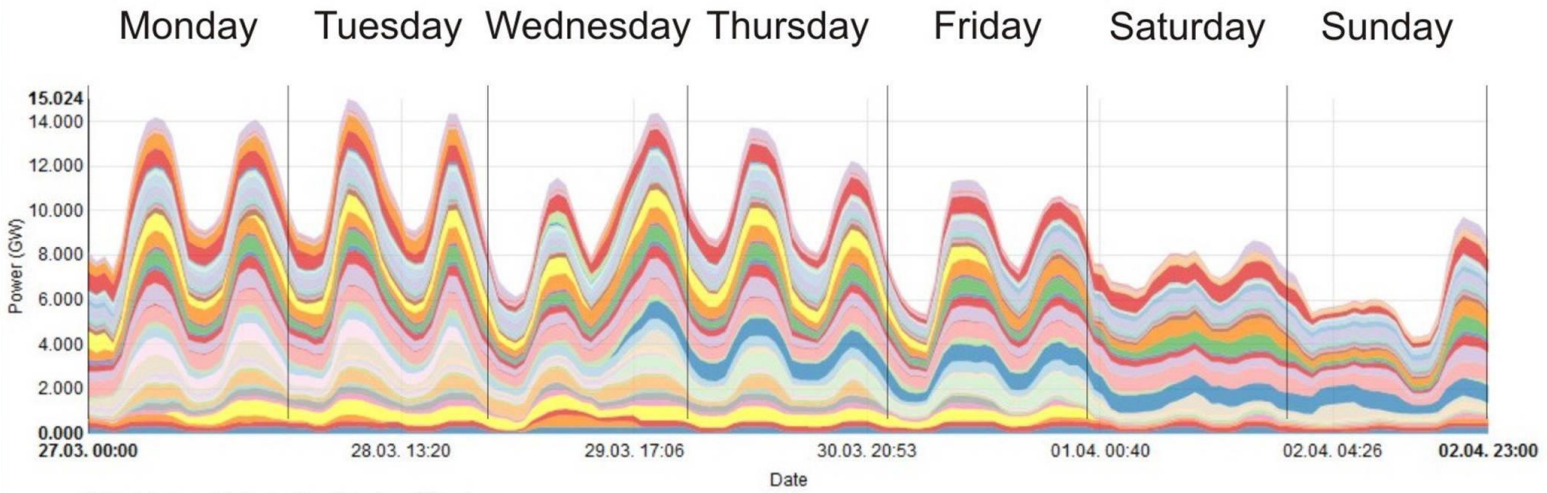
week: 13 << >>

- conv. >100MW
- all sources
- solar, wind
- import, export

- run-of-river
- nuclear
- lignite
- lignite per unit
- hard coal
- oil
- gas
- waste
- pumped storage
- wind offshore
- wind onshore

Stacked / Expanded

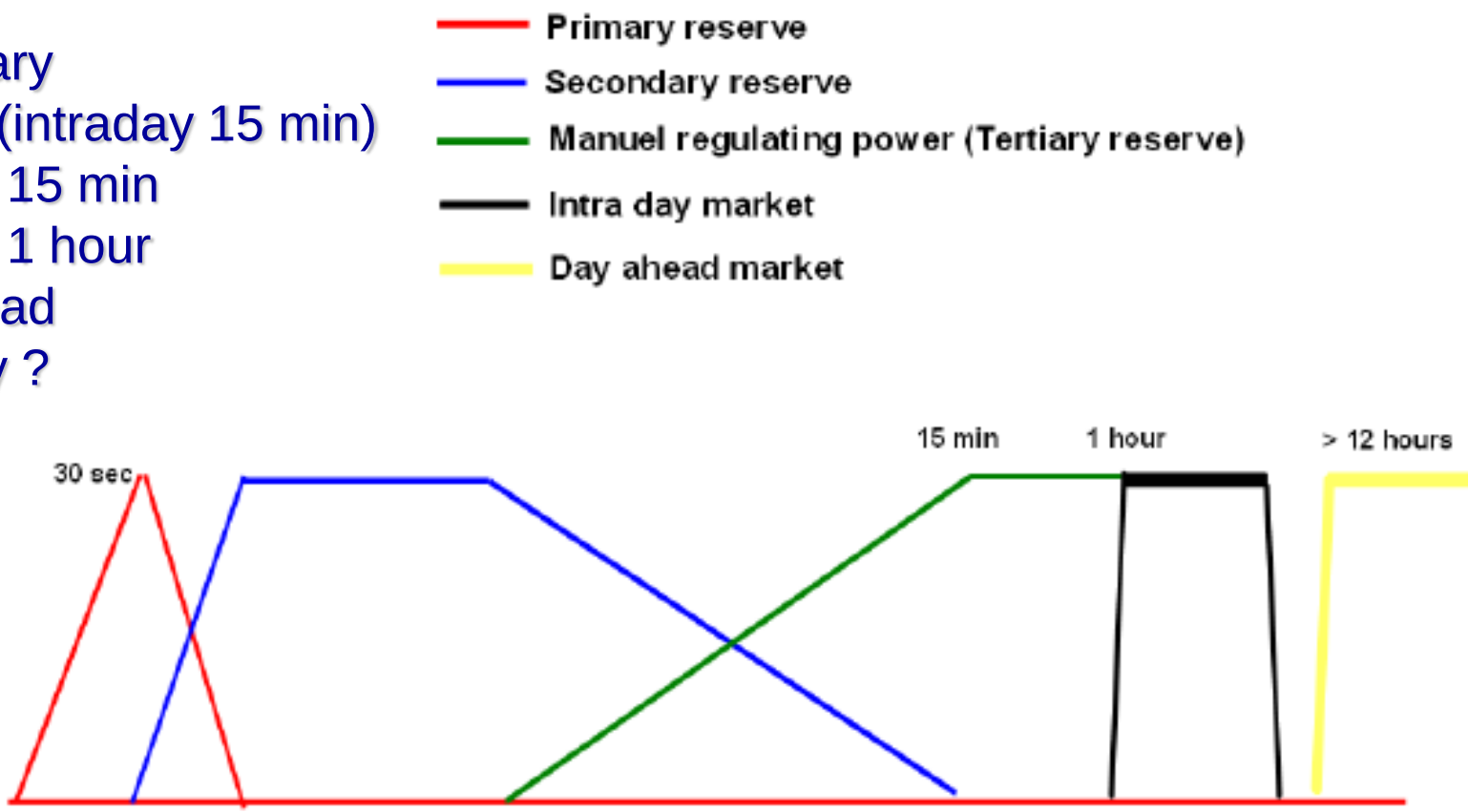
Altbach 1, Altbach 2, Bergkamen A, Bexbach 1, Bremen 6, Dürnrohr 2, Duisburg Walsum 9, Duisburg Walsum 10, Ensdorf 1, Ensdorf 3, Farge, Fenne HKV, Fenne MKV, Gersteinwerk K2, Hannover 1, Hannover 2, Hastedt 15, Heilbronn 7, Herne 3, Herne 4, Hyden, Ibbenbueren B, Karlsruhe 7, Karlsruhe 8, Kiel, Luenen 1, Luenen 6, Luenen 7, Mannheim TNG, Mannheim Amprion, Mannheim DB, Mehrum 3, Mellach, Moorburg A, Moorburg B, München 2, Reuter C, Reuter D, Reuter E, Riedersbach 2, Rostock, Scholven B, Scholven C, Staudinger 5, Tiefsack 2, Voerde A, Voerde B, Voerde 1, Voerde 2, Wedel 1, Wedel 2, Weiher 3, Westfalen E, Wilhelmshaven E.ON, Wilhelmshaven GDF, Wolfsburg West 1, Wolfsburg West 2, Zolling



This data is published with a time lag of five days.
Datasource: EEX
Last update: 09 Apr 2017 19:51

Electricity markets – reserve:

- Primary
- Secondary
- Tertiary (intraday 15 min)
- Intraday 15 min
- Intraday 1 hour
- Day ahead
- Capacity ?

