Techno-economic Assessment of Flexible Combined Heat and Power Plant with Carbon Capture and Storage

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Abstract—As Carbon Capture and Storage (CCS) is now regarded as on its way to become a mature technology to reduce dramatically CO₂ emissions from conventional generation, its economic ineffectiveness may still be preventing its large-scale adoption. In this respect, new strategies for flexible operation of Carbon Capture and Storage systems could bring substantial benefits allowing achieving both ambitious CO₂ reductions and higher profits. In addition, further economic and environmental benefits could be achieved by adopting high efficiency Combined Heat and Power (CHP) plants. On these premises, this paper investigates the benefits of coupling a flexible CCS system and a flexible CHP plant, with the aim of deploying the flexibility available in both CCS and CHP to consume/produce more or less electricity in response to market conditions. A mathematical model is developed to maximise profit responding to volatile market prices by optimally switching the CCS and CHP plants between different operating modes. The effectiveness and the usefulness of the proposed model are demonstrated on a realistic case study with extensive sensitivity analyses.

Keywords—carbon capture and storage; combined heat and power; flexibility; cap-and-trade market

I. INTRODUCTION

Carbon Capture and Storage (CCS) is one of the most promising technologies to reduce CO₂ emissions from conventional fossil fuel-fired generation. In this respect, there are on-going studies worldwide with the aim of retrofitting CCS to existing generation assets [1], [2]. However, while the results are encouraging in terms of environmental benefits, operating CCS units require additional electricity and heat, known as “energy penalties”, with respect to a non-CCS operation, which eventually decreases the overall plant energy efficiency and impacts on the economic performance of the plant [3].

Combined Heat and Power (CHP) plants, also commonly referred to as cogeneration, are already well known for being highly efficient and flexible in the delivery of both electricity and heat. For instance, CHP plants based on steam turbines (STs) and in general multi-generation plants have the capability of maximising their operations profitability by adjusting the quantity of heat and electricity delivered responding to changing demand and in case market conditions [4]–[6]. Since CCS units require additional heat besides electricity, they appear to be very suitable to be operated jointly with CHPs.

While to date the development of CCS technologies has been driven by the desire to reduce CO₂ emissions solely and to prove the technical feasibility of the technology, with control strategies mostly limited to full capacity operation, alternative control options could be put forward to exploit different opportunities that could arise in the marketplace, particularly if deploying the flexibility that could be made available by switching from a mode of operation to another. In fact, similarly to CHP plants, CCS could offer the flexibility to operate not only at full, but also at adjustable capacity, and with the CCS system switched off at given times of the day to maximise the electricity production (for instance, at times of peak prices). The aforementioned economic implications of energy penalties could thus be significantly reduced if there was the possibility to respond to real time variation of market prices, for instance to be traded against the cost of the additional CO₂ emissions, and by also considering the CHP operation. Some preliminary work in this direction has been conducted on the feasibility of flexible post-combustion carbon capture [7]. A flexible CCS system has been studied in [8] where it is applied to a coal power plant. Not much else is available in the literature, and in particular considering applications with CHP plants.

In the light of the above, this paper proposes an optimisation-based techno-economic model of a flexible CHP+CCS plant. The model describes a representative coal fired cogeneration plant coupled to a flexible CCS system by taking into account the operation characteristics of the system while responding to real time price signals and taking into account the market cost of different commodities (electricity, heat, coal, and CO₂). In contrast to conventional schemes where such systems would be used to capture the maximum possible amount of CO₂ regardless of the changing market conditions, the proposed model provides a means to maximise the operational profitability while satisfying ambitious CO₂ reduction targets. More specifically, the proposed model
assesses extensively the flexibility offered by the integration of flexible post-combustion CCS with monoethanolamine (MEA) solvent to a CHP plant.

II. FLEXIBLE OPERATION OF CHP-CCS

A. Flexible coal fired CHP plant

A coal fired CHP plant [6] is typically composed of two main parts: the burner (furnace) and the ST. In an “extraction” plant, when operating in cogeneration mode the heat is extracted (“bled”) directly at an intermediate pressure level from the steam turbine. With such architecture, the CHP plant can increase its overall electricity-and-heat efficiency up to 90%, while typical electricity-only efficiencies are around 44% for today’s best available plants. This architecture is also highly flexible, allowing dynamic adjustment of the quantity of electricity and heat delivered within fast response times by changing the “bleeding” level of steam that is extracted.

