Micro Combined Heat and Power Systems – Evaluation of a Sample Application

Anayo A. Ezeamama, American Council for an Energy-Efficient Economy.

ABSTRACT

The growing need for a secure, cost-effective, less polluting and efficient form of energy has contributed to an increasing interest in the use of micro combined heat and power (MCHP) systems. In this paper, the environmental performance and economic feasibility of a 1 kW_e internal combustion engine (ICE) MCHP system in a one-family house was assessed and compared with the baseline scenario were residential energy demands are met with grid electricity and natural gas fired condensing boilers. The result of the analysis shows that MCHP systems present opportunities for savings in energy costs. Based on a social discount rate (SDR) of 5 % and a calculated 3259 operating hours, a simple payback period of about 4.8 years (Table 3) was calculated as the time needed to recover the extra investment cost of the ICE unit. The result of the sensitivity analysis reveals that, both the running hours and price of electricity have significant effects on the payback period of the project. Considering the end of useful life period of the systems, MCHP offer a good replacement for conventional gas boilers of 90 % efficiency. However, their high initial costs (when compared to high efficiency condensing boilers), could be seen as the major factor hampering market diffusion. Also, considering the optimal environmental benefits, MCHP system produced more on-site CO_2 emissions in reference to the condensing boiler but generally, annual CO_2 emission is reduced by about 38 % when compared to the overall separate generation of heat and power scenario.

Keywords: Micro-combined heat and power (MCHP), Heat, Power, Energy, and Emission.

Introduction

Policies geared towards ensuring security of energy supply at reduced cost and with minimum environmental consequences play leading roles in the energy policies of most developed nations. Such measures include technological development of advanced and efficient infrastructures, related policies to improve supply- and demand-side energy management, renewable energy, and decentralized generation. Energy is needed, among other things, for electricity and heat generation especially in the building sector. One of the major short-comings of the conventional method, where electricity and heat are produced and distributed via separate mechanisms, is that, due to the inability to transport heat over long distances, the enormous amount of heat produced is not utilized purposefully but rather lost as waste heat to the environment. This reduces the efficiency of grid electricity generation to about 33 per cent (EPA 2013). Conventional gas fired boilers generate heat for space heating and hot water with an efficiency of over 90 per cent; however, due to electricity transmission losses, the overall efficiency of the entire system is estimated at 51 per cent (EPA 2013).

Studies by “Arbeitsgemeinschaft für Sparsamen und Umweltfreundlichen Energieverbrauch” (ASUE) show that in Germany, space heating and hot water production accounts for more than one third of all primary energy consumption and that in residential buildings, about 90 per cent of the final energy is used for producing heat and domestic hot water

(ASUE 2008, 5). Furthermore, studies have shown that indirect emissions from electricity generation in Germany, contribute more than half of total emissions from building energy use (Amecke et al. 2013). Undoubtedly, measures geared towards reducing primary energy consumption in this sector will create a good potential for energy savings and reduction of environmental emissions associated with energy production, not to mention other socio-economic benefits.

Cogeneration is the production of heat and electricity simultaneously in a single, integrated system using one fuel source (Ren, Gao, and Ruan 2007). Natural gas and renewables are some of the various primary energy sources for a cogeneration system. The implementation of small-scale CHP systems (MCHP) for residential space heating and hot water production is becoming popular in Europe especially in Germany, United Kingdom and the Netherlands (COGEN Europe 2005). This system mainly meets the need for heat generation first with the secondary product being electricity. They are considered future replacement of the present domestic heating systems with production of heat and power on a small scale, typically with electric capacities of less than 50 kW (EC 2004). The electricity produced through this means, through grid integration, can also be sold back to the power grid. The main advantage of this cogeneration system is that the heat produced during electricity generation that would have instead been wasted in a conventional system is captured and utilized. The overall system efficiency of the cogeneration system is estimated at approximately, 80 per cent (EPA 2013) .[1] EU policies on energy acknowledges the use of MCHP as a significant means of reducing emissions in the residential sector and thus an avenue of achieving Kyoto target (EC 2004; Uyterlinde, van Sambeek, and Cross 2002). Also, the IEA/ECBCS (International Energy Agency/Energy Conservation in Buildings and Community systems) Annex 42 indicates that, *"The concurrent generation of electricity and heat from a single fuel source can reduce primary energy consumption and associated greenhouse gas emissions"* (IEA/ECBCS Annex 42 2004). Economically, it is believed that cogeneration of heat and power could assist end users in saving energy and associated cost since transmission and distributional charges are avoided.