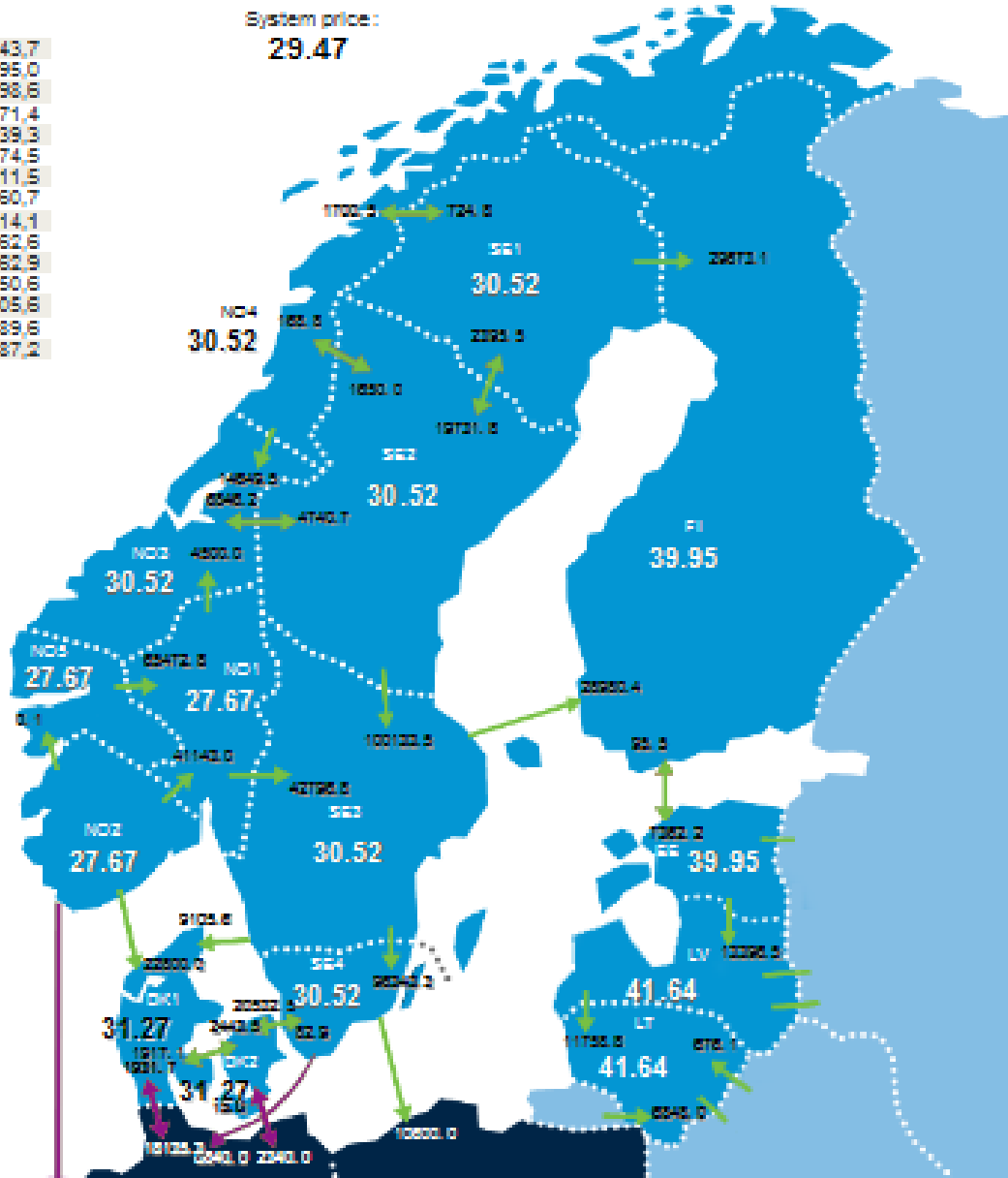


31-03-2014 Resolution Whole Day Currency EUR Capacities Flow Area Prices

ITVC ITVC

Elspot volumes

	Buy	Sell
NO1	95 762,7	36 443,7
NO2	114 151,9	178 095,0
NO3	62 653,6	41 398,6
NO4	47 716,4	62 871,4
NO5	51 566,6	117 039,3
DK1	62 253,7	30 874,5
DK2	35 987,5	15 011,5
SE1	28 675,6	76 660,7
SE2	40 392,6	123 814,1
SE3	239 363,6	230 862,6
SE4	88 356,6	12 462,9
FI	159 337,4	107 950,6
EE	21 975,8	28 105,6
LT	28 248,4	16 489,6
LV	5 124,9	3 487,2



Nord pool spot
DK+EE+FI+LT+ LV+NO+SE
85% market

http://www.nordpoolspot.com/Market-data1/Maps/Elspot-Market-Overview/Elspot-Prices

Go-live!

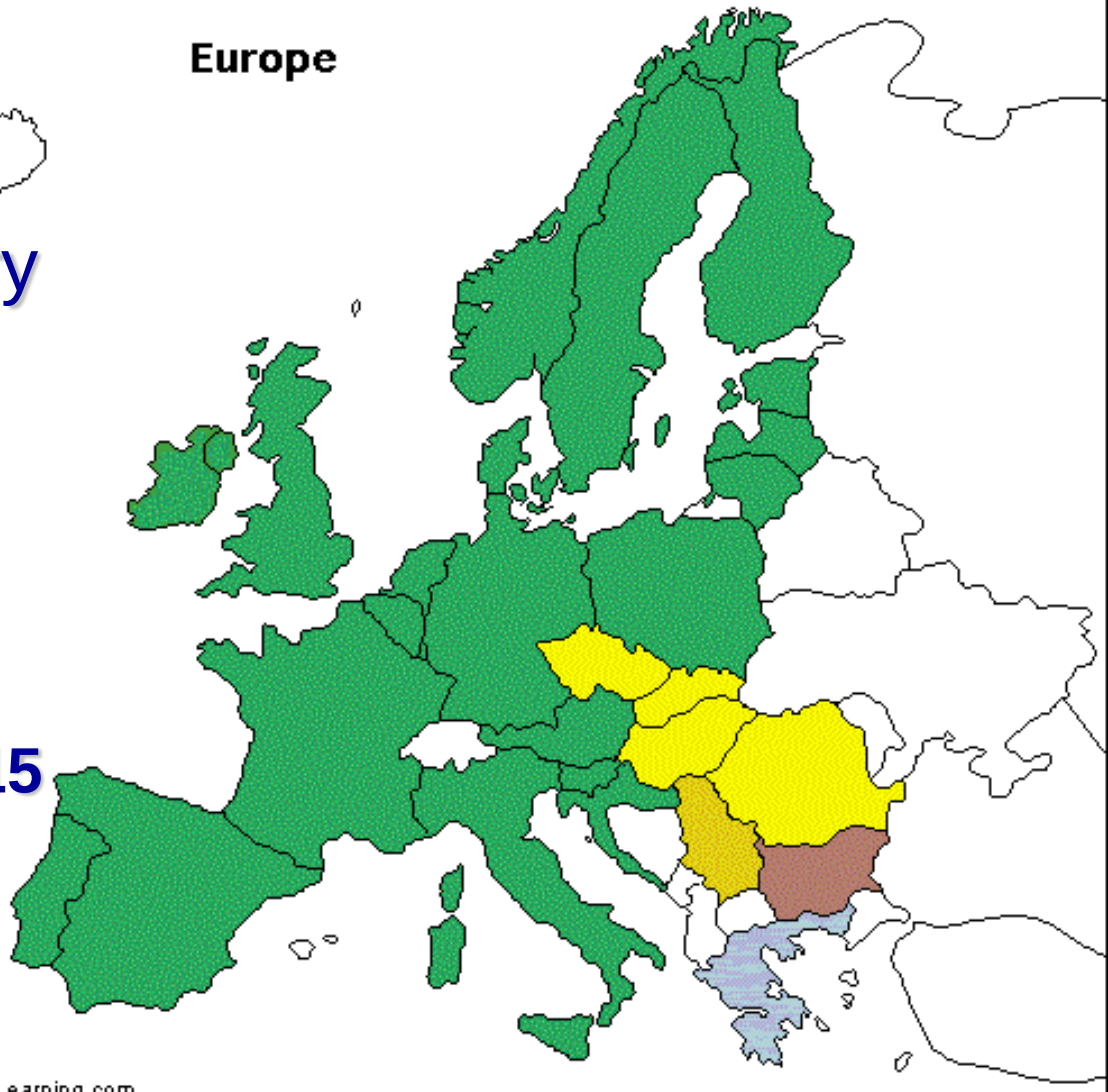
NWE+CWE price coupling on February 4, 2014

