Intelligent Energy Europe

Intelligent Energy Europe MASSIG

Market Access for Smaller Size Intelligent Electricity Generation (MASSIG)

Analyzing the optimal size of a CHP-unit and thermal store when a German CHP-plant is selling at the Spot market

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Abstract:
In MASSIG the challenge is to show that even small plants get more independent from subsidies or grants when they participate in the "big energy markets". The aim of this report is to find the optimal size of a CHP-unit and a thermal store for a German CHP-plant selling the electricity production at the EEX spot market. As one example it is shown that a CHP-plant with 4 MW electricity has a convincing feasibility at a Stadtwerke delivering 30.000 MWh-heat per year.
This analysis has been restricted to a CHP-plant participating in the spot market. It should be noticed that the feasibility is expected to be even further improved, if the plant together with other CHP plants also participates in e.g. the Minuten Reserve market or peak shaving.

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1. Introduction

The aim of this report is to find the optimal size of a CHP-unit and a thermal store for a German CHP-plant selling the electricity production at the EEX spot market. The analysis has been conducted using the energyPRO software and comparing the results in a spreadsheet.

In the EU-project MASSIG (Market Access for Smaller Size Intelligent Electricity Generation, http://www.iee-massig.eu/) the challenge is to show that even small plants get more independent from subsidies or grants when they through aggregation participate in the "big energy markets". In the MASSIG project we are looking at CHP-plants up to 5 MW-electricity. The analysis in this report shows that at a Stadtwerke delivering 30.000 MWh-heat per year, a CHP-plant with 4 MW electricity has a very convincing feasibility, when the investment includes a 650 m^3 thermal store, allowing this plant to make "Intelligent Electricity Generation" and that no additional support is necessary. The results will depend significantly on the actual heat demand profile. In this analysis it is assumed that the district heating system primarily supplies heat to private houses.

This analysis has been restricted to a CHP-plant participating in the spot market. It should be noticed that the feasibility could be even further improved, if the plant together with other CHP plants also participates in e.g. the Minuten Reserve market.

2. Assumptions about the CHP-plant

The optimal size of the thermal store and the CHP-unit is examined using the plant data described in the German energyPRO-example "Beispiel-Anlage+Speicher mit EEX-Spot-Vergütung.epp" which follows the Demo of energyPRO, to be downloaded from www.emd.dk

The annual heat delivered from the plant is assumed to be 30 000 MWh:

- Space heating – 18 000 MWh
- Hot water – 9 000 MWh
- Network loss – 3 000 MWh

The plant is assumed only to sell the electricity production at the spot market. The prices of spot market for 2008 are forecasted as the spot price variation of EEX (European Energy Exchange) in 2006 multiplied with a scaling factor so that the average spot price in 2008 is 40.00 €/MWh-el. The price curve during 2008 is presented in Figure 1.

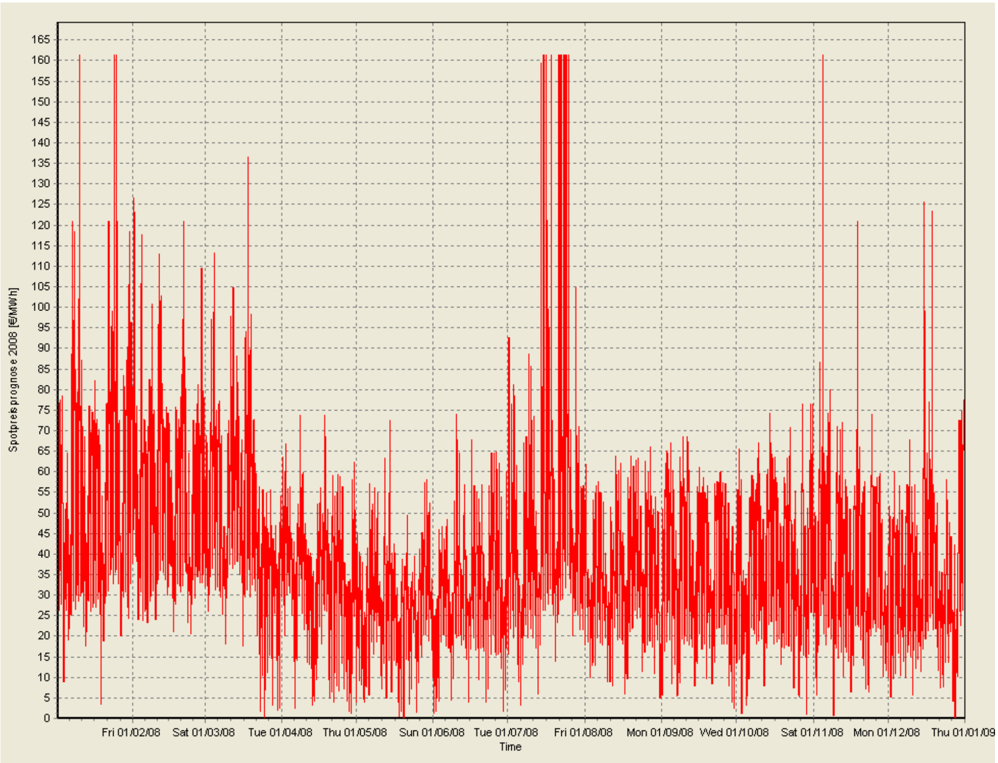

Figure 1: Spot prices, EEX 2008 (prognosis)

In order to calculate the Net Present Value (NPV) and the Simple Pay Back Time (SPBT), the following assumptions are made:

- Real discount rate without inflation: 4.0 % (equal to approximate a nominal discount rate of 6.0 %)
- Specific investment in a CHP unit (equal to typical costs in Denmark): 0.67 mill. €/MW-el (5 mill. DKK/MW-el)
- Specific investment in a thermal store (equal to typical costs in Denmark): 268 €/m^3 (2000 DKK/m3)
- Lifetime of investment: 20 years
- CO2 emission: 242.0 kg/MWh (received fuel), CO2 certificate: 20.0 €/t
- Sale of heat: 55.0 €/MWh

Technical and economical assumptions of the CHP-unit and the boiler are shown in Table 1:

