Potential of fossil and renewable CHP technology to reduce CO_2 emissions in the German industry sector

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Abstract: Based on statistics about fuel demand in industry sectors a method is developed for the estimation of additional combined heat and power (CHP) potential in the main industry sectors. Electricity generation costs of several CHP technologies are then compared to the purchase of electricity on electricity markets. It is found that additional heat potential for CHP is limited in the chemical industry; additional potential is found in the paper industry, food industry and in the manufacturing industry. Additional electricity potential for CHP can be found in all sectors as electricity to heat share is 0.34 at the moment and can be increased with new installations to more than 0.7. The share of renewable fuels used in CHP is highest in the wood and paper industry, additional potential can be found in several branches, but costs are high at the moment.
Markets can pick up CHP electricity in the short term and installations are profitable when long operating hours can be reached. Looking in electricity markets with a higher share of renewable energy sources (RES), operation become more restricted making new operation strategies necessary. Times with electricity prices below short term generation costs of CHP installations increase in the future, so that operation will be less profitable.
In short term CHP can bring additional CO_2 reduction, specific emissions are below new combined cycle units. In the medium to long term additional use of RES fuels and adapted operation strategies will be necessary to lead to further CO_2 reductions.

Keywords: *Combined Heat and Power, Renewable energy, Electricity market, Industrial applications*

1. Introduction

Reduction of CO_2-emissions in all energy consuming sectors will be necessary to fulfill short and long term goals to stabilize climate change. The usage of combined heat and power technologies (CHP) is promising to provide cheap CO_2 reductions especially in the industry sector, but is questioned to be the right technology option regarding long term goals [1]. The EU commission tries to promote CHP technologies with the CHP directive 2004/08/EC [2]. Various support schemes has been implemented throughout Europe [3] and the member states have to report progress to the EU commission. So far progress in the German industry sector has been limited although potential is expected to be large [4]. The purpose of the work is to identify reduction potential in the German industry sector based on fossil but also on renewable fuels. Furthermore the work analysed the possibilities of selling CHP electricity on future power markets with increasing renewable electricity generation.

2. Methodology

2.1. Approach

Statistics of final energy demand in Germany’s industrial sector and estimates of the electricity demand in the future were used as a basis for the identification of the industrial heat demand and industrial CHP potentials [5], [6]. The final energy consumption less electricity demand was applied as an indicator for the heat demand. Sector specific energy intensity and indicators of sectoral economic development served as important influencing factors for the estimation of the future heat demand of the German industry. With the help of estimated heat demand the technical potential which could be covered by CHP was then projected (Fig. 1). In this projection the evaluated distribution of heat demand according to the temperature levels for different industry sectors and technical assumptions of conversion efficiency and CHP heat coverage were also integrated.

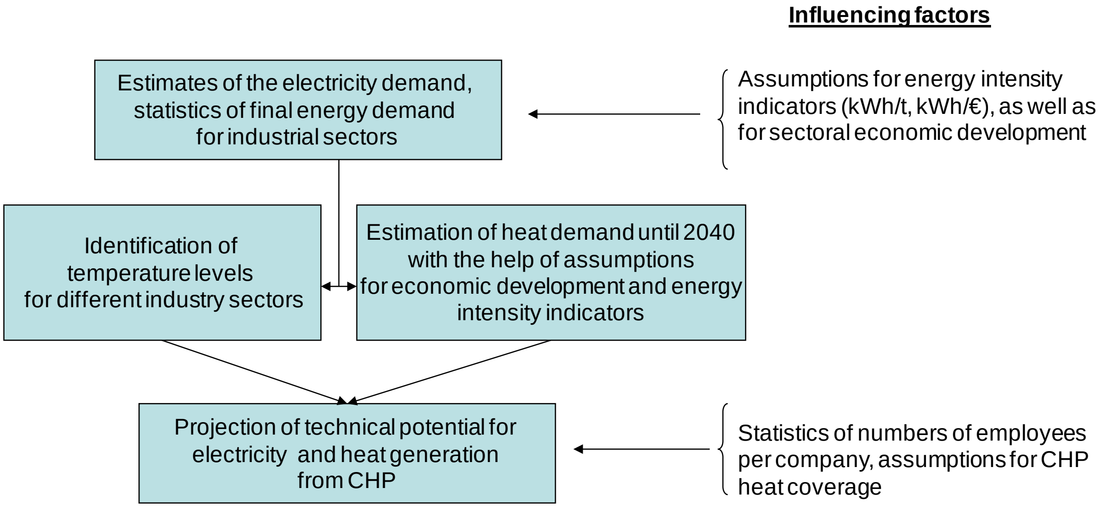


Fig. 1. Methodical approach for estimation of the heat demand in German industry and technical CHP potential.

