Possibilities and Limits of Cogeneration with Regard to Energy Saving and CO_2 Reduction

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Abstract:
The combined heat and power production by cogeneration power plants is considered as a very interesting technology because of its high energy conversion efficiency. Thus, district or local heat is able to cover a part of the energy need for the space and process heat and for the hot-water supply in the public and in the industrial sector. This paper presents the newest estimations of the potential of cogeneration for the energy system in the Federal Republic of Germany. The results are critically discussed with regard to the contribution of cogeneration in saving energy and reducing CO_2 as well as to the results of other studies.

Introduction:

During the last years the danger of an anthropogenous climatic change has been in the focal point of the environmental discussion. Already today there are sufficient scientifically substantiated indications and signs which make it necessary to begin now with measures to limit the threatening climatic changes and which do not allow to wait until open questions are answered. In energy policy a fundamental reconstruction concerning the energy and the traffic system is discussed to reduce the energy-related CO_2 emissions [1]. This includes the intensified use of cogeneration in the public and the industrial energy supply and the use of industrial waste heat, the use of modern power plant's technology as well as the improvement of the thermal insulation of buildings and the use of efficient heating technologies and lightning systems.

In order to find the best measures to reduce the energy-related CO_2 emissions, in 1987 the 11th German Bundestag (the German parliament) set up the Enquete Commission "Preventiv Measures to Protect the Earth's Atmosphere" which should work out proposals how the CO_2 emissions can be reduced sensible and efficiently. In october 1990 that Enquete Commission presented a third status report with the title "Protecting the Earth" summarizing its work. There it made a lot of recommendations in which way considerable reductions of energy-related emissions of radiatively active trace gases for the conversion and supply of energy can be achieved by improving the energy efficiency [2]. As one of the elements for a strategy to be developped the Enquete Commission mention an increasing application of cogeneration including the extension of the local and district heat supply. Taking the year 1987 as reference year, the commission demands a reduction of CO_2 emission in the Federal Republic of Germany by 30 % until the year 2005, by 50 % until the year 2020 and by 80 % until the year 2050.

Fundamental basis 1987

In the Federal Republic of Germany (old)[1] 716 mio. t CO_2/a (including 10 mio. CO_2t/a of the international air traffic) were emitted in 1987 on the whole. Worldwide, the Federal Republic of Germany (old) contributes with 3.2 % on the total CO_2 emission on the earth. In 1987, 232,4 PJ/a were fed in the district heat networks of the FR Germany (old) [3]. The district heat was provided by 71.6 % of cogeneration plants and by 26.1 % of heating stations, while 2.3 % originated from the use of waste heat. In the same time, 15.5 TWh/a electricity (net) was generated by cogeneration power plants of the district heat supply. This corresponds to a share of 4.7 % of the

[1] before the unification in 1990.

net-electricity generation in the public electric power supply. 254.3 PJ/a of fossil fuels were used for the district heat and power generation in cogeneration units. This involved CO_2 emissions of 20.6 mio. t CO_2/a according to 2.9 % of the total CO_2 emissions in the Federal Republic of Germany (old). In addition the cogeneration was used in industrial self-production plants. Following [4], there were generated 267 PJ/a of heat and 22.9 TWh/a of electricity on the whole in 1987. These are 40.4 % of the total gross-electricity generation in industrial units. The totally needed fuel amounts to 399.1 PJ/a corresponding to CO_2 emissions of 30.6 mio. t CO_2/a. These are 4.3 % of the total CO_2-emissions in the Federal Republic of Germany (old).

Starting from this situation in 1987 the possible contribution of cogeneration for reducing CO_2 was analized in different single studies within the framework of the whole analysis of the Enquete Commission. That means that not only the possible potentials of the district heat supply and the contribution of cogeneration basing on fossil fuels [4] were analized. Also the potential of cogeneration based on biomass [5] and the potential based on the heat extraction from nuclear power plants were evaluated. Finally the potential of using the high-temperature-reactor for the industrial process heat and steam generation [6] was determined. In the following the potentials of cogeneration determined in these single studies are presented and discussed critically.

Potential of the district heat supply and of the cogeneration by fossil fuels

The development of the district heat supply was examined first assuming that the district heat will increase in the same way as it did in the past years (potential B, expected potential). Furthermore an optimal development (potential A) was assumed where all technically possible and economically sensible measures for conserving the atmosphere should be realized.