75% of European power market

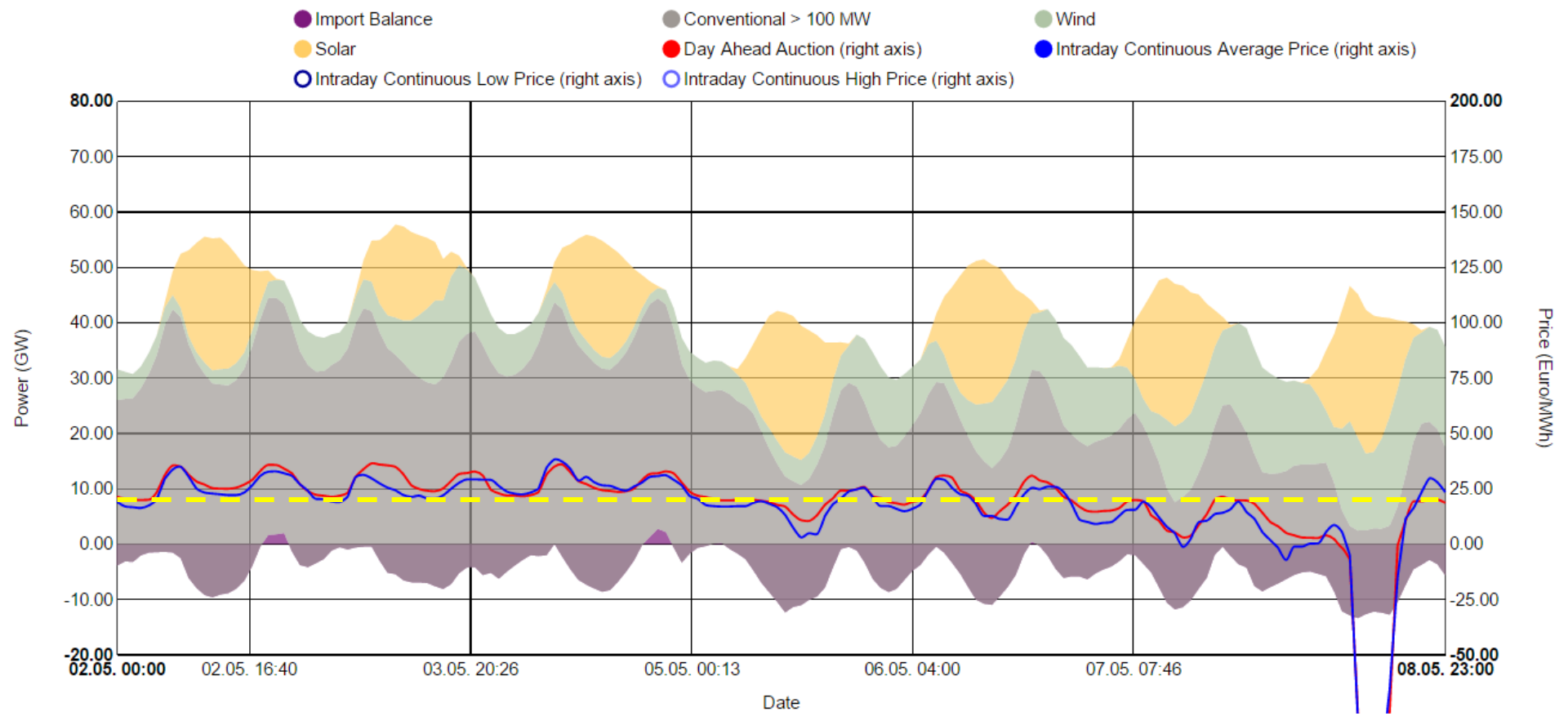
ES+PT coupled in May 2014

IT+SI coupled in Feb 2015

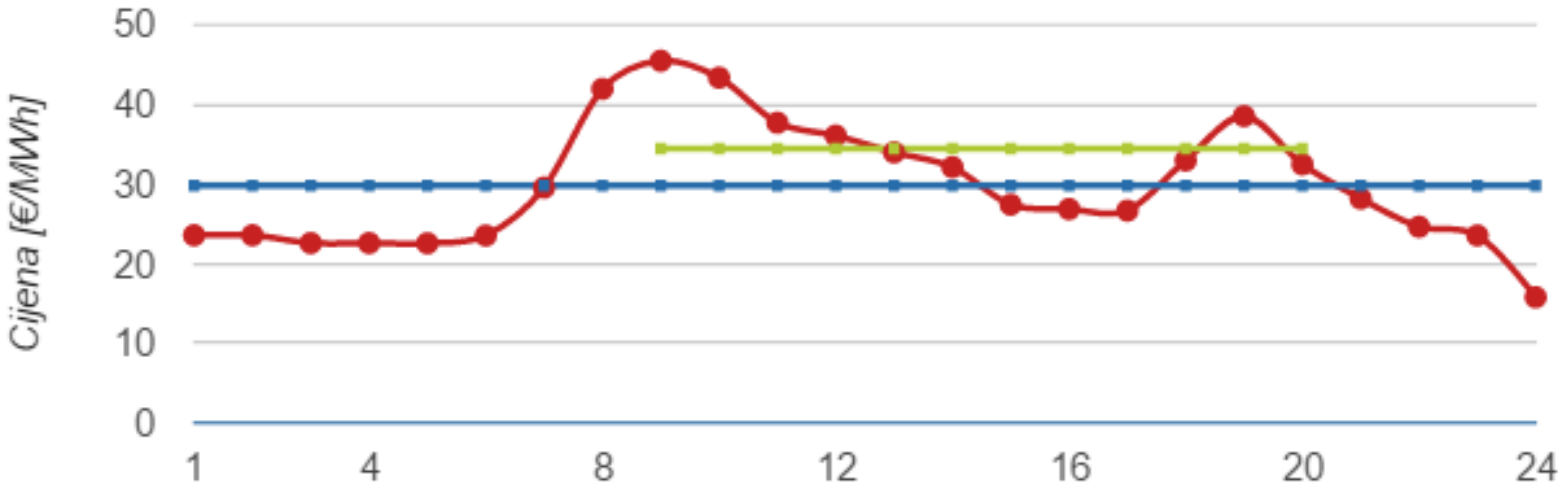
IE+HR coupled in Jun 2018



Electricity production in Germany in week 18 2016



CROPEX

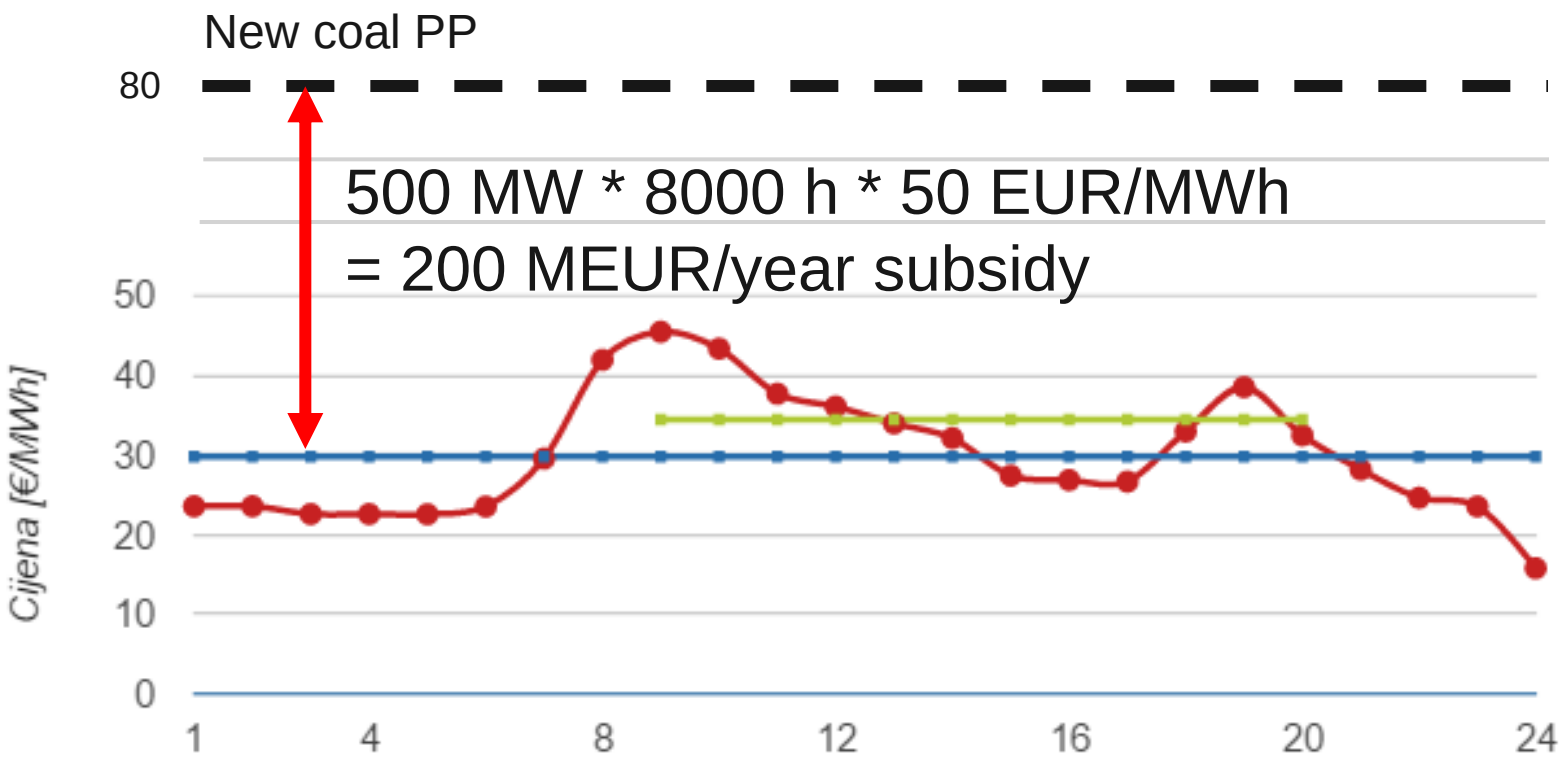


Bazna: 29,80 €/MWh
Vršna: 34,45 €/MWh

Bazna Vršna Cijena

www.cropex.hr, 19.2.2016

A new coal power plant?

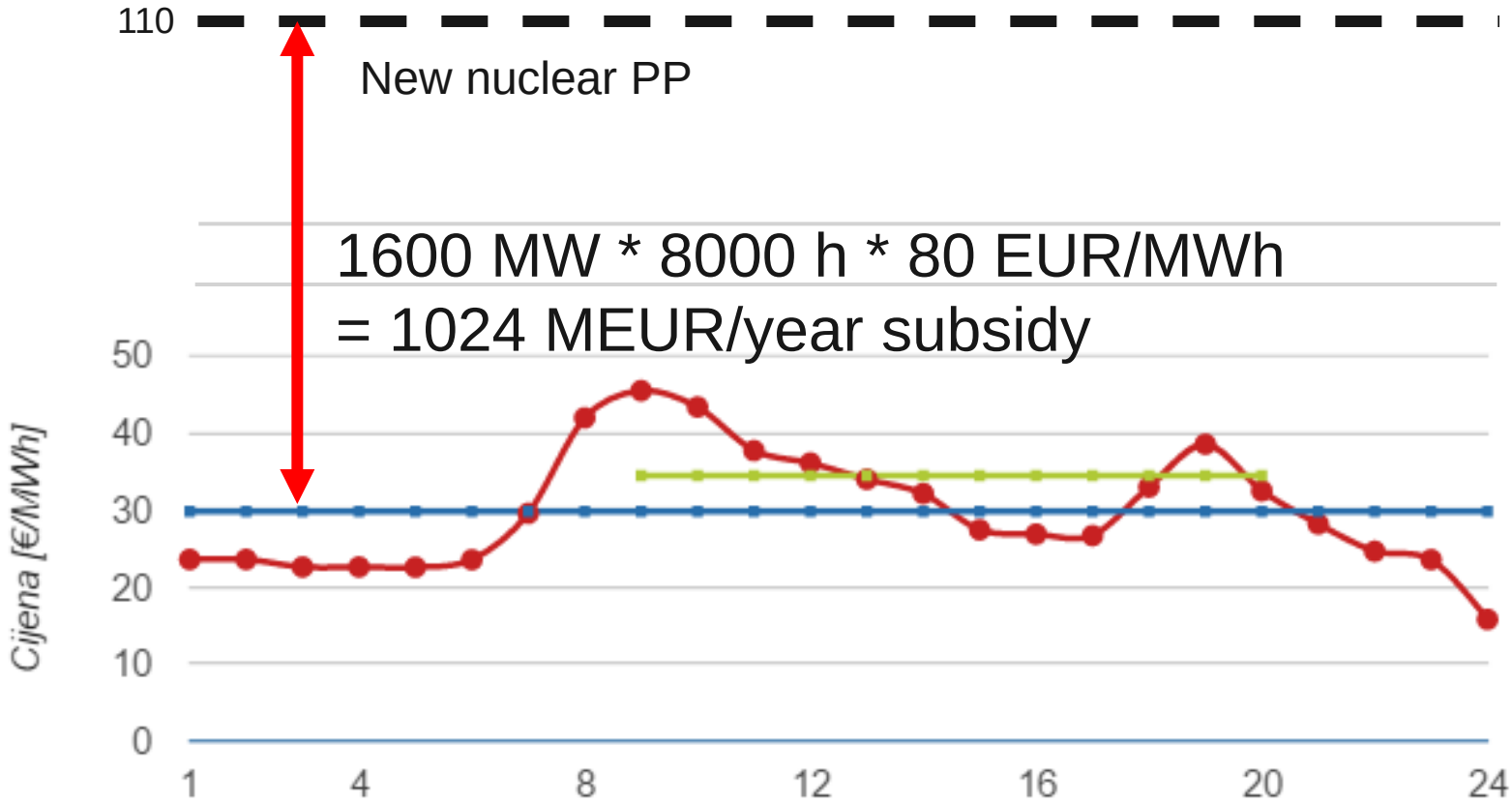


Bazna: 29,80 €/MWh
Vršna: 34,45 €/MWh

Bazna Vršna Cijena

www.cropex.hr, 19.2.2016

And a new nuclear power plant?