B. Flexible Carbon Capture technology

The carbon capture system has to be compatible with the considered coal fired CHP plant. Currently, there are three different technologies to capture the carbon: pre-combustion, post-combustion, and oxy-fuel combustion [3]. Post-combustion is regarded as the most promising technology since it offers interesting retrofitting possibilities as well as high carbon capture performance (90%). There are three different technologies to separate the CO2: by solvent/sorbent, by membrane, and by distillation and refrigeration. The solvent/sorbent approach is the most common one when the post-combustion approach is considered [3]. Therefore, a post-combustion system with MEA solvent is chosen.

More specifically, the capture system is made of three main elements: the absorber, the stripper, and the compressor (shown in Fig. 1). The proposed system is equipped with an upstream venting channel to control the quantity of flue gas being sent to the carbon capture system. Two additional solvent storage tanks are also considered, acting as buffers between the capture and the regeneration process [9]. Hence, the capture and the regeneration process can be operated at different times.

![Fig. 1. Post-combustion with MEA solvent carbon capture](image)

The exhaust flue gas is sent to the absorber where the CO2 is absorbed by the MEA solvent, while the remaining gases are vented into the atmosphere. The rich MEA solvent is transferred to the rich solvent tank and then to the stripper, which separates the CO2 and regenerates the solvent. The lean solvent is sent back to the lean solvent tank and then to the absorber in a closed-loop circuit. The CO2 is compressed for transportation to the storage facility.

C. Carbon Capture energy penalties

As stated previously, adding carbon capture to a generation system affects heavily its performance. Indeed, the carbon capture system needs both electrical and thermal energy in significant quantity to operate. These needs are commonly referred to as energy penalties since they stem from the net output difference of similar plants with and without CO2 capture. These penalties can be expressed proportionally to the rate of CO2 treated by the carbon capture system and can be divided into three groups [10], as expanded on below.

1) Solvent regeneration penalty

The solvent regeneration penalty $\mu^{SR}$ (MWh/tCO2) corresponds to the thermal energy required to reverse the chemical binding of CO2 in the rich solvent. The MEA solvent requires low-pressure steam (120°C, 2 bar). This energy is provided by the CHP cogenerated heat.

2) Compression penalty

The compression penalty $\mu^{C}$ (MWh/tCO2) corresponds to the electrical energy required to compress the CO2 for successive transportation to the storage facility. This energy comes directly from the CHP generated power.

3) Auxiliary power penalty

The auxiliary power penalty $\mu^{AP}$ (MWh/tCO2) corresponds to the electrical energy required to supply all the auxiliary electric equipment in the carbon capture system (flue gas blower, flue gas cooler, lean solvent cooler, stripper top condenser). Similarly to the compression penalty, this energy comes directly from the generated power.

D. Combined flexibility offered by the CHP-CCS plant

On the generation side, the quantity of electricity and heat delivered can be dynamically adjusted from power-only to CHP mode. On the capture side, unlike typical carbon capture systems, the addition of a venting channel for the exhaust flue gas allows controlling the quantity of CO2 being captured from zero to full system capacity. The addition of the two solvent storage tanks adds even more flexibility to the system by decoupling the regeneration and compression process from the capture. One tank is filled with lean solvent ready for the next carbon capture cycle, while the other tank is filled with rich solvent waiting for regeneration. This flexibility brings opportunities for a better scheduling of the CHP-CCS system operations. The proposed CHP-CCS combined system is shown in Fig. 2. Three capture strategies can be distinguished:

1) Always ON capture

In this case, the carbon capture system is operated constantly at full capacity, the solvent is regenerated continuously, and the CO2 is compressed immediately. This approach is very efficient in capturing the major share of the emissions but might prove to be economically not viable if carbon prices are
The solvent regeneration process and CO₂ extraction product of the fuel input efficiency also limits exposure to losses by not capturing CO₂ when venting channel. The solvent regeneration process and CO₂ extraction product of the fuel input efficiency also limits exposure to losses by not capturing CO₂ when venting channel. This control strategy allows taking advantage of high CO₂ prices by selling unused freely allocated emission rights. It also limits exposure to losses by not capturing CO₂ when prices drop down to a certain level.

2) ON/OFF capture
In this case, the carbon capture system is operated at full capacity only if it proves to be economically more profitable. This control strategy allows taking advantage of high CO₂ prices by selling unused freely allocated emission rights. It also limits exposure to losses by not capturing CO₂ when prices drop down to a certain level.

