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CO_2 emission assessment of combined heat and power in global and local approach

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ABSTRACT This paper investigates effect of combined heat and power (CHP) in production of CO_2 as the most important greenhouse gas (GHG). The study has been done in Sepidan industrial estate in Fars province. The assessment is examined in two different points of view. First, in global scale, which consider emission of centralized power plants and heat supply equipments in industrial state. In the next stage, the local analysis is done based on heat supply equipment in industrial state, regardless of the pollutant of power plants. With the new regulations for distributed generation (DG) in 2008 and financial incentives, private sector could enter into the business and compete with governmental sector. CHP units have advantages in efficiency and pay-back time compared to separate production and even DG. Many studies presented the advantages of CHP over conventional ways of supplying heat and power, but environmental aspect is still a matter of question. This study showed that CHP has a great potential for CO_2 reduction in global point of view. On the other hand, CHP significantly increases CO_2 emission in local scale. This means that if carbon dioxide is not properly distributed in the air, it will break the air quality standards of Iran department of environment.

Keywords CHP; Greenhouse gas; CO_2; Local and global approach

INTRODUCTION

Combined Heat and Power or CHP is defined as “the simultaneous utilization of heat and power from a single fuel or energy source”[IEA 2008]. The advantages of CHP are: improving voltage stability, improving reliability, reduction of network stress, reduction of network overload, reduction of power transmission loss, cost reduction of electricity producing, increasing efficiency, pollution reduction, and opportunity for private sector to invest [IEA 2008, CHP guidance 2009]. A CHP unit consists of prime mover, generator, heat exchanger and control system [IEA 2008]. Prime mover can be reciprocating engine, gas turbine, steam turbine, microturbine and more recent technologies like fuel cell and Stirling engine [EPA 2002, Wu 2006] Reciprocating engines are preferred for lower capital cost, maintenance, variety of manufacturers, high availability, and favorable part load efficiency, less sensible to atmosphere pressure and temperature, fast start-up and black-start capability. Their power is in the range of 50 to 8000 kW [CHP guidance 2009]. Variety of fuels can be used for such engines like natural gas, gasoline, biogas, LPG and sour gas [EPA 2002]. Based on specific condition of delivered natural gas (more than 98 percent methane) to consumers in Iran like extensive distribution and relatively low price, electricity production has the lowest expense [Hoseinian 2006]. IEA [2008] declared that CHP currently generates around 10% of worldwide electricity generation; Unfortunately Iran has no share [CHP guidance 2009]. After the effect of greenhouse gases in global warming had been recognized, numerous attempts were made to reduce emitted CO_2. In 2005, about 32 per cent of national CO_2 emitted in power and oil refinery and 12 per cent in industry section [IFCO 2009]. In global point of view, Danesing [2007] and Dorer [2009] showed that CHP can decrease primary energy consumption and therefore reduction in emission emitted. Moreover utilization of environmental friendly fuels like natural gas, increasing efficiency, waste heat recovery leads to major reduction of power plants fuel consumption due to reducing electricity demand [e.g. Jazaeri 2009]. But in local aspect, CHP raises local fuel consumption [Env. aspect 2004, Fumo 2009], which leads to emission increment [Canova 2008, Pehnt 2008]. Sanaye [2009] and Fragaki [2008] described some methodologies for sizing and operational strategies on cost-oriented basis. Because CHP plants are located near human societies, environmental factors become more important. So in some cases sizing and operational strategies are based on environmental consideration [e.g. Fumo 2009, Strachan 2006].

In this paper the impact of combined heat and power plant on CO_2 emission in Sepidan industrial state, is studied in local and global point of view. The 6 MW power plant include three natural gas fueled internal combustion engines. The most important assumptions were the following: 1) engines always operate in full-load; 2) gas fueled boiler efficiency is 85%; 3) natural gas is pure methane; 4) complete combustion is assumed in CHP prime mover and boiler.

