Flexible Mid-Term Biomass Contract Planning for CHP Plants

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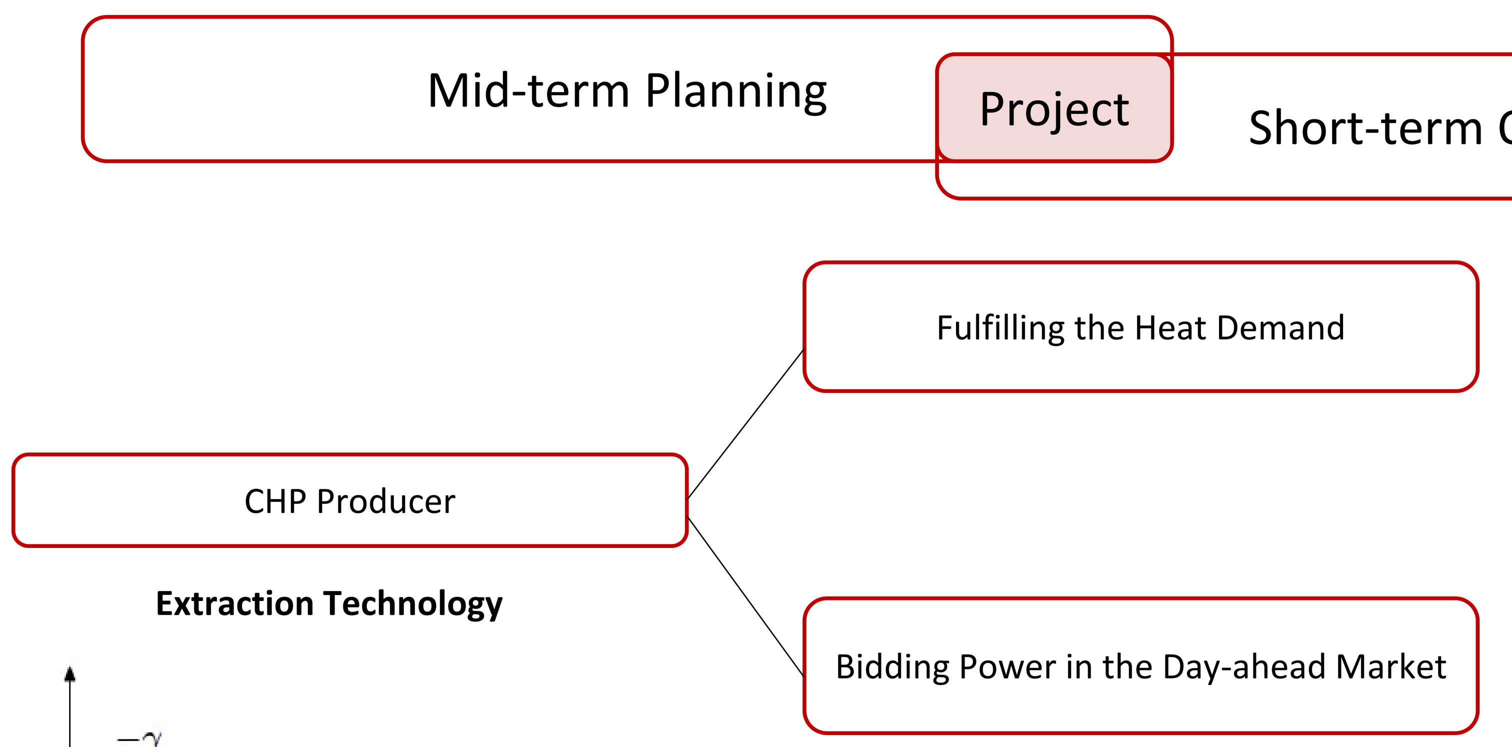
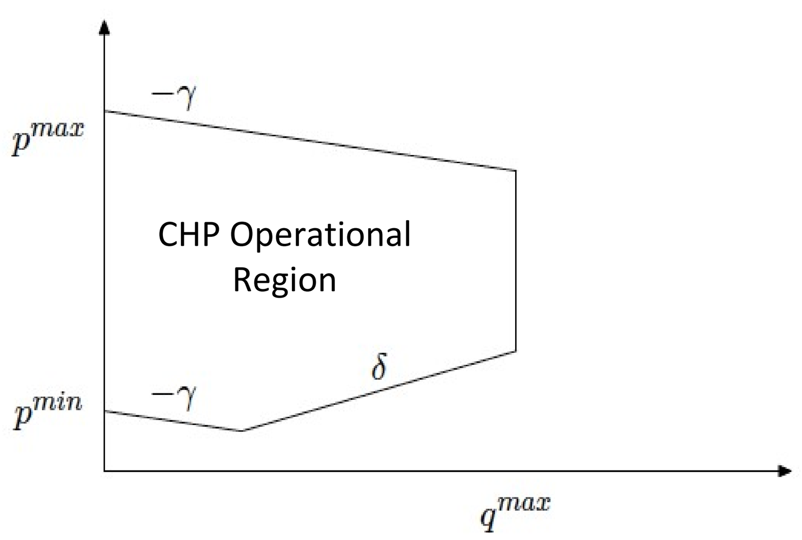
PROJECT DESCRIPTION





