IfE Institut für Energietechnik an der HAW Hochschule Amberg-Weiden

Model Configurations for Improving the Efficiency of CHP-Units

Short version

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1 Aims of the study

Under the pressure of rising energy costs numerous technical innovations for improving the efficiency of co-generation units (combines heat and power = CHP) have been developed in the recent years. Due to the long lifetime of co-generation units of up to 20 years, many existing plants are not up to date with modern technologies and do not make use of their full efficiency potential. In addition the expectations of efficiency and economy of the original design are often no longer met due to changes of heat demand and economic and legal frameworks (e.g. fuel prices, feed-in tariffs for electricity). This leads to unnecessary resource consumption and CO_2-emissions as well as poor economic efficiency. Therefore the aim of the project was to elaborate model configurations for improving efficiency, economy and environmental compatibility of co-generation units, based on real case data of 18 typical CHP installations.

2 Methodology

Based on data acquisition in a twelve-month cycle the actual situation of 18 typical CHP systems was analyzed ecologically and economically. Derived from the current situation system specific model-configurations were developed, that show possibilities to increase efficiency and economics of CHP systems. Full cost accounting was used to evaluate the model configurations economically, for the ecological evaluation the CO_2 emissions were calculated. The calculation has been standardized in order to obtain comparable results. This means that the boundary conditions for the calculation, such as fuel prices, were assumed to be equal for all systems. The influence of single determining parameters, like the fuel prices, on the economy were then examined by means of a sensitivity analysis. The project results were abstracted to generally applicable recommendations for improving efficiency and cost-effectiveness of existing and newly planned cogeneration plants. Table 1 gives an overview of the CHP-systems selected for the project.

Table 1: Co-generation units analyzed in the project

Number	Utilization of heat	Commissioning	Power source	Fuel	Power input fuel kW	Electric power output kW	Thermal power output kW	Mode of operation	Electricity ac-counting
1	District heating	2007	Gas-engine	Biomethane	1.990	801	942	Heat led	Feed-in tariff EEG
2	District heating	2006	Gas-engine	Biomethane	1.925	746	973	Heat led	Feed-in tariff EEG
3	District heating	2006	Gas-engine	Natural gas	1.363	526	708	Heat led	Net metering
4	Process heat	2007	Plant oil diesel engine	Plant oil	565	240	220	Heat led	Feed-in tariff EEG
5	Process heat	1991	Gas-engine	Natural gas	-*	320	528	Heat led	Own utilization
6	Archive / library	2006	Gas-engine	Natural gas	332	112	196	Heat led	Own utilization
7	District heating	2006	Gas-engine	Biogas	904	335	455	Electricity led	Feed-in tariff EEG
8	Process heat	2008**	Molten Carbonate Fuel Cell	Natural gas	532	245	150	Heat led	Own utilization
9	Office building / CCHP	2005	Gas-engine	Natural gas	337	116	194	Heat led	Own utilization
10	Correctional facility	2008	Gas-engine	Natural gas	148	50	80	Heat led	Own utilization
11	Training center	2006	Gas-engine	Natural gas	204	68	109	Heat led	Own utilization
12	District heating	1990	Gas-engine	Natural gas	1.382	450	793	Heat led	Net metering
13	Hotel	2006	Plant oil diesel engine	Plant oil	76	25	44	Heat led	Feed-in tariff EEG
14	Office building / CCHP	2000	Gas-engine	Natural gas	1.200	450	620	Heat led	Own utilization
15	Office building	2005	Gas-engine	Natural gas	649	230	358	Heat led	Own utilization
16	Office building	2005	Gas-engine	Natural gas	350	120	200	Heat led	Own utilization
17	Indoor pool	2006	Plant oil diesel engine	Plant oil	475	200	160	Heat led	Feed-in tariff EEG
18	Process heat	2007	Plant oil diesel engine	Plant oil	475	200	160	Heat led	Feed-in tariff EEG
*	not known								
**	decommissioned 2010								
EEG	German Renewable Energy Law								
CCHP	Combined cooling, heat and power								

3 Summary of Results

In table 2 the results of the calculations based on the data gathered during the twelve month cycle are shown, split into the different CHP-technologies. The power based values were taken from the manufacturers‘ datasheets, whereas the work based values represent the real performance of the CHP system during the data acquisition cycle. The primary energy savings were calculated according to the EU directive 2004/8/EC and the CO_2 emission factors were calculated using the Finnish method, which was derived from 2004/8/EC.