This study attempts to perform an empirical assessment of the energy costs and emissions savings potentials of MCHP systems with a German residential apartment as a case study. A literature review has been conducted to gain basic background knowledge of this technology and to aid this author to establish a theoretical-based hypothesis in terms of system use. Following this will be an assessment of the environmental compatibility of this system and economic benefits to end-users. It is thus, the intention of this author to establish if this system presents any economic prospects to end users and the feasibility of serving as a viable replacement of the current conventional method of heat and electricity production especially in old and existing buildings.

[1] Efficiency of the MCHP unit adopted as at the time of research. However, presently systems with efficiency levels of 90 per cent are available.

Aim and Objective

This paper is structured to assess the operational performance of an installed and functioning MCHP system for the provision of space heating and electricity in a one-family house apartment and to compare it with the conventional method of heat and electricity generation. The basis of this assessment is to establish the actual potential of MCHP systems in terms of its possible economic benefits to end users and the environment as a whole and not to rely only on theory-based expectations. In achieving this aim, the paper establishes empirical findings in support of policies to encourage the use of MCHP systems, over the condensing gas boilers, as a means of reducing energy consumption and emissions from the residential sector. The research is mainly focused on assessing the performance of MCHP system in old and existing buildings which constitutes bulk of Germany building stock. Germany has a relatively old building stock, a low construction rate and long building lifetime; and despite the low construction rates, policy that enforces reduction in thermal energy demand in new buildings (the Energy Savings Ordinance) prevails (Amecke et al. 2013). MCHP systems may not be economically viable in buildings with low thermal energy demand. Also, the research was not intended to compare energy cost and emissions savings potentials of MCHP systems with other residential energy efficiency measures.

Research Methodology

Annual electricity consumption and its related cost for a single family apartment house (with three occupants) in Germany was estimated based on published mean values for a similar apartment from the Stadtwerke Cottbus (SWC) utility (SWC 2005). Also, information on gas consumption (per m^2 and year, using the conventional gas boilers) for both heating and hot water production and associated unit cost per kWh as published by the SWC (2005), was used to compute annual heat consumption (in kWh) in the selected case study and the corresponding annual heating costs. The percentage distribution of the energy mix for grid electricity generation in the region and corresponding CO_2 emission in total was adopted from the SWC utility (Table 3). National support scheme (average value in 2011 for feed-in-tariffs at 5.45 €cent/kWh, the electricity bonus payment for cogeneration with efficiency of greater than 70 % at 5.11 €cent/kWh and the gas subsidy payment of 0.55 €cent/kWh) that rewards the positive externalities of CHP usage in Germany was implemented (BAFA 2012). This payment structure applies to MCHP with electricity capacity up to 50 kW_e and is applicable as at the period this research was carried out. However, the amount and the duration of payment for the electricity generated now depend on the date of commencement of the continuous operation of the CHP plant. This is as a result of the revised payment structure which took effect from 1 January, 2015 (BAFA 2012)

A detailed literature review was carried out to present a theoretical basis relevant in gathering vital information on the state-of-art residential MCHP systems. As a result, the ECOWILL model 1 kW_e ICE micro CHP unit with a thermal output of 3.5 kWh was considered suitable for a single family house (ASUE 2008, 14). Information on system parameters, (e.g. investment and operational costs, etc.), of the selected MCHP unit was adopted from previous studies (Ren, Gao, and Ruan 2007; Houwing 2010) (Table 1). The table also includes price for the currently used high efficiency condensing boilers for comparison purposes. Based on expert knowledge gained from consulted literatures, careful assumptions were made to generate a model for a cost and benefit analysis of system operation for both cogeneration and separate heat and power production scenarios. It is assumed that the use of the MCHP system will generate equal benefits for each of the ten year useful life period of the system beginning at $t = 1$ (Table 2). A simple payback period needed to recover the extra cost on investment for a MCHP system was derived by calculating the present values (value at $t = 0$) of the benefits of plant use. The payback period gives an insight on the economic feasibility of the system considering its end of useful life period; the lower the return on investment, the less is the financial risk and the more attractive to customers.