3) Flexible capture
In this case, which corresponds to the proposed control strategy, the system is operated dynamically capturing merely the desired amount of CO₂ (enabled by the controllable venting channel). The solvent regeneration process and CO₂ compression are decoupled from the capture as a result of the two solvent storage tanks addition. This approach enables ambitious carbon capture objectives, maximises operation profit, and limits exposure to risk in a volatile market environment.

![Diagram of flexible capture](image)

### III. PROBLEM FORMULATION

#### A. Coal fired CHP plant
The steam turbine electric power output \( W_{\text{ST}}^t \) is defined as the product of the fuel input \( F_{\text{ST}}^t \) and the steam turbine electrical efficiency \( \eta_{\text{ST}}^t \) minus the power energy penalty for steam extraction \( \alpha_{\text{ST}}^t \) in (1), where the \( \varepsilon \) term corrects the loss of efficiency occurring when the steam turbine is not operated at full load. The subscript \( t \) stands for the time periods.

\[
W_{\text{ST}}^t = F_{\text{ST}}^t \cdot (\eta_{\text{ST}}^t - \varepsilon(W_{\text{ST}}^t)) - \alpha_{\text{ST}}^t
\]  
(1)

As steam extraction will increase to generate more heat, the power generation (and then electrical efficiency) will decline. The trade-off between generated heat \( H_{\text{ST}}^t \) and power depends on the pressure and temperature level the steam is bled at from the steam turbine, and can be defined by the Z-ratio [11] \( z_{\text{ST}}^t \) as in (2).

\[
H_{\text{ST}}^t = \alpha_{\text{ST}}^t \cdot z_{\text{ST}}^t
\]  
(2)

The steam turbine output operating limit constraints are given in (3). The maximum up and down ramping constraints are given in (4). The steam extraction operating limits are given in (5).

\[
W_{\text{ST,min}}^t \leq W_{\text{ST}}^t \leq W_{\text{ST,max}}^t
\]  
(3)

\[
-\Delta_{\text{ST}}^t \leq W_{\text{ST}}^t - W_{\text{ST}}^{t-1} \leq \Delta_{\text{ST}}^t
\]  
(4)

\[
0 \leq \alpha_{\text{ST}}^t \leq \alpha_{\text{ST,max}}^t
\]  
(5)

#### B. CO₂ emissions
Emissions are coming from the steam turbine’s burner and the amount of CO₂ emitted \( e_{\text{ST}}^t \) is directly proportional to the quantity of fuel consumed through the coal-related CO₂ emission factor \( \kappa_{\text{CO₂}}^t \) [6], [12]:

\[
e_{\text{ST}}^t = F_{\text{ST}}^t \cdot \kappa_{\text{CO₂}}^t
\]  
(6)

#### C. Carbon capture system
The quantity of MEA solvent loaded \( \text{MEA}_{\text{loaded}}^t \) is defined as the product of the CHP emissions \( e_{\text{ST}}^t \), the carbon capture efficiency \( \eta_{\text{CCS}}^t \), and the venting channel coefficient \( \beta_{\text{CCS}}^t \). The venting channel coefficient varies continuously from 0 to 1 sending the desired amount of flue gas to the capture system and the rest directly in the atmosphere.

\[
\text{MEA}_{\text{loaded}}^t = e_{\text{ST}}^t \cdot \eta_{\text{CCS}}^t \cdot \beta_{\text{CCS}}^t
\]  
(7)

Equation (8) defines the regeneration limits on the quantity of MEA solvent \( \text{MEA}_{\text{lean}}^t,\text{min} \) - \( \text{MEA}_{\text{lean}}^t,\text{max} \):  

\[
\text{MEA}_{\text{lean, min}}^t \leq \text{MEA}_{\text{lean}}^t \leq \text{MEA}_{\text{lean, max}}^t
\]  
(8)

Equations (9) and (10) define the level of MEA in the two additional solvent storage tanks.

\[
\text{MEA}_{\text{tank, rich}}^t = \text{MEA}_{\text{tank, rich}}^{t-1} + \text{MEA}_{\text{loaded}}^t - \text{MEA}_{\text{lean}}^t
\]  
(9)

\[
\text{MEA}_{\text{tank, lean}}^t = \text{MEA}_{\text{tank, lean}}^{t-1} + \text{MEA}_{\text{lean}}^t - \text{MEA}_{\text{loaded}}^t
\]  
(10)