Bazna: 29,80 €/MWh
Vršna: 34,45 €/MWh

Bazna Vršna Cijena

www.cropex.hr, 19.2.2016

Markets and RES

- Consequences of market liberalisation:
  - Demission of base load
  - The importance of balancing power (gas, accumulation hydro)
  - Cycling of old coal power plants (4000 hours by 2020)
  - Market arbitrage and demand response (power-to-heat, power-to-water, e-mobility, power-to-e-fuels -> power-to-X) – where **cities** come in!

Demand response – power-to-X

The role of cities (power+heat+transport)

- 20th century energy systems: supply follows demand
- 21st century energy systems: demand follows supply -> smart energy systems

3 options for heat sector

1. Savings (Everywhere)

- Reduce our demand for heat:
  - Space heating
  - Hot water

2. Individual Units (Everywhere)

- Use a heating unit in each building:
  - Boilers:
    - Oil
    - Biomass
  - Heat Pumps
  - Electric Heating

3. Networks (Urban Areas)

- Share a heating network:
  - Gas
  - Water (i.e. district heating)

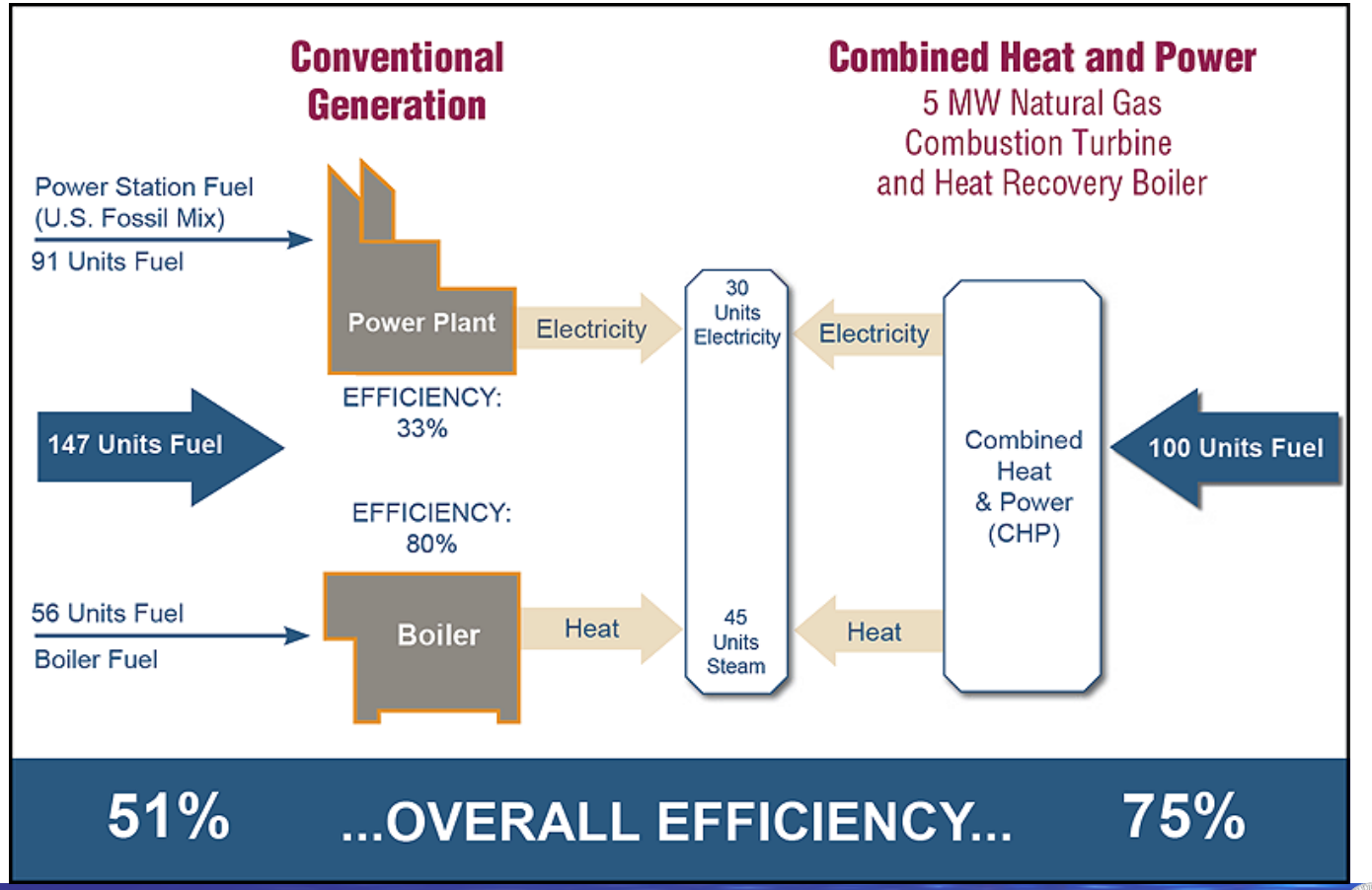
Individual heating

Heating Unit	Sustainable Resources	Efficient	Cost
Electric Heating	☺	☹	☹
Heat Pumps	☺	☺	😐
Oil Boilers	☹	😐	😐
Biomass Boilers	☹	☹	☺

Heat networks

Heating Unit	Sustainable Resources	Efficient	Cost
Gas Grid	☹	😐	😐
District Heating	☺	☺	☺

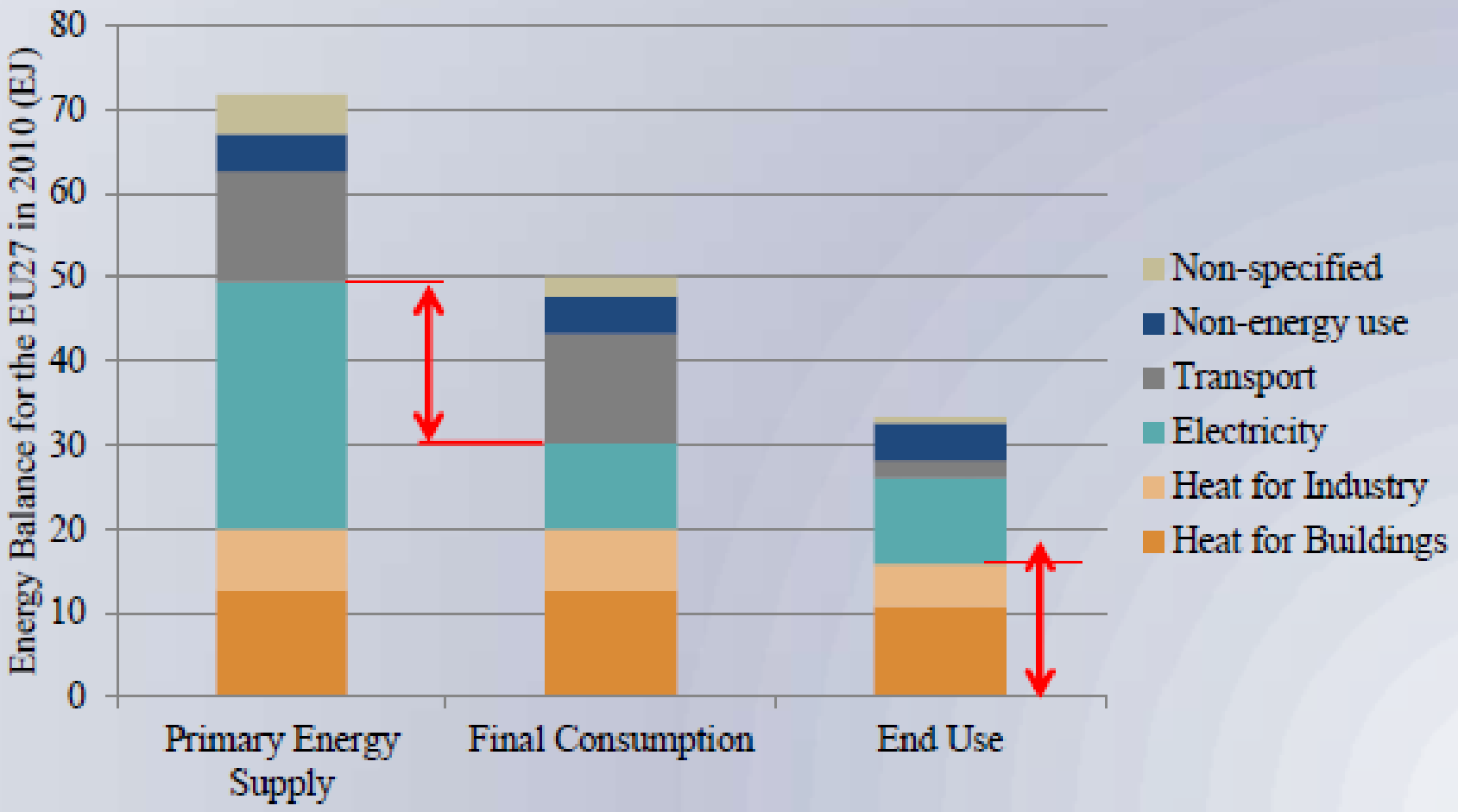
CHP is better than separate heat and power