Table 1. System parameters “2007”

Power output	1 kWe
Thermal output	3.25 kWt
Electrical efficiency	20 %
Total efficiency	85 %
Maintenance cost	1.7 €cent/kWhe
Boiler price	€ 1500 – 3000
ICE MCHP	€ 5500 – 7000
Extra investment cost for MCHP	€ 4000
Expected lifetime	10 years

Characteristics of Honda Ecowill MCHP model. *Source*: Ren, Gao, and Ruan 2007 Study of different micro CHP alternatives for residential application, Japan; Houwing 2010 Smart heat and power: utilizing the flexibility of micro cogeneration, Next generation infrastructures foundation, Delft, the Netherlands. ASUE 2008 Power-generating heating systems: opportunities for improving energy efficiency, Kaiserslautern.

For the environmental assessment, data on emission factor for the combustion of natural gas was adopted from the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (2006) and the emission factor value was used to estimate the total annual CO_2 emission from the cogeneration system (Table 5). Direct quantitative comparison with the information gathered on CO_2 emission rate of grid electricity mix was used to compute the emission reduction ratio or the emission savings with a MCHP system and this gives an insight on the overall emission savings potential of the MCHP system in comparison with the conventional method of heat and power generation.

Scenario description

A single-family house has been modeled to represent a typical Germany residence, having a total floor area of approximately 120 m^2 with three persons as inhabitants. The major energy demand in this one-family apartment is divided into electrical and thermal demand. Thermal demand consists of space heating and hot water (hot water at 60^{o}C). The average warm water demand is 40 liters per person per day (43,800 liters per year) which corresponds to typical demand according to 2015 published data (Paschotta 2016). The annual heat demand is estimated as 10,590 kWh (88.25 KWh per m^2 and year). This value is in the lower middle range of the statistical value for Cottbus (BMU 2009) and thus, can be interpreted to represent a thermally upgraded detached house. Average electricity usage is estimated as 3,750 kWh per year and is deemed a good average value considering German published average values in 2015 (SWC 2015).

A micro cogeneration unit is being considered for installation. The system is assumed to be a 1 kW_e output internal combustion engine (ICE) MCHP plant with 3,25 kW thermal output and consists of a 140 litres storage tank capacity (Tanaka et al. 2011) and a back-up burner. The MCHP plant runs on natural gas as a fuel source and supplies both the electricity and heat demand of the apartment. The storage tank serves as a store for thermal energy during periods of low heat demand and also to supply heat energy during periods of high thermal energy demand. If more heat is required, an additional burner can be used. Likewise, if the generated electricity does not satisfy customer's load, top-up electricity can be purchased from the utility grid.

The model was carefully developed to represent an average energy use apartment (neither in the lower level nor in the upper-limit of energy use) (BMU 2009) and it is expected that this would give a good analysis of the performance of a MCHP system. A low energy demand apartment will make the idea of a MCHP less attractive and an apartment with a very high energy demand may produce over-promising results.

Results and Discussion

Economic Assessment

Based on the model created from the parameters of plant usage and data analysis (Table 3), it was estimated that using a MCHP in this apartment could result in annual net savings of € 990. This includes benefits from avoided electricity costs, sale of excess electricity back to the grid, government support mechanisms and savings from gas costs. The costs taken into consideration for the plant usage were the extra investment cost for a micro CHP, operational costs (cost of gas) and the purchase of top-up electricity from the grid, presumably, at off peak periods. In respect to information adopted from expert knowledge, an additional investment cost of € 4,000 (Houwing 2010) is needed to install a micro CHP unit in reference to a gas fired boiler (Table 1). No data on the residual value of the system was provided; as a result it is assumed that at the end of the useful life period, the product no longer provides any cash flow and is discontinued without any additional costs. A social discount rate (SDR) of 5 % was adopted based on the recommendation of the European Commission (EC) on cost and benefit analysis (CBA) methodology in member states (EC 2014, 57). The present value (value at $t = 0$) of the economic benefits of MCHP use for each of the year is as shown in table 2.

Table 2. Present value calculation for each year

Year	T=0	T=1	T=2	T=3	T=4	T=5	T=6	T=7	T=8	T=9	T=10
Cash Flow	990	990	990	990	990	990	990	990	990	990	990
Present value	990	942.86	897.96	855.20	814.48	775.68	738.75	703.58	670.05	638.17	607.77

From table 2, it was estimated that a simple payback period of around 4.8 years (see table 3 for data sets) is required to recover the extra investment of € 4000 needed for the installation of a MCHP unit considering a 3259 operating hours. From the manufacturer's instruction, the useful life period of a 1 kW_e Ecowill ICE MCHP unit that was reviewed is 10 years (or 20,000 hours). The calculated and estimated data sets used for the economic analysis are summarized in table 3.