Table 1 shows the relevant results of the assumed developments of the public district heat supply and the industrial cogeneration for the year 2005. Here the important assumption was made that the ratio of generated electricity to the heat production (REH) of a cogeneration unit increases because of better processes with a higher yield in electricity of new and improved cogeneration power plants. Concerning the industrial cogeneration an enormous increase of the REH has been assumed at gasfired combined heat and power generating processes with gasturbines, at combined cycle processes and at combustion engines. For both developments a total system efficiency of 87.7 % yields for the cogeneration power plants in 2005. The low improvement of the total system efficiency (1987: 87.6 %) can be reached by using more efficient technologies although an increasing REH comes normally along with a decreasing efficiency of a single cogeneration plant.

What kind of changes in the CO_2 emissions correspond with these potentials of cogeneration depends on several parameters. On the one hand one has to distinguish, if just a transition takes place from a separated to a coupled generation of heat and electricity or if at the same time a substitution of fuel occurs (from CO_2-rich to CO_2-poor or CO_2-free sources of energy). On the other hand one has to define a time-base (here: 1987) for the comparison of the separated heat and electricity generation. Concerning this investigation a credit for the cogeneration was determined with regard to the in addition to the situation of the year 1987 produced amounts of heat and electricity. This credit has been summed up to the CO_2 emissions connected to the additional consumption of fuel in cogeneration power plants. The results of the achieved reduction of CO_2 emission are listed in table 1. They correspond to a reduction of the total CO_2 emissions by 3.1 % (potential B) or by 10.0 % (potential A) compared to the year 1987. Unfortunately, it cannot be indicated which contribution of the CO_2 reduction comes from the extension of the cogeneration and which comes from the substitution of fuel. This indication is not possible because the use of the CO_2-rich fuel (hard coal and heavy fuel-oil) decreases and the use of the CO_2-favourable natural gas increases in the assumptions underlying the potential calculations.

Table 1: Potential of the district heat supply and of the cogeneration by fossil fuels [5]

	1987	2005	
		"expected" development, potential B	"optimal" development, potential A
public district heat supply:			
infeeding of district heat [PJ/a]	232.4[1)]	338	494[2)]
(annual increase [%/a])	-	(1.4)	(3.5)
cogeneration:			
- network-infeeding [PJ/a]	166.4	239	349
(annual increase [%/a])	-	(2.0)	(4.2)
- electricity generation [TWh/a]	15.5	27.9	46.1
(annual increase [%/a])	-	(3.2)	(6.2)
- REH [kWh_{el}/kJ]	92.8	116.7	123.1
- fuel consumption [PJ/a]	254.3	387	587
- CO_2 emission [Mio. t CO_2/a]	20.6		
industrial cogeneration:			
- heat generation [PJ/a]	267.0	367	624
- electricity generation [TWh/a]	22.9	37.9	76.9
- REH [kWh_{el}/kJ]	85.8	103.3	123.2
- fuel consumption [PJ/a]	399.1	578	1,049
- CO_2 emission [Mio. t CO_2/a]	30.6		
CO_2 reduction [Mio. t CO_2/a]		22.2	71.7

1) following [3], whereas 265 PJ/a are indicated for the year 1987 in [4].
2) calculated following the statements of the potential B.

A similar difficulty yields by looking at the economical side of the cogeneration. The essential problem of the calculation of costs in coupled processes lies in the fact that it is not possible to calculate the costs following the identity or cause principle and to take each product of the coupled process as cost factor [7]. Under this point of view in this single study [4] just the investment costs were calculated. For the potential B they sum up to 21.9 billion DM and to 67.3 billion DM for the potential A.

Potential of cogeneration based on renewable energies

In addition to fossil fuels renewable sources of energy (wood, surplus straw and biomass) and waste fuels (waste, rotten, dump and sewage gas) can be used in cogeneration power plants. From the technical point of view, the use of biomass could be extended considerably in the Federal Republic of Germany.

The technical and economic potentials have been evaluated for the year 1987 and 2005 in detail. Regarding the contribution of the cogeneration it has to be realized first, that the single processes have very different REH (biogas from liquid manure: 87.9 kWh_{el}/kJ, dump gas: 111.1 kWh_{el}/kJ, sewage gas: 90.9 kWh_{el}/kJ). Whereas the economic potential of the energetic use of biogas from liquid manure can be neglected in the year 1987, for 2005 it has be assumed, that 1 - 3 TWh/a electricity and 16 - 36 PJ/a heat can be generated under economical conditions. Concerning the burning of sewage and dump gas in cogeneration units, the economic potential of power generation comes to 1 TWh/a in the year 1987 according to a potential of 13.8 PJ/a of generated heat. The economic potential in 2005 has been calculated to 2 - 3 TWh/a electricity and 20 - 38 PJ/a heat. Concerning the burning of wood and straw, only the heat generation is to the fore.