The evaluation of heat demand according to the temperature distribution for different industry sectors was performed on the basis of previous estimations by Wagner et al. [7] as shown in Fig. 2. As one can see this temperature distribution provides indication for temperature levels of heat demand applicable for possible CHP generation. In this case the process heat at temperature levels lower than 500 °C and heat use for space heating and process water were of high relevance for the identification of the technical CHP potential.

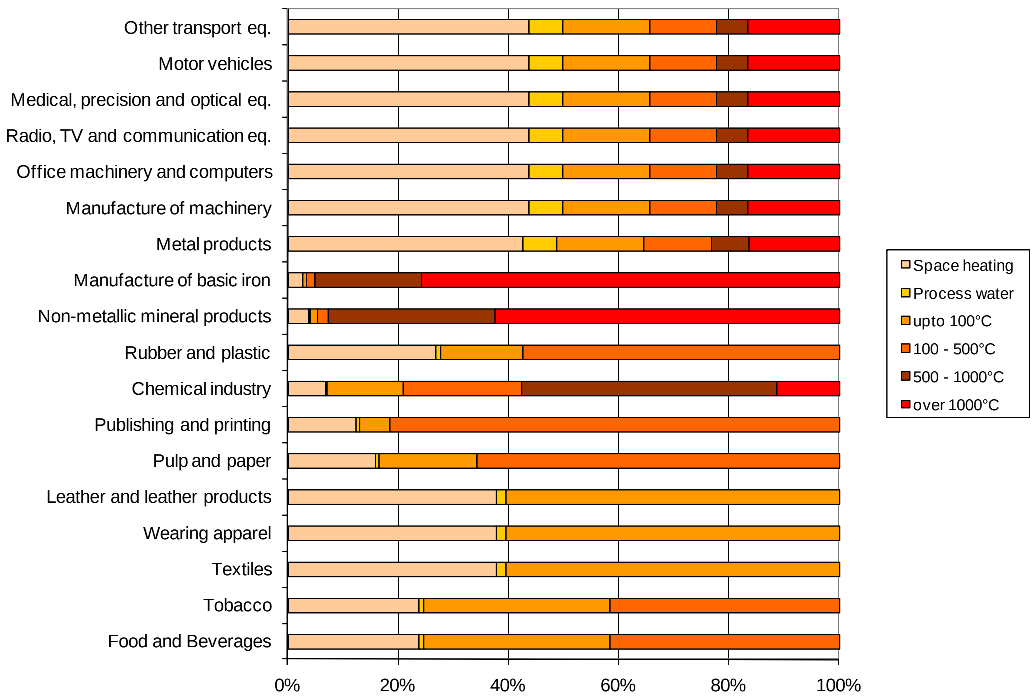


Fig. 2. Distribution of heat demand according to temperature levels and industry sectors in Germany in 2001.

Besides the technical potential also the economic (cost-effective) potential for CHP in the German industry is estimated. The parameters for the technical and economic potentials are defined as follows:

- Technical potential

The technical potential is derived from the useful heat demand applicable for CHP installations (< 500 °C). The conversion from fuel input (final energy) to useful energy is performed with the constant conversion efficiency factor of 90% which corresponds to the boiler efficiency of the separate heat generation. The CHP installation is assumed to apply for 75% of the heat demand. The rest of heat demand will always be generated via a peak load boiler.

