COGMCI – Toward a Zero CO_2 Economy

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ABSTRACT

Despite a higher share of renewable electricity, the CO_2 emission in the electricity industry is on the rise. New electricity demands and resilient electricity (to stabilize intermittent production) can explain this. Engine CHP can save up to 40% energy (CO_2 emissions), depending on (i) building energy consumption (ii) site equipment technology, (iii) thermal plants efficiency used to stabilize the grid, and (iv) the existing electrical grid losses. COGMCI is 20 years of developing software to design and simulate engine CHP systems. It joins the known science of building energy analysis and thermal equipment design and simulation methodologies to predict engine CHP performance on an annual basis. Several case studies were developed. Most of the cases reveal that oversized engines (able to export electricity to the grid) can save more energy than baseload systems. Oversized engines can operate as a demand response system or can export high-efficiency electricity to the grid, accelerating the move to renewables.

Keywords: engine CHP, energy efficiency, CO_2 emissions, cogeneration, trigeneration.

1 INTRODUCTION

Intermittent electricity (solar and wind) needs to be equilibrated with a resilient supply. Despite a big investment in green electricity, IEA (International Energy Agency) reported that the share of total renewable electricity was 31.8% in December 2021 [1]. “Global CO_2 emissions from energy combustion and industrial processes rebounded in 2021 to reach their highest ever annual level. A 6% increase from 2020 pushed emissions to 36.3 gigatonnes (Gt). The biggest increase in CO_2 emissions by sector in 2021 took place in electricity and heat production, where they jumped by more than 900 Mt” [2].

Fossil fuel demand can be partially replaced by green fuels, electric cars, heat pumps, electrical equipment, etc. How much additional electricity will be required? How much green fuel? How much electricity for green fuel production? How to build an equilibrated electricity grid and fuel supply?

These are difficult questions! Every country has its electricity generation and fuel market share that is affected by climate, person purchasing power, technology costs, local taxes, natural resources, industrialization, government incentives, etc. A quick move to renewables requires an evaluation of how the different technologies can contribute.

Efficiency is the right move! High-efficiency solutions reduce the demand and consumption, accelerating the move to renewables while requiring lower infrastructure. Using the best solution for each application is the challenge.

Figure 1 reveals a scheme of electricity production supplying a big city. City buildings are already producing electricity (solar), but cities need to import electricity. From where is coming this electricity? On the right side of figure 1, we have renewables technologies. If renewables contribute 31.8% [1], what technology is supplying the 68.2%?

Figure 1 – Electrical system layout – smart grid

Nuclear power and fuel thermal plants are the answer (figure 1 – left side). Nuclear power doesn´t have a big contribution in most countries. Thermal plants are the main supplier. What fuel is being used? What is the average efficiency?

Engine CHP can reduce up to 40% CO_2 emission when compared with the best available technology of centralized thermal plants, fuel boilers, and air conditioning equipment. If fueled by green fuels no CO_2 emissions are achieved.

High-efficiency engine CHP requires a high-efficiency engine, well-designed heat exchangers, and an absorption chiller. Annual energy loads and simulation should be used for system sizing and savings prediction. COGMCI is an engine CHP design and simulation software with more than 20 years of development [3-7]. Detailed part-load performance analysis of the integrated engine CHP system is developed (engine, heat exchangers, HRSG, absorption chiller, etc).

As engine CHP is an energy-saving technology, depending on the thermal loads, oversized systems can save more energy (less CO_2) than engines sized for the site base electrical load. Engine CHP should be designed and sized to attend site thermal loads – using annual energy analysis.

Engine flexibility can contribute to a stabilized grid exporting electricity at low renewables production hours or operating as a demand response system.

Engine CHP can help existing buildings (close to 40% of world energy consumption) reduces their CO_2 footprint.