Table 1: Technical and economical assumptions of the CHP-unit and the boiler

CHP-unit		
Fuel	natural gas	
Natural gas price	25.00	€/MWh-fuel
Heat efficiency	47.0%	
Electrical efficiency	40.0%	
Operation&Maintenance (O&M)	8.00	€/MWh-el
Net using Bonus	1.50	€/MWh-el
Boiler		
Fuel	natural gas	
Natural gas price	25.00	€/MWh-fuel
Fuel tax	5.50	€/MWh-fuel
Fuel input	16.50	MW-gas
Heat output	15.00	MW
Heat efficiency	90.9%	
Operation&Maintenance (O&M)	1.00	€/MWh

The heat production cost at the boiler is calculated and shown below:

Table 2: Heat production cost at the gas boiler

Price for producing 1 MWh-heat at the gas boiler			
(all amounts in €/MWh-heat)			
Natural gas purchase (fuel consumption)	1.10	MWh	27.50
Fuel tax			6.05
Operation&Maintenance (O&M)			1.00
CO2 certificate	0.266	ton	5.32
Total			**39.87**

Bidding price on the spot market is calculated, using the boiler heat production cost.

Table 3: Bidding price on the spot market, where the heat produced by the engine is assumed to replace heat produced at the boiler

Bidding price at spot market, where an engine replaces the boiler			
(all amounts in €/MWh-el)			
Natural gas purchase (fuel consumption)	2.5	MWh	62.50
Operation&Maintenance (O&M)			8.00
CO2 certificate	0.605	ton	12.10
Net using Bonus			-1.50
Value of heat (boiler substitution)	1.18	MWh-heat	-46.85
Bidding price at a spot market			**34.25**

It is assumed that the minimum operation time of the CHP-unit is 3 hours.

3. Optimization

3.1 Finding the optimal size

As a reference situation is assumed that there is no CHP and thermal store, and that a natural gas boiler produces the necessary heat. Investments in the natural gas boiler are not included in the analysis, since the size of the boiler is equal in all cases and the natural gas boiler is assumed alone to be able to meet all heat demand.

Only relevant payments for the investment analysis are modelled in energyPRO. An example is shown in Annex 1. This example shows the operation of the reference case and a 4 MW-el capacity CHP-unit with a 650 m^3 thermal store.

It was found that with the assumed heat demand of 30 000 MWh-heat when a CHP-unit has a capacity of 1 MW-el there is no need to use a thermal store at this energy plant, because the CHP-unit can run all hours of the year.

When the CHP-unit is bigger than 1 MW-el capacity, a CHP-unit needs to have a thermal store that should be found for each case. At first, the optimal store when CHP capacity is 2 MW-el is found. Six calculations with increasing thermal store are performed for a 2 MW-el capacity CHP-plant. The optimal thermal store capacity is found to be 250 m^3 at a CHP capacity of 2 MW-el. Results are presented in Table 4 and Figure 2.

Table 4: Optimal thermal store, 2 MW-el CHP

Thermal store	CHP-unit	Total investment	Total starts of engine	Yearly net operation income	Increase in operation income	Simple Pay Back Time	NPV, 20 years
[m3]	[MW-el]	[mill. €]	[starts]	[mill. €]	[mill. €]	[Years]	[mill. €]
0	2.0	1.340	278	0.417	0.128	10.45	0.402
150	2.0	1.381	438	0.451	0.162	8.51	0.823
200	2.0	1.394	416	0.454	0.165	8.44	0.850
250	**2.0**	**1.408**	**407**	**0.456**	**0.167**	**8.41**	**0.866**
300	2.0	1.421	405	0.457	0.168	8.45	0.864
400	2.0	1.448	403	0.457	0.169	8.58	0.845

Note:
It was calculated that the yearly operation income of relevant payments for the reference situation is 0.289 mill. €. The reference case is also shown in Annex 1.

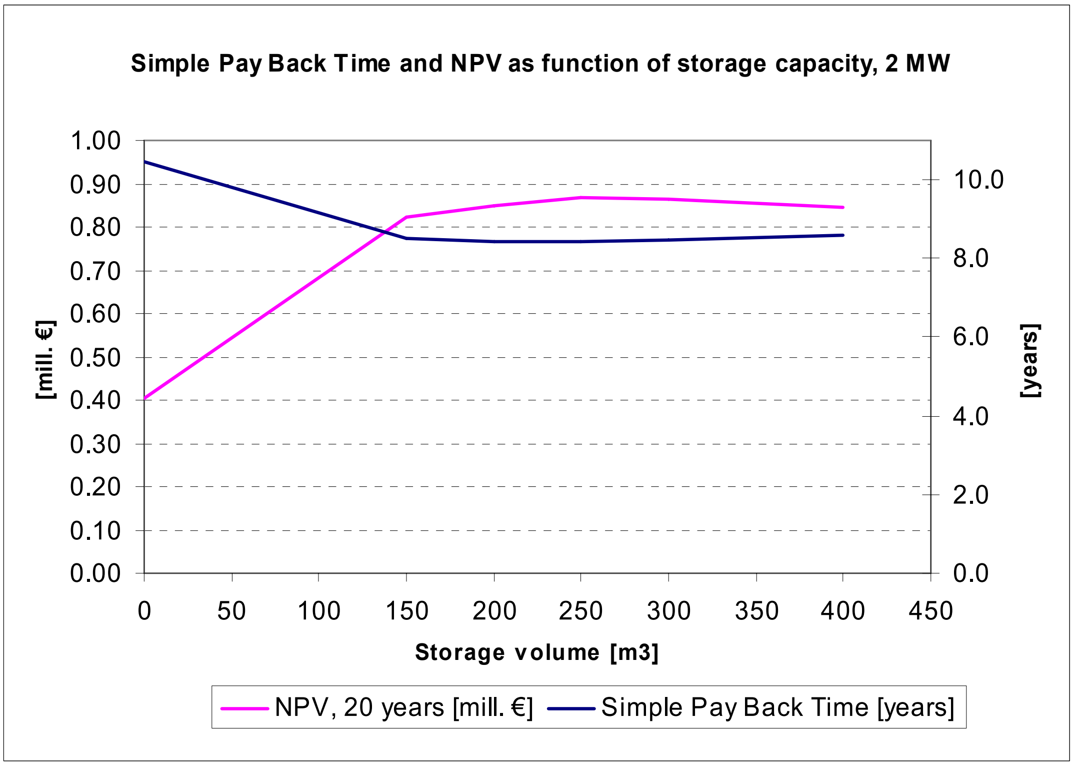

Figure 2: Optimal thermal store, 2 MW-el CHP

Similar calculations were performed for CHP plants of 3, 4, 5, 6, 7, 8 and 10 MW-el capacities. Polynomial (the second order) coherence was found between the CHP capacity and the store volume:

