The Danish triple tariff and the radically changing role of CHPs through the transition to a renewable energy system

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4th International Conference on Smart Energy Systems and 4th Generation District Heating 2018
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The Danish triple tariff

Working days	Low load	High load	Peak load
Winter (October-March)	21.00– 06.00 All holidays All weekends	06.00 – 08.00 12.00 – 17.00 19.00 – 21.00	08.00 – 12.00 17.00 – 19.00
Summer (April-September)	21.00– 06.00 All holidays All weekends	06.00 – 08.00 12.00 – 21.00	08.00 – 12.00

The Danish triple tariff

- Payment for reducing fossil fuel use at power plants
- Payment for reducing variable operating costs at power plants
- Payment for reducing fixed operating costs at power plants
- Payment for reducing the need for new power plants
- Payment for reducing the need for transmission grid expansion
- Payment for reducing the need for distribution grid expansion
- Payment for reducing grid loss in transmission grids
- Payment for reducing grid loss in distribution grids

Detailed legislation governing the Danish triple tarif

Power plant net electrical efficiency	η	58%	
Power plant, Variable operation and maintenance cost	V_{Plant}	2.54	EUR/MWh$_e$
Power plant, Yearly fixed operation and maintenance cost	YF_{Plant}	13,597	EUR/MW$_e$
Real discount rate	r	3%	
Investment cost in power plant	I_{plant}	0.905	MEUR/MW$_e$
Life time of power plant	L_{plant}	25	years
Yearly capital cost factor of investment in power plant	YC_{plant}	0.05743	
Investment cost in the 150 kV-grid	I_{150}	0.286	MEUR/MW$_e$
Investment cost in the 60 kV-grid	I_{60}	0.095	MEUR/MW$_e$
Investment cost in the 10 kV-grid	I_{10}	0.054	MEUR/MW$_e$
Investment cost in the 0.4 kV-grid	$I_{0.4}$	0.054	MEUR/MW$_e$
Life time of electrical grids	L_{grid}	25	years
Yearly capital cost factor of investment in electrical grids	YC_{grid}	0.05743	

Table 2: The power plant and grid data not depending on the tariff periods, used for calculating the triple tariff.

Detailed legislation governing the Danish triple tarif

		Low tariff	High tariff	Peak tariff
Hours per year	H_i	5010	2498	1252
Full load hours of electricity demand	FLH_i	2475	1728	1097
Distribution keys for investment and yearly fixed costs	D_i	0	0.5	0.5
Net Loss percentage in the 150 + 400 kV-grid	$NL150_i$	2.8%	4.2%	4.7%
Net Loss percentage in the 60 kV-grid	$NL60_i$	2.1%	3.2%	3.6%
Net Loss percentage in 10 kV-grid	$NL10_i$	1.4%	2.7%	3.5%
Net Loss percentage in 0.4 kV-grid	$NL0.4_i$	2.8%	5.1%	6.8%

Table 3: The power plant and grid data depending on the tariff periods, used for calculating the triple tariff.

Detailed legislation governing the Danish triple tarif

$$SC_i = \frac{GP * 3.6}{\eta} + V_{Plant} + \frac{(YC_{plant} * I_{plant} + YF_{Plant}) * D_i}{FLH_i}$$

$$YC = \frac{r}{1-(1+r)^{-L}}$$

$$P@60_i = SC_i/(1 - NL150_i) + YC_{grid} * I_{150} * D_i/FLH_i$$

$$P@10_i = P@60_i/(1 - NL60_i) + YC_{grid} * I_{60} * D_i/FLH_i$$

$$P@0.4_i = P@10_i/(1 - NL10_i) + YC_{grid} * I_{10} * D_i/FLH_i$$

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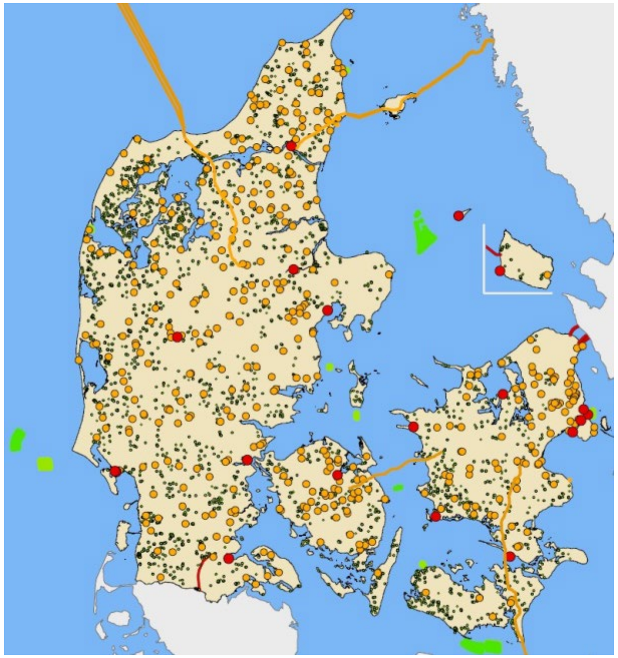
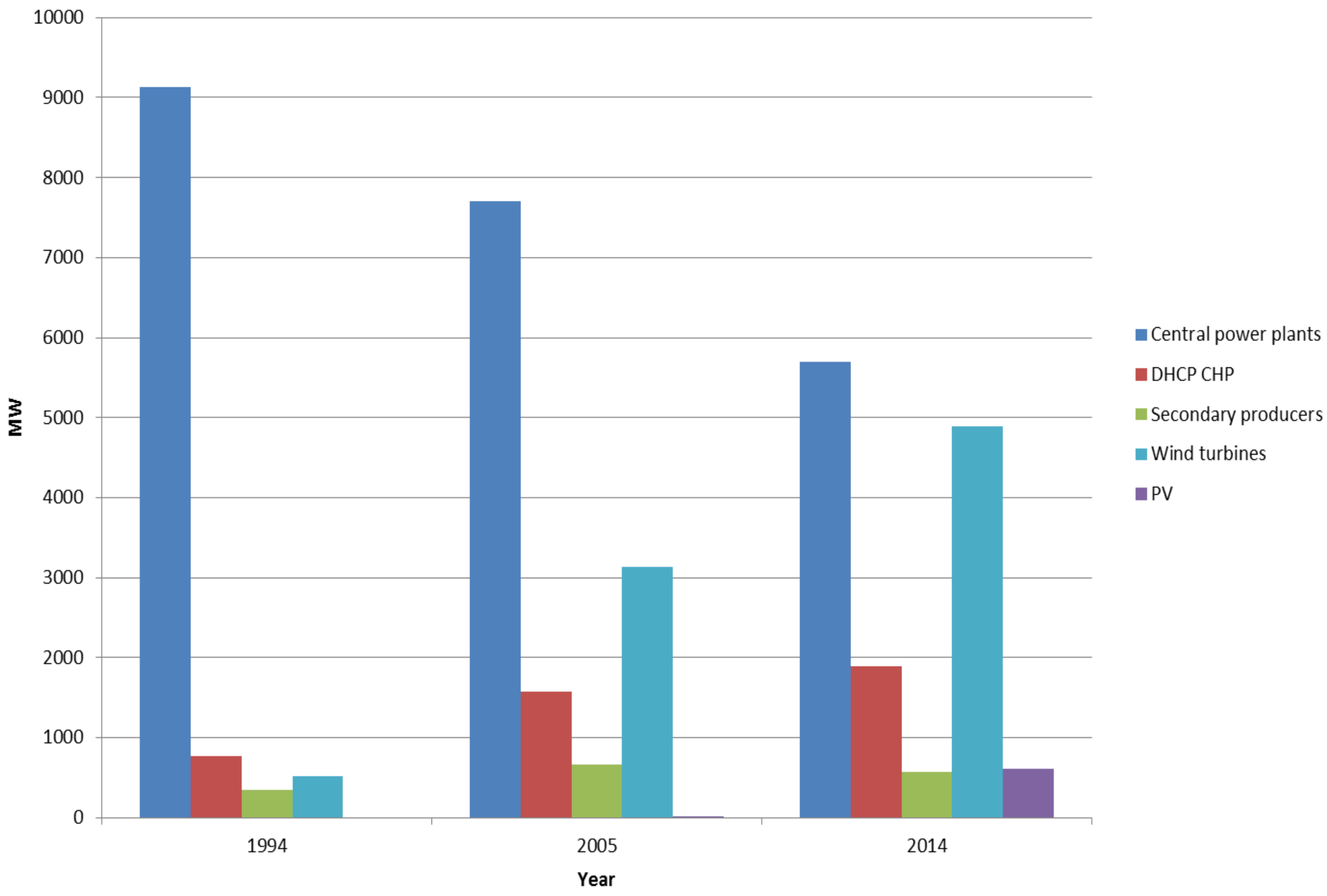
To be paid for distributed electricity production at the triple tariff October to December 2015			
EUR/MWh	**Low load**	**High load**	**Peak load**
Saved fuel costs at power plants	21,85	21,85	21,85
Saved variable operating costs at power plants	2,54	2,54	2,54
Saved fixed operating costs at power plants	0,00	3,92	6,30
Saved investment costs at power plants	0,00	20,44	32,82
Total saved at power plants	**24,39**	**48,76**	**63,51**
Saved grid loss at 150 + 400 kV	0,70	2,14	3,13
Saved grid expansion, 150 kV	0,00	6,46	10,36
Total saved an 150/60 kV-transformer	**25,10**	**57,35**	**77,01**
Saved grid loss at 60 kV	0,54	1,90	2,88
Saved grid expansion, 60 kV	0,00	2,15	3,46
To be paid for electricity delivered at 60/10 kV-transformer	**25,63**	**61,40**	**83,34**
Saved grid loss at 10 kV	0,36	1,70	3,02
Saved grid expansion, 10 kV	0,00	1,22	1,95
To be paid for electricity delivered to the 10 kV-grid	**26,00**	**64,32**	**88,31**
Saved grid loss at 0.4 kV	0,75	3,46	6,44
Saved grid expansion, 0.4 kV	0,00	1,22	1,95
To be paid for electricity delivered to the low voltage-grid	**26,75**	**68,99**	**96,71**