2 ENGINE CHP ENERGY SAVINGS

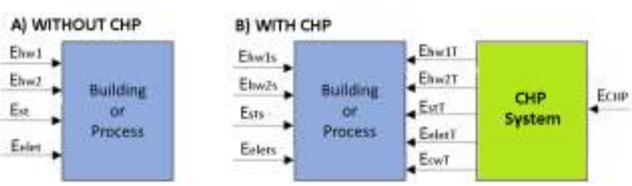

Figure 2 – building/process energy consumption

Engine CHP efficiency is normally calculated using the EUF (energy utilization factor). Engine CHP can have EUF up to 90%, but EUF cannot be compared with thermal plant thermal efficiency. An energy balance with and without an engine CHP system is more appropriate. A building or process energy consumption can be calculated as (figure 2A):

$$\dot{E}c = \dot{E}_{hw1} + \dot{E}_{hw2} + \dot{E}_{st} + \dot{E}_{elet} \quad (1)$$

The PEC (primary energy consumption) can be calculated using the conversion efficiencies:

$$PEC_{without} = \frac{\dot{E}_{hw1}}{\eta_{hw1}} + \frac{\dot{E}_{hw2}}{\eta_{hw2}} + \frac{\dot{E}_{st}}{\eta_{st}} + \frac{\dot{E}_{elet}}{\eta_{elet}} \quad (2)$$

When comparing a building / process without and with a cogeneration / trigeneration system, the following equations can be used (figure 2B):

$$\dot{E}_{hw1s} = \dot{E}_{hw1} - \dot{E}_{hw1T} \quad (3)$$

$$\dot{E}_{hw2s} = \dot{E}_{hw2} - \dot{E}_{hw2T} \quad (4)$$

$$\dot{E}_{sts} = \dot{E}_{st} - \dot{E}_{stT} \quad (5)$$

$$\dot{E}_{elets} = \dot{E}_{elet} - \dot{E}_{eletav} - E_{eletT} \quad (6)$$

$$\dot{E}_{eletav} = \dot{E}_{cwT}/COP \quad (7)$$

$$\dot{E}_{CHP} = \dot{E}_{hw1T} + \dot{E}_{hw2T} + \dot{E}_{stT} + \dot{E}_{cwT} + \dot{E}_{eletT} + \dot{E}_{losses} \quad (8)$$

$$PEC_{withCHP} = \frac{\dot{E}_{hw1s}}{\eta_{hw1s}} + \frac{\dot{E}_{hw2s}}{\eta_{hw2s}} + \frac{\dot{E}_{sts}}{\eta_{sts}} + \frac{\dot{E}_{elets}}{\eta_{elets}} + \dot{E}_{trig} \quad (9)$$

Equations 2 and 9 don´t take into account the electrical system grid loss (transformer, circuit breakers, transmission lines, etc). WEC reported that the natural gas (NG) average thermal efficiency is 41% and the average electricity grid loss is 12% [8]. It means that only 36% of the produced electricity reaches the customers (41 x 0.88). PES is calculated using equation 10. PES is directly connected with CO_2 emissions.

$$PES\,(\%) = \frac{(PEC_{WITHOUT} - PEC_{WITH\,CHP})}{PEC_{WITHOUT}} \quad (10)$$

When the engine CHP system is exporting electricity to the grid, the electrical efficiency should take into account the grid losses and the efficiency of the avoided centralized thermal plant. The exported electricity is used close to the production and grid losses are much lower. Thermal efficiency between 35-45% should be used on equations 2 and 9. Exported electricity should use a minus sign on equation 9.

3 COGMCI CASES

Some case studies illustrate how COGMCI can help you design a lower CO_2 emission solution. All cases use local weather data and 8760 hours of energy data.

3.1 NYC Mall

An engine CHP case study was developed for an NYC (temperate weather) one floor mall (figure 3). The building model and energy loads were obtained using the Energy Plus software (DOE-USA) [9].


Figure 3 – mall overview

The proposed engine CHP was selected to produce electricity, hot water for space heating (cold hours), chiller water for space cooling (hot hours), and sanitary use hot water – figure 4. Ten different cases were evaluated. PES calculated between 10 and 39.6%. The best solution is oversized (exports electricity to the grid) and operates at thermal dispatch [10].