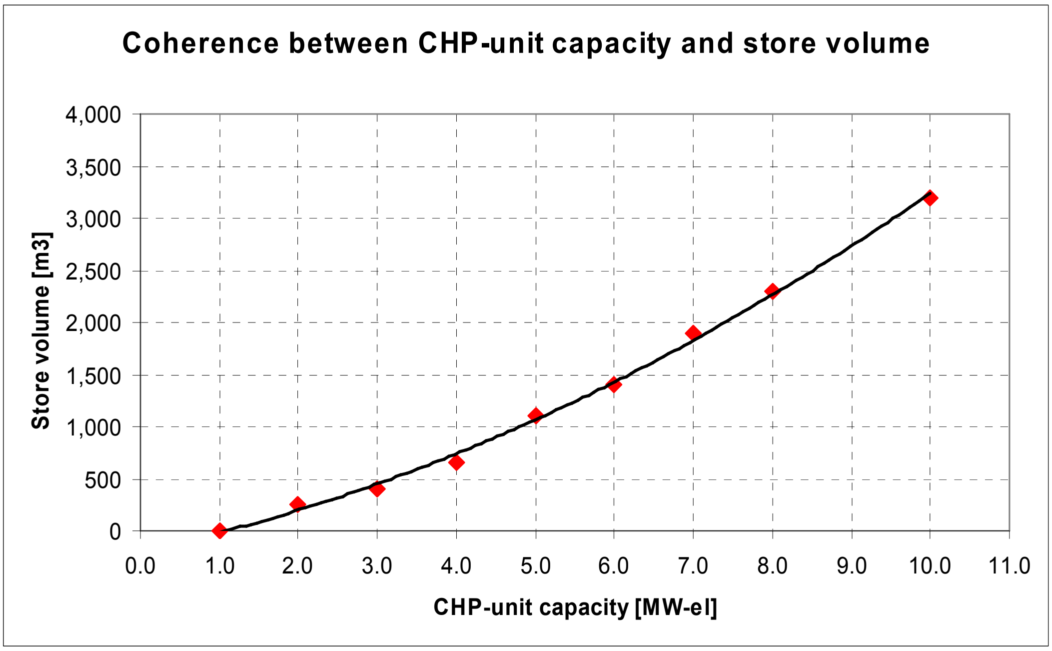

Figure 3: Coherence between CHP-unit capacity and store volume

A number of energyPRO calculations give the main results for different size of CHP-unit and thermal store. A graphical view of these results is shown in Figure 4:

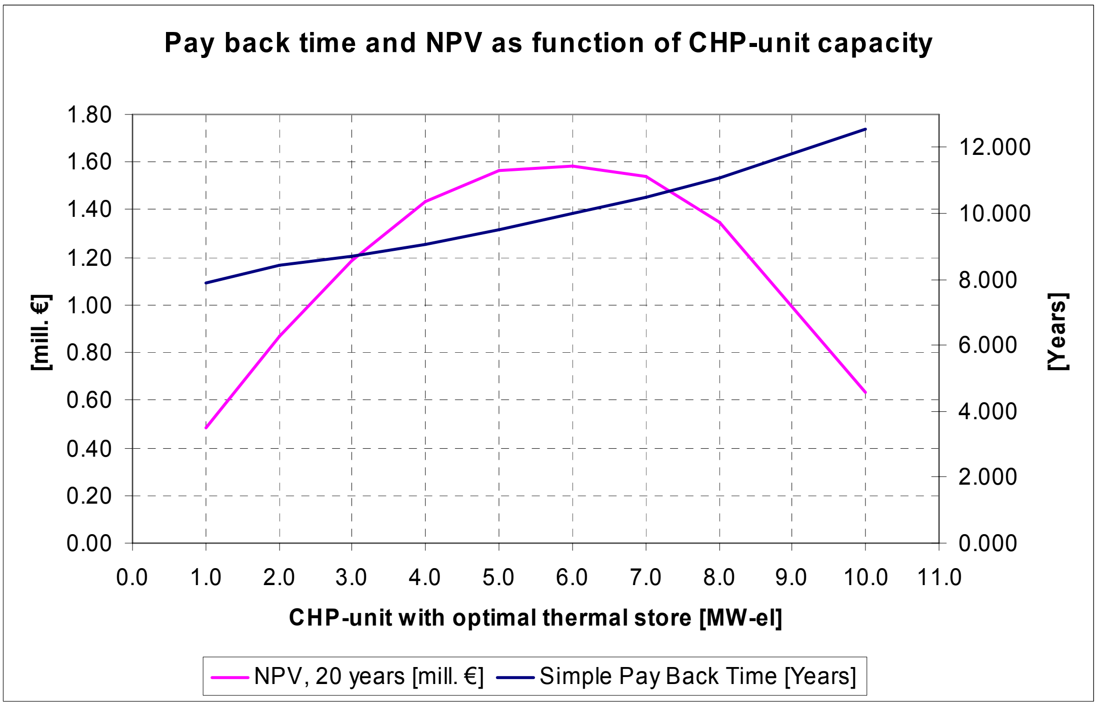

Figure 4: CHP-unit with optimal thermal store, graphically

Viewing the results from an economical viewpoint, a 6 MW-el capacity CHP-unit with 1400 m^3 thermal store gives the best NPV (1.584 mill. €). However, investment in this CHP-plant is riskier in comparison with 4 MW-el and 5 MW-el capacities CHP-units.

For further analysis, a 4 MW-el capacity CHP-unit with a 650 m^3 thermal store is chosen, because this CHP-plant shows good economical results and is less risky compared to 5 and 6 MW-el CHP-plants.