Table 2: Summary of results based on data acquired in the twelve month cycle

	Unit	Gas-Otto-Engines	Diesel Engines	Fuel Cell	Average
Electric efficiency power based	%	35.6	39.5	46.1	37.0
Electric efficiency work based	%	34.6	38.1	45.5	36.0
Thermal efficiency power based	%	53.8	41.8	28.2	49.7
Thermal efficiency work based	%	50.5	40.3	27.5	46.9
Total efficiency power based	%	89.4	81.3	74.2	86.7
Total efficiency work based	%	85.1	78.3	73.0	82.9
Power based CHP-coefficient	-	0.67	1.00	1.63	0.80
Work based CHP-coefficient	-	0.72	1.01	1.65	0.84
Electric full load hours	h/a	6,321	4,743	8,089	6,069
Thermal full load hours	h/a	6,076	4,681	7,988	5,840
Coverage of electric energy demand	%	33.3	-	-	33.3
Coverage of thermal energy demand	%	48.2	43.5	-	47.5
Primary energy savings according to 2004/8/EG	%	23.7[1] 26.6[2]	26.8	23.2	24.8
CO_2-emission factors	g/kWh_{el}	420[1] 201[2]	350	423	368
	g/kWh_{th}	213[1] 110[2]	163	215	185

[1] Fossil fuels (natural gas)
[2] Biofuels (biomethane / biogas)

Based on the above results twelve alternative model configurations were developed, that show typical examples of practical relevance for improving economy and efficiency of CHP systems:

CCHP 1:	Replacement of the existing compression chiller by an absorption chiller (example CHP system 15)
CCHP 2:	Replacement of the existing absorption chiller by a compression chiller (example CHP system 9)
Biomethane-CHP:	Upgrade of the existing CHP module with an additional biomethane (example CHP system 11)
Satellite-CHP:	Upgrade of the biogas CHP system number 7 with a satellite unit near to the heat customers
Waste gas turbine:	Upgrade of CHP system number 4 with a waste gas turbine in order to increase electric efficiency
Wood-gas-CHP:	Replacement of the existing plant-oil CHP unit number 15 by a wood-gas CHP system
Fuel cell:	Comparison of a fuel cell with a conventional gas-engine CHP unit with same thermal power (example CHP system 8)
Electricity led CHP:	Electricity led operation (example CHP system 6)
CHP upgrade:	Upgrade of CHP system number 10 with a second identical module
Modernized CHP 1:	Replacement of the existing CHP system number 5 by a modern CHP unit with same thermal power
Modernized CHP 2:	Replacement of the existing CHP system number 12 by a modern CHP unit with same thermal power
Opt. Maintenance:	Shift of annual maintenance date from winter to summer (example CHP system 16)

In figure 1 and 2 the primary energy savings and the specific energy production costs for the actual state of the CHP-system, which serves as the reference configuration, and the model configurations are shown. In table 3 the improvements through the model configurations are given as mean values.

Table 3: Improvements through model configurations (mean values)

	Reference	Modell Configuration	Improvement
Primary energy savings according to 2004/8/EG	23.8 %	25.8 %	8.4 %
CO_2-emission factor electricity	393,6 g/kWh$_{el}$	347,9 g/kWh$_{el}$	11,6 %
CO_2-emission factor heat	197,6 g/kWh$_{th}$	176,2 g/kWh$_{th}$	10,8 %
Spec. energy production costs	4,42 Ct/kWh	4,02 Ct/kWh	9,0 %

The mean primary energy savings are improved by 8.4 % through the model configurations, while the CO_2 emissions factors for the generated electricity and heat are reduced by 11.6 %, respectively 10.8 %. The improvement concerning greenhouse gas emissions is mainly due to the model configurations using regenerative fuels, such as biomethane or wood gas.

From an economic point of view the majority of the model configurations are also an improvement. Only the model configurations for electricity led operation and modernization example 2 result in higher energy costs (see figure 2). However both configurations could be economical under altered conditions, such as falling gas prices or rising revenues for the electricity produced. The average energy production costs are improved by 0.40 Ct/kWh, coming down from 4.42 Ct/kWh for the reference configuration to 4.02 Ct/kWh for the model configurations.