The electrical infrastructure in Denmark in 1985. Red circles indicate central power plants, yellow circles DHCP CHP and secondary producers above 500 kW

The electrical infrastructure in Denmark in 2015. Red circles indicate central power plants, yellow circles DHCP CHP and secondary producers above 500 kW



Electrical capacity in Denmark



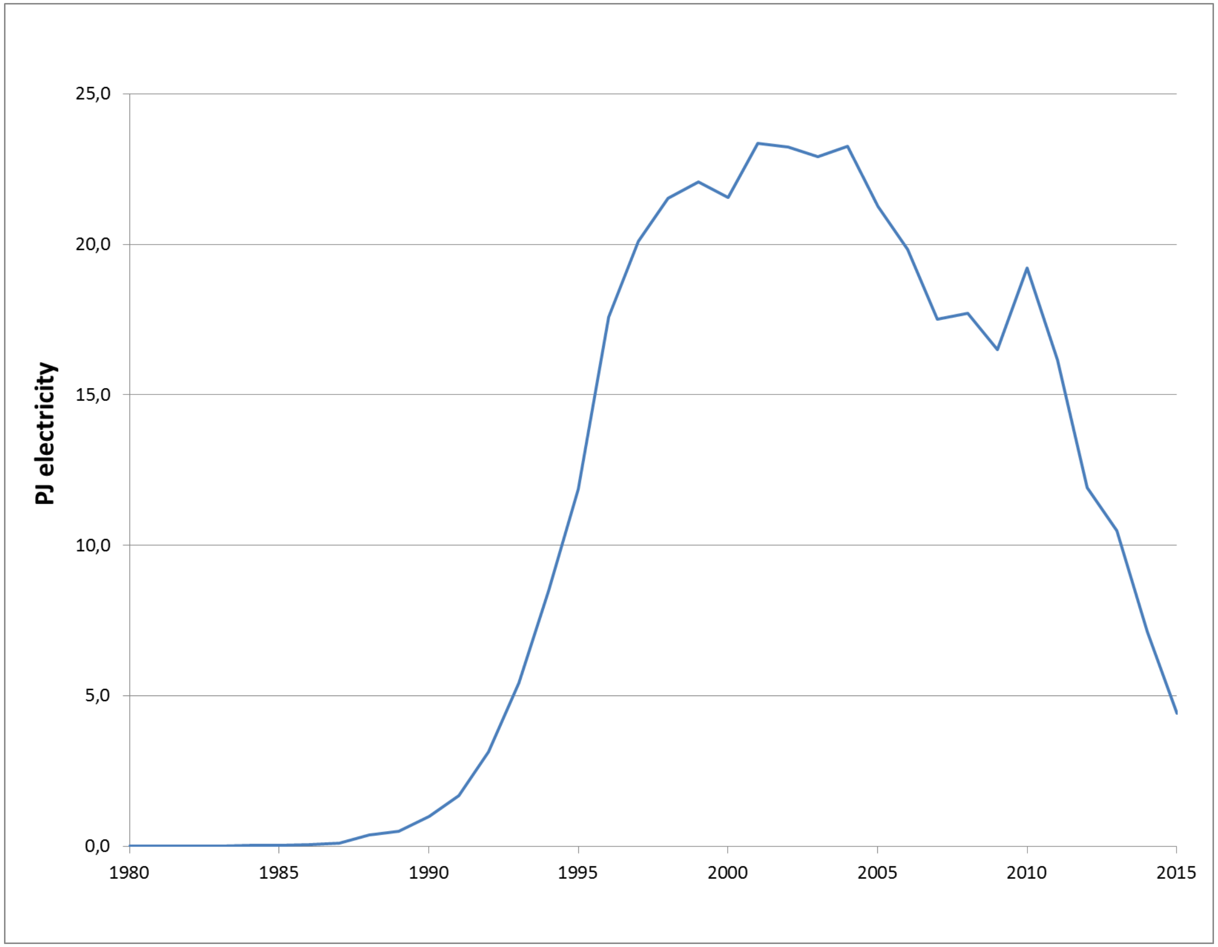
The radically changing role of CHPs

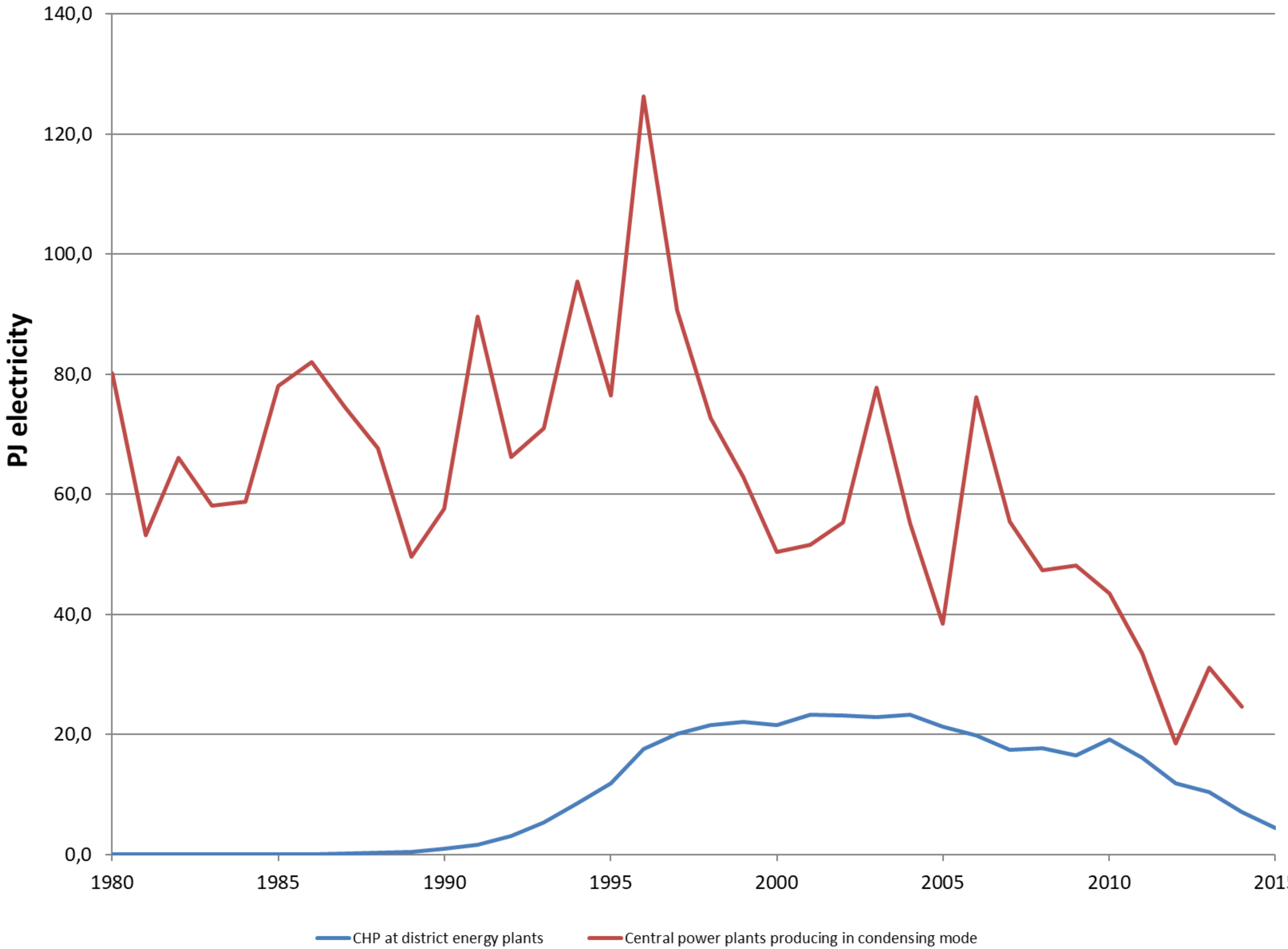
Phase 1: DHCP CHP displaces fossil fuelled power plants

Phase 2: DHCP CHP participates in the integration of fluctuating RES

Phase 3: DHCP CHP primarily delivers needed electrical capacity in few hours

Yearly electricity productions at Danish distributed CHP.