Table 5: Comparison of main yearly operation results between reference case and CHP plant of a 4 MW-el capacity

Yearly parameters	Reference case (RC)	4 MW-el, 650 m^3	Difference between 4 MW-el CHP and RC
Electricity production [MWh]	**0**	**16,410.5**	**16,410.5**
Total heat production [MWh]	**27,000**	**27,000**	**0.0**
Natural gas consumption [MWh]	**33,000.0**	**52,815.6**	**19,815.6**
Revenues			
Sale of Electricity			
Spot market [€]	0	889,906	889,906
Net using bonus [€]	0	24,616	24,616
Total sale of electricity [€]	**0**	**914,522**	**914,522**
Sale of heat [€]	**1,485,000**	**1,485,000**	**0**
Expenditures			
Natural gas purchase [€]	825,000	1,320,391	495,391
Fuel tax [€]	181,500	64,842	-116,658
Operation&Maintenance [€]	30,000	142,001	112,001
CO2-Certificate [€]	159,720	255,628	95,908
CHP-unit starting costs [€]	0	12,480	12,480
Operation income of selected payments [€]	**288,780**	**604,180**	**315,400**

As it can be seen from Table 5, a case with a 4 MW-el capacity CHP-unit with a 650 m^3 thermal store shows bigger natural gas consumption and expenditures for the natural gas purchase, CO2-certificate, operation and maintenance. Additionally, there are included CHP-unit starting costs. It is assumed that starting cost is 8.00 €/MW-el capacity, i.e. 32.00 €/start for a 4 MW-el capacity CHP-unit. But the CHP-unit produces electricity that is sold in spot market. Moreover, the CHP-plant receives Net using bonus for the delivered electricity. Also, the CHP-unit has not to pay fuel tax for the fuel consumption. These conditions make it possible to get better operation income of selected payments compared to the reference case, where only heat is produced on the natural gas boiler. The bigger natural gas consumption by the CHP unit is easily justified because conventional electricity generation will be replaced by the combined heat and power production (CHP) having a better total energy conversion efficiency. Hence, increased efficiency of energy utilization decreases the overall amount of fuel consumption and leads to reduction in environmental pollution.

The graphical overview in energyPRO of the 4 MW-el capacity CHP-plant operation during one week in winter, spring and summer is presented in the Figures below.

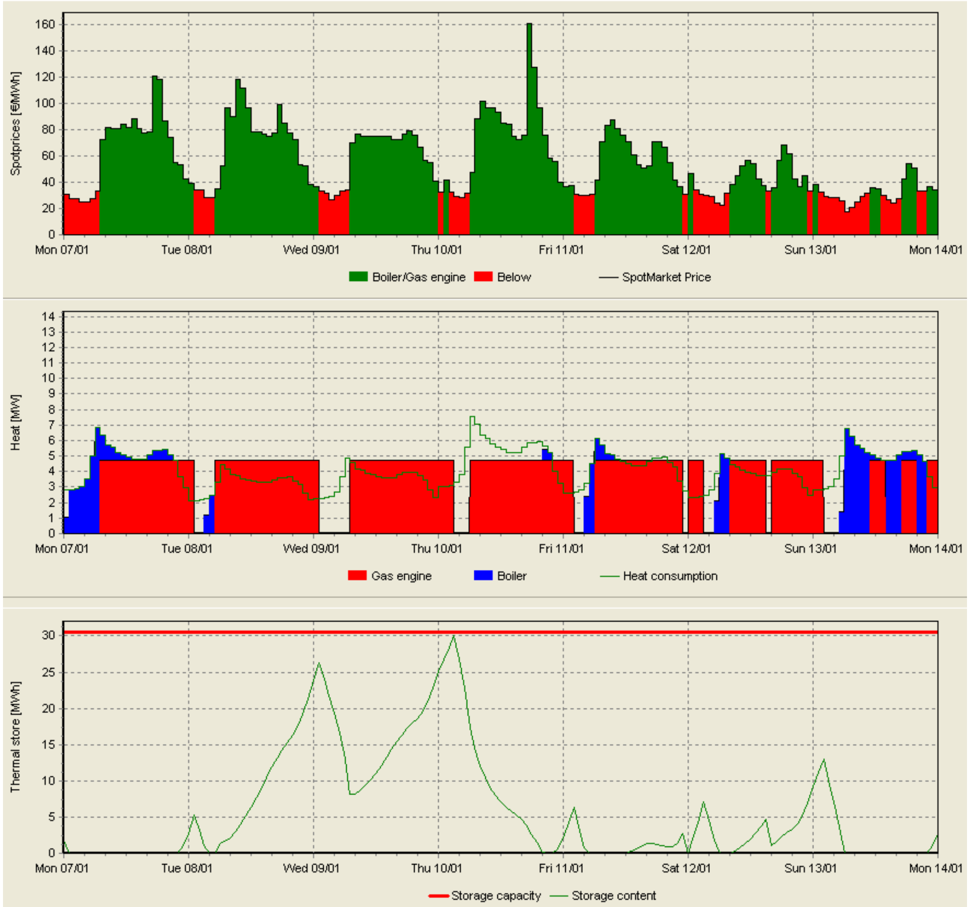

Figure 5: CHP plant, 4 MW-el, 650 m^3, from January 7 to January 14 (winter)