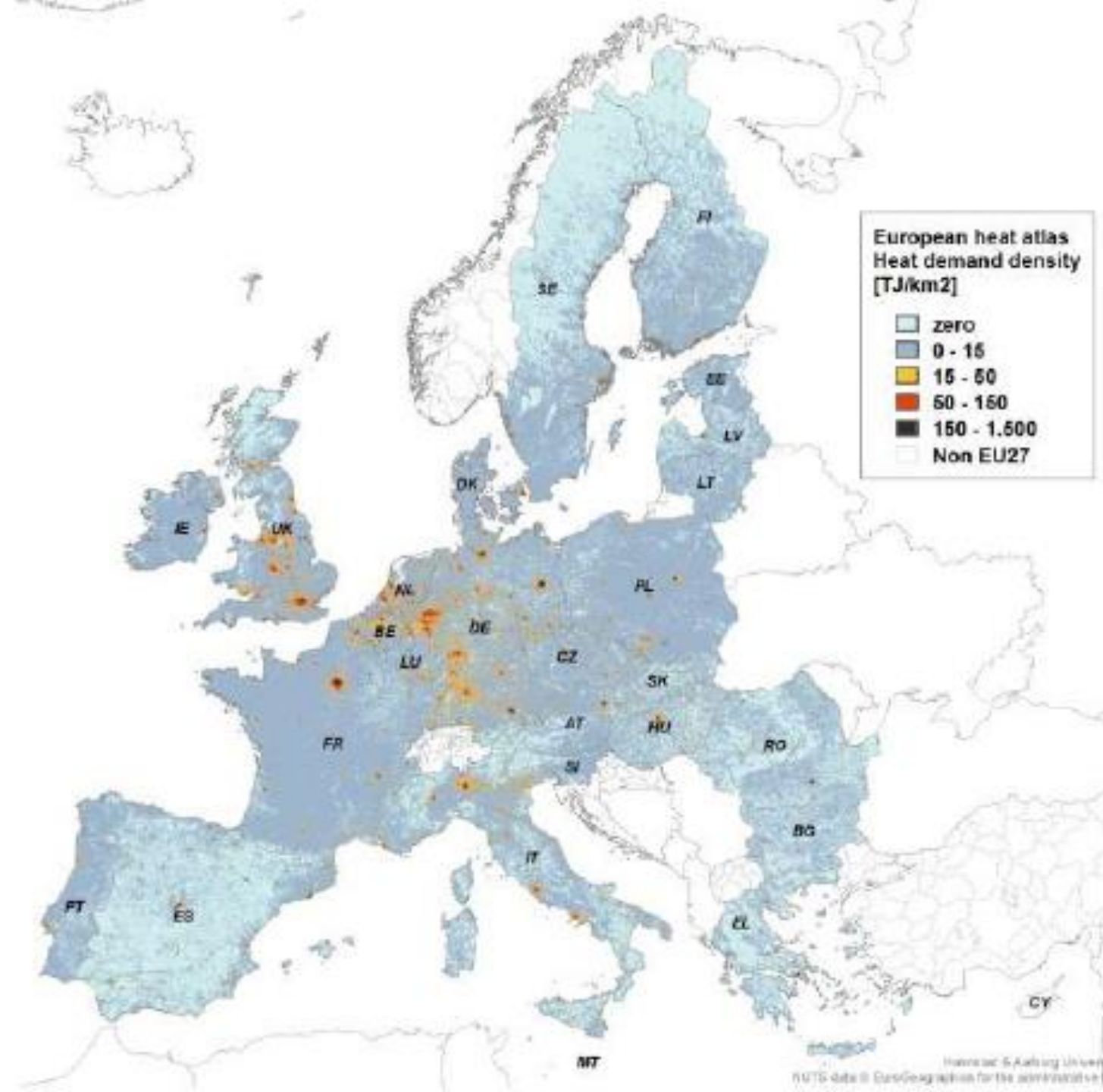


Why CHP+DHC+HP is better than gas boilers?

- Combined cycle 100 fuel
  - 45 units excess heat +
  - 55 units electricity -> $HP_{COP=6}$ 2DHC = 330 units heat
  - 475 units heat * losses …
- Gas heating 100 fuel -> 100 units heat * losses