PJ electricity
140,0
120,0
100,0
80,0
60,0
40,0
20,0
0,0
1980
1985
1990
1995
2000
2005
2010
2015
CHP at district energy plants
Central power plants producing in condensing mode

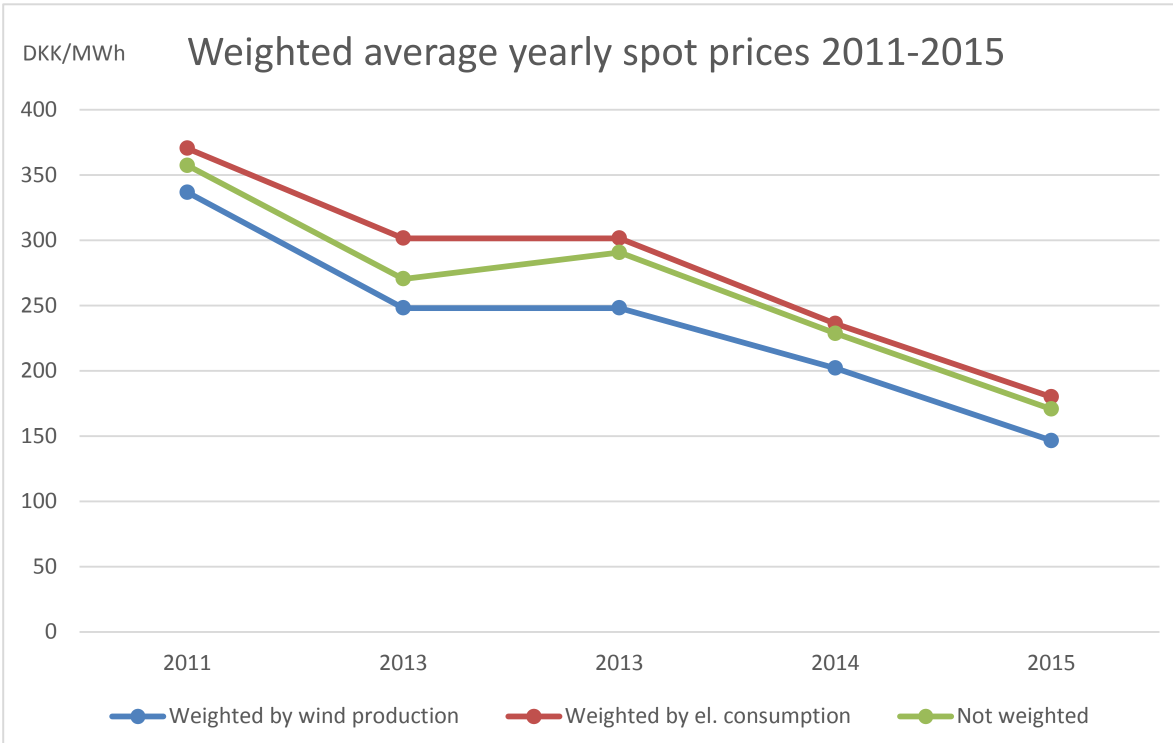
T

NOTICE:

There is no CHP in a 100% renewable energy system

CHP is a transitional technology

The Danish TSO, Energinet.dk´s plans for 100% renewable energy shows that the present CHP production in Denmark of 90 PJ-heat is in 2035 down to 40 PJ-heat and in 2050 down to 5 PJ-heat.



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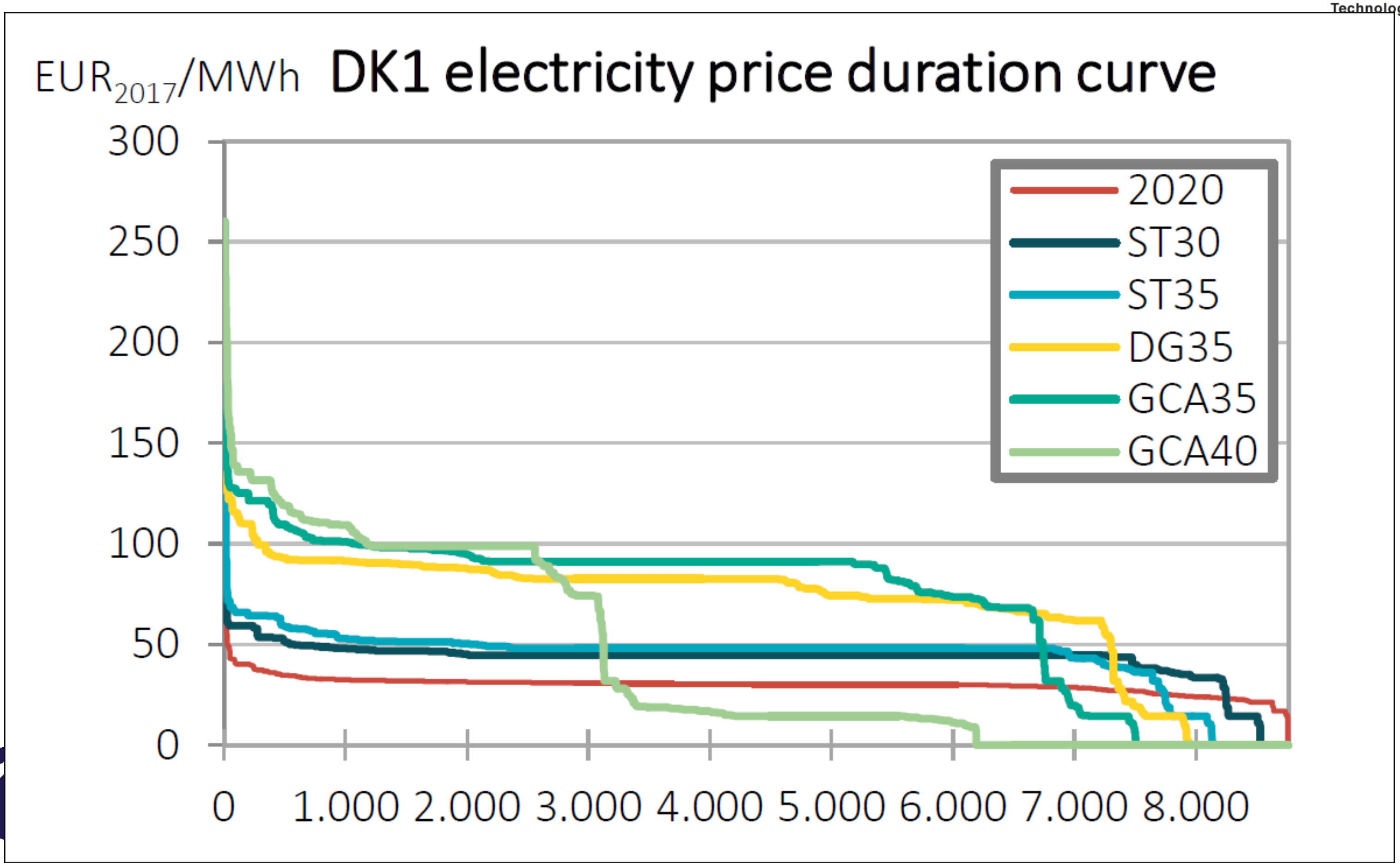
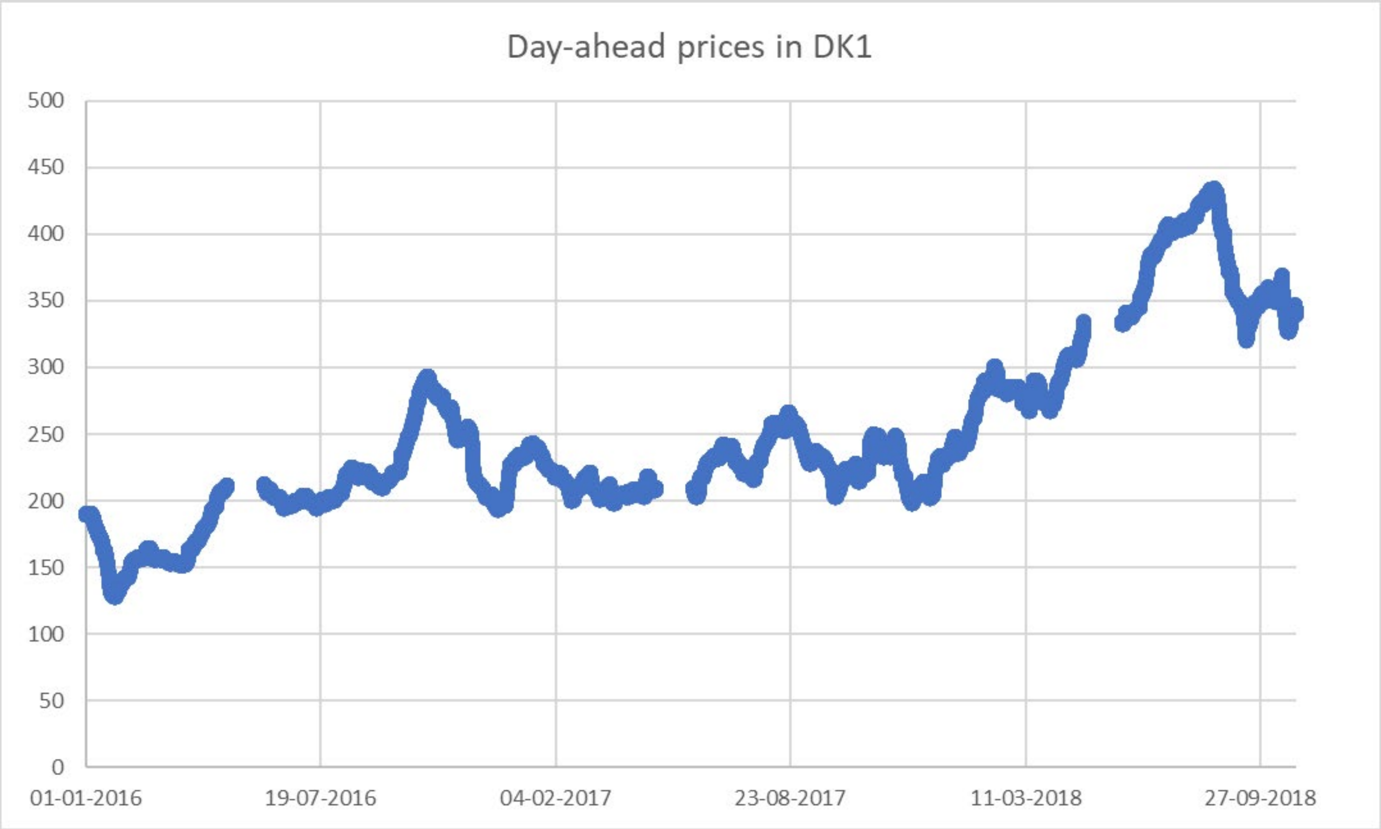
Energinet: System Perspective 2035 - Main Report_English



