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# Emissions spark spread and primary energy spark spread – Environmental and energy screening parameters for combined heating and power systems

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ABSTRACT

The spark spread, or price differential between electricity cost and fuel cost, may be used to indicate whether a combined heating and power (*CHP*) system shows a cost benefit in a certain situation over a conventional separate heating and power system. This paper extends the spark spread concept to address the emission of $CO_2$ and the consumption of primary energy by introducing two parameters: the emissions spark spread (*ESS*) and the primary energy spark spread (*PESS*). *ESS* and *PESS* are evaluated in 16 US cities for three different *CHP* system efficiencies, and compared to the minimum *ESS* and minimum *PESS* required for a *CHP* system to potentially reduce $CO_2$ emissions (CDE) or primary energy consumption (PEC). Since the fuel mix used in electricity production, which varies with location, affects the amount of CDE or PEC due to the use of a *CHP* system, this paper also presents the ratios $ESS/ESS_{min}$ and $PESS/PESS_{min}$ that could be used for a simple analysis of the potential of a *CHP* system based on CDE and PEC.



## 1. Introduction

Combined heating and power (*CHP*), or cogeneration, is the simultaneous production of electrical and thermal energy at or near the site of use. A *CHP* system may be advantageous over a traditional separate heating and power (*SHP*) system by reducing cost because the electricity is produced more efficiently with less transmission losses. The waste heat is also retained as useful thermal energy, and in the case of combined cooling, heating, and power (CCHP), or trigeneration, it may also be used for cooling.

In addition to monetary cost, the amount of harmful emissions and the amount of primary energy consumed are also factors in determining the benefit of a *CHP* system. Meunier [1] explained the importance of $CO_2$ emission reduction when developing *CHP* systems in order to mitigate the negative impact energy production has on the climate. John [2] asserted that a *CHP* system should only be considered if it is optimized to conserve energy. Fumo et al. [3] also advised that the primary energy savings of a *CHP* system must be considered along with the economic analysis.

The spark spread, or cost differential between electricity and natural gas [4], has been used as a screening parameter for the economic feasibility of a *CHP* project [4–6]. However, due to legislation and environmental regulations, a *CHP* project may have a social objective to meet other priorities rather than cost benefit alone. Both the European Union and United States government bodies have taken steps to analyze the benefits of *CHP* and the EU, in particular, has used government policy in an effort to promote *CHP* technology [7]. If emission allowances are regulated and assigned a market value, the emission considerations would also be part of the economic considerations [8]. Mago and Hueffed [9] evaluated a turbine driven CCHP system for large office buildings under different operating strategies and analyzed the effect of carbon credits on the overall system economic performance. They reported that carbon credits can successfully yield financial reward for reducing carbon emissions. The higher the carbon credit value (in \$/metric ton of $CO_2$-equivalent) the larger the cost reduction of the CCHP system operation.

Minciuc et al. [10] pointed out that efficient use of fuel by the *CHP* system can lead to reduced $CO_2$ emissions. Li et al. [11] reported that the energy savings potential of a CCHP system is also related to the system efficiencies. Although mathematical models exist for analyzing the economic, environmental, and energy benefits of a *CHP* system [11–22], a literature review did not reveal a simple method comparable to spark spread analysis which indicates the environmental or energy benefit of a *CHP* system. Therefore, variations of the spark spread which address emission of pollutants and PEC can also be useful for decision making when analyzing the potential for the use of a *CHP* system in a given situation. This paper presents an emissions spark spread (*ESS*) and a primary energy spark spread (*PESS*) as environmental and energy screening parameters for *CHP* systems. The objective of this work is to provide a simple screening tool which indicates *CHP*'s potential to reduce CDE or to reduce PEC, and investigate the

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**Nomenclature**

| | | | |
|---|---|---|---|
| *CHP* | combined heating and power | $F_{CHP}$ | fuel energy used by *CHP* system |
| CDE | $CO_2$ emissions | $PE_{ratio}$ | ratio of *ECF* to *FCF* |
| $Cost_{CHP}$ | cost to operate *CHP* system | PEC | primary energy consumption |
| $Cost_e$ | electricity cost | *PESS* | primary energy spark spread |
| $Cost_f$ | fuel cost | *PGU* | power generation unit |
| $Cost_{ratio}$ | ratio of a $Cost_e - Cost_f$ | *PHR* | power-to-heat ratio produced by the *CHP* system |
| $Cost_{SHP}$ | cost to operate *SHP* system | $Q_b$ | heat required by the building |
| $E_{b,v}$ | varying electric load required by the building | $Q_{b,v}$ | varying thermal load required by the building |
| $E_b$ | electricity required by the building | $Q_{CHP}$ | heat provided by the *CHP* system |
| *ECF* | electricity conversion factor or source-site ratio | SHP | separate heating and power |
| $E_{CHP}$ | electricity provided by *CHP* system | *SS* | spark spread |
| *EEF* | electricity emissions factor | $\eta_{CHP}$ | total efficiency of the *CHP* system |
| $Emissions_{ratio}$ | ratio of *EEF* to *FEF* | $\eta_{hs}$ | efficiency of the heating system associated with the *SHP* system |
| *ESS* | emissions spark spread | $\eta_{PGU}$ | efficiency of the *PGU* |
| *FCF* | fuel energy conversion factor or source-site ratio | $\eta_{te}$ | thermal efficiency of the *CHP* system |
| *FEF* | fuel emissions factor | | |

factors which influence the amount of improvement likely to result from choosing a *CHP* system over a traditional *SHP* system.