CO_2 IMPACT

Over millions of years, major part of atmospheric CO_2 was captured in fossil fuels like coal, oil and gas. Extreme rate of fossil fuel consumption began 50 years ago and is predicted to be the most important energy source in the next 50 years [Gorbani 2008]. It means that major part of CO_2 captured in fossil fuels in more than 200million years will be released to atmosphere in only 100years . This sudden increment of CO_2 and some other greenhouse gases like SO_2 and N_2O_2 will cause a shock to atmosphere and later to hydrosphere. CO_2 increase causes global warming and global warming leads to polar ice melting and rising ocean water level, which will cause some countries' sink and disappear. This still is not the main catastrophe because humans are capable to manage. Gorbani [2008] claimes that global warming causes more critical problems that cannot be fixed by human kind. It causes more evaporation from oceans and more rains. First this might seem to be favorable, but this increase will change the pattern of rains all over the world. Raining will increase in upper altitudes and decrease in tropical regions. Decrease of rains in winter and increase in summer. Also more rains than snow and more torrential rains. The most life threatening effect of GHG shows itself in PH changes of ocean water. Increment of GHG in atmosphere switch neutral rains to acidic ones, and this acidic water eventually goes to the oceans. PH of oceans are 8.2 and it is very delicate. Small changes of H^+ or OH^- lead to major changes in PH. Acidic rains and melting of polar ices (with PH=7) can decrease oceans PH. This sudden change will cause extinction of some sea creatures and destroy the oceans ecosystem balance and global ecosystem as well. It is clear that these global changes will be accompanied by extinction of vital species.

High amount of CO_2 can displace O_2 and the effects of oxygen shortage can be accompanied by toxicity effect of carbon dioxide. Workers exposed to up to 3.0% CO_2 for over 15 hours, for six days, may result decreasing night vision and color sensitivity. Exposure to 3.3% or 5.4% CO_2 for 15 minutes increases depth of breathing. At 7.5%, a feeling of an inability to breathe (dyspnea), increasing pulse rate, headache, dizziness, sweating, restlessness, disorientation, and visual distortion developed. Exposure for 20 minutes to 6.5 or 7.5% carbon dioxide decreases mental performance. Irritability and discomfort were reported with exposure to 6.5% for approximately 70 minutes. Several studies have monitored workers repeatedly exposed to elevated levels of CO_2 gas. Exposure to 1-1.5% for 42-44 days can cause a reversible acid-base imbalance in the blood. Some other problems are: impaired response of the circulatory system to exercise, decrement of blood pressure, decreased oxygen consumption, and impaired attentiveness [Health Eff. 2009].

SITE ESPICIFICATION

Iran industrial states company founded in 1984. Economy development, financial support and facilities provided in industrial states and settlement obligation of new founded manufacturers and factories in these states, swelled number of industrial states. In 2009 reported number of industrial states is 392 [Iran Ind. St. 2009]. Reliable electricity power is one of the key factors for reliable production rate, to insure that Tavanir (Iran power generation, transmission and distribution management Co.) sets up new policies. CHP, one of the recent trends in this scenario, along the reduction of grid loss, improving voltage profile and reliability, will considerably reduce the cost because of selling surplus electricity to grid. Fars Industrial State Company has 25 industrial states. Among them Sepidan industrial state was chosen for CHP power plant.

Sepidan industrial state is located 630 km from Shiraz and 12 km from Sepidan city. There are 20 active factories and 17 factories are under construction in 37 acres [Sepidan Ind. St. 2009]. Figure 1. shows different industries in Sepidan. Regarding weather condition and quality of mineral water resources, considerable numbers of mineral water producers are in this area and it is expected to grow to become the largest mineral water production region in country [Sepidan report 2009].

Heat recovered from CHP can be used in district heating or industrial process for factories nearby. Some industries like food production, paper and textile which have great and rather fixed amount of hot water or steam consumption. Hence, they can be potential customers for CHP heat production [Energy auditing manual 2002].