But prices are going up



A method for assessing support schemes promoting flexibility at District Energy plan

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Applied Energy
Volume 225, 1 September 2018, Pages 448-459

A method for assessing support schemes promoting flexibility at district energy plants

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https://doi.org/10.1016/j.apenergy.2018.05.053

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This method was tested on typical District Energy plants

CHPs		
Electrical efficiency	44.0%	
Heat efficiency	48.9%	
Total efficiency	92.9%	
Fixed operation costs	10000	EUR/MW_e/year
Variable operation costs	5.40	EUR/MWh_e
Investment in CHPs	650000	EUR/MW_e
Investment in installation	350000	EUR/MW_e
Thermal storage		
Investment in thermal storage	200	EUR/m^3
Existing boilers		
Heat efficiency	97.1%	
Variable operation costs	1.10	EUR/MWh_{heat}

Table 2: Technical and economic CHP, TES and existing boilers characteristics

Finding optimal Net Present Value for each support scheme in a matrix of CHP capacity and Thermal Energy Storage

Total CHP capacity [MW_e]	TES [m^3]									
	0	**60**	**120**	**180**	**240**	**300**	**360**	**420**	**480**	**540**
3.00	2.515	2.585	2.627	2.651	2.662	2.665	2.663	2.659	2.654	2.648
3.20	2.563	2.642	2.692	2.722	2.738	2.744	2.744	2.742	2.739	2.735
3.40	2.598	2.686	2.742	2.777	2.797	2.805	2.807	2.806	2.803	2.800
3.60	2.623	2.715	2.775	2.815	2.838	2.849	2.853	2.853	2.851	2.848
3.80	2.632	2.727	2.794	2.838	2.865	2.878	2.884	2.885	2.884	2.882
4.00	2.627	2.727	2.797	2.846	2.878	2.895	2.902	2.905	2.905	2.903
4.20	2.605	2.713	2.790	2.845	2.883	2.903	2.913	2.917	2.918	2.917
4.40	2.570	2.687	2.772	2.834	2.876	2.902	2.915	2.922	2.924	2.924
4.60	2.522	2.648	2.742	2.809	2.857	2.887	2.904	2.913	2.916	2.917
4.80	2.461	2.596	2.698	2.772	2.823	2.857	2.877	2.888	2.893	2.896

Table 1: An example of the path to an optimal solution, shown in a section of a decision matrix of Net Present Values in Mio. EUR of investment in CHP and TES at a DE plant.

In this presentation I have used this method to compare the two support schemes:

The Danish triple tariff

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Premium Scheme

Electrical CHP capacity as function of support level in the Premium scheme

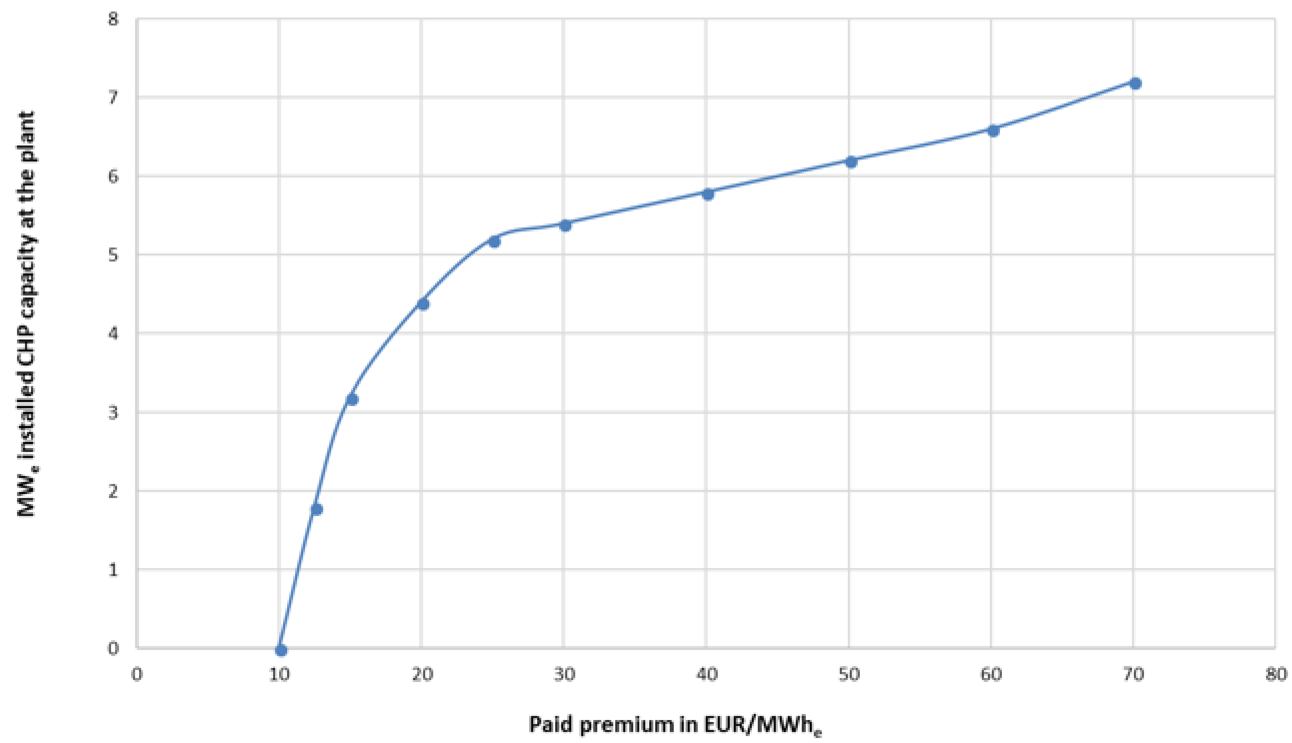

Figure 4: Optimal electrical CHP capacity as function of support level in the Premium scheme with a Day-ahead market price level of 26.7 EUR/MWh.

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Installed CHP capacity as function of the NPV of the paid support in 20 years for both the triple tariff and for different levels of the Premium scheme.