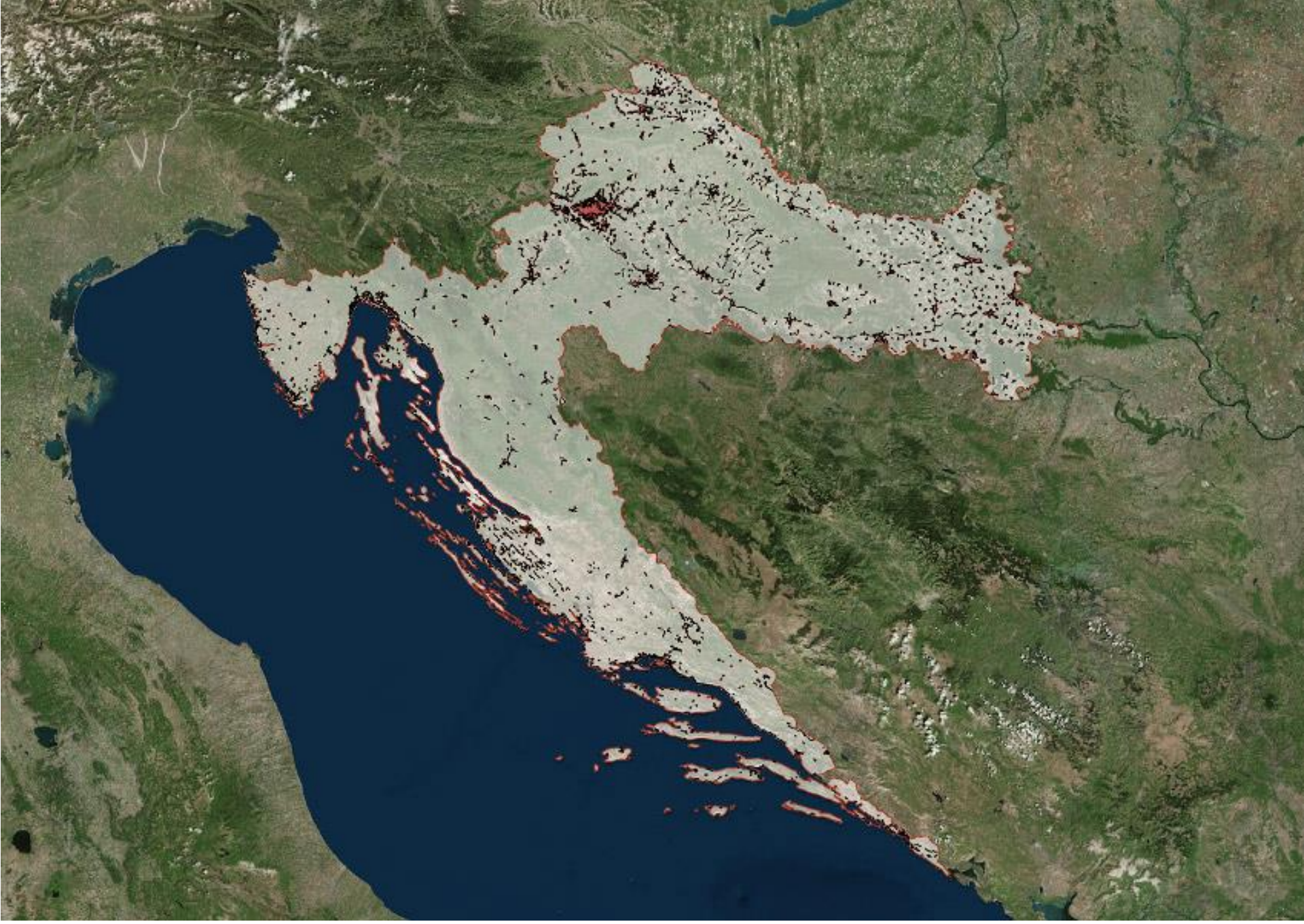
Surplus heat today in Europe



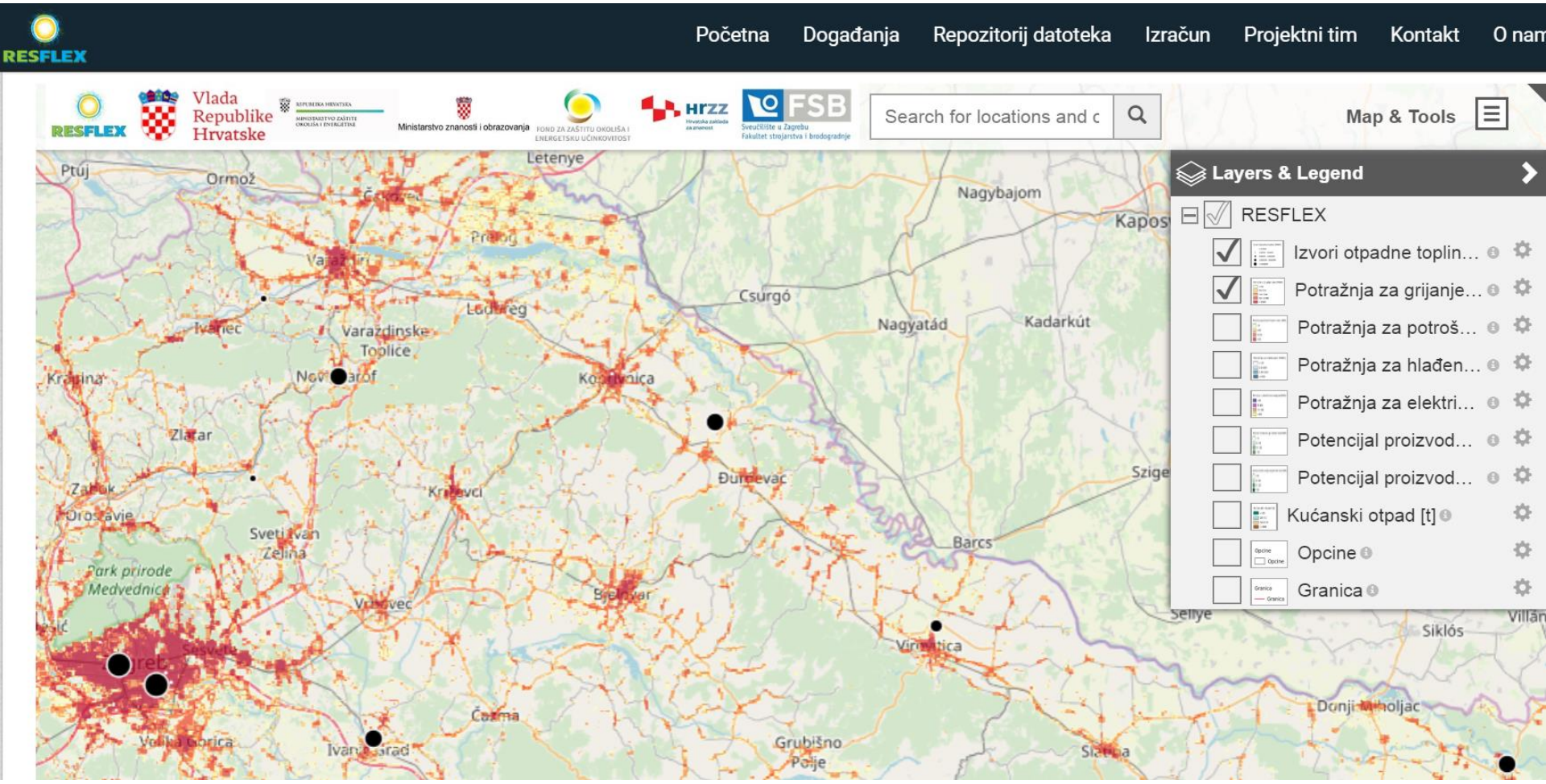


EU Heat Atlas from HRE

District Heating can supply ~50% of the heat demand

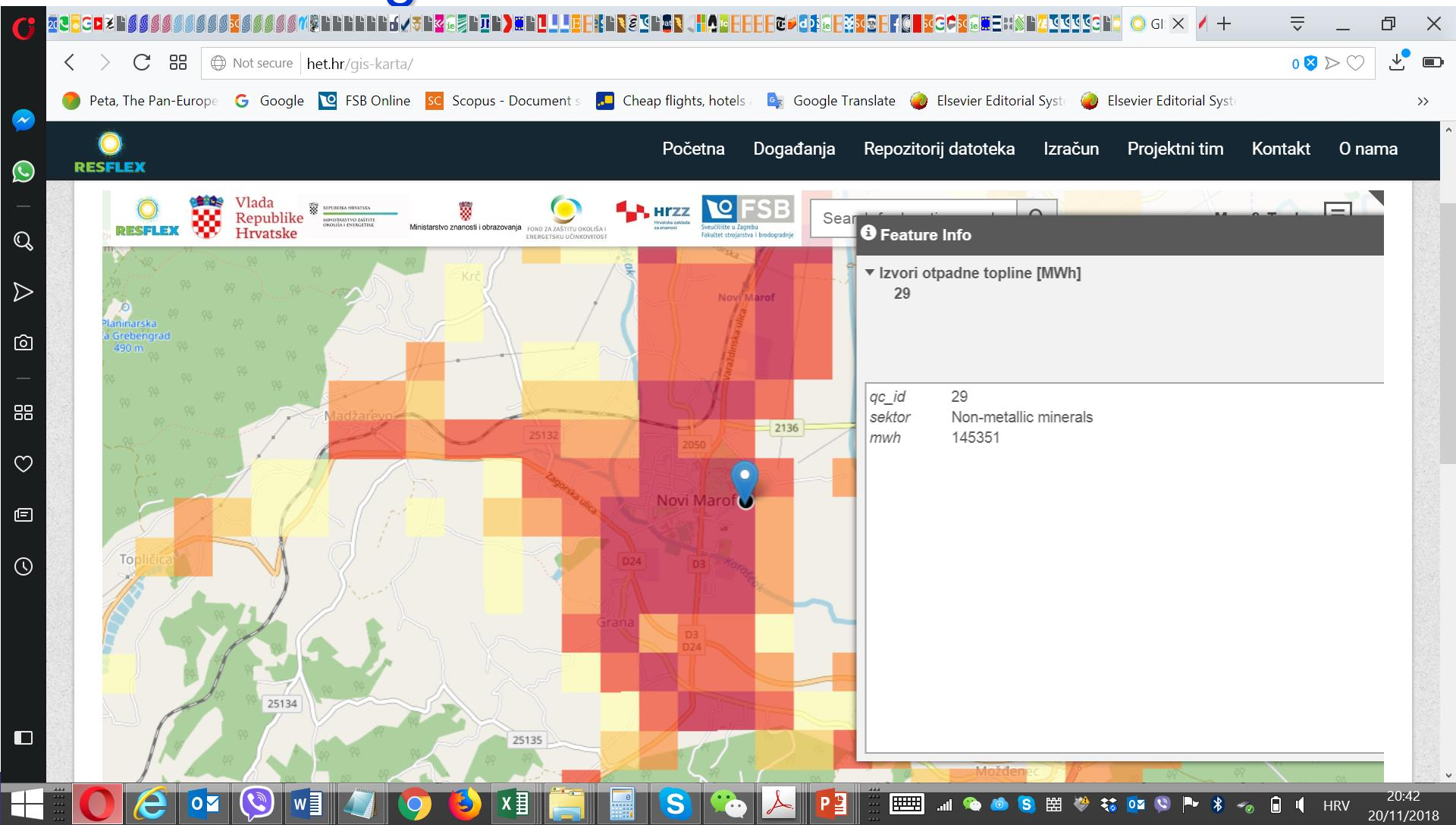


GIS Heat map of Croatia - http://het.hr/gis-karta/

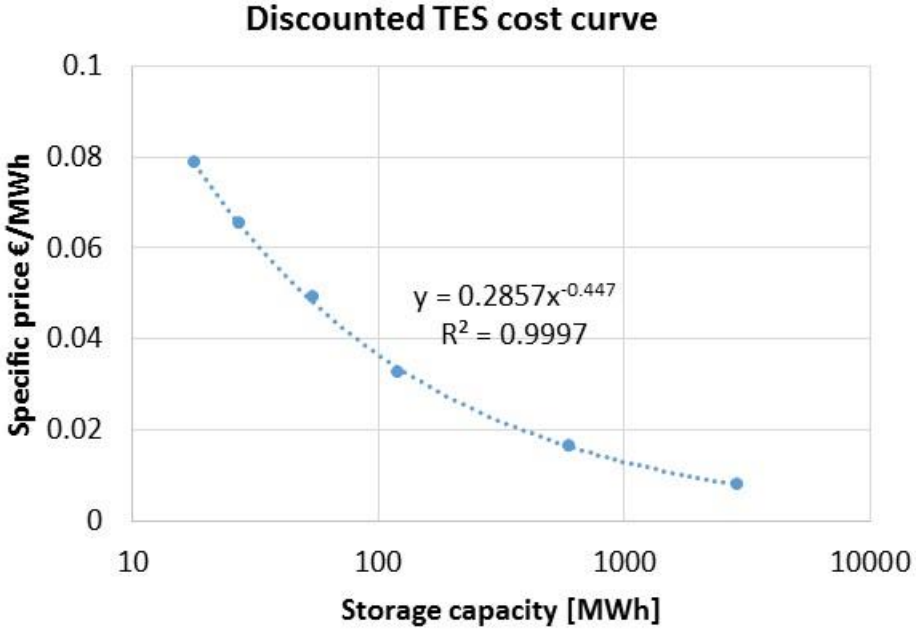


UNIVERSITY OF ZAGREB
FACULTY OF MECHANICAL ENGINEERING AND NAVAL ARCHITECTURE
DEPARTMENT OF ENERGY, POWER AND ENVIRONMENTAL ENGINEERING

Pairing DH with excess heat source

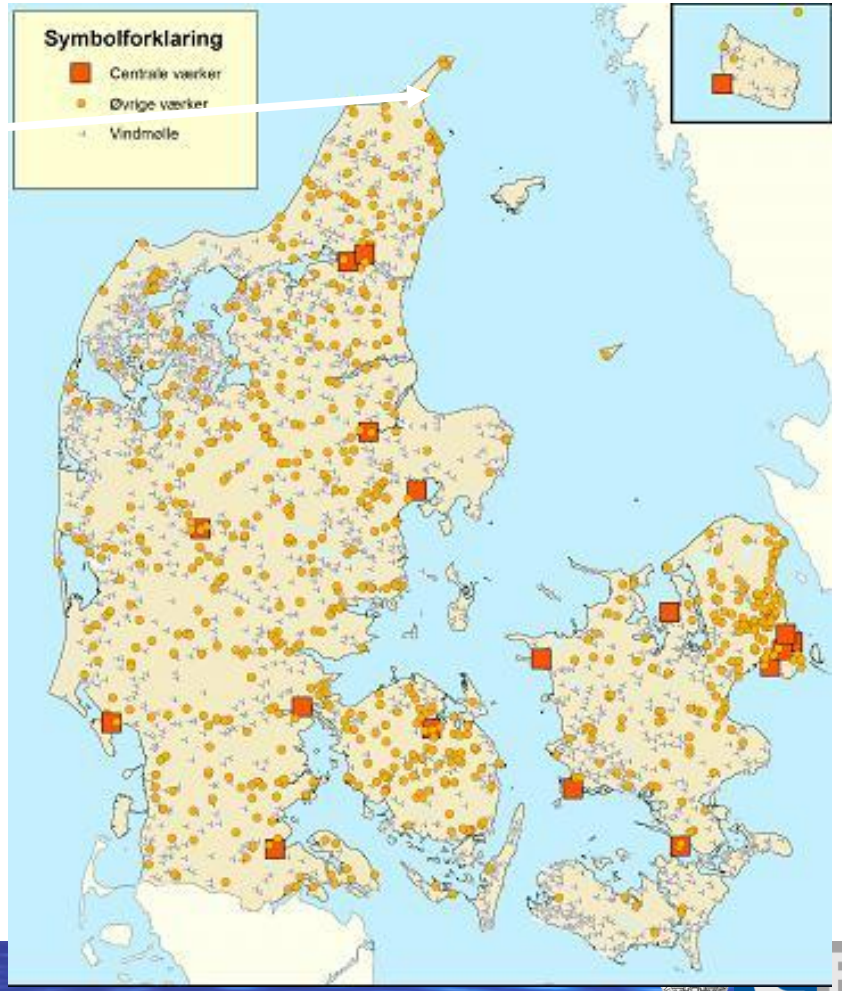


Thermal energy storage



- Seasonal pit thermal storage
- Discounted to represent hourly cost of storing heat in PTES

Case: Skagen CHP plant



Skagen CHP plant

- CHP capacity: 13 MWe and 16 MWth (Three 4.3 MWe Wärtsilä Natural Gas engines)
- 250 MWh heat storage
- 37 MW peak load boilers
- 10 MW electric boiler
- Heat Pumps Investment under consideration

Operated together with a Waste Incineration plant (heat only).