## 2. Spark spread

Smith et al. [6] analyzed the spark spread necessary for a *CHP* system to produce cost savings over an *SHP* system. Spark spread is defined [4] as:

$$SS = Cost_e - Cost_f \tag{1}$$

where $Cost_e$ is the cost of purchased electricity and $Cost_f$ is the cost of fuel.

In their model, Smith et al. [6] assumed that the *CHP* system operates at full load and full efficiency and that the building uses all energy produced by the *CHP* system, as shown in Fig. 1. The *CHP* system provides electricity in the amount of $E_{CHP}$ and thermal energy as $Q_{CHP}$. Additional electricity or thermal energy above this constant amount provided by the *CHP* system becomes variable energy above this baseline and it was not considered in their analysis. If this additional electricity, $E_{b,v}$, or thermal energy, $Q_{b,v}$, were to be considered, the *CHP* system would not be able to provide this energy because it already operates at full load. Therefore, $E_{b,v}$ would be purchased from the grid and $Q_{b,v}$ would be supplied by a conventional heating system. In this case, the energy consumption amounts $E_{b,v}$ and $Q_{b,v}$ are the same for both systems (*CHP* and *SHP*), so they do not contribute to the comparison.

The cost to operate the *SHP* system was given by Smith et al. [6] as:

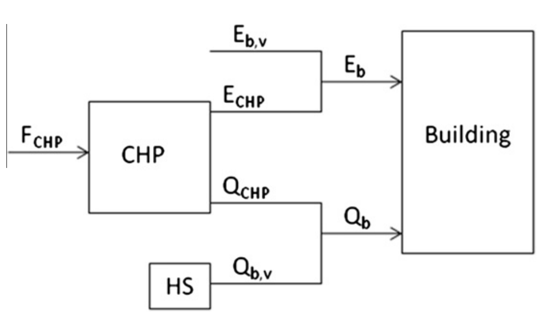


**Fig. 1.** Schematic of a *CHP* system.

$$Cost_{SHP} = Cost_f \frac{Q_{CHP}}{\eta_{hs}} + Cost_e E_{CHP} \tag{2}$$

where $Q_{CHP}$ is the useful heat output of the *CHP* system (which is also the heat used by the building under the given assumptions), $\eta_{hs}$ is the efficiency of the reference building's heating system, and $E_{CHP}$ is the electricity output of the *CHP* system (which is the same as the electricity used by the building, $E_b$, under the given assumptions).

The cost to operate the *CHP* system was given by Smith et al. [6] as:

$$Cost_{CHP} = Cost_f \left( \frac{E_{CHP} + Q_{CHP}}{\eta_{CHP}} \right) \tag{3}$$

where $\eta_{CHP}$ is the overall efficiency of the *CHP* system.

As a result, Smith et al. [6] proposed the following equation for the ratio of electricity cost to fuel cost required for a *CHP* system to show monetary savings.

$$Cost_{ratio} \geqslant \frac{1}{PHR} \left( \frac{1}{\eta_{CHP}} - \frac{1}{\eta_{hs}} \right) + \frac{1}{\eta_{CHP}} \tag{4}$$

where the power-to-heat ratio produced by the *CHP* system, *PHR*, is the proportion of electricity to heat energy produced by the *CHP* system as:

$$PHR = \frac{E_{CHP}}{Q_{CHP}} = \frac{\eta_{PGU}}{\eta_{te}} = \frac{\eta_{PGU}}{\eta_{CHP} - \eta_{PGU}} \tag{5}$$

where $\eta_{PGU}$ is the efficiency of the *CHP* system's power generation unit (*PGU*) and $\eta_{te}$ is the overall thermal efficiency of the *CHP* system.

The $Cost_{ratio}$ represents the ratio of electricity cost to fuel cost that is required to keep the *CHP* operation costs from exceeding the *SHP* operation costs, given specific system characteristics.

## 3. Emissions spark spread and primary energy spark spread

Costs, CDE, and PEC for *CHP* and *SHP* systems will vary with the location where the system is installed. The amount of harmful emissions associated with purchased electricity varies with the fuel mix used by the utility which produces that power [23]. The energy consumed at the site is also related to the energy consumed at the utility by a local source-site ratio [12].