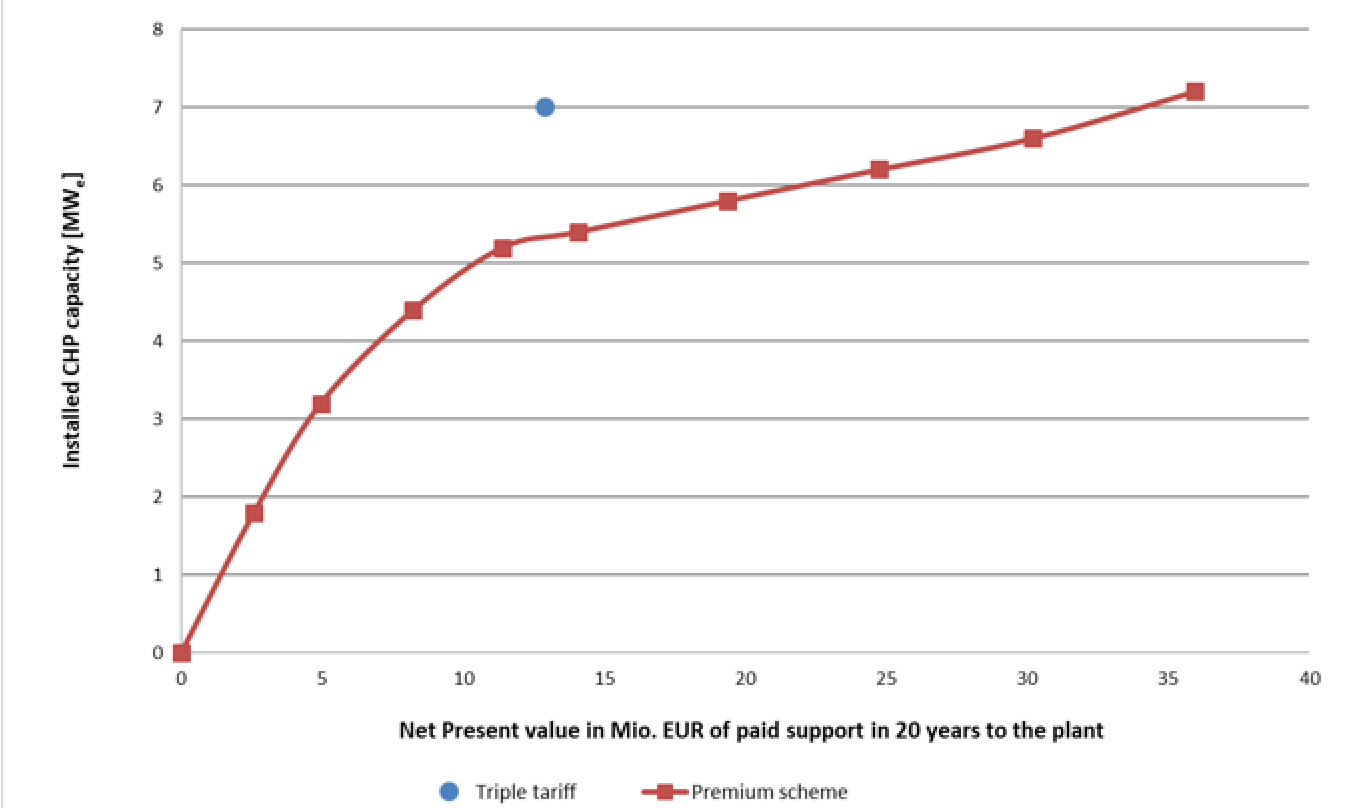

Figure 5: Installed CHP capacity as function of the NPV of the paid support in 20 years for both the triple tariff and for different levels of the Premium scheme.

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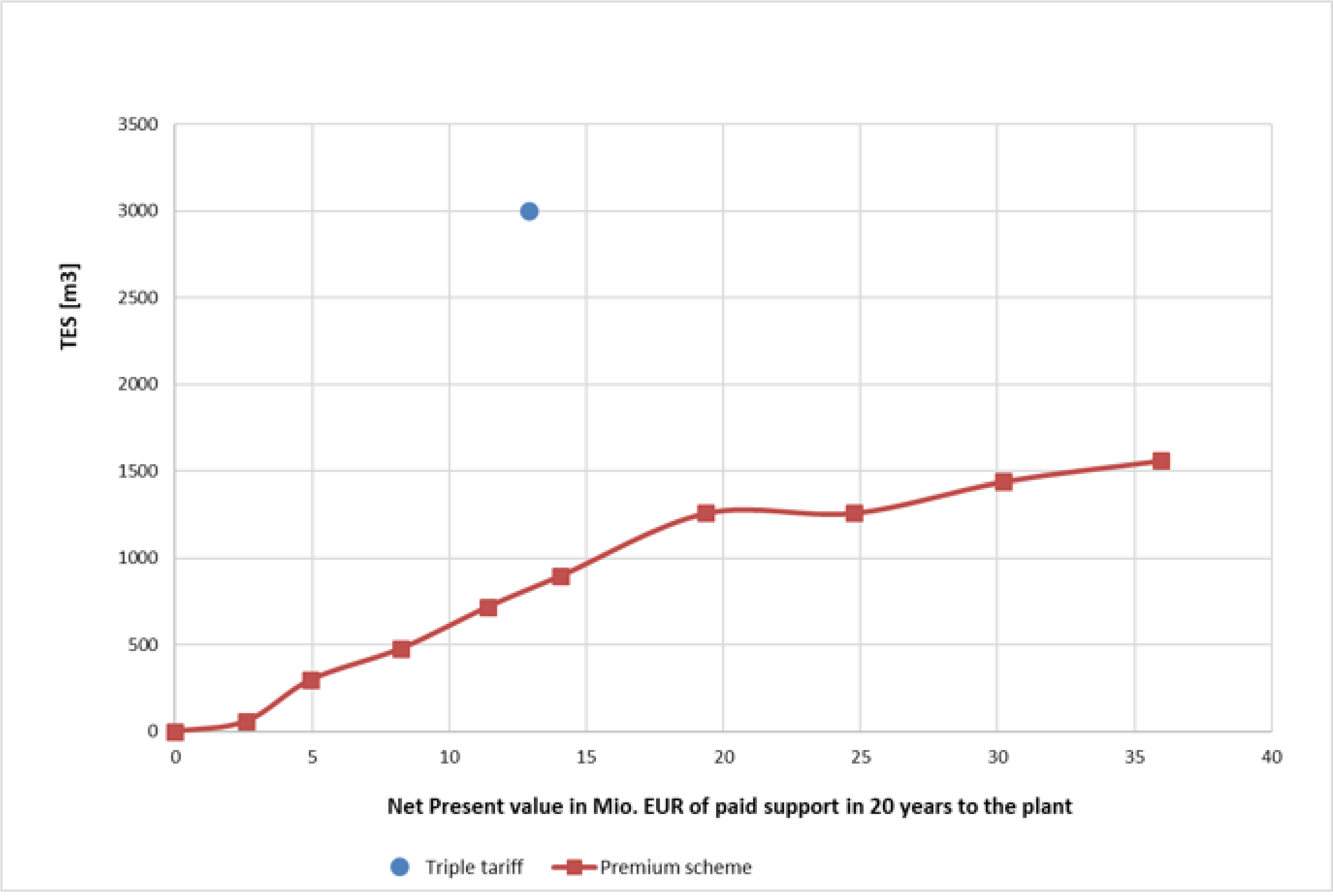

Figure 6: Installed TES capacity as function of the NPV of the paid support in 20 years for both the triple tariff and for different levels of the Premium scheme.

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	CHP-capacity [MW]	Thermal store size [m³]	Net Present Value of paid support to the plant in 20 years [Mio. EUR]	Yearly electricity production [MWh_e]
Triple tariff	7.00	3 000	12.917	34 440
Premium scheme	5.31	822	12.917	31 066

Table 6: Comparing installed capacities and yearly electricity productions at the same NPV of paid support to the plant in 20 years on the Triple tariff and the Premium scheme.