- Economic (cost-effective) potential

Economic (cost-effective) potential is defined as a potential that can be supplied more economically attractive via CHP installation than with a separate electricity and heat generation. The base load price on the European Energy Exchange (EEX) served as a reference for electricity generation. The heat generation is considered via a heat bonus. These reference costs were calculated as saved fuel costs in case of separate heat generation. The life cycle of installations was assessed depending on installation type and was defined as 12 years for small installations and up to 20 years for large installations. The interest rate for calculations was set at 10%. Also the financial remuneration of CHP and grid access fees were taken into consideration. In Germany operators of CHP plants get a CHP premium on the electricity production guaranteed by law. The premium is paid to promote new installations of CHP power plants. It is typically between 1.5 and 2 €/MWh and is paid additionally to the revenues for the electricity production. The premium is paid for 4 to 6 years after the installation of the power plant. A comparison of costs and revenues is presented in Table 1.

Table 1. Costs and Revenues for identification of cost-effective CHP potential in the industry.

Costs	Revenues
Investment (life cycle of 12 – 20 years, 10 % real interest rate)	For electricity
Fixed operating costs	For heat
Variable operating costs	CHP premium
Fuel expenses	Avoided grid access fees
CO_2-allowances	

The impacts on the electricity markets are calculated using today's spot market prices from the EEX. Spot market prices for a future scenario with higher RES shares of 40 % have been calculated using the agent based electricity market model PowerACE [8].

2.2. Technical and economic specifications

The spectrum of industrial CHP technologies varies from CHP installations with 1 MW of electric power output to large power plants with several hundred MW of electric power output. In this research the complete spectrum of various CHP technologies available for combined heat and power generation was analysed. For that purpose so called reference installations were defined and their various technical and economic parameters were described. In Table 2 one can see a clear cost decrease with growing power output of an installation.

Table 2: Parameters of CHP installations for output range from 2 to 220 MW (el).)

Parameters	**Unit**	**CC-GT**	**CC-GT**	**OC-GT**	**CC-GT**	**OC-GT**	**Gas Engine**
Power output [MW]	MW (el)	**220**	**100**	**90**	**20**	**10**	**2**
el. efficiency	%	47.6	47.1	33.0	44.4	31.0	39.0
heat efficiency	%	40.3	41.0	52.4	42.3	49.0	47.6
Efficiency total	%	87.9	88.1	85.4	86.7	80.0	86.5
Investment	€/kW (el)	742	756	722	820	700	800
fixed operating costs	€/kW/a % of Investment	37.1 7 %	37.8 7 %	33.3 6 %	57.4 7 %	42.0 6 %	16.0 2 %
other variable operating costs	€/ MWh_{el}	0.5	0.5	0.5	0.5	0.5	8

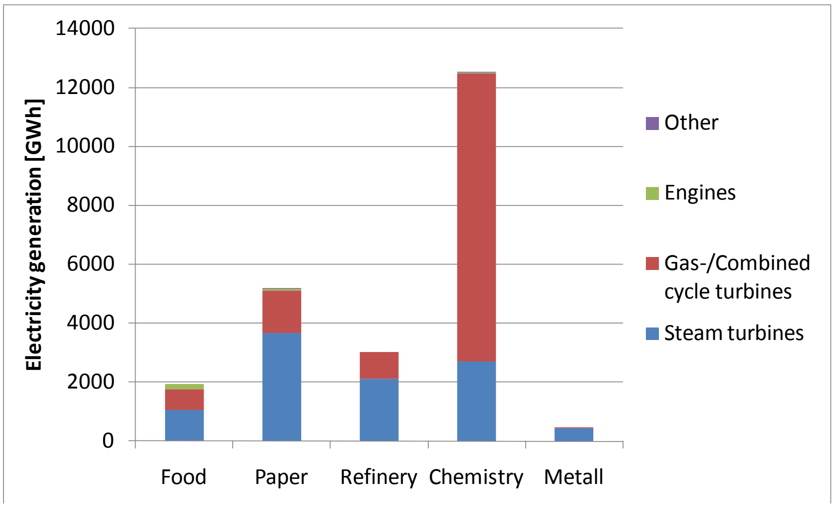
Source: own assumptions based on information from project developers, CC-GT: combined cycle gas turbine, OC-GT: open cycle gas turbine