Equations (11) and (12) define the maximum capacity of the additional solvent storage tanks.

\[
0 \leq \text{MEA}_{\text{tank, rich}}^t \leq \text{MEA}_{\text{tank, rich, level, max}}^t
\]  
(11)

\[
0 \leq \text{MEA}_{\text{tank, lean}}^t \leq \text{MEA}_{\text{tank, lean, level, max}}^t
\]  
(12)

Equation (13) ensures a constant quantity of MEA in the system at any time. For the sake of simplicity, the quantity of solvent contained in the absorber, the stripper, and the close-circuit system is incorporated in the two tanks level calculation.

\[
\text{MEA}_{\text{total}}^t = \text{MEA}_{\text{tank, rich}}^t + \text{MEA}_{\text{tank, lean}}^t
\]  
(13)
Equations (14) and (15) represent $W_{t}^{\text{CCS}}$ and $H_{t}^{\text{CCS}}$, the electrical and thermal penalties imposed by the CCS system.

\begin{equation}
W_{t}^{\text{CCS}} = ME_{t}^{\text{lean}} \cdot (\mu_{AP} + \mu_{C})
\end{equation}

\begin{equation}
H_{t}^{\text{CCS}} = ME_{t}^{\text{lean}} \cdot \mu_{SR}
\end{equation}

D. Energy balances

Equations (16) and (17) represent the power and heat balance, respectively. In (16), once the local demand $W_{t}^{\text{demand}}$ and the CCS needs $W_{t}^{\text{CCS}}$ are supplied, the excess of power generated is sold to the grid $W_{t}^{\text{grid}}$. In (17), the local demand $H_{t}^{\text{demand}}$ and the CCS needs $H_{t}^{\text{CCS}}$ are supplied by the CHP but the excess of heat generated is wasted (could be different under different framework).

\begin{equation}
W_{t}^{\text{ST}} - W_{t}^{\text{CCS}} = W_{t}^{\text{demand}} + W_{t}^{\text{grid}}
\end{equation}

\begin{equation}
H_{t}^{\text{ST}} - H_{t}^{\text{CCS}} \geq H_{t}^{\text{demand}}
\end{equation}

IV. ECONOMIC FRAMEWORK FOR THE STUDIES

A. Energy market

The high efficiency achieved by CHP plants comes from delivery of both heat and electricity. Part of the electricity is sold to load serving entities through long-term bilateral agreements at a fixed price, while the rest is sold on the day-ahead spot market. The heat is sold to load serving entities through long-term bilateral agreements or on the spot market, as from above. The price of CO2 is considered exogenous. Thus, for every shortage of CO2 emission rights, additional contracts are set equal to 200 MW\(_{e}\). The bilateral contract prices (relative to the fuel energy) is assumed equal to 320 kg/MWh. The CO2 trading is defined as in (19). If the CO2 emitted is below the CO2 cap (free allowance), a profit is made on CO2.

\begin{equation}
\text{CO}_2\text{Trading} = (\text{CO}_2\text{Emitted} - \text{CO}_2\text{Cap}) \cdot \text{CO}_2\text{Price}
\end{equation}

V. CASE STUDY EXAMPLE

A. CHP-CCS data

1) CHP plant data

The generation set considered in this study is based on a state-of-the-art 600 MW\(_{e}\) coal fired CHP plant, whose main characteristics are shown in Table I. The overall efficiency reached by the generation in electricity-only and cogeneration modes are $\eta_{\text{el-only}} = 0.44$ and $\eta_{\text{CHP}} = 0.90$ respectively. The power plant is thus able to deliver up to 600 MW\(_{e}\) (electricity-only) or up to 480 MW\(_{e}\) and 750 MW\(_{i}\) in full CHP mode. The loss of efficiency is assumed to be 4% when the steam turbine is operating at half-load (300 MW\(_{e}\)), also corresponding to the minimum stable generation limits. The $z_{\text{ST}}$ ratio is the one corresponding to 2.5 bar pressure and 120°C extracted steam required by the carbon capture system. Steam under these conditions can also be transported through a heat network and be sold to the market. The cost of generation (fuel, operation and maintenance) is set at 20 £/MWh\(_{e}\). The coal emission factor (relative to the fuel energy) is assumed equal to 320 kg/MWh.