Table 3. Costs and benefits parameters of plant usage

Parameter	Value	Unit
Average annual electricity usage	3750	kWh
Annual heat demand	10590	kWh
Running time	3259	Hours
Electricity generated (avoided grid electricity)	3259	kWh
Utilization (careful assumption based on experts' knowledge)	70 % (2281)	kWh
Efficiency of boiler (value as at time of research)	90	%
Efficiency of MCHP (value as at time of research)	85	%
Unit cost of electricity	25,4	€cent/kWh
Value of avoided electricity	828	€
Unit cost of off-peak electricity (top-up electricity)	5,52	€cent
Top-up electricity	491	kWh
Value of top-up electricity	27,10	€
Unit value of export (average value in 2011)	5,45	€cent/kWh
Exported electricity	978	kWh
Total value of export	53,3	€
Electricity bonus (stromerzeugungsbonus) for cogeneration with efficiency > 70 %	5,11	€cent/kWh
Total value of bonus payment	167	€
Unit cost of gas	6,39	€cent/kWh
Cost of gas consumed by boiler	752	€
Cost of gas consumed by mCHP (less gas subsidy 0,55 €cent)	728	€
Savings in gas cost with mCHP	24	€
Total Net Savings (NS) at $t = 0$	990	€
Extra investment cost for the mCHP system	4000	€
Simple payback period (at SDR of 5 %)	4.8	Years

Research findings, however, show that to maximize economic benefits it would be more reasonable for the investor to utilize most, if not all, of the electricity generated by the unit because the cost of purchase of grid electricity is higher than the prevalent feedback tariff as at the time this study was conducted.[2] With the tariff structures used in the economic assessment, the avoided grid electricity constitutes bulk of the economic advantage of plant usage whereas the applied incentives do not really contribute any significant measure to the economic feasibility of the system. In addition, during off-peak periods, the value of the generated heat by the MCHP system does not automatically offset the high cost of its electricity generation. As a result, it does not make any economic sense to keep the MCHP in operation because of the lower grid electricity tariff at these times. Thus, it would be more beneficial to shut the unit down and buy power from the grid (top-up electricity). The thermal demand can be met from the heat storage system. Under the prevailing

[2] The observed current electricity price of 26.93 €cent per kWh (SWC 2015) effective from 1 March, 2015, does not deviate much from the value of 25.4 €cent per kWh which was adopted in the economic assessment in table 3 and prevalent as at the time of research.

conditions and assumptions, a total of € 3644.5 extra savings in energy cost can be realized by the end of the useful life of the system. From the sensitivity analysis carried out, both the full load operating hours and unit cost of electricity have significant influence on the payback period of the project. A 10 % increase in the full load operating time, reduces the payback period to 4.2 years; whereas if the operating hours decrease by 10 %, the payback period will increase to 5.4 years. Likewise, with a 10 % rise in the electricity cost, the payback period improves to 4.3 years; whereas there is only a 6.3 % increase in the payback period (from 4.8 years to 5.1 years) when the electricity cost was reduced by 10 %.

Environmental Assessment

Emission reduction basically depends on the fuel mix of central power production which the cogeneration system replaces as well as the efficiency of the CHP system operation and the carbon intensity of the natural gas fuel. The CO_2 emission factor from burning natural gas reflects the full carbon content of the fuel under the assumption of a complete oxidation of carbon in the fuel during combustion. The default CO_2 emission factor for natural gas (56100 kg CO_2/TJ) was adopted from the Intergovernmental Panel on Climate Change (IPCC) guidelines for national greenhouse gas inventories (IPCC 2006, 2.16). The average country-specific CO_2 emission factor for Germany (56000 kg CO_2/TJ) does not deviate much from the IPCC default emission factor (Herold 2003, 4). From the IPCC Guidelines for National Greenhouse Gas Inventories, greenhouse gas emissions from stationary combustion can be derived from the following equation:

$$\text{Emissions}_{GHG,fuel} = \text{Fuel Consumption}_{fuel} \bullet \text{Emission Factor}_{GHG,\ fuel}$$

Where:

$\text{Emissions}_{GHG,fuel}$ = the emissions of a given GHG by type of fuel (kg GHG)
$\text{Fuel Consumption}_{fuel}$ = is the amount of fuel combusted (TJ)
$\text{Emission Factor}_{GHG,\ fuel}$ = is the default emission factor of a given GHG by fuel type (kg gas/TJ).

The fuel mix distribution for the local grid electricity generation and the corresponding $C0_2$ emission is represented in Table 4.