Flexible Heat-Power Production

$$p^{min} \leq p + \gamma\, q \leq p^{max}$$

$$q \leq \delta\, p$$

$$q \leq q^{max}$$

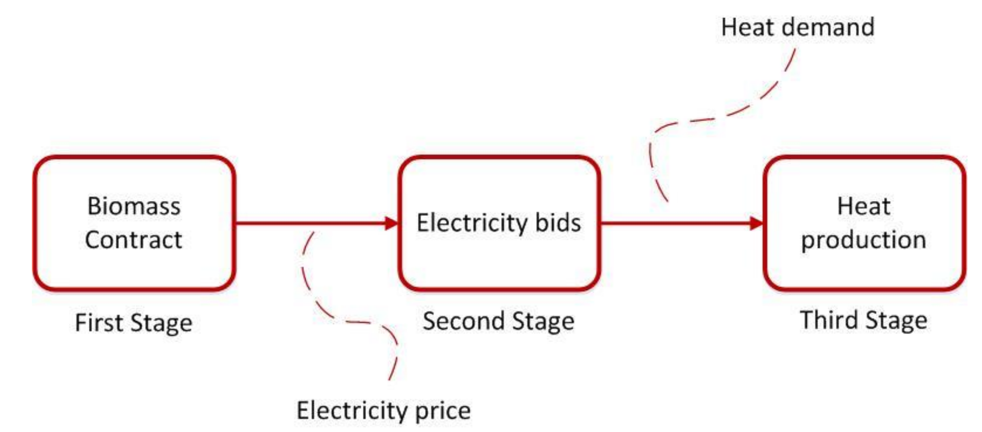
γ → Maximum Heat to Power Ratio

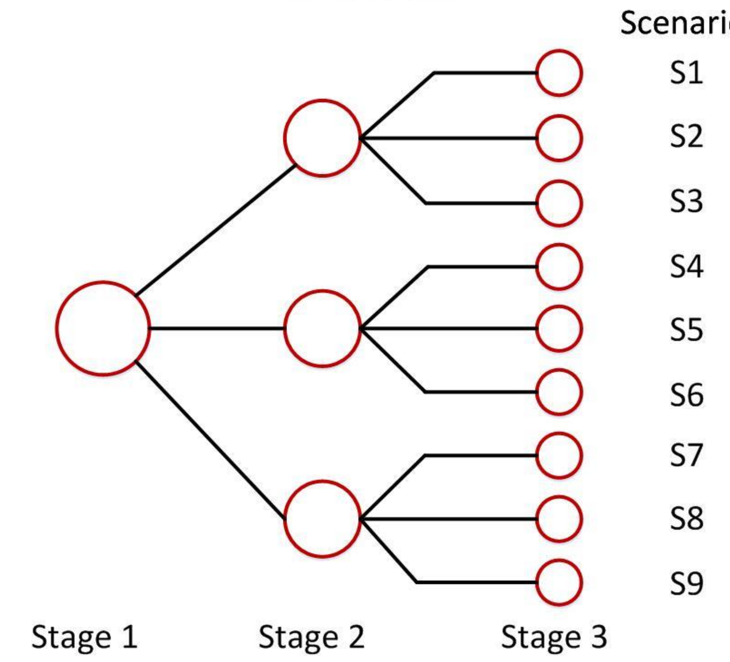
δ → Fraction of Power Reduction

- If both electricity prices and heat storage are high, empty the heat storage.
- If heat demand is low and electricity price is high, full the heat storage.

Biomass is considered the only fuel in the system, to be more specific, wood pellets. The wood pellet markets for large-scale users as CHP plants consists mostly on mid-term contracts (up to three years) combined with short term deliveries from daily spot markets.

METHODOLOGY





$$\Upsilon = \{B\} \quad \Lambda(s)=\{p(s),q(s),A(s),sl(s), B^{used}(s),x^S(s),x^P(s)\}$$

For this model the CHP plant operator needs to make an estimate of its heat and power production in order to be able to predict the optimal quantity of biomass contracted. Flexible solutions are given by the introduction of two different CVaR in the objective function. CVaR1 for the expectation of electricity production revenues and CVaR2 for the expectation of heat production costs.

First Stage:
The CHP producer has to decide the contract that defines an amount of biomass to be delivered.

Second Stage:
The CHP producer has to submit its bid in the day-ahead market.

Third Stage:
Is the real time operation. The heat demand has to be fulfilled as well as the power production bid.

Here and now decisions: Υ
Biomass delivered periodically in tones.

Wait and see decisions: $\Lambda(s)$
Power production, heat production, heat storage level, biomass storage level, biomass used, biomass sold and purchase in the last minute.

Objective Function:

$$\underset{\Upsilon,\Lambda(s)}{\text{maximize}} \; -C^{BC}B\sum_{d\in D}\sum_{h\in H}\tau_{d,h}$$

$$+\zeta_1 - \frac{1}{1-\alpha_1}\mathbb{E}[\eta_1(s)]$$ → **CVaR 1:** Power production. profits

$$+\zeta_2 - \frac{1}{1-\alpha_2}\mathbb{E}[\eta_2(s)]$$ → **CVaR 2:** Heat production costs.

Non-anticipativity constraints:

$$p_{d,h}(s) = p_{d,h}(s')$$

The power production bid in one node of stage 2 has to be applied in stage 3 for all the branches coming from that node.