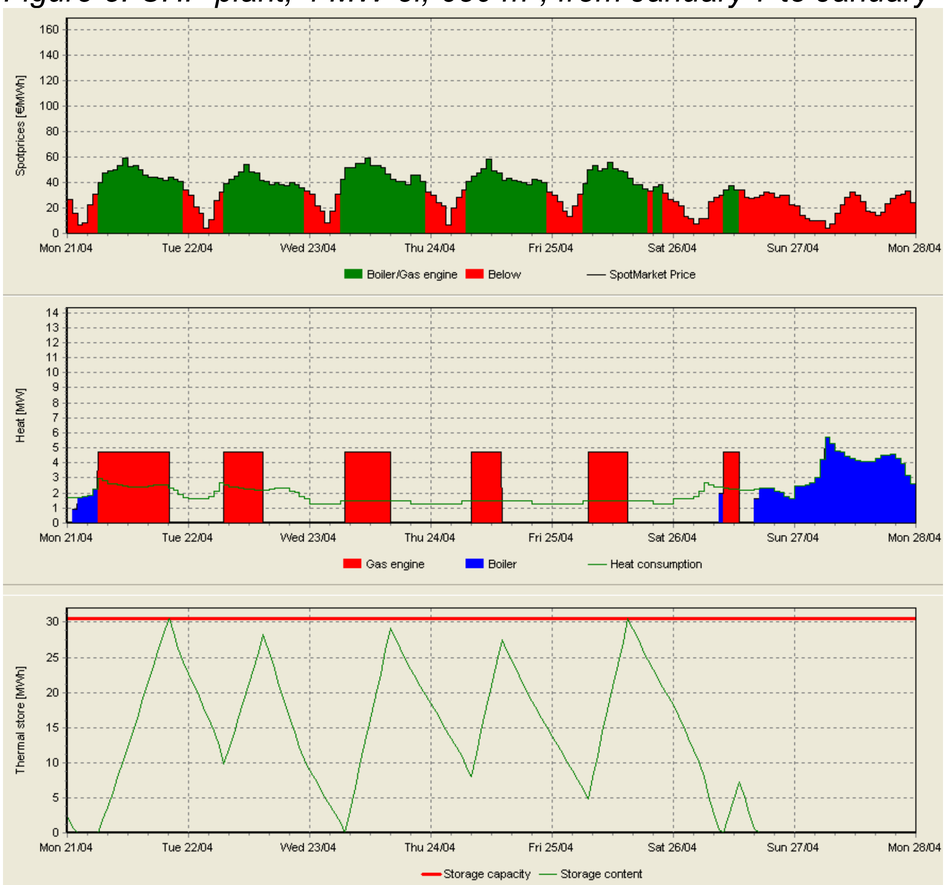

Figure 6: CHP plant, 4 MW-el, 650 m^3, from April 21 to April 28 (spring)

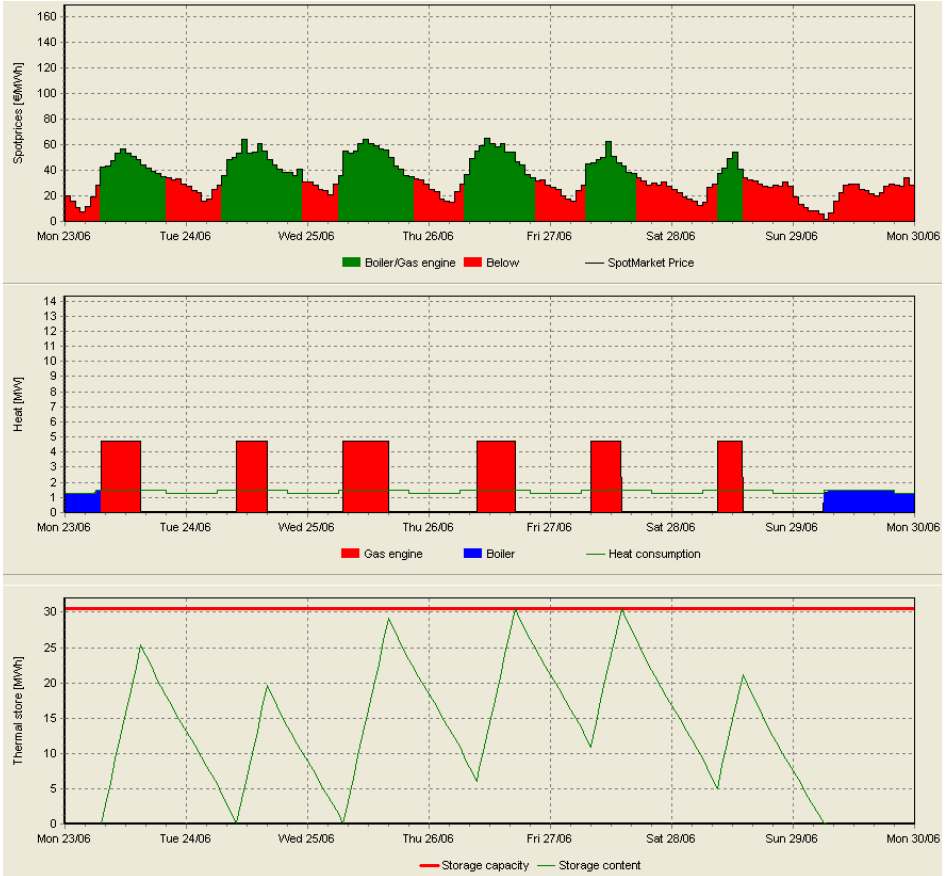

Figure 7: CHP plant, 4 MW-el, 650 m^3, from June 23 to June 30 (summer)

It was found that investment in the 4 MW-el CHP-unit and a 650 m^3 thermal store gives a Net Present Value (20 years) of 1.43 mill. € and the Simple Pay Back time of 9.1 years.

3.2 High efficiency CHP-unit

A CHP-unit with average efficiencies has been used in this analysis. If we instead choose a high efficiency 5.1 MW-el CHP-unit (Rolls Royce, Bergen B35:40-V12AG), which has an electrical efficiency of 46.3%, a thermal efficiency of 48.2% and a specific investment of 0.76 mill. €/MW-el the following results are achieved (eight calculations with an increasing thermal store were performed for this case). The optimal thermal store capacity is found to be 1200 m^3 for this CHP-unit. Results are presented in Table 6.

Table 6: Optimal thermal store, high efficiency CHP-unit

Thermal store	Total investment	Net Cash from Operation	Increased yearly operation income	Simple Pay Back Time	NPV, 20 years
[m3]	[mill. €]	[mill. €]	[mill. €]	[Years]	[mill. €]
400	3.99	0.751	0.462	8.64	2.288
800	4.10	0.785	0.496	8.26	2.644
1000	4.16	0.791	0.502	8.27	2.672
1100	4.18	0.794	0.505	8.28	2.683
1200	4.21	0.796	0.507	8.30	2.684
1300	4.24	0.798	0.509	8.32	2.683
1400	4.26	0.799	0.510	8.35	2.674
1500	4.29	0.800	0.512	8.38	2.663

When the high efficiency CHP-unit with 1200 m^3 thermal store operates under nominal conditions, the NPV becomes 2.684 mill. €. This value is much higher than the NPV for a 4.0 MW-el capacity CHP-unit calculated above; even if the high efficiency CHP-unit needs more capital investment (29 mill. DKK). Simple pay back time of the CHP-unit with thermal store reduces to 8.3 years.