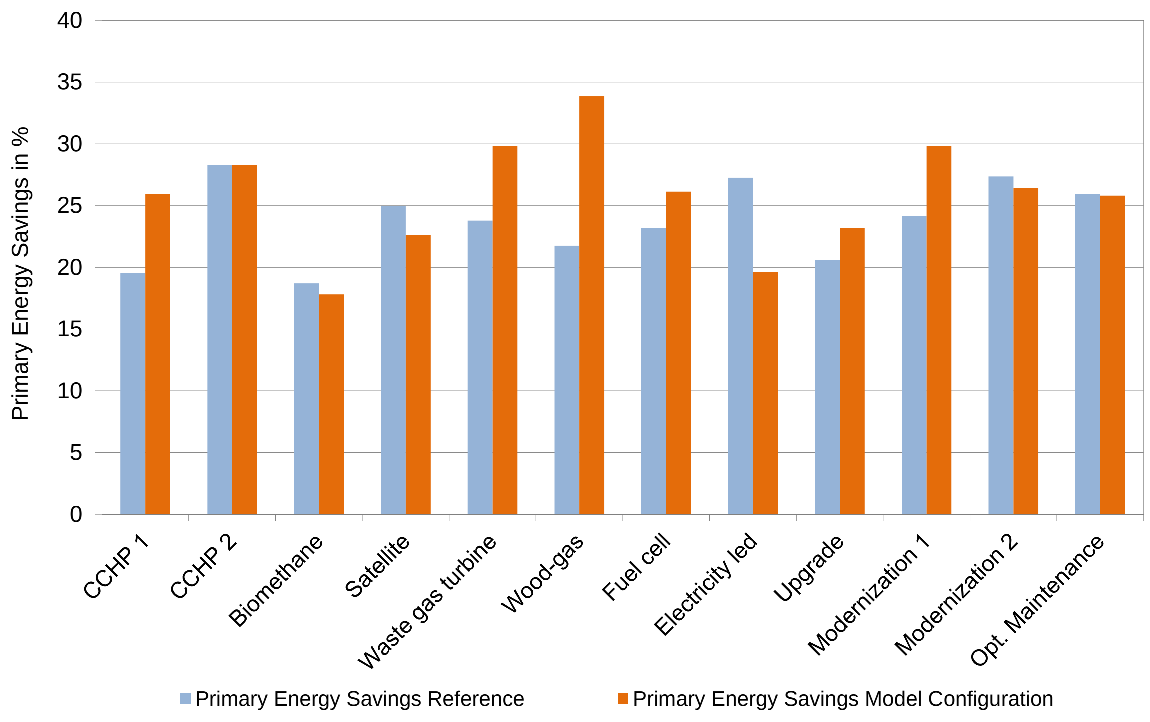

Figure 1: Primary energy savings of reference and model configurations

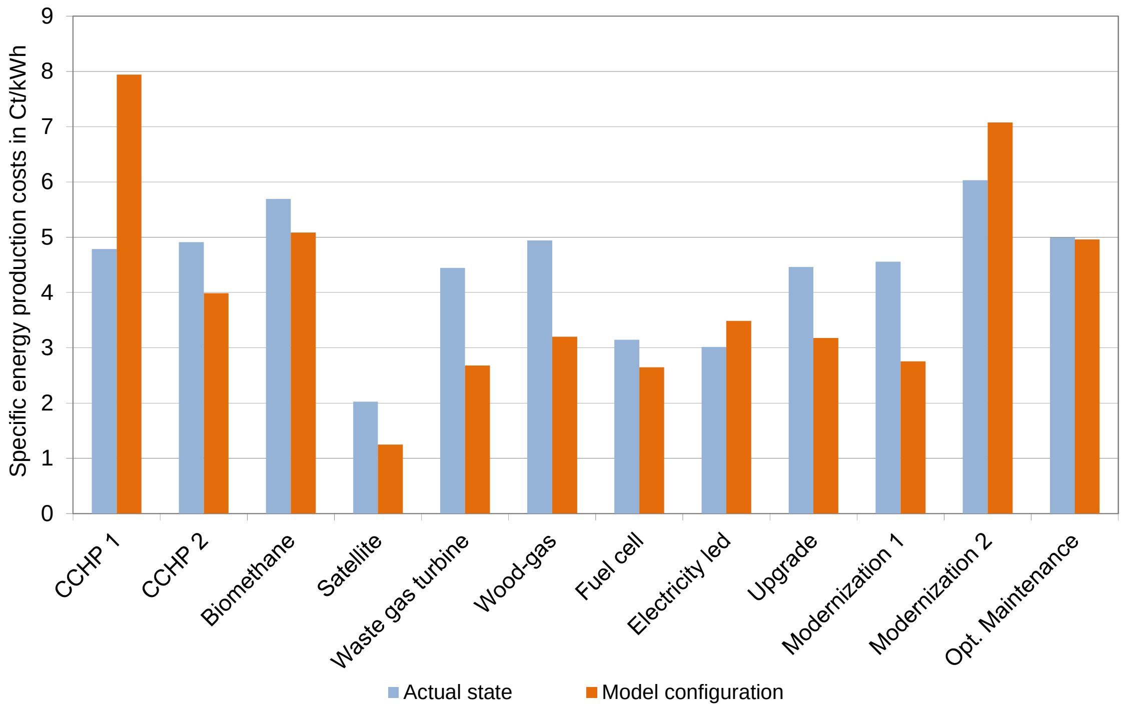

Figure 2: Specific energy costs for reference and model configurations

Based on the results of the data acquisition cycle and the model configurations general advices concerning siting and dimensioning, integration into the hydraulic and control system, choice of fuel, upgrading and modernization, trigeneration systems and alternative CHP-concepts were developed. The essential conclusion of the project is that correct dimensioning as well as the correct integration into the hydraulic and control system is crucial for efficient and economic operation of a CHP-unit. By adapting the system configuration to the legal framework, e. g. by suitable choice of fuel and modular layout, significant economic advantages can be achieved. Because of the complex legal, economic and fiscal issues arising in this context, aid by experts is suggested for development of system configurations and operating models. For most of the applications that were considered in the project, CHP units based on combustion engines will still be widely used today, while alternative CHP concepts, like fuel cells, only play a role for niche applications.

In last step of the project checklists for planning of new CHP-systems and optimization of existing CHP-units were developed based on the project results:

Optimization Checklist for Existing CHP Systems	
1) Clarify responsibilities	Who is responsible for which tasks (operation of CHP unit, recording and evaluation of data, maintenance, purchasing, accounting,…)?
2) Check and complement existing meters	Are all relevant meters (electricity, heat, fuel consumption) installed and fully functional? Are the meters suited for the specific measuring task and are they calibrated?
3) Check and evaluate data from meters	Is reading of meters carried out correctly and regularly? Evaluate data and calculate performance figures (efficiency, full load hours,…)
4) Check legal framework	Are all the possible subsidies for CHP-units fully exploited (Renewable Energy Law (EEG), CHP Law (KWKG), tax incentives)?
5) Check service contracts	Is service fast and reliable? Are the costs within the normal range (cross-check with average market prices)? Can some of the maintenance jobs be carried out by the operator himself?
6) Check operating model	Is the operating model up to date? Could a contracting model be advantageous? Due to the complex economic and legal questions aid form experts is suggested for this step.
7) Check dimensioning of the CHP-system	Does the CHP-system operate according to the original design parameters? Are the predicted capacity utilization and availability reached?