Table 4. Percentage distribution of grid electricity mix

Fossil fuels	77.6 %
Nuclear fuel	3.2 %
Renewable sources	19.2 %
CO_2 emission in total = 570 g/kWh (669 g/kWh in 2015)	

Source: SWC 2015

Table 5 shows the breakdown of CO_2 emissions between the various components of energy use in both the conventional and the cogeneration scenarios.

Table 5. Average balance of CO2 emissions from reference and cogeneration scenarios

Parameter	Unit	Given data	Calculated data	Comment
Total CO_2 emissions from centralized generation	Kg/kWh	0.570		Fuel mix emission level
Average electricity usage	kWh	3750		Average electricity usage in the reference scenario
Electricity generated by MCHP system	kWh_e		3259	See table 3
Emission factor	Kg/TJ	56100		Default IPCC CO_2 emission factor for natural gas
Condensing boiler gas consumption @90% efficiency	kWh TJ		11767 0.0423612	See table 3
MCHP gas consumption @85% efficiency	kWh TJ		12459 0.0448524	See table 3
Annual CO_2 emissions from grid electricity generation	Kg CO_2		0.570 x 3750 = 2138	Fuel mix emission level (kg/kWh) x average electricity usage (kWh)
Condensing boiler emissions	Kg CO_2		56100 x 0.0423612 = 2377	Default emission factor (kg/TJ) x boiler gas consumption (TJ)
Total emission conventional	Kg CO_2		2138 + 2377 = 4515	Total annual CO_2 emissions from separate generation of heat and power
Avoided electricity	kWh		3259	See table 3
Top-up electricity (average usage – avoided electricity)	kWh		3750 – 3259 = 491	See table 3
Corresponding Top-up emission	Kg CO_2		0.570 x 491 = 280	Fuel mix emission level (kg/kWh) x top-up electricity (kWh)
Emissions from MCHP heat generation	Kg CO_2		56100 x 0.0448524= 2516.2	Default emission factor (kg/TJ) x micro CHP gas consumption (TJ)
Total emission MCHP	Kg CO_2		2516.2 + 280 = 2796.2	Total CO_2 emissions from cogeneration system.
CO_2 emission reduction ratio (ERR)	%	ERR = (E_{con} - E_{CHP}) / E_{con} x 100%	38.1	

E_{con} and E_{CHP} are annual CO_2 emissions of the conventional and MCHP systems respectively. *Source:* Ren and Gao 2010 Economic and environmental evaluation of micro CHP systems with different operating modes for residential buildings in Japan, Elsevier.

From the environmental assessment carried out (Table 5), the MCHP system produced more onsite CO_2 emissions (2516.2 kg CO_2 per year) in respect to the condensing boiler (2377 kg CO_2 per year). This is as a result of the higher operational efficiency of the condensing gas boiler. However, when compared to the baseline scenario of separate generation of heat and power, the CO_2 emissions from annual energy consumption could be reduced by as much as 38.1% when the average grid mix electricity is replaced with a 1 kW_e ICE MCHP system (1719 kg CO_2 per year, equivalent to offsetting the annual Greenhouse Gas (GHG) emissions from 4,093 miles driven by an average passenger vehicle). The obtained result is comparable to estimates (20 – 40 %) given in a study by Pehnt et al. 2006.

Conclusion and Recommendations

The results obtained from this paper show that MCHP systems offer a good replacement for conventional gas boilers with potential for emission reduction and energy cost savings. However, their high initial cost hampers market diffusion. With improved support mechanisms to reduce initial cost, MCHP systems could become more attractive to end users. At the same time, this research work did not carry out the economic valuation of other benefits from the use of MCHP system, such as, emission reduction, savings in capital intensive grid expansion projects, etc. It was largely focused on the immediate costs and benefits of system operation.

Since combustion is not the only source of greenhouse gases, a complete Life Cycle Assessment (LCA) is recommended in order to carry out a comprehensive environmental assessment of cogeneration. The operational efficiency of the MCHP systems will determine the magnitude of emission and cost savings. Thus, technology advancement to improve the efficiency of the system operation will maximize both economic and environmental benefits.