3.3 CHP-plant with CHP-bonus

In this section is analyzed the consequences, if a CHP-Bonus is introduced in a new German CHP-law. The consequences are calculated for the CHP-plants of 4 MW-el and 5 MW-el capacities. It is assumed that CHP-Bonus for the delivered electricity is 8.20 €/MWh-el. Other assumptions remain the same.

The heat production cost at the boiler remains the same as calculated in Table 2. However, the biding price of electricity decreases for a CHP-plant. New bidding price at a spot market with CHP-Bonus is calculated in Table 7.

Table 7: New bidding price on the spot market

Bidding price at spot market, where an engine replaces a boiler			
(all amounts in €/MWh-el)			
Natural gas purchase (fuel consumption)	2.5	MWh	62.50
Operation&Maintenance			8.00
CO2 certificate	0.605	ton	12.10
CHP-Bonus			-8.20
Net using Bonus			-1.50
Value of heat (boiler substitution)	1.18	MWh-heat	-46.85
Bidding price at a spot market			**26.05**

Getting CHP-Bonus, both CHP-units show better economical results, presented in Table 8. The NPV increases and simple pay back time is reduced with three years compared to the situation without CHP-Bonus.

Table 8: Comparison of 4 MW-el and 5 MW-el capacity CHP plants, getting CHP-Bonus

No	CHP-plant characteristics	NPV, 20 years [mill. €]		Simple pay back time [years]	
		Without CHP-Bonus	With CHP-Bonus	Without CHP-Bonus	With CHP-Bonus
1	4 MW-el, 650 m^3	1.431	3.474	9.05	6.13
2	5 MW-el, 1100 m^3	1.564	3.911	9.51	6.56
Difference (No 2- No 1)		0.132	0.438	0.46	0.43

As it can be seen, adding CHP-Bonus to CHP-plant for produced electricity gives much better NPV to the 5 MW-el capacity CHP-plant compared to the 4 MW-el capacity CHP-plant. Such promotion makes it possible to install bigger capacity CHP-units.

3.4 Influence of daily spot price variation

A higher variation of spot prices during a day has an influence on the CHP-plant production. In this analysis the EEX daily spot price variation during 2006 was used to forecast a daily spot price variation during 2008. If we instead choose the daily price variation from 2007, the following results at the 4 MW-el capacity CHP-plant with 650 m^3 thermal store are achieved.

Table 9: Comparison of calculation results when spot price variations are forecasted from electricity prices in 2006 + 2007, but the average spot price is the same (40.00 €/MWh-el)

Yearly parameters	Prognosis from EEX-2006	Prognosis from EEX-2007*	Prognosis difference between EEX-2007 and EEX-2006
Electricity production [MWh]	**16,410.5**	**13,956.8**	**-2,453.7**
Total heat production [MWh]	**27,000**	**27,000**	**0.0**
Natural gas consumption [MWh]	**52,815.6**	**49,852.9**	**-2,962.7**
Revenues			
Sale of Electricity			
Spot market [€]	889,906	851,188	-38,718
Net using bonus [€]	24,616	20,935	-3,681
Total sale of electricity [€]	**914,522**	**872,124**	**-42,399**
Sale of heat [€]	**1,485,000**	**1,485,000**	**0**
Expenditures			
Natural gas purchase [€]	1,320,391	1,246,321	-74,070
Fuel tax [€]	64,842	82,284	17,442
Operation&Maintenance [€]	142,001	125,255	-16,746
CO2-Certificate [€]	255,628	241,288	-14,340
CHP-unit starting costs [€]	12,480	13,024	544
Operation income of selected payments [€]	**604,180**	**648,951**	**44,771**
Simple pay back time [years]	**9.05**	**7.93**	**-1.13**
NPV, 20 years [mill. €]	**1.431**	**2.040**	**0.608**

Note:
* Spot prices for 2008 are forecasted as the spot price variation of EEX during 2007 multiplied with a scaling factor so that average spot price would be 40.00 €/MWh-el.
It is known that the daily spot price variation was higher in 2007 compared to 2006, and as it can be seen, the CHP-plant has better economical results when spot prices prognosis is made with price variation from 2007. The NPV increases from 1.431 mill. € to 2.04 mill. €. Higher daily spot variation will promote the use of thermal stores in CHP-plants.

4. Sensitivity analysis

A sensitivity analysis is made to determine how sensitive the results of the analysis are. Parameters on which a sensitivity analysis is made are:

- Real discount rate
- Investment cost (CHP-unit and thermal store)
- Natural gas and electricity prices

Only the main case – 4 MW-el CHP-unit with 650 m^3 thermal store is analyzed. Results of the sensitivity analysis are shown for the NPV criteria.

4.1 Real discount rate

This rate is used to discount future cash flows to their present values and it is a key variable of finding NPV. The discount rate is changed from 4.0% to 7.0%. The impact of the real discount rate on the NPV is shown in Figure 8.