The total economic potential of cogeneration by biomass sums up to a power generation of 6 - 8 TWh/a in the year 2005. This corresponds to a heat generation of 57 - 74 PJ/a and to a reduction of CO_2 emissions by 2 - 3 mio. t CO_2/a. The technical potential is about twice as high as the economic potential.

Potential of cogeneration by nuclear energy

Besides the renewable energy sources the use of the nuclear power, as an additional energy, is independent from the emission of greenhouse-gases. Therefore the substitution of CO_2-involved energy generation by nuclear power can contribute to reduce the greenhouse-gases. In this context not only the electric power generation by nuclear power plants and the production of other sources of secondary energy but also the supply of process, district and local heat by nuclear energy have been considered.

In the field of the district heat supply besides the use of small nuclear heating stations the extraction of district heat out of nuclear power plants has been analized. Here, just regarding the fossil fuel-use of the generation of district heat, a maximum technical potential of CO_2 reduction of 5 mio. t CO_2 can be found in the year 2005. By substituting the electric power generation of fossil cogeneration units too, the technically possible CO_2 reduction amounts to nearly 13 mio. t CO_2/a. Demanding economic conditions, only a small share of the total technical potential of CO_2 reduction, i. e. about 0.5 - 1.5 mio. t CO_2/a, could be reached in the year 2005.

The generation of process steam and process heat for the industry by nuclear reactors is a further possibility to contribute to the CO_2 reduction. Here, the high-temperature-reactor (HTR) with a size of 150 - 200 MW_{th} can be used. Analizing the structure of industrial fuel-consumption a technical potential of about 30 mio. t CO_2/a by nuclear plants can be found for the field of the generation of process steam. Taking moreover into account the generation of process heat the technical potential of CO_2 reduction increases to about 35 mio. t CO_2/a. Demanding economical conditions, about 24 mio. t CO_2/a, i. e. about 70 % of the technical potential, could be used in the year 2005.

Scenarios of CO_2 reduction

The estimated potentials for the use of cogeneration were put in three different scenarios of CO_2 reduction with the goal to reach a reduction of CO_2 emissions by about 30 % until the year 2005. Concerning the extension of the cogeneration here the technical progress of energy saving on the side of the respective application of energy (e. g. lowering of the heating energy consumption, direct gas or fuel-oil heating of dryers) was considered, too. Therefore the generation of heat and electricity by cogeneration units was lower in the reduction scenarios than in the "optimal" development mentioned above. Also, in contrast to the "expected" and "optimal" development of cogeneration, the district heat supply was considered without a peak load system in the reduction-scenarios. From the wide spectrum of possible scenarios the particularly relevant CO_2 reduction scenarios "Elimination of Obstacles and Price-Policy" (in the following treated as the two different scenarios "Elimination of Obstacles" and "Price-Policy"), "Nuclear Energy Phase-Out" and "Increasing Nuclear Energy Use" were chosen. Clearly it had to be considered that in practice not all potentials can be reached at the same time. With the results of these scenarios it can be judged, how the intensified use of cogeneration contributes to the reduction of CO_2 emissions.

Within the "Elimination of Obstacles" and "Price-Policy"-variants the CO_2 reduction was analized under the assumptions that the impediments which do not allow an economical use of the energy saving potential and of renewable energies can be cut back by political measures and that the capacity of nuclear power plants remained constant. In addition in the "Price-Policy"-variant the energy prices and the electricity prices were increased by

5 DM/GJ and 2 Dpf/kWh$_{el}$, respectively, introducing new taxes and duties. Above all in both variants energy saving-measures and the cogeneration as CO_2 reducing option are taken as well as an intensified use of renewable energies. Here, the use of natural gas increases by 30 %. Within the variant "Nuclear Energy Phase-Out" it has be investigated what kind of political measures are necessary to reach the goal of CO_2 reduction by a renunciation of this CO_2-free source of energy. As CO_2 reduction measures there are mainly the option of big energy savings and a further extension of the cogeneration and the use of renewable energies. Although, the potential of cogeneration was not exhausted completely. The use of natural gas increases by 50 %. Finally in the variant "Increasing Nuclear Energy Use" the Enquete Commission made an attempt to reach the reduction of radiatively active trace gases with measures as cost effective as possible. This is connected to a significant contribution of the CO_2-free sources of energy, the nuclear energy and the biomass. At the same time considerable reconstructions within the district heat supply are necessary.