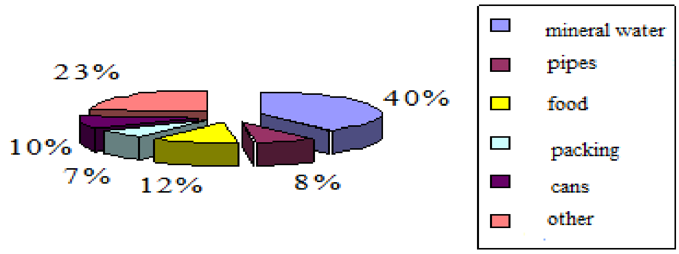

Figure 1. Sepidan industries [Sepidan report 2009]

Prime Mover Internal combustion engines and microtorbines are most common type of prime movers in Iran. Microtorbines have lower electric efficiency, more expensive, sensible to pressure and temperature of site, sensible and low efficiency in part load, lower power (30-500 kW) and limited number of manufacturers, so their comparators seems to be more preferred [CHP guidance 2009, EPA 2002]. Internal combustion engine works more efficient at full-load condition. At reduced loads, efficiency decrease; thus multiple engines may be preferable to a single large unit to avoid efficiency penalties where significant load reductions are expected on a regular basis [EPA 2002]. It should be mentioned that although multiple smaller engine have advantages in efficiency, flexibility and reliability, capital cost ($/kW) will rise [CHP guidance 2009].

With these considerations, three engines were selected. Table 1 contains characteristics of typical engine. In this case CHP plant is always connected to national electricity grid and at any time surplus electricity will be transferred to national grid and the only limitation for working hours is maintenance time which can be illustrated as a coefficient, named availability factor [EPA 2002]. Natural gas engine availabilities vary with engine type, speed, and fuel quality, but typically availability factor for gas engines with electrical power more than 800kW is 0.91 [EPA 2002].

Table 1
Typical engine characteristics

Electrical power (%)	Thermal power (%)	Fuel consumption (kW)
42	**42**	**4619**

As it is showed in figure 2 heat recovery resources in internal combustion engines are cooling lubrication oil system, cooling jacket water system and exhaust gas [Wu 2006, ASHRAE 1984]. Amount of heat recovered from exhaust gas depends on exhaust gas temperature. If this temperature drops below dew point, steam water condenses and cause corrosion in heat exchanger. The outlet gas temperature must be above 150 ˚C [ASHRAE 1984].

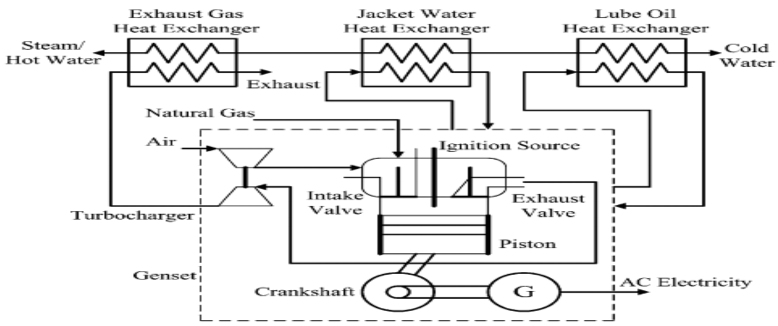

Figure 2. Schematic of reciprocating engine heat recovery [Wu 2006]

CO_2 EMISSION MODEL

The combustion of fossil fuels leads to CO_2 and H_2O and also trifle amount of intermediate by-products such as CO, So_x, NO_x, particulate matter (PM) and unburned hydrocarbons (UHC). The amount of formation of these by-products depends on chemical kinetic factors like temperature, oxygen excess, fuel and air mixing and the like. CO_2 emissions are more important because of the GHG characteristics of carbon dioxide. In most new gas engines air to fuel ratio is more than adequate and complete combustion can be assumed with very good approximation. In this case amount of CO_2 can be calculated through stoichiometric reaction of fuel. CO_2 emitted depends on carbon content of fuel, heating value and efficiency of the equipment. Complete combustion assumption may not be a good approximation when engine is working in partial load for most of the time or is an aged or badly maintained engine. Canova [2008] suggests in these cases an experimental investigation to determine amount of each pollutant is necessary.