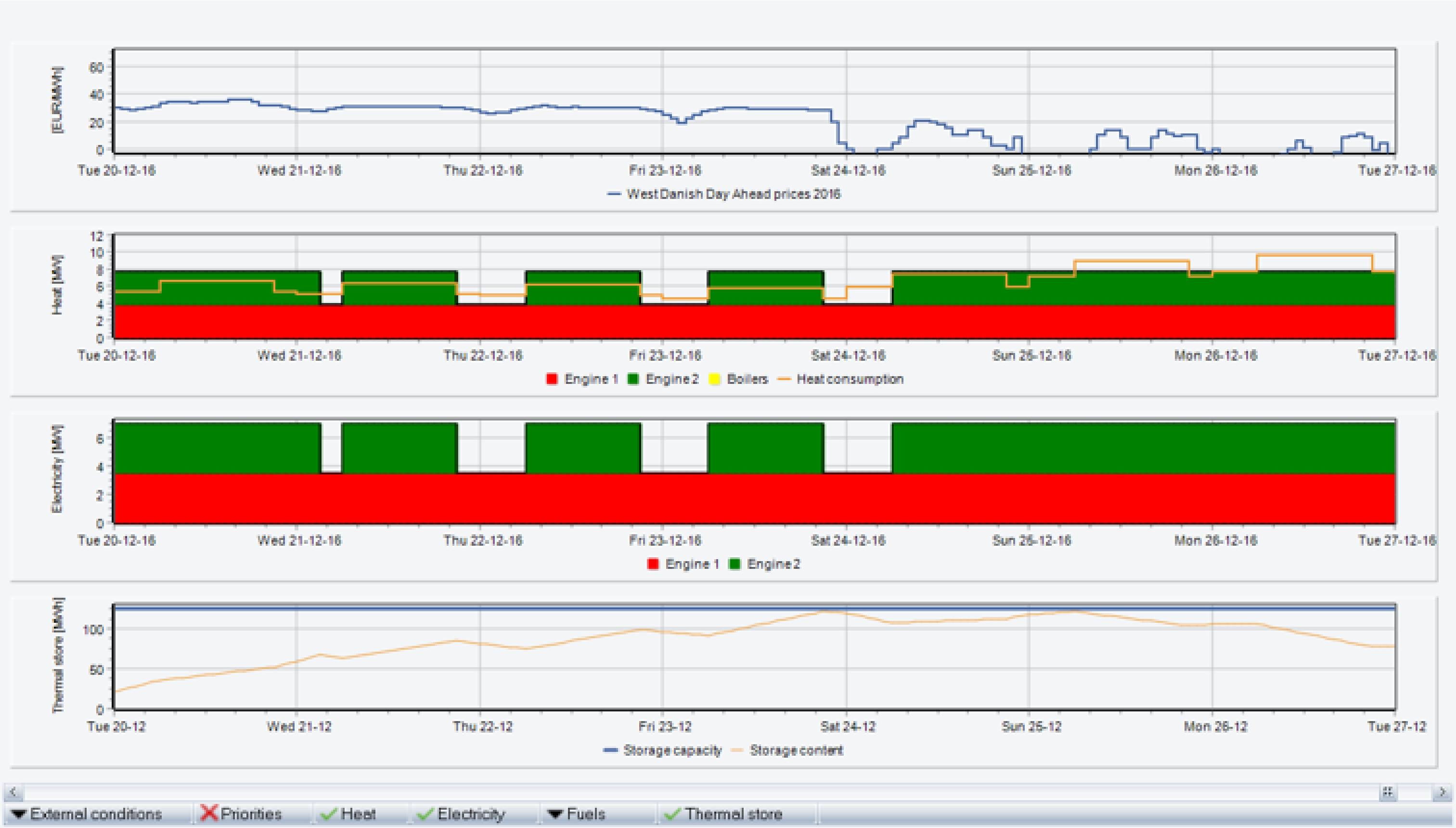


Figure 7: Operation on the triple tariff of the DE plant equipped with the CHP and TES capacity given in Table 6 in 7 days from 20th December to 26th December.

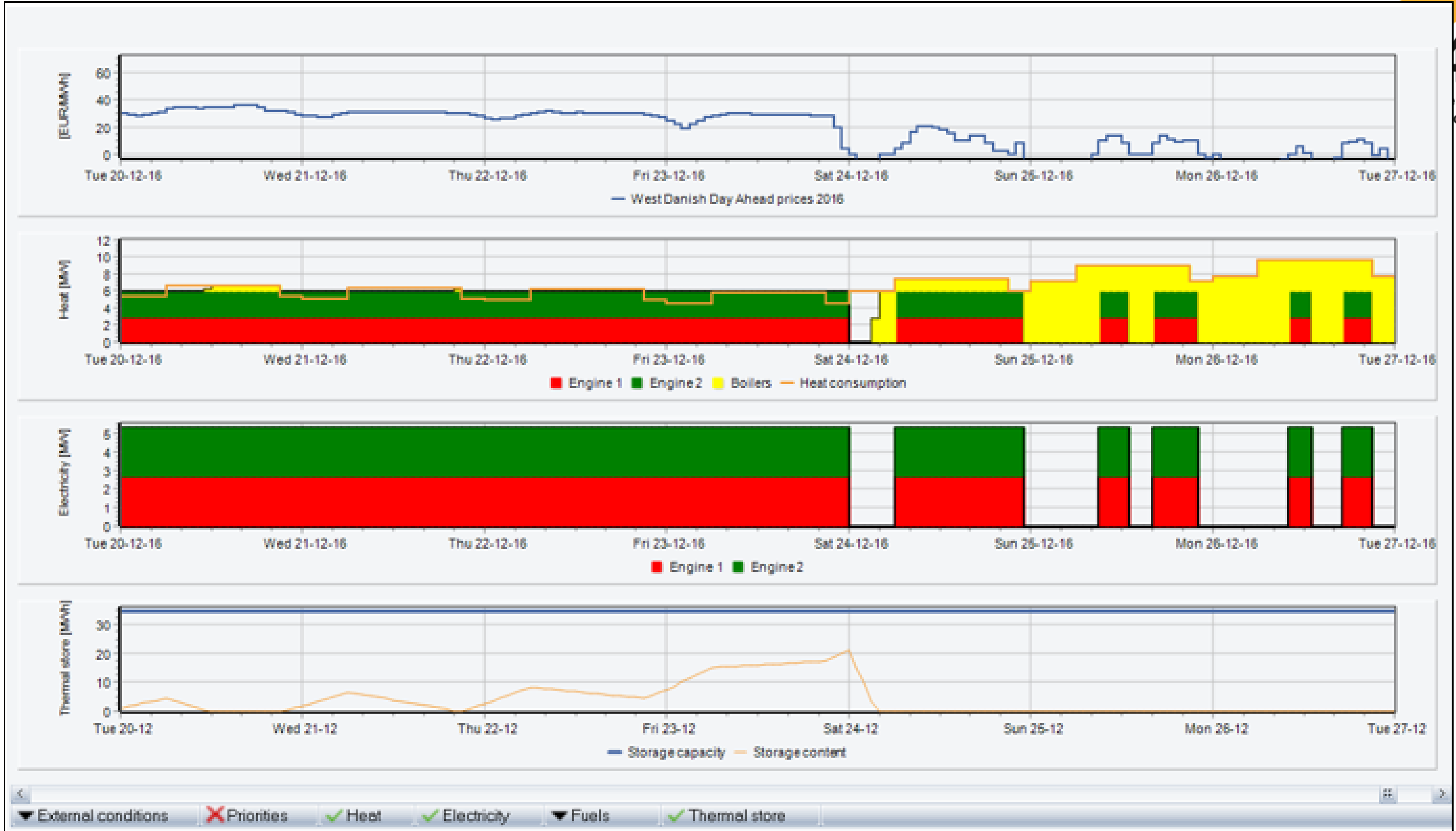
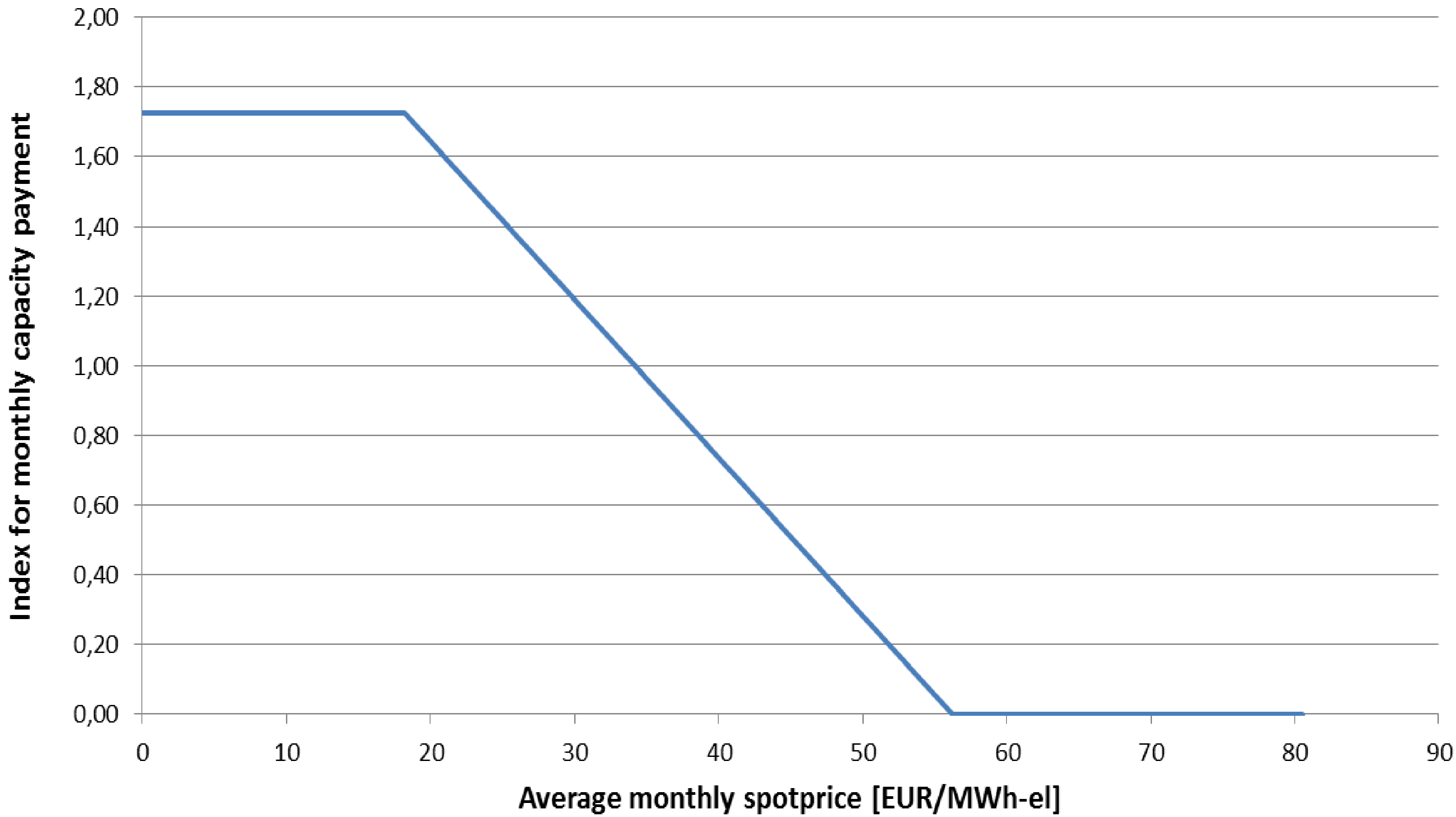