3. Results

3.1. Additional technical CHP potential

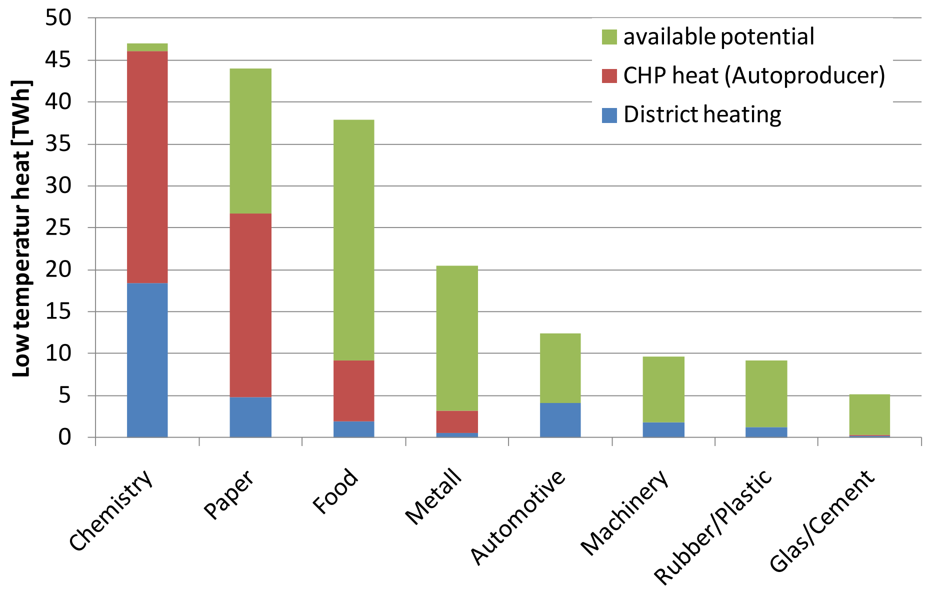
Today the major industry sectors using CHP power plants are the chemical industry, the paper industry and the food industry in Germany (see Fig. 3). They provide around 74 % or more than 19 TWh of the CHP electricity production in the industry sector in 2009 [6]. Additional electricity generation is possible without an increase of the heat generation as the average electricity to heat factor of the CHP installations is only ca. 0.34. The modernization of old CHP devices can increase the electricity to heat ratio above 0.7 and double the electricity generation.

Next to modernization of old CHP generation units, there is also the possibility to find new heat sinks that can be supplied by CHP units. It is found that additional heat potential for CHP heat generation is limited in the chemical industry, some additional potential is found in the paper and food industry (see Fig. 4). Further additional heat potential is found in the manufacturing industry. Final energy demand in the industry sector has been 700 TWh in 2008 with around 214 TWh of low temperature heat. Around 45 % of this low temperature heat is already supplied by district heating or by CHP auto producers. The technical potential to increase CHP heat production is then around 118 TWh. Only a small part of it is a cost-effective and realizable potential. In some sectors like metal or glass industry a lot of high temperature heat is available that could be used first before new CHP units would be installed. In other sectors with small companies the installation of CHP units might not be profitable as only small units with shorter operation times could be used.



Source: [6]

Fig. 3. CHP electricity generation in major industry sectors related to the generation technology in 2009 in Germany



Source: Own figure based on [5, 6, 7]

Fig. 4. Provision of low temperature heat by CHP heat generation, district heating and available CHP heat potential in major industry sectors in 2008