Emission pollutant P can be calculated by [12,25]:

$$m_P^X(X) = \mu_P^X(X).\ X \qquad (1)$$

where m_P^X is the mass of pollutant P while producing energy X and μ_P^X is emission factor or specific emissions [kg/kWh]. Canova [2008] claims this approach is suitable for assessments of cases with different energy vectors production, from different equipment (such as the electrical grid, CHP prime movers, and boilers), fed by different and various fuels and in different operating conditions. Regarding complete combustion and content of carbon and heating value in methane and complete conversion of methane carbon into CO_2:

$$CH_4 + 2\ (O_2 + 3.76\ N_2) \rightarrow CO_2 + 2H_2O + 7.52\ N_2 \qquad (2)$$

For one mole (16.043 kg) of methane consumption, one mole of carbon dioxide (44.01kg) is produced. For one kilogram of methane combustion 13.89kWh is pro duced (based on low heating value). In other words, producing one kWh leads to 0.197kg CO_2. So $\mu_{CO2}^{CH4} = 0.197$ (referred to LHV)

Mancarella [2009] describe two main cases that can be chosen for environmental assessment in separate production reference of heat and electricity:

1. Comparison of CHP to average conventional technologies, considering, CHP is displacing a variety of separate production technologies.
2. Comparison of CHP to the Best Available Technologies, assuming that CHP is displacing most efficient and environmental friendly equipments (such as low-emission high-efficiency boilers and combined cycles).

Depending on which of these two streamlines are chosen, different conclusion might happen. In this paper first scenario is selected.

CHP Combined heat and power unit supply thermal and electrical energy for the Sepidan industrial state. It uses natural gas (100% methane) with 0.197kg CO_2 emitted per kWh energy consumption. The annual analysis of electricity, heat and CO_2 emission for CHP plant is demonstrated in Table 2.

Table 2
Annual analysis for CHP

	Energy consumption (GWh)	electricity production (GWh)	Heat production (GWh)	CO_2 emitted (ton)
Each engine	36.822	15.465	15.465	7.271
CHP unit	110.468	46.396	46.396	21.814

Separate Heat and Power Supply System In absence of combined heat and power system, the alternatives for heat and electricity should be the next most cost effective supply options. In many cases, these will be supplies that are readily available at the site [e.g. Pout 2005]. In Sepidan industrial state the most common equipment to produce heat is mid-efficiency gas boilers. These boilers are improved by copper fins. CO_2 emission of gas boilers depends on efficiency, working condition and condition of boiler. Durkin [2006] listed the average of different boilers. Efficiency of a common mid-efficiency is taken to be 0.85 and combustion to be complete. The annual analysis of natural gas fueled boiler is presented in Table 3.

Table 3
Annual analysis for boiler

	Heat production (GWh)	Fuel consumption (GWh)	CO_2 emitted (ton)
Gas boiler	46.396	54.584	10.779

The alternative electricity supply is grid electricity. The average characteristics of Iran power plants are used. Iran electricity grid power loss is relatively high. In this paper information of 2005 was used. Total electric grid loss reported to be 19.5 [Statistics of Iran 2008], it is also interesting to explain that when transmission and distribution loss is 19.5, peak hour loss is more than 1.69 times. It means in peak hour grid loss reach to 33 per cent [CHP guidance 2009]. CO_2 emission factor for 2005 was 0.592kg per kWh of net electricity produced in power plants [Tavanir site 2009]. Annual analysis of average power plant characteristics is presented in Table 4.

Table 4
Annual analysis for power plant

	Electricity consumption in the industrial state (GWh)	Net electricity production of power plant site (GWh)	CO_2 emitted (ton)
Power plant	46.396	57.635	34.120

DISCUTION

Installation of Sepidan CHP will produce 46.396 GWh electricity per year and the same amount for thermal energy and consume 110.468 GWh fuel energy. This will lead to 21.814 ton CO_2 emission. In absence of CHP, to produce the same amount of thermal energy, boilers consume 54.584 GWh and emit 10.779 ton CO_2. To deliver the 46.396 GWh of electricity, power plants produce 57.635 GWh electricity and emit 34.120 ton CO_2. Figure 3 shows the amount of carbon dioxide produced in each energy supplier system.