Skagen

- Day ahead spot market in Jan. 2005
- Regulating power market in approx. 2006
- Automatic primary reserve market in Nov. 2009

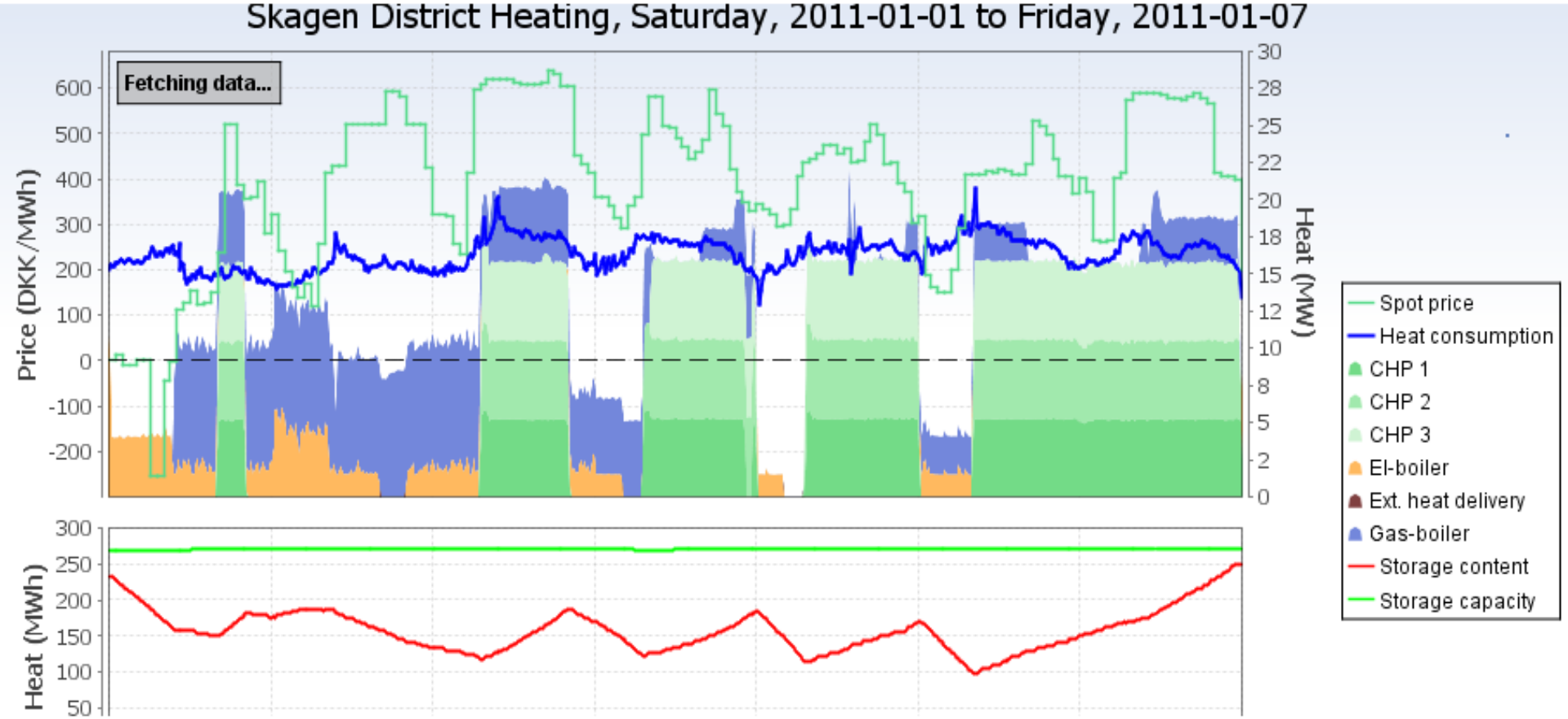
Cost of entering primary automatic reserves market

- Cost of making +- 1.4 MW available on the engines: Only approx. 27.000 EUR.

- Investing in 10 MW electric boiler:

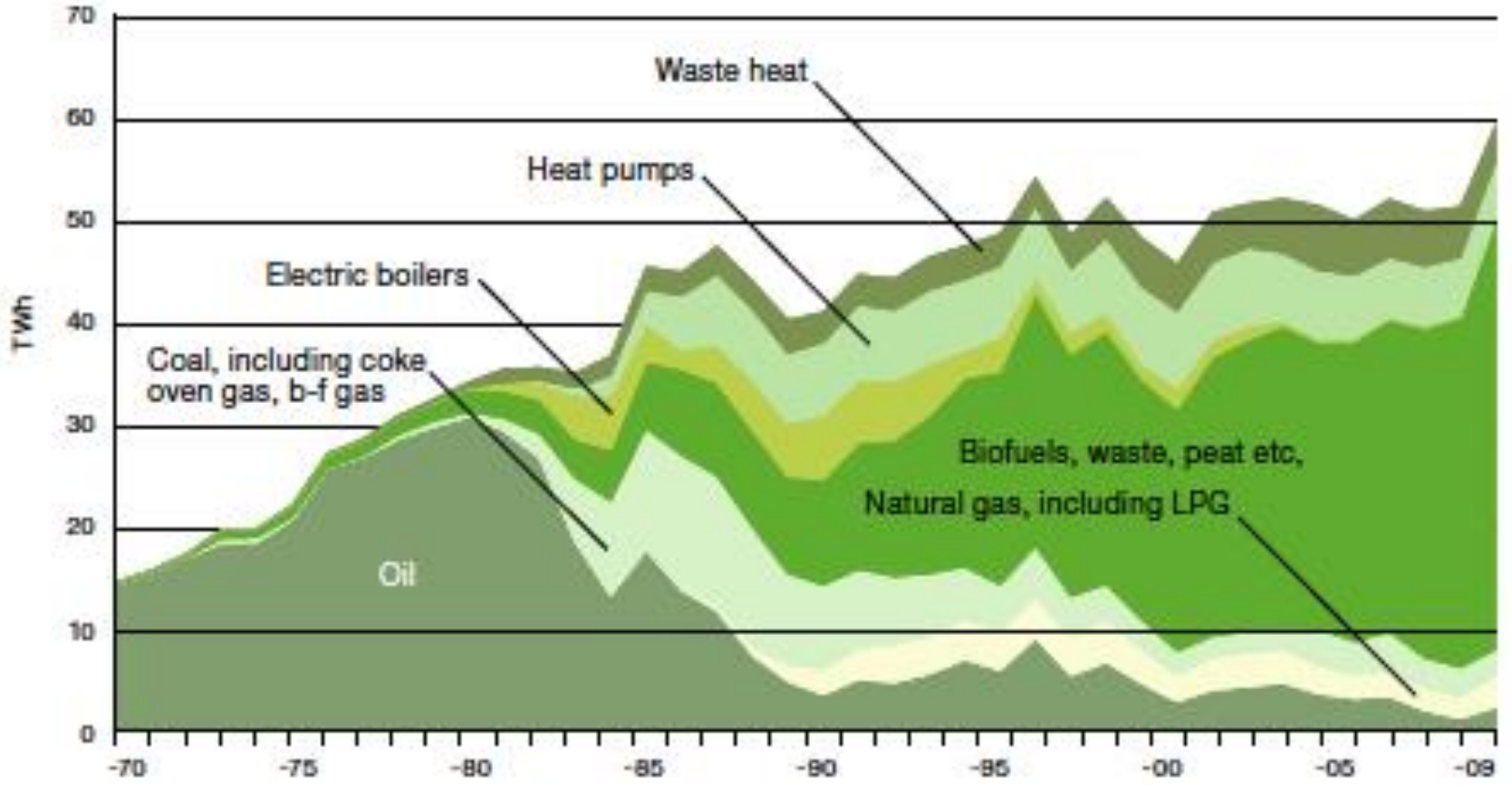
  Approx 0.7 MEUR.

Skagen CHP plant – power-to-heat



DH in Sweden

Figure 30 Energy input for district heating, 1970–2009



Source: Statistics Sweden and the Swedish Energy Agency

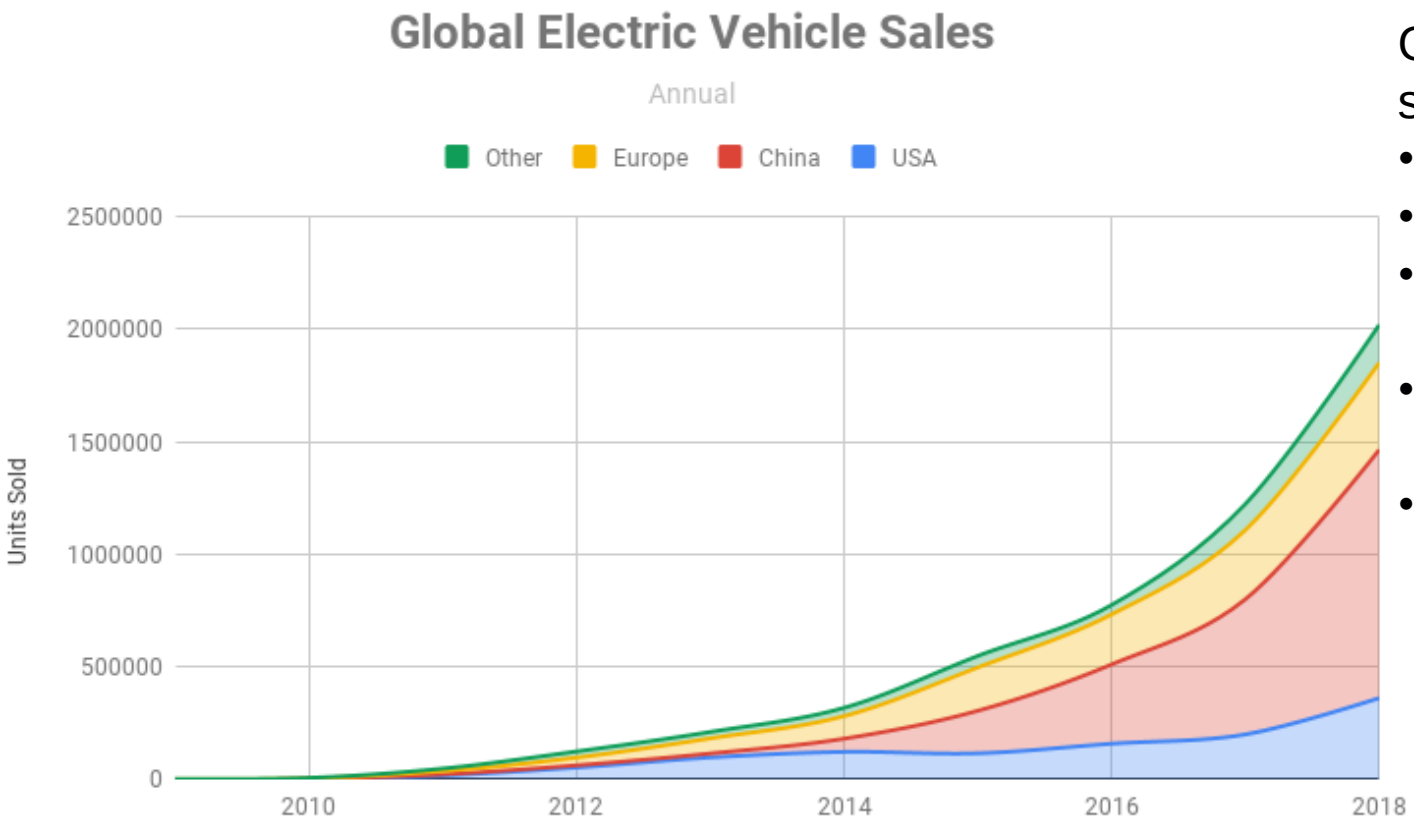
District heating

- 4th generation district heating
  - Low temperature 60-70/40
  - Low ratio heating/hot water – continuity of heat load
  - Heat storage (4 m^3/customer)
  - CHP – follows electricity market
  - Waste heat from various sources (power plants, waste to energy, industry)
  - Heat from solar, biomass, gas
  - Electric heaters – primary reserve market (in future heat pumps, also secondary reserve)

What about gas heating?