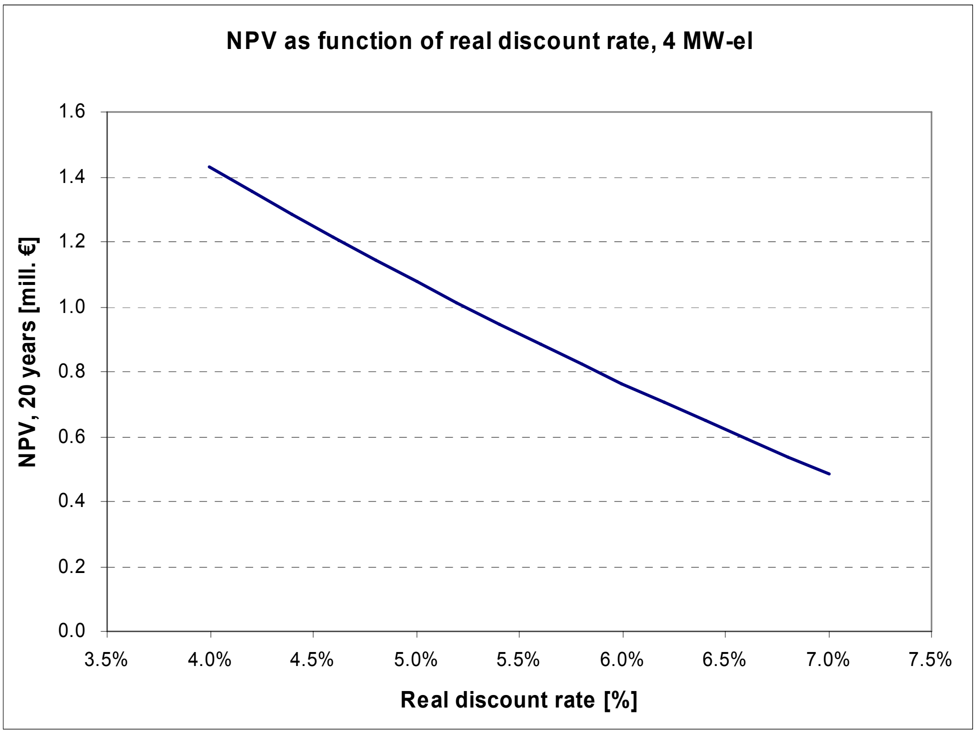

Figure 8: Impact of real discount rate

As it can bee seen a real discount rate has a big influence on the NPV. However, 4 MW-el CHP-plant has a positive NPV (0.486 mill. €) at a real discount rate of 7%.

4.2 Investment, electricity and natural gas prices

Investment, electricity spot prices and natural gas prices are varied ±10% of the reference prices, shown in Section 2.

The impact of the investment cost, electricity prices and natural gas prices on the NPV and Simple pay back time is shown in the Figures below.

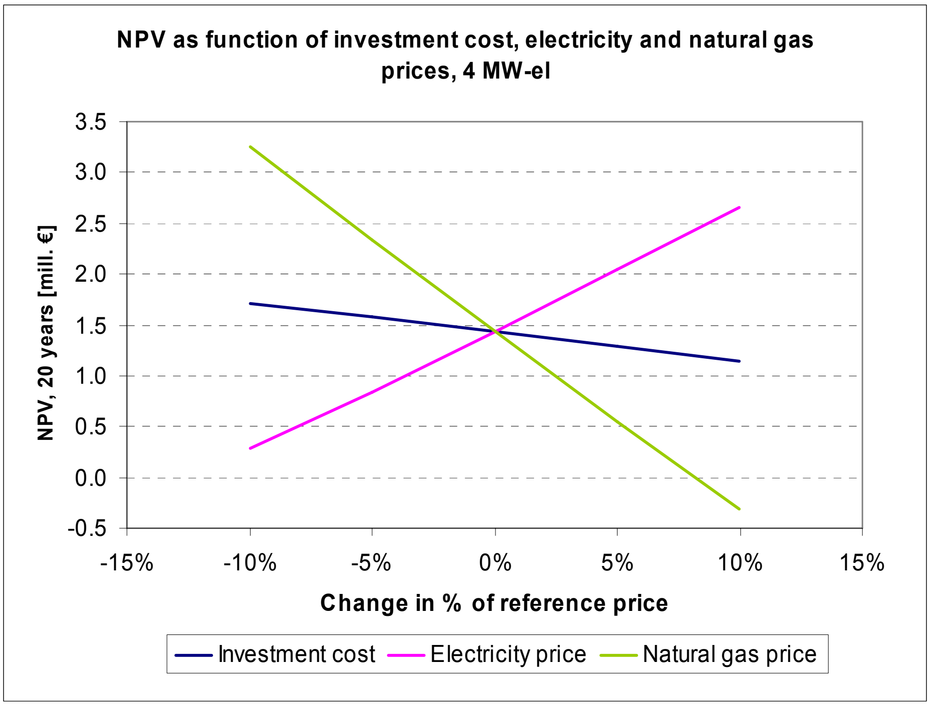

Figure 9: Impact of prices variation on the NPV

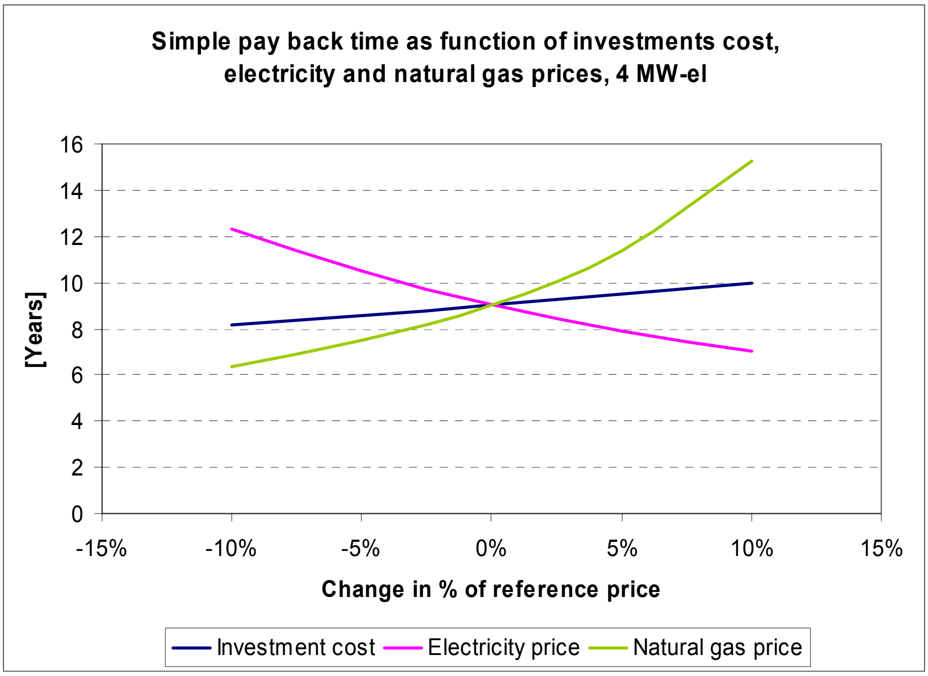

Figure 10: Impact of prices variation on Simple pay back time

As it can be seen from Figure 9 and Figure 10, a variation of investment costs has the least influence on the NPV compared to a variation of natural gas and electricity prices. Even if the investment price is 10% bigger, a 4 MW-el capacity shows a good NPV, and the NPV decreases to 1.146 mill. €. Simple pay back time increases from 9.1 years to 10.0 years.