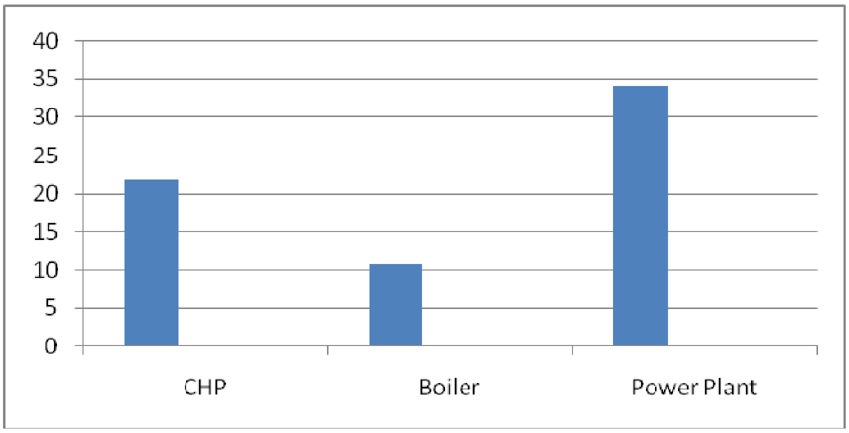

Figure 3. CO_2 emission in each equipment (ton/year)

In figure 4 presents a model for local aspect of CO_2 emission. In local scale only boilers have influence on air pollution condition and power plant has a much smaller impact because of the distance between power plant and industrial state so, the impact of emission from power plants are neglected and comparison is between CHP and boilers. This means the amount of CO_2 emission in the industrial state is increased by 202%. On the other hand, in global point of view, CHP replaces boilers and centralized power plant. This case is illustrated in figure 5. In this point of view, major decrease of 48.5% occurred.

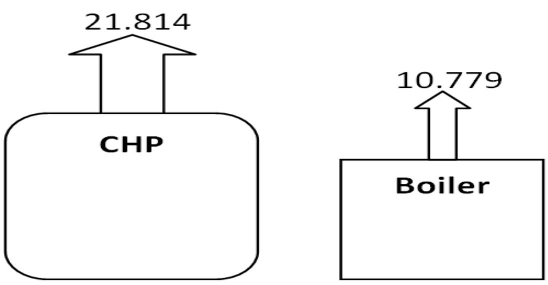

Figure 4. Local model impact of CHP (ton/year)

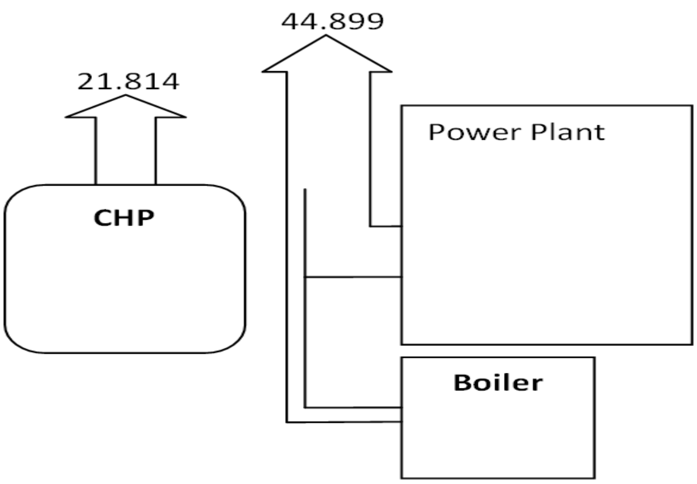

Figure 5. Global impact of CHP (ton/year)

CONCLUSION

The local and global impact of combined heat and power systems, in producing CO_2 as the most important greenhouse gas is analysed. Reciprocating gas engines were selected as prime movers. Average characteristics for common boilers and average characteristics of national electric network were chosen for comparison. Results show that:

- Globally, CHP has a significant potential for CO_2 reduction. In this case study it is reduced to more than half.

- Locally, CHP will increase CO_2 by two times because of increment fuel consumption.

CHP location is adjacent to factories, where people are subjected to pollutant from 8 to in some cases 24 hours a day. Regarding vital impact of air pollutant on working condition and more important on human health, extra caution must be paid, in order to decrease the intensity of CO_2 in places near CHP plant. A higher stack can improve dispersion of exhaust gases. A CFD analysis can be helpful to model dispersion of gases and intensity of pollutants over the industrial state.

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