References

Amecke, H., J. Deason, A. Hobbs, A. Novikova, Y. Xiu, and Z, Shengyuan. 2013. Buildings Energy Efficiency in China, Germany, and the United States. San Francisco: Climate Policy Initiative. http://climatepolicyinitiative.org/wp-content/uploads/2013/04/Buildings-Energy-Efficiency-in-China-Germany-and-the-United-States.pdf

ASUE (Arbeitsgemeinschaft für Sparsamen und Umweltfreundlichen Energieverbrauch e.V.). 2008. *Power-generating Heating Systems: Opportunities for Improving Energy Efficiency*. Kaiserslautern. http://www.gerg.eu/public/uploads/files/publications/brochures/brochure_asue.pdf

BAFA (Bundesamt für Wirtschaft und Ausfuhrkontrolle – Federal Office for Economic Affairs and Export Control) 2012. KWK – Zuschlag: KWKG 2012. www.bafa.de/bafa/de/energie/kraft_waerme_kopplung/stromverguetung/kwk-anlagen_bis_50kw/kwk_zuschlag/index.html

BMU (Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit – Federal Ministy for the Environment, Nature conservation, Building and Nuclear Safety) 2009. Heizspiegel Cottbus 2009: Vergleichswerte zu Heizenergieverbrauch, Heizkosten und CO_2-Emissionen. Stadt Cottbus. www.heizspiegel.de/fileadmin/hs/heizspiegel/khsp/cottbus/heizspiegel-cottbus-web.pdf

COGEN Europe (Cogeneration Europe). 2005. The European association for the promotion of cogeneration. News archive.

EC (European Commission). 2004. "Directive 2004/8/EC of the European Parliament and of the Council of 11 February 2004 on the Promotion of Cogeneration based on a Useful Heat Demand in the Internal Energy Market and Amending Directive 92/42/EEC." *Official Journal of the European Union* 47 (52): 50-60.

EC (European Commission). 2014. Guide to Cost-Benefit Analysis of Investment Projects: Economic Appraisal Tool for Cohesion Policy 2014 – 2020. December 2014. Brussels: Belgium. European Commission Directorate-General for Regional and Urban policy. http://www.ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf

Herold, A. 2003. Comparison of CO2 Emission Factors for Fuels used in Greenhouse Gas Inventories and Consequences for Monitoring and Reporting under the EC Emissions Trading Scheme. ETC/ACC Technical Paper 2003/10. Bilthoven, the Netherlands: European Topic Centre on Air and Climate Change. http://acm.eionet.europa.eu/docs/ETCACC_TechnPaper_2003_10_CO2_EF_fuels.pdf

Houwing, M. 2010. *Smart Heat and Power: Utilizing the Flexibility of Micro Cogeneration*. Delft, the Netherlands: Next Generation Infrastructures Foundation.

IEA/ECBCS Annex 42. 2004. FC+COGEN-SIM The simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems – Annex text. cogen-sim.net/

IPCC (Intergovernmental Panel on Climate Change). 2006. Guidelines for National Greenhouse Gas Inventories. http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf

Paschotta, R. 2016. "RP-Energie-Lexikon" RP Photonics Consulting. Accessed March 2. http://www.energie-lexikon.info/warmwasser.html

Pehnt, M., M. Cames, C. Fischer, B. Praetorius, L. Schneider, and K. Schumacher. 2006. *Micro Cogeneration: Towards Decentralized Energy Systems*. Berlin: Springer.

Ren, H., W. Gao, and Y. Ruan. 2007. Study of different micro CHP alternatives for residential application. http://inive.org/members_area/medias/pdf/Inive%5CIAQVEC2007%5CRen.pdf

Ren, H., and W. Gao. 2010. "Economic and Environmental Evaluation of micro CHP systems with different operating modes for Residential Buildings in Japan." Energy and Building 42 (2010): 853-861

SWC (Stadtwerk Cottbus) Rev. Code Ann. § 42 (2005) www.stadtwerke-cottbus.de/index.php?option=com_content&view=article&id=76&Itemid=223

Tanaka, H., A. Suzuki, K. Yamamoto, I. Yamamoto, M. Yoshimura, and K. Togawa. 2011. New ECOWILL – A new Cogeneration Gas Engine Micro CHP. Japan: International Gas Union Research Conference. http://members.igu.org/old/IGU%20Events/igrc/igrc2011/igrc-2011-proceedings-and-presentations/poster-papers-session-3/P3-56_Hiroki%20Tanaka.pdf

U.S. EPA (United States Environmental Protection Agency). 2013. CHP: Efficiency Benefits. http://www.epa.gov/chp/basic/efficiency.html

Uyterlinde, M.A. van Sambeek, E.J.W. and E.D. Cross. 2002. *Decentralized Generation: Development of EU policy*. Report in the Framework of the DECENT Project. Petten, the Netherlands: Energy Research Centre of the Netherlands. http://ecn.nl/docs/library/report/2002/c02075.pdf