3.2. Renewable fuel use in the industry sector

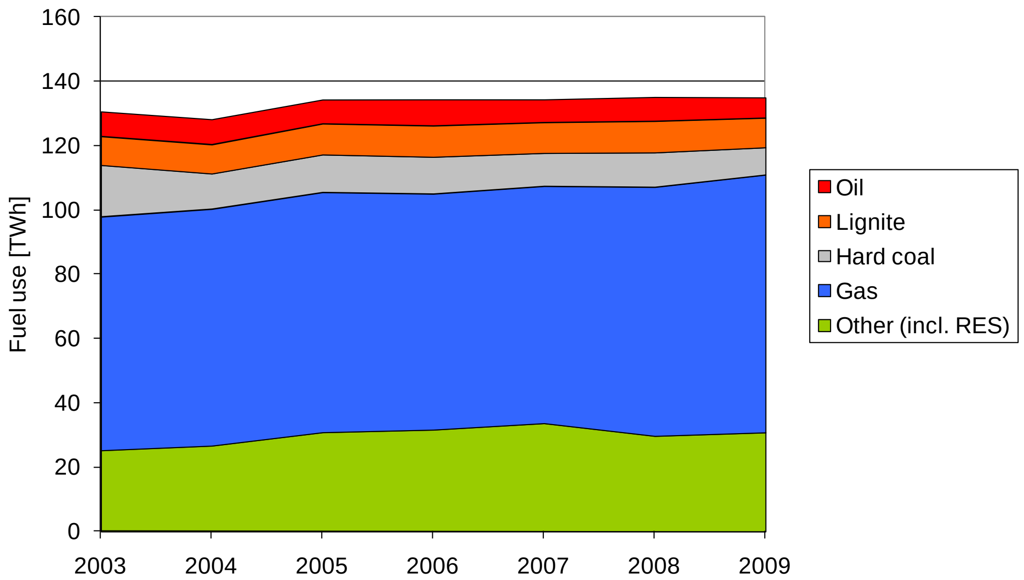
Until now renewable fuels have only a very limited share of 4 % in the industrial sector corresponding to around 27.5 TWh (final energy demand) in 2008 [5]. It increased from 15.5 TWh in 2003. Most of it is used in the wood and furniture industry followed by the pulp and paper industry (see Table 3). In this figure fuel use for heat production in CHP power plants is included. The fuel use for CHP electricity production is covered by the statistics for the power plant sector. The renewable fuel use for electricity production in industrial power plants was 7.8 TWh in 2008 (with 3 TWh in 2003).

Table 3. Distribution of renewable fuel use in major industry sectors in Germany 2008.

Sector	Wood/ furniture	Paper	Chemistry	Cements	Food	Other
Share [%]	37	27	22	8	3	3
Total [TWh]			27.5			

3.3. Renewable CHP generation

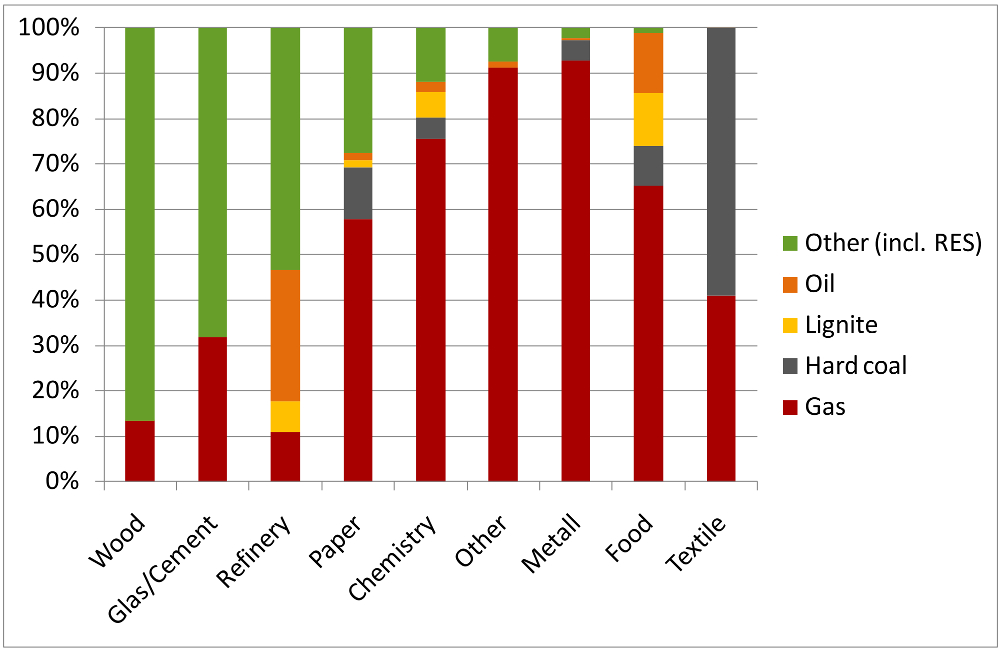
The share of renewable fuels used in CHP power plants is covered in the statistic [6] together with other fuels like waste (refuse-derived fuels, RDF). In the past the use of renewable and RDF fuels has slightly increased from 25.3 TWh in 2003 to 29.8 TWh in 2008 (see Fig. 6). In 2003 around 24 % (6 TWh) of the 25.3 TWh are renewable fuel due to statistics from EUROSTAT [9]. This corresponds to almost 5 % of the fuel used in CHP power plants. For 2008 no statistics are available. Under the assumption that the fuel use in CHP power plants has increased similar to the total renewable fuel use in the industry sector, it should be around 11 TWh in 2008. Progress in the sector is difficult to estimate, but there should have been some in the past.