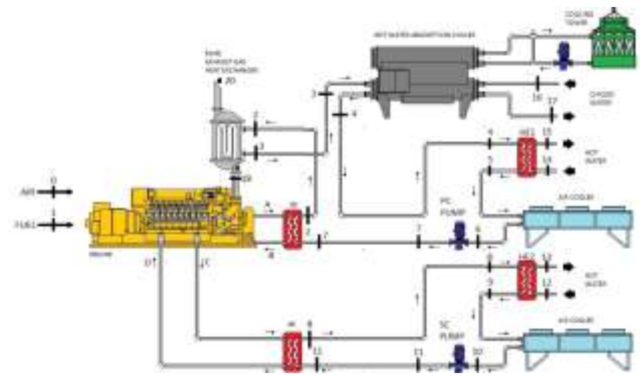

Figure 4 – NYC mall engine CHP scheme

3.2 Singapore Mall

The same mall of section 3.1 was used to develop a study for Singapore (equatorial city) [10]. The proposed solution produces (i) electricity, (ii) chilled water in an exhaust gases and hot water absorption chiller and (iii) hot water for sanitary use – figure 5. PES between 5.3 and 20.8% were calculated. Better results are for oversized systems.

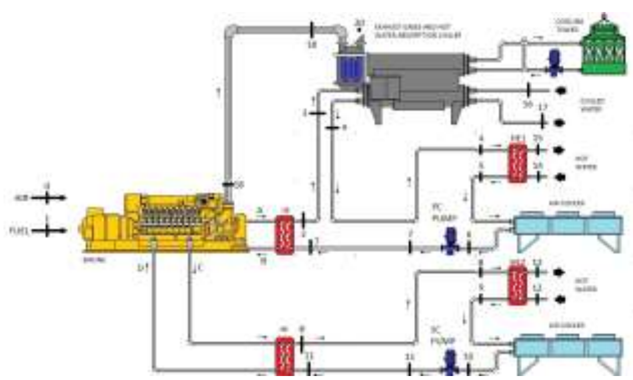

Figure 5 – Singapore mall engine CHP scheme

3.3 Viena Hotel

A hotel building model situated in Vienna – Austria was simulated using the Energy Plus software (figure 6). Results are used as input for the COGMCI software [10].

The proposed engine CHP scheme is the same one used in section 3.1 – figure 4. PES between 10 and 20% were calculated.

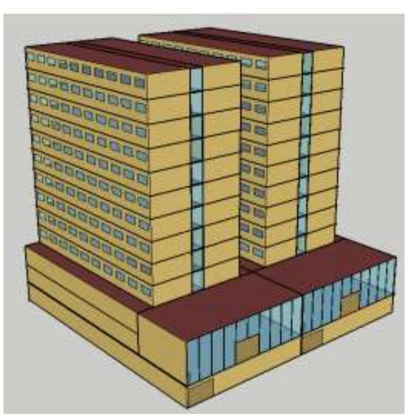

Figure 6 – Vienna Hotel Building

3.4 Campinas Hospital

An engine CHP case was developed for a Campinas hospital (figure 7) – a tropical city. Annual energy loads were obtained through a data acquisition system and used as COGMCI input [10].

The proposed engine CHP produces (i) electricity, (ii) steam – HRSG, (iii) chilled water – single-effect absorption chiller, and (iv) sanitary use hot water – figure 8. PES between 13.6 and 18.6% were calculated. Better results are for oversized systems.