Figure 8: Operation on the Premium scheme of the DE plant equipped with the CHP and TES capacity given in Table 6 in 7 days from 20th December to 26th December.

Monthly capacity payment replaced the triple tariff



An example of that market based operation includes more electricity markets than just Day-ahead market

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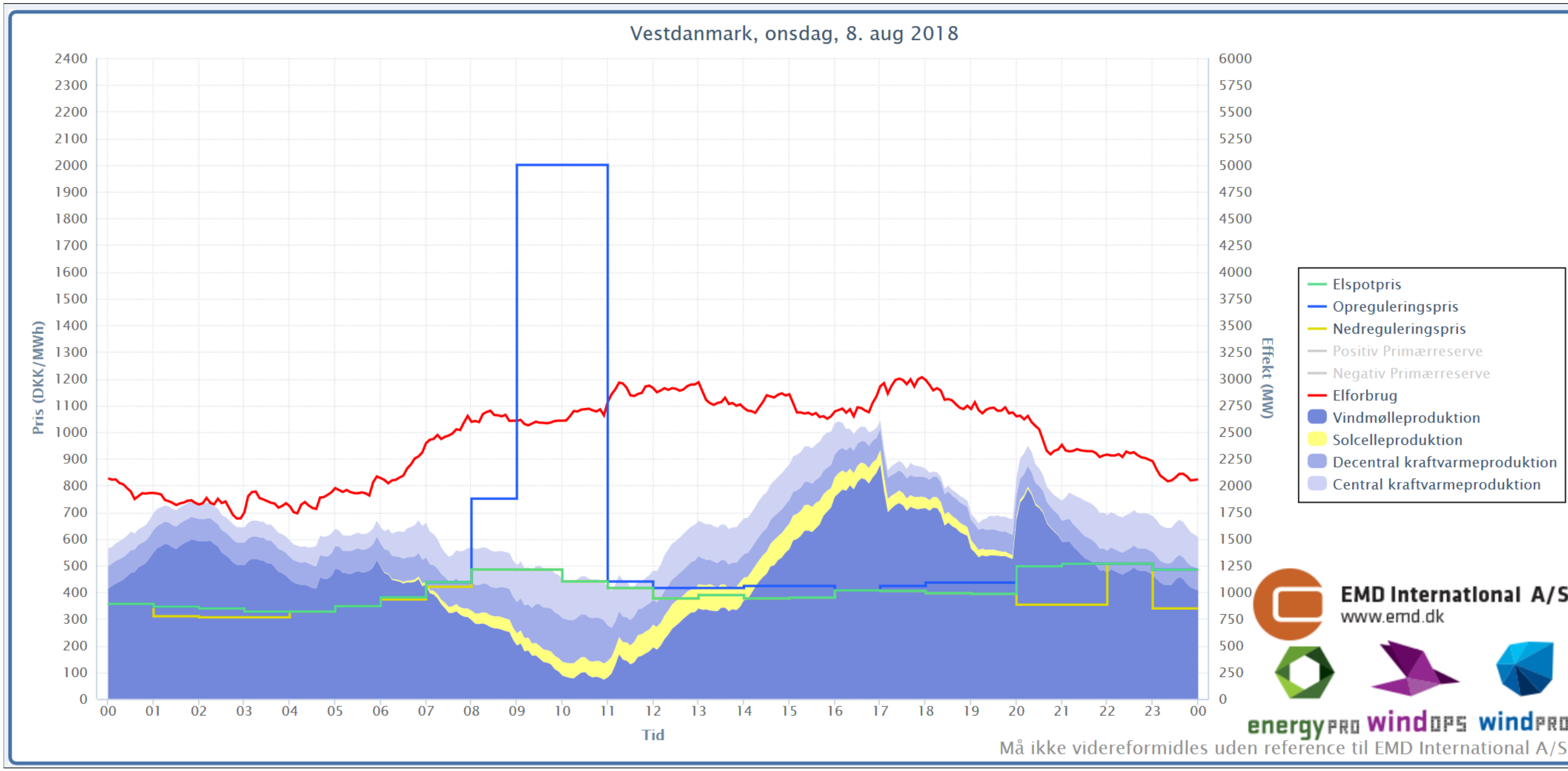
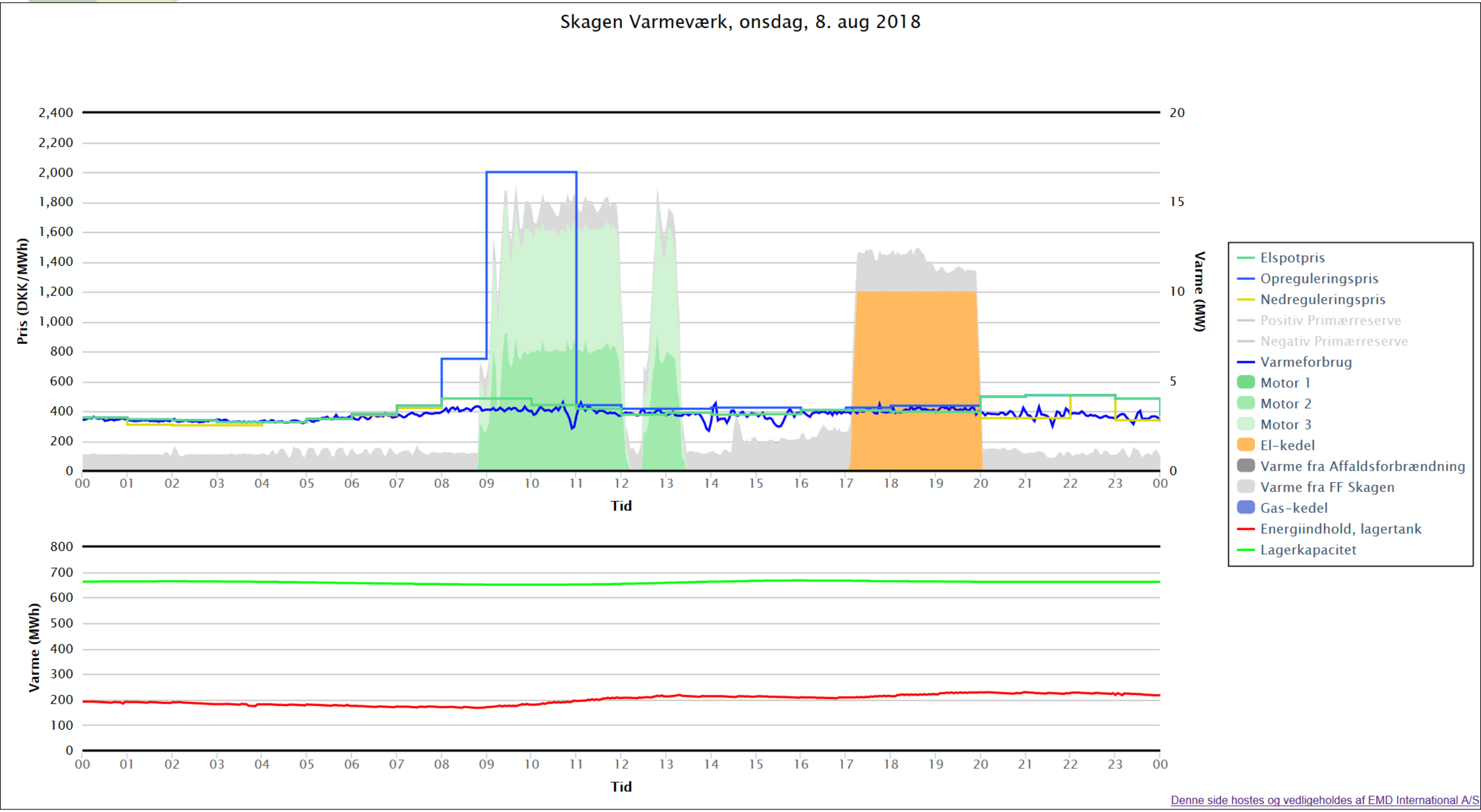
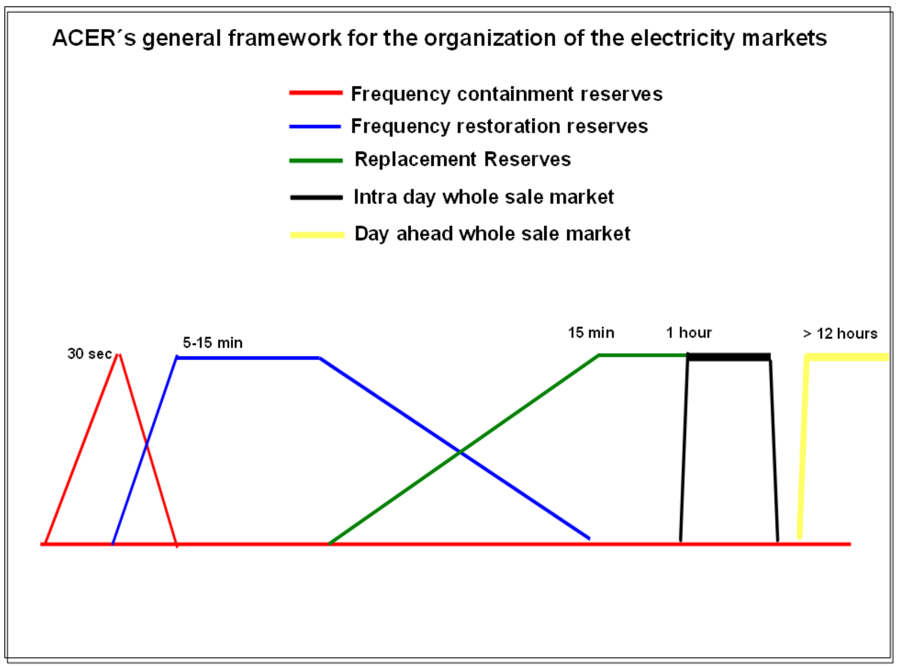
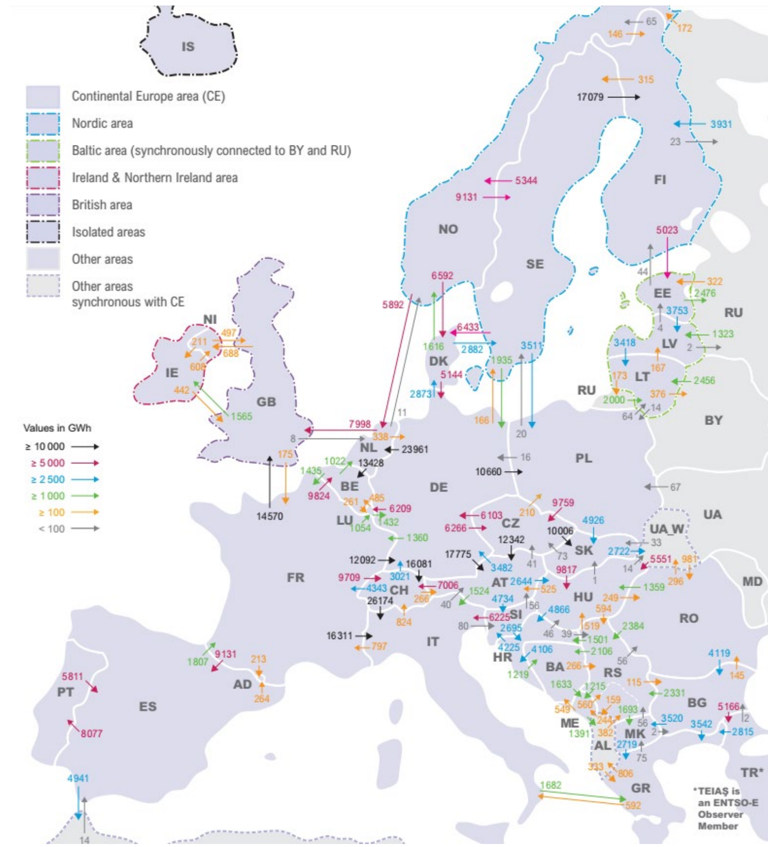
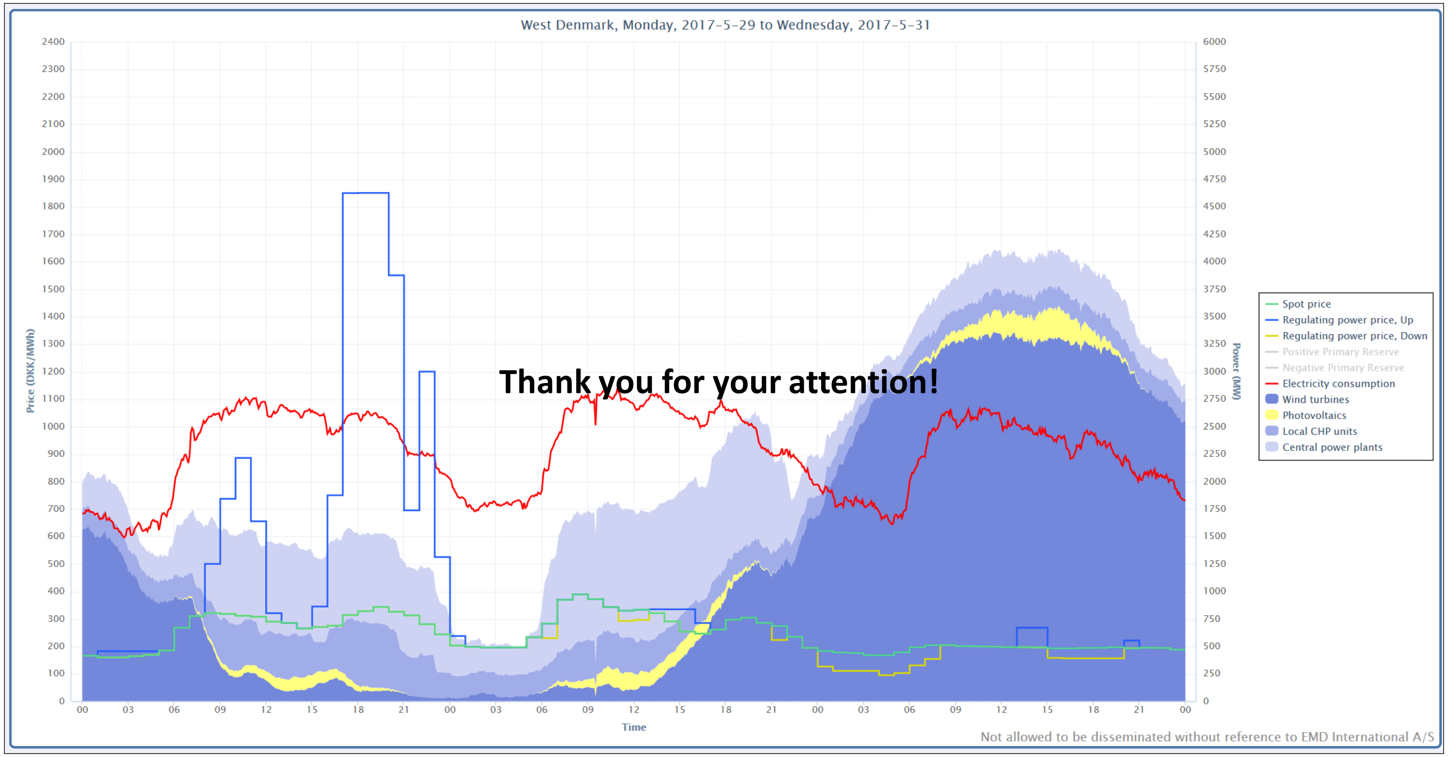



Skagen Varmeværk, onsdag, 8. aug 2018
Pris (DKK/MWh)
Varme (MW)
Tid
Varme (MWh)
Elspotpris
Opreguleringspris
Nedreguleringspris
Positiv Primærreserve
Negativ Primærreserve
Varmeforbrug
Motor 1
Motor 2
Motor 3
El-kedel
Varme fra Affaldsforbrændning
Varme fra FF Skagen
Gas-kedel
Energiindhold, lagertank
Lagerkapacitet
Denne side hostes og vedligeholdes af EMD International A/S

The 5 European electricity markets that are able to integrate intermittent production from photo voltaic and wind energy







Thank you for your attention!

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