Simulation and LCA of amine scrubber for CO_2 capture with heat pump and electric boilers

Abstract

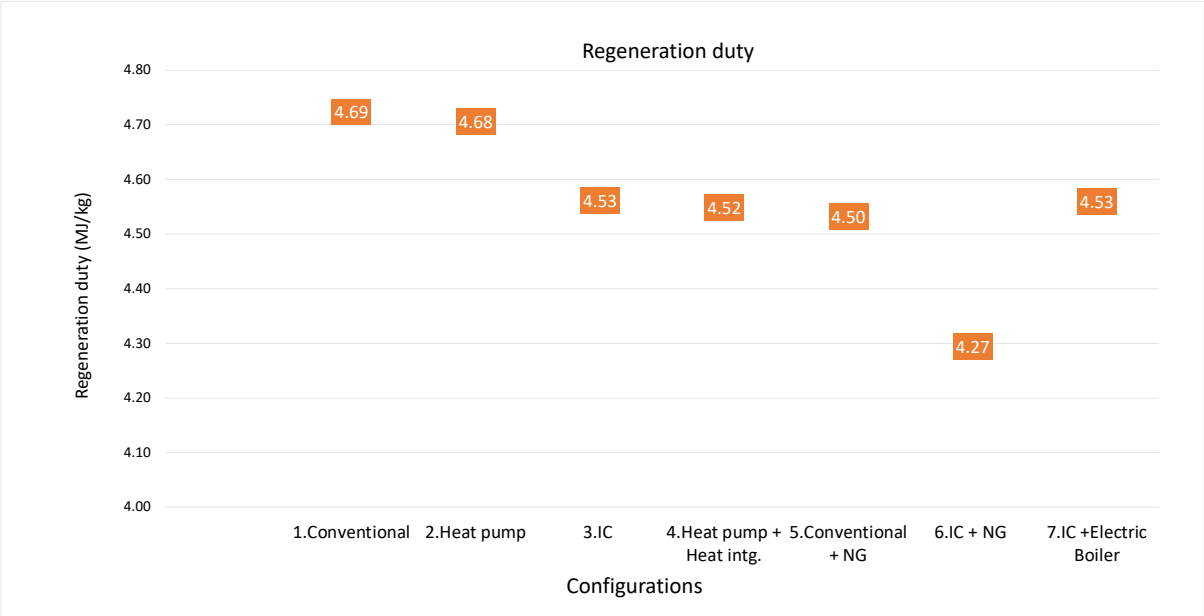
Terms such as "global warming," "net zero," and "CO_2 capture" are frequently encountered in discussions surrounding climate change. Although the mitigation of climate change through CO_2 capture is widely acknowledged, the sustainability of this process depends on the source of energy. This study involves performing simulations and life cycle assessments (LCA) to analyze the environmental impacts of different configurations employing amine-based CO_2 capture. Specifically, certain configurations include an electric boiler, heat pump technology, and mixing the concentrations of CO_2 in the ongoing flue gas by recycling CO_2 from the natural gas combustion, distinguishing them from the conventional method.