Figure 7 – Campinas hospital Building

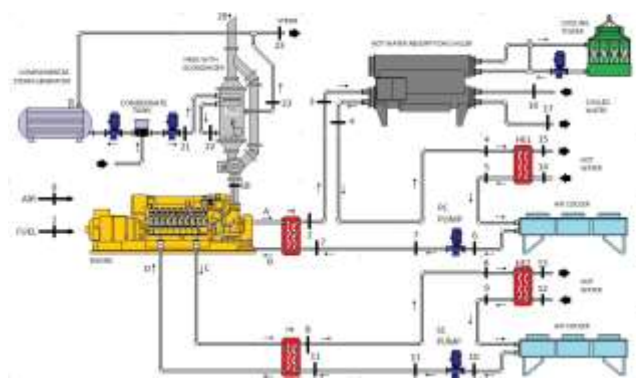

Figure 8 – Campinas hospital engine CHP scheme

3.5 Washington Airport

An airport building engine CHP system case study was evaluated (figure 9). Building loads were calculated using the Energy Plus software with Washington weather files [11].

The proposed engine CHP system is similar to figure 4. It produces electricity, hot water for space heating (cold hours), chiller water for space cooling (hot hours), and sanitary use hot water. PES between 8 and 35% were calculated. Better results are for oversized systems.

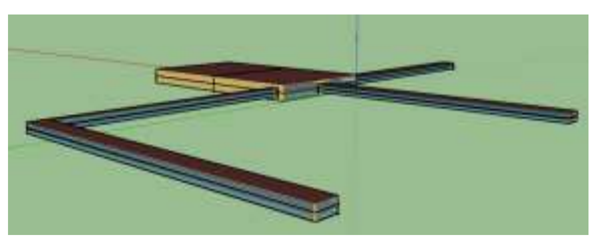

Figure 9 – Washington airport building

4 ENGINE CHP POTENTIAL

Cities have several engine CHP possibilities, some of them are revealed in figure 10. Oversized engine CHP systems can export electricity to the grid at low renewables production hours. Figure 11 suggests that several oversized systems can contribute to meeting the city's electricity demand – by exporting electricity to the neighborhood (red circles).

Figure 10 – Engine CHP opportunities

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Figure 11 – engine CHP electricity export.

5 RESULTS AND DISCUSSION

COGMCI can contribute to designing a high-efficiency engine CHP system. Depending on the thermal loads, an oversized system can be the best solution. Most of the big cities have hundreds of engine CHP opportunities. Engine CHP can accelerate the move to renewables. It can also operate as a zero-emission system if green fuel is utilized.

A smart city should identify the energy savings potential and adopt solutions that can quickly reduce its CO_2 footprint. The challenge is to see the city as a complex system with different opportunities and to adopt the best solutions.

COGMCI analysis and engine CHP systems reveal several opportunities:

1) Can size engine CHP for site loads – electricity import or export.
2) Good projects can reduce up to 40% CO_2 emissions.
3) When exporting electricity, engine load is higher and more energy is available to met site thermal demands.
4) Exported electricity to customers close to the site – high efficiency, resilience, and small grid losses.
5) Engines can quickly change their load, adapting the production to the grid needs – renewables priority.
6) Oversized engines can be seen as a reserve grid capacity reducing the need for peak power plants and batteries.
7) Engine CHP can be fuelled by green fuels.
8) Engine CHP systems can operate at (i) full load, (ii) electrical dispatch, or (iii) thermal dispatch – COGMCI allows a detailed analysis of operational modes and part load performance.

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7 NOMENCLATURE

E_c	energy consumption (kWh)
E_{hw1}	hot water energy consumption - medium temperature (kWh)
E_{hw2}	hot water energy consumption - low temperature (kWh)
E_{st}	steam energy consumption (kWh)
E_{elet}	electricity consumption (kWh)
$PEC_{without}$	PEC without a CHP system (kWh)
$PEC_{withCHP}$	PEC with a CHP system (kWh)
PES	Primary Energy Savings (%)
η_{hw}	hot water production efficiency
η_{st}	steam production efficiency
η_{elet}	electricity production efficiency
COP	coefficient of performance – electrical chillers.
CHP	combined heat and power

Subscripts

S	complementary / surplus
T	CHP system production
av	avoided
cw	chilled water