Source: [6]

Fig. 5. Fuel use in CHP power plants from 2003 until 2008 in the industry sector in Germany

High shares of renewable fuel use in CHP power plants can be found in the wood industry and in the paper industry (see Fig.7). Renewable fuels are also used in the chemical industry. Additional potential in the wood and paper industry is very limited as the major waste material from production processes is already in use [10]. An increase of renewable fuels in CHP power plants can be done with external biomass like wood chips or pellets. Another option is the usage of biogas. Until now this option has not been used as renewable fuel costs were much higher than fossil fuel prices.



Source: [6]

Fig. 6. Share of renewable fuel use in CHP power plants in major industry sectors in Germany 2008

3.4. Economic potential and CO_2 savings

The economic assessment is driven by the size of the CHP units as investment costs typically decreases for larger units. Furthermore utilization decreases costs. Electricity production costs range between 10 Cent/kWh(el) for small CHP units (500 kW) and 6 Cent/kWh for big CHP units (400 MW), when units are in operation for 4000 h/a. If the value of the heat generation is estimated with saved fuel costs then electricity production costs are typically reduced by 2 to 4 Cent/kWh. In this case, CHP units are profitable compared to the electricity purchase. With a higher utilization the benefits typically increase.

Markets can pick up CHP electricity in the short term and installation are profitable when long operating hours can be reached. Profit margins are in the range of 13 to 25 €/MWh for more than 5000 hours per year.

Looking in electricity markets with a higher RES share of 40 %, operation become more restricted making new operation strategies necessary. Times with electricity prices below short term generation costs of CHP installations increase in the future, so that operation will be profitable in fewer hours than today. This is because natural gas and CO_2 allowances will be more expensive. This will be partly compensated by higher revenues for electricity, but the increase of electricity prices will be limited due to wind and solar power production. Typical profit margin increases up to 40 €/MWh, but can be reached only 2500 – 4000 hours per year.

The heat bonus for CO_2 emissions on the CHP heat generation is calculated using a reference heat technology. Assuming gas as fuel and a 90 % efficiency of the heat generation the heat bonus is 223 g CO_2/kWh(heat). Resulting CO_2-Emissions for the electricity generation reach 230 – 280 g CO_2/kWh(el) depending on the CHP technologies. Compared to the German electricity mix with specific emissions of 575 g CO_2/kWh(el) savings up to 60 % can be reached. A comparison with a modern combined cycle power plant, specific emissions are at 340 - 350 g CO_2/kWh(el), leads to a reduction of ca. 35 %.

4. Discussion and conclusions

In short term CHP can bring additional CO_2 reduction in the German industry sector as specific emissions are below the actual electricity mix and also below new combined cycle power plants with no heat or steam generation. As gas is already the dominant fuel source in the industry sector savings in the heat production are limited. Major reductions can be achieved by the substitution of fossil electricity generation outside the industry sector. Renewable fuel use is already done in sectors that have renewable waste from its production process. These potentials within the different sectors are already used today, so that an increase of renewable fuels can be mainly achieved by using additional renewable fuels like wood chips, pellets or biogas from outside the industry sectors. In the medium to long term additional use of RES fuels and adapted operation strategies will be necessary to lead to further CO_2 reductions.

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