In table 2 the single contributions of cogeneration in the different scenarios are summarized. Comparing the public district heat supply in the different scenarios it becomes obvious, that the contribution of the cogeneration and the extension of the district heat supply is the highest in the variant "Nuclear Energy Phase-Out". In contrast the variant "Increasing Nuclear Energy Use" shows the lowest growth-rate. The other variants lie in between, but they are closer to the "Nuclear Energy Phase-Out"-variant. Concerning the heat generation by industrial cogeneration, the results are the same for the variants "Elimination of Obstacles and Price-Policy" and "Increasing Nuclear Energy Use". The variant "Nuclear Energy Phase-Out" shows a heat generation which is 100 PJ/a higher. Considerable differences between the variants result in the structure of the used energy. In the variants "Elimination of Obstacles" and "Price-Policy" the share of CO_2-free sources of energy on the total heat-supply amounts to 8.7 % or 9.6 %, respectively. Their contribution rises in the variant "Nuclear Energy Phase-Out" to 12.3 % and in the variant "Increasing Nuclear Energy Use" to 66.0 %.

Corresponding to the various developments of the heat generation and of the structure of the used energy different CO_2 emissions are the result for the public district heat supply and for the industrial cogeneration[3] (see table 3). Here the CO_2 emissions lie between 16 mio. t CO_2/a ("Increasing Nuclear Energy Use") and 82 mio. t CO_2/a ("Nuclear Energy Phase-Out") in the year 2005 compared with 38 mio. t CO_2/a in 1987. With regard to the year 1987 the heat generation in cogeneration units is higher in 2005. This can be considered by a credit when fuels in the final-consumption-sector are substituted. Then net-CO_2 emissions result in between 4 mio. t CO_2/a in the variant "Increasing Nuclear Energy Use" and 51 - 53 mio. t CO_2/a in the other variants.

Nevertheless this does not already allow to compare the CO_2 emissions with the emissions in the year 1987 of 38 mio. t CO_2/a, because in all scenarios the electric power generation in cogeneration units rises compared with 1987. To indicate the CO_2 emissions connected to the electricity generation without an extension of cogeneration, this can be done only hypothetically. Here a likely reduction of CO_2 emission was calculated, assuming that the higher electricity generation would be supplied by condensing power plants based on fossil fuels only (case 1) or by a CO_2-free electricity generation in addition to the fossil-fired power plants (case 2). Under these assumptions a real reduction of CO_2 emissions results.

The substitution of the use of cogeneration power plants for fossil fuels does not always reduce CO_2 emissions but makes also possible to save fuels in general. The fuel-substitution due to the cogeneration in the end-use sector is listed in table 4. The most fuel would be substituted in the variant "Nuclear Energy Phase-Out" (- 439 PJ/a in the year 2005), whereas the fewest quantities results in the "Increasing Nuclear Energy Use"-

[3] without the electric power generation by industry for its own use which comes to 9.7 TWh/a

variant (- 171 PJ/a in 2005).

Table 2: Comparison of the contribution of the cogeneration in the year 2005 in the CO_2 reduction-scenarios

	1987	"Elimination of Obstacles"	"Price-Policy"	"Nuclear Energy Phase-Out"	"Increasing Nuclear Energy Use"
heat generation [PJ/a]					
- on the whole	499.4	762.8	770.8	908.0	679.5
- from cogeneration units	433.3	762.8	770.8	908.0	576.0
electr. generation by cogen. [TWh/a]	38.4	89.4	91.6	108.1	58.2
public district heat supply					
- heat generation [PJ/a]					
- on the whole	232.4	388.5	396.5	434.0	305.5
- fossil	215.6	322.5	322.5	322.5	101.8
- biomass	16.5	66.0	74.0	111.5	66.0
- nuclear cogeneration	0.3	0.0	0.0	0.0	34.2
- nuclear heating stations	0.0	0.0	0.0	0.0	103.5
- heat gener. in cogen. units [PJ/a]					
- on the whole	166.3	388.5	396.5	434.0	202.0
- fossil	153.8	322.5	322.5	322.5	101.8
- biomass	12.2	66.0	74.0	111.5	66.0
- nuclear	0.3	0.0	0.0	0.0	34.2
- electricity generation [TWh/a]					
- on the whole	15.5	49.5	51.7	56.6	26.1
- fossil	13.3	41.7	41.7	41.7	14.3
- biomass	2.2	7.8	10.0	14.9	7.8
- nuclear	0.0	0.0	0.0	0.0	4.0
- fossil fuel consumption [PJ/a]					
- on the whole	326.3	539.0	539.0	539.0	166.0
- by cogeneration	254.3	539.0	539.0	539.0	166.0
Industrial cogeneration					
- heat generation [PJ/a]					
- on the whole	267.0	374.0	374.0	474.0	374.0
- fossil	267.0	374.0	374.0	474.0	129.0
- nuclear	0.0	0.0	0.0	0.0	245.0
- electricity generation [TWh/a]					
- on the whole	22.9	39.9	39.9	51.5	32.1
- fossil	22.9	39.9	39.9	51.5	11.4
- nuclear	0.0	0.0	0.0	0.0	20.7
- fossil fuel consumption [PJ/a]	399.1	607.0	607.0	775.0	195.0