2) Capture system data

The post-combustion carbon capture system characteristics are given in Table II. The energy penalties were elaborated as typical figures from information available from several studies (see for instance [10]). The capacities for lean and rich solvent tanks are expressed in terms of tonnes of CO2 for the sake of simplicity. The capacities chosen allow storing up to 2 hours of carbon under full-load conditions. The ramping rate of the regeneration process in the stripper is assumed to be 100%.

3) Energy and carbon markets data

The local electricity demand served through long-term bilateral agreements is set equal to 300 MW. The local heat demand is set equal to 200 MW. The bilateral contract prices of electricity and heat are set equal to 50 £/MWh\(_{e}\) and 35 £/MWh\(_{i}\) respectively. The electricity price forecast for the day-ahead spot market is shown in Figure 3.
Under full-load conditions, the CO₂ emissions for 24 hours of operation go up to 9000 tonnes. A cap corresponding to the actual Phase III of the EU ETS which started in 2013 is adopted. The target reduction of free allocation is set for 17.56% in 2020, leading to a reasonable free allocation for the plant of around 50% of the total emissions [14]. Hence, for the sake of example the freely allocated cap adopted in this study covers 4500 tonnes of CO₂ daily. The baseline price of one tonne of CO₂ is set to £20.

B. Results and analysis

The model is run for 24 hours of operations maximising profit on a standard Intel Core i5 desktop PC and by using the optimization programming language AIMMS [15]. Given the non-linearity of the problem, the CONOPT solver is used and a relevant solution is reached in 0.03 seconds.

Figure 4 and Figure 5 show the optimal power and heat gross production schedule of the CHP system. During period of high electricity prices, the CHP plant increases its power production to maximise its profit. During period of low electricity prices, the plant increases its heat production for solvent regeneration.

The total electricity production over the day is 10,981 MWhₑ with an hourly average of 458 MWₑ. The total heat production over the day is 10,012 MWhₜ with an hourly average of 417 MWₜ. The average power to heat ratio is 1.1:1 and the net global efficiency is 52%. The total net electricity production is 10,509 MWhₑ. The total net heat production is 4800 MWhₜ. The energy supplied to the capture system accounts for 27% of the total gross production, with 5,213 MWhₑ and 471 MWhₜ. The total economic benefit over the “always ON” capture control strategy is 54%. The total benefit over the “ON/OFF” capture control strategy is 6%.

The heat energy penalty for solvent regeneration is about 11 times higher than both compression and auxiliary power penalties. While the excess of electricity production can be sold and exported to the grid, the excess of heat production is simply wasted. Hence, there is a strong incentive in producing only the quantity of heat required. The addition of the two solvent storage tanks allows the decoupling of the regeneration from the capture process. Without the solvent storage tanks, the MEA would be regenerated whenever it is
used and it would be impossible to shift this operation. Therefore, the heat required for the regeneration process is produced during low electricity price hours and the production of electricity is increased during high price hours maximising the overall operation profit.

C. Sensitivity Analysis

1) Carbon price and free allowance cap

Since, it is impossible to predict the price of a tonne of CO₂ as well as the structure of the cap-and-trade market in the next few years, it is crucial to examine the performance of the capture strategy against a broad range of CO₂ prices.

2) Solvent technological evolution

As explained previously, the heat duty for solvent regeneration is by far the largest energy expense in the carbon capture process. It is therefore relevant to look at the possible benefits coming from improvements in MEA solvent technology. This evolution is also very interesting from an investment prospective since it would not require further investment besides acquiring the new solvent.

Figure 8 shows the evolution of total profit for 24 hours of operation when the price of CO₂ changes. The three sets of curve represent flexible and “ON/OFF” control strategies for a 50% cap, a 25% cap, and no cap. From the “ON/OFF 50% cap” curve, it can be observed that below 30 £/t CO₂ the profit decreases constantly as the capture system is not operated. Above that price level, the profit increases constantly as it is profitable to operate the capture system. The “flexible 50% cap” curve is consistently equal or higher than the corresponding “ON/OFF” one, proving that the flexible capture strategy brings benefits to the system. The gained flexibility can then be defined as the difference between the two curves. This flexibility value so defined peaks at 25.3% when 29 £/t CO₂ is reached. When the emission price goes beyond 45 £/tCO₂, the flexibility value offsets the profit by a constant £11,500. The capture system is then run at full capacity while the two solvent storage tanks still enable shifted regeneration during lower energy price periods. While it can be observed how the overall profit is severely affected by the size of the free allowance cap (as one could expect), the flexibility value is not: the flexible control strategy always outperforms the “ON/OFF” one.