CASE STUDY

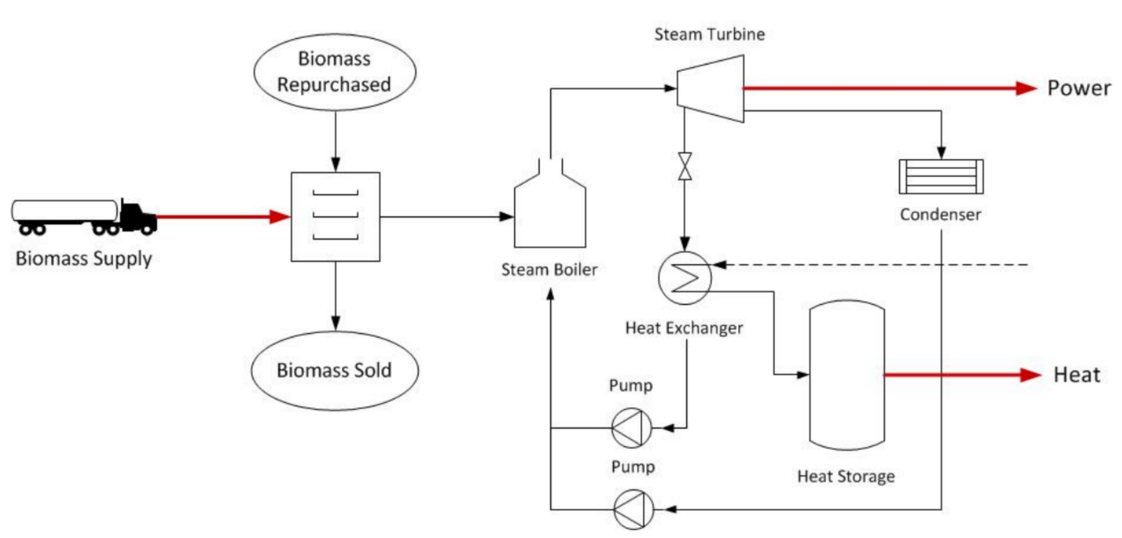


Figure 1 CHP configuration used in our work.

Table 1: CHP plant data

Parameter	Value	Unit
P^{max}	6.1	MW
P^{min}	2.7	MW
Q^{max}	8.7	MW
Heat generation efficiency, κ_{BS}	0.77	-
Variable O&M, C^a	3.9	€ /MWh
Biomass storage capacity, SC^{max}	35	MWh
Max heat-to-power ratio, δ	1.8	-
Fraction power reduction, γ	0.18	-
Max heat storage capacity, A^{max}	70	MWh
Min heat storage capacity, A^{min}	0	MWh
Min bio storage capacity, SC^{min}	0	t
Max bio storage capacity, SC^{max}	1295	t
Initially stored biomass , SL^{init}	600	t

Table 3: Different scenarios used in the optimization model

Scenario	Heat Demand	Electricity Price
1	High	High
2	Nominal	High
3	Low	High
4	High	Nominal
5	Normal	Nominal
6	Low	Nominal
7	High	Low
8	Nominal	Low
9	Low	Low

Table 2: Biomass data

Parameter	Value	Unit
Cost of biomass, C^{BC}	44	€ /t
Last minute biomass cost, C^{BLM}	60	€ /t
Last minute biomass revenue, R^{BLM}	25	€ /t
Lower calorific value, E	5.3	MWh/t
Density, ϱ	1100	kg/m^3

The case study is performed considering one year of planning horizon and weekly biomass delivering.

The case study is performed using data from the city of Nordborg, located in the Sønderborg municipality. Hourly district heating demand was calculated from the obtained measurements for the 53 buildings and scaled to the whole DH grid. From these data we generate our scenarios. Three scenarios for heat demand and another three for electricity prices. The combination of all of them defines our scenarios, presented in Table 3.

Nominal electricity prices were set as the price in the DK-west sector in the year 2015. *Low* and *High* electricity prices, were obtained by multiplying the *Nominal* prices with the factors of 0.8 and 1.2, while low and high heat demand was obtained by multiplying the *Nominal* demand with the factors 0.9 and 1.1.

Table 1 displays the technical data for the CHP plant . Table 2 shows the characteristics of the biomass fuel.

The CHP plant used for our case, described in Figure 1, is inspired in the CHP plant serving Nordborg district heating network. The plant is a gas driven plant equipped with a peak gas boiler. However, for our case we have chosen the CHP plant to be biomass driven and to have a large thermal storage instead of the peak boiler

RESULTS

Table 4 Case Study results.

Contract	α_1	α_2	Profit [€]	Revenues [€]	Cost [€]	Biomass Contract $[\frac{tones}{week}]$
1	0	0	362166	1067556	705389	221.415
2	0.5	0	257979	903204	645224	204.599
3	0.99	0	248832	882005	633172	172.156
4	0	0.5	356525	1062391	705866	221.916
5	0.5	0.5	219088	900767	681679	212.443
6	0.99	0.5	187235	837959	650724	209.481
7	0	0.99	354000	1072381	718380	221.841
8	0.5	0.99	213779	901006	687226	212.415
9	0.99	0.99	145010	816447	671436	206.522