Critical discussion

Looking at the latest estimations of the cogeneration's potential in the Federal Republic of Germany which were evaluated during the investigations of the Enquete Commission some kind of disappointment cannot be hidden. Some of the assumptions and results must be analized critically. In the following only a few critical points are listed:

1. The potential B (expected potential) was be considered as a moderate development which should be surely reached. Compared with the newest publication of the PROGNOS AG [8] here the expected heat-fed in the heating-networks amounts to 282.6 PJ/a instead of 338 PJ/a that is expected in the potential B.
2. The same can be realized in the other direction looking at the optimal development (potential A). Compared to other publications [9, 10] the estimations are rather conservative.

Table 3: Variations of CO_2 emissions by using cogeneration in the year 2005 in the CO_2 reduction-scenarios in mio. t CO_2/a

No.		1987	"Elimination of Obstacles"	"Price-Policy"	"Nuclear Energy Phase-Out"	"Increasing Nuclear Energy Use"
1	CO_2 emissions of the public district heat supply and partly of the industrial cogeneration[1]	38	71	71	82	16
2	Avoided CO_2 emissions by substituting fuels in the final-energy-sector because of cogeneration		- 20	- 20	- 29	- 12
3	Net-CO_2 emissions, 1st step [(1) + (2)]		51	51	53	4
	Avoided CO_2 emissions by substituting fuels in the power-generation-sector because of cogeneration					
4	case 1[2]		- 44	- 41	- 47	- 17
5	case 2[3]		- 20	- 16	- 40	- 4
	Net-CO_2 emissionen, 2dn step					
6	case 1[2] [(3) + (4)]		+ 7	+ 10	+ 6	- 13
7	case 2[3] [(3) + (5)]		+ 31	+ 35	+ 13	0
	Variation to 1987					
8	case 1[2] [(6) - (1)]		- 31	- 28	- 37	- 51
9	case 2[3] [(7) - (1)]		- 7	- 3	- 25	- 38

[1] without the electric power generation by industry for its own use.
[2] with regard to the fossil fuel-mix of the respective variant in condensing power plants.
[3] with regard to the total fuel-mix of the respective variant in condensing power plants.

Table 4: Fuel-substitution due to cogeneration in the end-use sector in the year 2005 in the CO_2 reduction-scenarios in PJ/a

	"Elimination of Obstacles"	"Price-Policy"	"Nuclear Energy Phase-Out"	"Increasing Nuclear Energy Use"
Fuel-substitution compared to 1987	300	309	439	171
Share of the substituted fuel on the total fuel use	5.5 %	6.4 %	10.9 %	3.1 %

3. As a big disadvantage it turned out that the potentials of cogeneration have not been estimated under the assumption of changing energy-prices. The "Gesamtstudie district heat" already mentioned [9], that the potential of the district heat depends sensitively on the price-level of natural gas and fuel-oil.

4. To judge the possible contribution of the cogeneration correctly the electricity and the heat demand must be well-known in detail. Here the seasonal variations of the electricity and heat consumption should be taken into account as well as the temporal load-curve of the electricity and heat demand [11]. Against this background the formulation in the reduction-scenarios to consider the district heat supply without a peak load system and with a total system efficiency of 87.7 % seems to be the most questionable. Either a heat storage must be installed or the total efficiency of the cogeneration unit decreases or an electric surplus-power must be taken into consideration if condensing power plants guarantee the electricity production during the summer time. Each

restriction has its consequences on the total costs. In general by following economical points of view the cogeneration power plants supplying district heat-networks are only designed for 30 % to 50 % of the thermal peak load [11].