3) Solvent storage tanks capacities

A large share of the flexibility offered by the proposed capture system comes from the addition of the two solvent storage tanks. The size chosen in the case study allows up to 2 hours of rich solvent storage (600 tCO₂), which is the capacity needed to avoid binding conditions on the stored loaded solvent.

Figure 9 shows the evolution of the flexibility net gain for 24 hours of operation for different solvent regeneration heat duties when the price of CO₂ changes. The actual technology of MEA solvent requires 1.25 MWh of heat per tonne of CO₂ removed. Projections can be found in the literature for technological improvement in the future [10] and simulation were performed for three different improved heat duties. For 1.125 MWh/tCO₂, the flexibility peaks at 23% at 27 £/tCO₂ and stays around 5% when the price of CO₂ increases. For 1 and 0.875 MWh/tCO₂, the maximum flexibility is reached at 25 and 23 £/tCO₂, respectively, and lies between 4 and 6% when the price of CO₂ increases. Therefore, further improvement in the solvent technology allows capturing at lower CO₂ prices but does not bring much incremental benefit.

Figure 10 shows the evolution of the flexibility net gain for 24 hours of operation for different solvent storage tanks sizes when the price of CO₂ changes. When no storage tanks are
used with the capture system, the flexibility value peaks at around 25% at 29 £/tCO2. When the price of CO2 goes up, the flexibility value decreases rapidly and eventually drops under 1% beyond 55 £/tCO2. The addition of storage tanks does not increase the peak flexibility still reached at 29 £/tCO2 but provides benefits when the price goes up. It is interesting to note that the size of the storage tanks does not influence much the flexibility value; hence, the system does not benefit from larger storage capacities under current market framework.

4) Price of electricity
The profit made by the generation system is highly dependent on the price agreed for the long-term bilateral agreements (50 £/MWh in this study). Therefore, possible changes in the agreed price of electricity is to be taken into consideration.

Figure 11 shows the evolution of the flexibility net gain for 24 hours of operation for different combination of CO2 and electricity prices with the flexible control strategy compared to “ON/OFF”. The system always reach maximum flexibility around 30 £/tCO2. While the price of electricity goes up, the flexibility is mainly affected around 30 £/tCO2, starting at 41% for 40 £/MWh and ending at 10% for 90 £/MWh. It can be observed that the flexible control strategy provides consistent benefits. It is also important to note that higher volatility in the electricity spot price would lead to higher benefits for the flexible control strategy.

VI. CONCLUSION
In this paper, a profit maximisation model for a flexible CHP+CCS generation plant has been presented. The model has been implemented in a mathematical optimisation tool able to quantify the operational benefits of using such a flexible carbon capture system downstream a CHP plant. The developed model maximises the overall operation profit by finding the optimal control strategy for both the CHP plant and the capture system responding to volatile market conditions. The novelty of this works lies first in the integration of post-combustion CCS with MEA solvent to a CHP plant where the available heat adds another layer of flexibility, and secondly in the extensive assessment of the flexibility offered by such a system. The tool can be used to assess the techno-economic performance of CHP+CCS plants given certain energy and carbon market conditions. Numerical case studies have shown the potential of the tool to perform techno-economic studies, as well as exemplified in a quantitative manner the benefits from flexible CHP-CCS plant operation. As a result, the proposed model demonstrates economic superiority relative to the existing inflexible control schemes, which might potentially boost the business case for the CCS technology in case coupled to CHP plants.

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Figure 11. Price of electricity influence


[6] H. Chalmers and J. Gibbins, “Initial evaluation of the impact of post-combustion CCS technology in case coupled to CHP plants. The integration of post-combustion CCS with MEA solvent to a CHP plant where the available heat adds another layer of flexibility, and secondly in the extensive assessment of the flexibility offered by such a system. The tool can be used to assess the techno-economic performance of CHP+CCS plants given certain energy and carbon market conditions. Numerical case studies have shown the potential of the tool to perform techno-economic studies, as well as exemplified in a quantitative manner the benefits from flexible CHP-CCS plant operation. As a result, the proposed model demonstrates economic superiority relative to the existing inflexible control schemes, which might potentially boost the business case for the CCS technology in case coupled to CHP plants.

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