An increase of the natural gas price has the highest impact on the NPV. If natural gas price reduces 5% of its reference price (25.0 €/MWh), the NPV is 1.6 times bigger. A higher natural gas price reduces the NPV and increases a simple pay back time significantly. When the natural gas price raises 10% the NPV becomes negative (-0.316 mill. €). Simple pay back time increases from 9.1 years to 15.3 years.

However, electricity price has also a big impact on the NPV. In contrary to the increase of the natural gas price, an increase in electricity price raises the NPV. If electricity price increases 10% of its reference price, the NPV becomes 1.85 times bigger.

Natural gas price will often influence the electricity price. Thus, if a change in these prices is in the same trend, this will minimize each of these prices influence on the NPV. This could help to keep a more stable NPV.

5. Conclusions

The use of a thermal store improves the feasibility of a CHP unit. Analyzing a German energy plant delivering 30.000 MWh-heat per year it was found that with the assumed economical conditions a 4 MW-el capacity CHP-unit with a 650 m^3 thermal store is feasible.

Installing a high efficient CHP-unit could improve the feasibility of the plant. Furthermore, this high efficient CHP-unit has bigger capacity (5.1 MW-el) and shows 1.9 times better NPV compared to the 4 MW-el capacity CHP-unit.

Adding CHP-Bonus to the CHP-plant improves the economical feasibility of the plant. CHP-Bonus could promote an installation of bigger capacity CHP-plants.

The sensitivity analysis showed that the variation of natural gas price has the biggest impact on the feasibility of the CHP-plant. However, the variation of both electricity and natural gas prices in the same direction could minimize a negative impact of the increased natural gas price influence on the NPV.

6. Annex 1

An operation of the reference case calculated by energyPRO is shown in Table 10. energyPRO calculates only selected payments during the yearly operation of the plant.

Table 10: Yearly operation income of selected payments, the reference case

energyPRO 3.3.0.18 April 2008

German CHP-0_TS-0
Optimal size of CHP-unit and thermal store when a CHP plant is selling at German Spot market
Boiler: 15 MW-th
Only selected payments

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Courseversion
Time-limited until June 13. 2008

Operation Income from 01-01-2008 00:00 to 31-12-2008 23:59

(All amounts in €)

Revenues									
Sale of electricity									
Spot market	:				=	0			
Net using Bonus	:	0.0 MWh	at	1.5	=	0			
Sale of electricity Total								**0**	
Total sale of heat									
Space heating	:	18,000.0 MWh	at	55.0	=	990,000			
Hot water	:	9,000.0 MWh	at	55.0	=	495,000			
Total sale of heat Total								**1,485,000**	
Total Revenues									**1,485,000**
Operating Expenditures									
Natural gas purchase	:	33,000.0 MWh	at	25.0	=	825,000			
Fuel tax									
Gas engine	:	0.0 MWh	at	0.0	=	0			
Boiler	:	33,000.0 MWh	at	5.5	=	181,500			
Fuel tax Total								**181,500**	
Operation&Maintenance									
Gas engine	:	0.0 MWh	at	8.0	=	0			
Boiler	:	30,000.0 MWh	at	1.0	=	30,000			
Operation&Maintenance Total								**30,000**	
CO2-Certificate	:	7,986.0 t	at	20.0	=	159,720			
Total Operating Expenditures									**1,196,220**
Operation Income									**288,780**

An operation of the 4 MW-el capacity CHP-plant with 650 m^3 thermal store is presented in Table 11.

Table 11: Yearly operation income of selected payments, the 4 MW-el CHP-unit

energyPRO 3.3.0.18 April 2008

German CHP-4_TS-650_3h_fin
Optimal size of CHP-unit and thermal store when a CHP plant is selling at German Spot market
CHP-unit: 4 MW-el, Thermal store: 650 m3
Boiler: 15 MW-th
Onlyselectedpayments

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Time-limited until June 13. 2008

Operation Income from 01-01-2008 00:00 to 31-12-2008 23:59

(All amounts in €)

Revenues								
Sale of electricity								
Spot market	:				=	889,906		
Net using Bonus	:	16,410.5 MWh	at	1.5	=	24,616		
Sale of electricity Total							**914,522**	
Total sale of heat								
Space heating	:	18,000.0 MWh	at	55.0	=	990,000		
Hot water	:	9,000.0 MWh	at	55.0	=	495,000		
Total sale of heat Total							**1,485,000**	
TotalRevenues								**2,399,522**
OperatingExpenditures								
Natural gas purchase	:	52,815.6 MWh	at	25.0	=	1,320,391		
Fuel tax								
Boiler	:	11,789.5 MWh	at	5.5	=	64,842		
Fuel tax Total							**64,842**	
Operation&Maintenance								
Gas engine	:	16,410.5 MWh	at	8.0	=	131,284		
Boiler	:	10,717.7 MWh	at	1.0	=	10,718		
Operation&MaintenanceTotal							**142,001**	
CO2-Certificate	:	12,781.4 t	at	20.0	=	255,628		
Starting cost	:	390.0 turn on	at	32.0	=	12,480		
TotalOperatingExpenditures								**1,795,342**
OperationIncome								**604,179**

An increased operation income is calculated by subtracting operation income of the reference case (only gas boiler) from the operation income of the calculated case.

For example:
604,179 – 288,780 = 315,399 [€]

The yearly increased operation income of the 4 MW-el capacity CHP plant with 650 m^3 thermal store is 0.315 mill. €.