5. Looking at the variations of CO_2 emissions by using cogeneration in the year 2005 in the CO_2 reduction scenarios (see table 3) it can be realized that the most CO_2 has been reduced in the "increasing nuclear energy use"-variant where the cogeneration increases the lowest. Compared to the results of the other variants where the use of natural gas (the most CO_2-favorable fossil energy sources) highly increases the conclusion could be that the structure of the energy sources is of bigger importance than the use of cogeneration.

Regarding the important role the cogeneration owns in the energy policy and in the public discussion concerning its contribution to solve the present energy and environmental problems, the chances of the cogeneration in the Federal Republic of Germany should be analized more extensively. The generation of district and local heat and the industrial self-production should taken into account as well as the possibilities of saving heat. In addition other important influences like the development of energy-prices, of the economy and of the population should be considered, too.

Literature:

[1] ENERGIE SPEKTRUM: Bemerkenswerte wirtschaftliche Chancen, Programm der Bundesregierung zur Reduzierung der CO_2-Emissionen in der Bundesrepublik Deutschland bis zum Jahre 2005, in: ENERGIE SPEKTRUM, 1991, 6, S. 15 - 22

[2] Enquete-Kommission (Hrsg.): Schutz der Erde, 3. Zwischenbericht der Enquete-Kommission "Vorsorge zum Schutz der Erdatmosphäre" des 11. Deutschen Bundestages, Economica Verlag, Bonn, 1991, also published under the title "Protecting the Earth: a status report with recommendations fo a new energy policy"

[3] Kröhner, P., Ruppert, K.: Hauptbericht der Fernwärmeversorgung 1987, in: Fernwärme international (FWI), 18(1989), 1, S. 82 - 94

[4] Kaier, U., u. a.: Emissionsminderung durch rationelle Energienutzung im Umwandlungssektor, Studienschwerpunkt A.1.7, in: Energie und Klima, Band 2: Energieeinsparung sowie rationelle Energienutzung und -umwandlung, hrsg. von der Enquete-Kommission "Vorsorge zum Schutz der Erdatmosphäre" des 11. Deutschen Bundestages, Economica Verlag, Bonn, 1991, S. 741 - 819

[5] Hrubesch, P., Schulz, W.: Biomasse, Studienschwerpunkt A.2.4, in: Energie und Klima, Band 3: Erneuerbare Energien, hrsg. von der Enquete-Kommission "Vorsorge zum Schutz der Erdatmosphäre" des 11. Deutschen Bundestages, Economica Verlag, Bonn, 1991, S. 271 - 436

[6] Fahl, U., u. a.: Abschätzung der technischen und wirtschaftlichen Potentiale des Beitrags zur Energieversorgung und zur Minderung klimarelevanter Spurengase durch Kernenergie in der Bundesrepublik Deutschland, Studienschwerpunkt A.4.2, in: Energie und Klima, Band 5: Kernenergie, hrsg. von der Enquete-Kommission "Vorsorge zum Schutz der Erdatmosphäre" des 11. Deutschen Bundestages, Economica Verlag, Bonn, 1991, S. 191 - 316

[7] Belting, Th.: Analyse der Bewertungsmethoden für Strom- und Nutzwärmekosten, in: Brennstoff - Wärme -Kraft (BWK), 36(1984), 11, S. 457

[8] PROGNOS: Die energiewirtschaftliche Entwicklung in der Bundesrepublik Deutschland bis zum Jahr 2010, Untersuchung im Auftrag des Bundesministeriums für Wirtschaft, Basel, Oktober 1989

[9] Bundesministerium für Forschung und Technologie (Hrsg.): Gesamtstudie über die Möglichkeiten der Fernwärmeversorgung aus Heizkraftwerken in der Bundesrepublik Deutschland (Gesamtstudie Fernwärme), Bonn, 1977

[10] Fritsche, U.: Potentiale zur Kraft-Wärme-Kopplung und Stromeinsparung in der BRD, Werkstattreihe des Öko-Instituts, Nr. 38, Freiburg, Juni 1987

[11] Pruschek, R., Bock, J.: Energieeinsparung durch Kraft-Wärme-Kopplung - Potentiale und Grenzen, in: VDI Berichte Nr. 923, Düsseldorf, 1991