- Increases import dependence
- No local experience in Macedonia
- No synergy in smart energy systems
- High cost, not sustainable
- Netherlands banned gas boilers since 2018, UK since 2025, Denmark replacing gas networks with district heating

Transport electrification has started



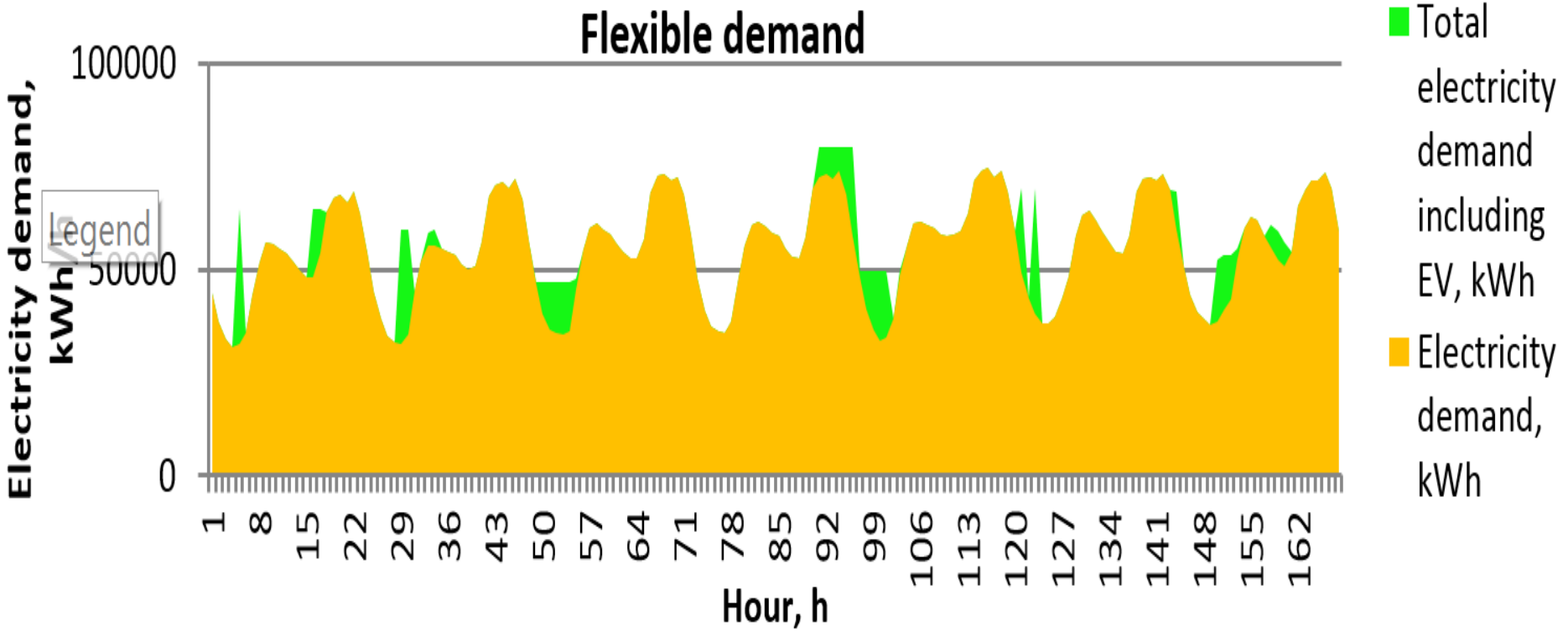
Global light vehicles sales in 2018

- 2 mln EV
- 95.5 mln total
- 2.1% global sales
- 65% EV sales growth
- 1.1% cars sales growth

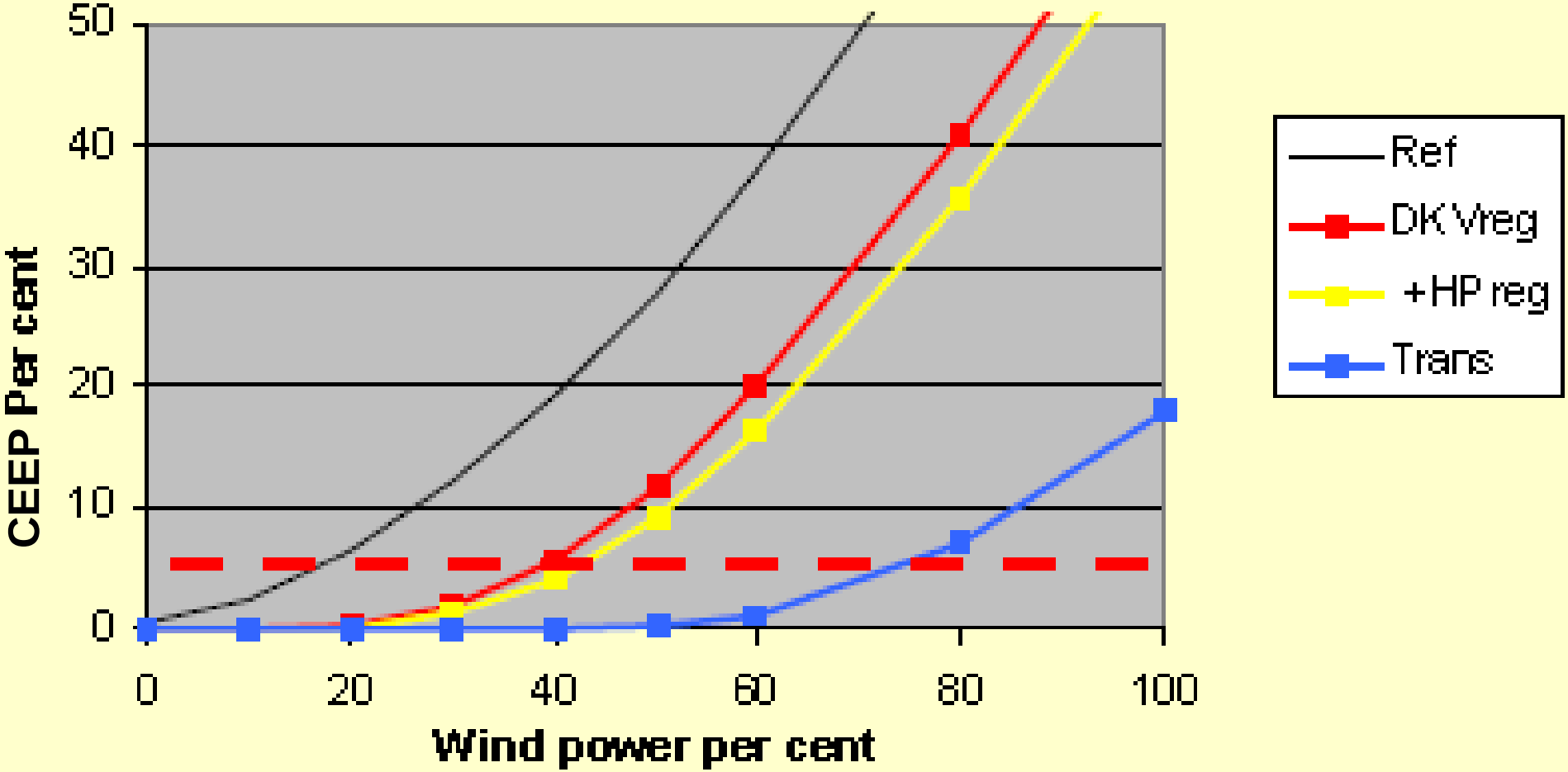
Demand response – power-to-transport

- Electromobility
  - Only personal cars and short distance utility vehicles, 2 mln PHEV and BEV sold in 2018
  - If RESe 80% reduction of primary energy
  - Fast charging 70 kW – huge problem if left uncontrolled, ex AT, 4 mln cars arrives home, plugs in – 280 GW (14 GW installed cap)
  - Smart charging – market based, smoothing the demand

Smart charging



Surplus Electricity Production
Including grid-stbilisation



Issues on the way

- Road freight – maybe electrified roads
- Shipping, aviation cannot yet be electrified
- High temperature processes sometimes cannot be electrified
- Winter windless weeks
- It all makes up to 20% of energy demand
- If biomass is used only for the above it could cover half of the missing demand
- And the rest? Synthetic or e-fuels?

100% RES Southeast Europe 2050

Zero carbon energy system of South East Europe in 2050, D.F. Dominković, I. Bačeković, B. Ćosić, G. Krajačić, T. Pukšec, N. Duić, N. Markovska, Applied Energy, doi:10.1016/j.apenergy.2016.03.046

- PV: 65 GW, CSP: 11 GW
- Wind: 50 GW
- Dammed hydro: from 18.8 to 23.5 GW
- DH supplies 51.5% of heating demand
- Large-scale HPs: 1.5 GW
- Solar thermal with energy storage in DH: 13.3 %
- Seasonal thermal energy storage: 230 GWh
- Waste incineration plants: 0.96 GWe
- Geothermal plants: 1.25 GWe
- Geothermal heating plants: 7.5 GW
- River hydro, pumped-hydro 2 GW, 1000 GWh
- Decommission of nuclear PPs
- Reduction in thermal power plants capacity to 24.7 GW

Conclusions

- Wind and solar are coming, but difficult to integrate
- Integration of power, heating, cooling, water and transport system necessary – **cities** are important as energy hubs
- Demission of base load. Natural gas and/or accumulation hydro critical for transition
- Smart energy systems – cheap and simple
- Great time for engineers!

THANK YOU FOR YOUR ATTENTION!

Благодарам за вниманието!

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