8) Check integration into hydraulic and control system	Is the CHP unit always operated with priority? Is a heat storage available in the system and is it used efficiently? Are the return temperatures within the limits of the CHP system? Can full load hours be improved by optimizing the hydraulic system and the CHP control (e. g. high level control for the heating system, series or parallel connection,…)?
9) Check change of operation mode and fuel	Can it be advantageous to change the operation mode (heat led, electricity led, mixed operation) or the fuel, and thus the feed in-tariff regulations?
10) Check alternative system configurations	In many cases the technical, economical and legal framework changes during the lifetime of a CHP-system. Therefore it should be periodically checked if an alternative system configuration could be advantageous. This applies particularly if relevant laws are changed, like the EEG (Renewable Energy Law) or KWKG (CHP Law).

Planning Checklist for New CHP Systems	
1) Determination of energy demand	Determination of heat and – if needed – electricity demand and demand for cooling and the respective demand profiles. Determination of the annual load curves.
2) Development of energy supply concept	Development of different variants for the energy supply system, considering the relevant technical requirements and particular objectives (e. g. maximum primary energy efficiency, minimal investment costs, maximum security of supply,…).
3) Economic and ecologic evaluation of energy supply concept	Economic evaluation of the different energy supply options (full costing), sensitivity analysis, CO_2 and primary energy balance. Determination of a preferred system configuration.
4) Check for possible subsidies	Evaluation of possible subsidies available in the relevant federal state and on national level.
5) Development of operating model	Particularly for operators whose genuine business is not providing energy supply, contracting models can be an interesting option. Due to the complex legal, economic and fiscal questions experts for operating models should be involved in this step.
6) Detailed technical planning	Detailed technical planning and tendering procedure. For small CHP systems planning can usually be accomplished by the CHP system manufacturer or the vendor respectively installer. Bigger CHP systems should be planned by expert engineers.
7) Construction phase	Installation of the CHP system by individual companies or general contractor. An independent expert should be involved for final acceptance of the works.
8) Commissioning and test runs	Final acceptance test. Check of the warranted technical specifications (electrical and thermal power output, fuel consumption, exhaust gas emissions,…). Protocol of final acceptance test for future inspections.
9) Monitoring	Monitoring of operating data in close intervals during the first heating period in order to identify possible problems. For CHP systems with combustion engines monitoring of lubrication oil is recommended in order to detect abnormal engine wear and to determine the oil change intervals.