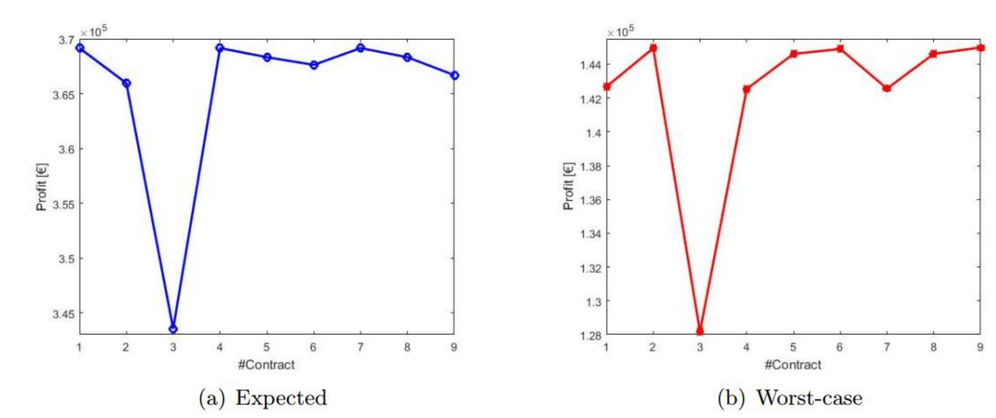


Figure 1 Performance of the different contracts according the expected and worst-case realization of the uncertainties when 9 scenarios are studied.

Table 5: Best/Worst performance of the biomass contracts in terms of expected and worst-case realization of the uncertainties.

	Contract	α_1	α_2	Profit [€]
Best Expected	1	0	0	369150
Worst Expected	3	0.99	0	343533
Best Worst-case	9	0.99	0.99	144989
Worst Worst-case	3	0.99	0	128171

Results displayed in Table 4 provide 9 different types of contracts based on the quantity of biomass distributed weekly.

The performance of the 9 different contracts is studied using probability density functions for different realization of the uncertainties:

- The 9 scenarios depicted in Table 3. (Table 5, Figure 1)
- 100 scenarios applying a random distribution for the heat demand and a normal distribution for the electricity prices. (Table 6, Figure 2)

Conclusion:

CHP producer profits are significantly more affected by the risk level assumed in the electricity prices rather than heat demand. Being conservative in the power profits expectations leads to bad contracting decisions because the amount of biomass contracted is employed to cover the heat demand and not to obtain profits from bidding in the day-ahead market. As a consequence, if an unexpected realization of the electricity prices performs, the producer limits its profits to the amount of biomass available.

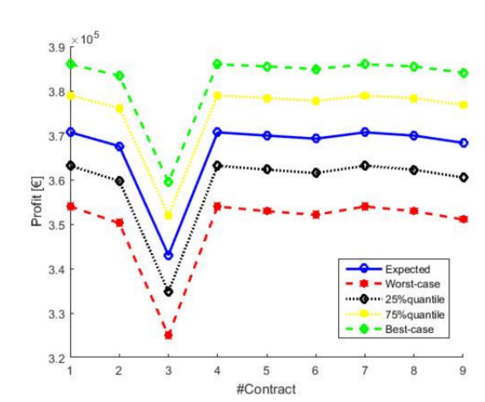


Figure 2: Performance of the different contracts according the expected, worst-case, best-case, first quartile and third quartile of the uncertainties realization when 100 scenarios are studied.

Table 6: Best/Worst performance of the biomass contracts in terms of expected and worst-case realization of the uncertainties.

	Contract	α_1	α_2	Profit [€]
Best Expected	1	0	0	370655
Best Worst-case	1	0	0	353955
Best Best-case	1	0	0	385965
Best 75% Quantile	1	0	0	378948
Best 25% Quantile	1	0	0	363143
Worst Expected	3	0.99	0	343019
Worst Worst-case	3	0.99	0	324915
Worst Best-case	3	0.99	0	359449
Worst 75% Quantile	3	0.99	0	352021
Worst 25% Quantile	3	0.99	0	334805