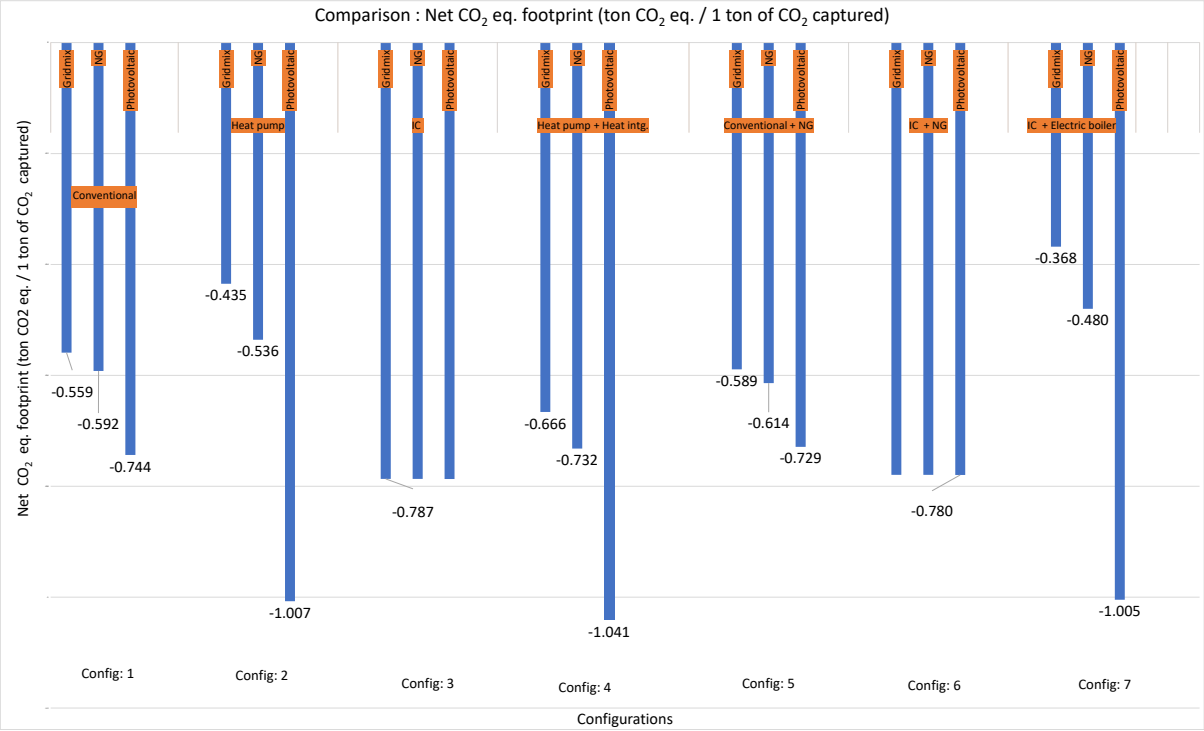
For the evaluation of different configurations, Aspen Plus v12.1 was used for simulation and GaBi 8.7 was used for LCA. Pinch analysis, which includes heat integration, was performed to minimize the reboiler duty for specific configurations.

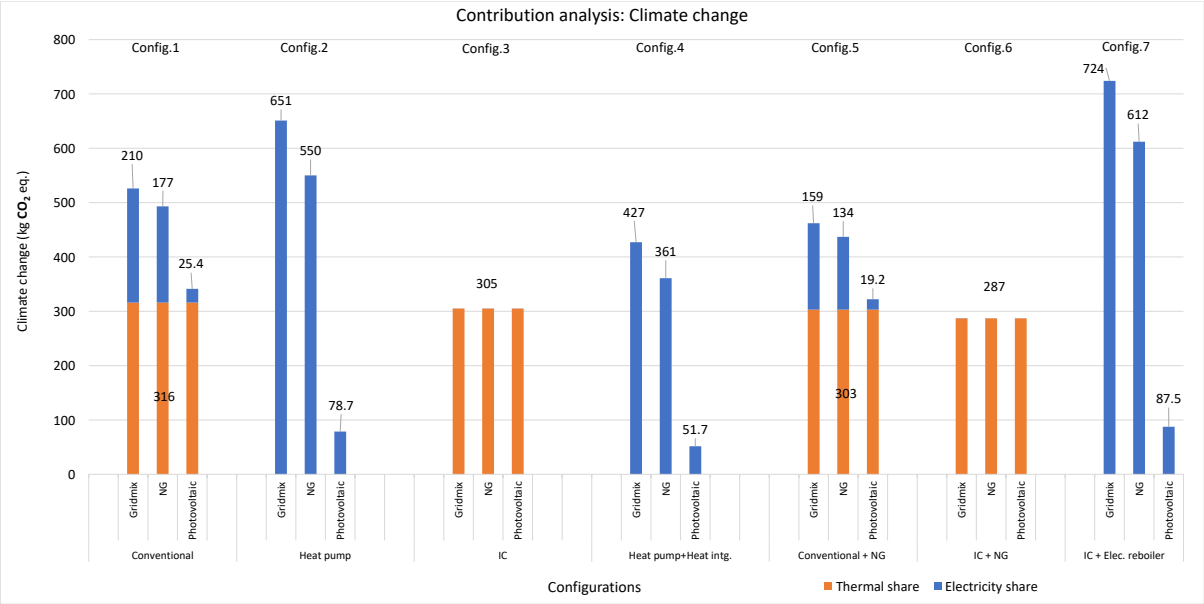
Key results indicate the importance of the energy source, with configurations employing heat pump technology and electrode boilers that prove to be more sustainable. If operations are powered by renewables, these configurations exhibit lower emissions and greater net reductions of CO_2 equivalents.

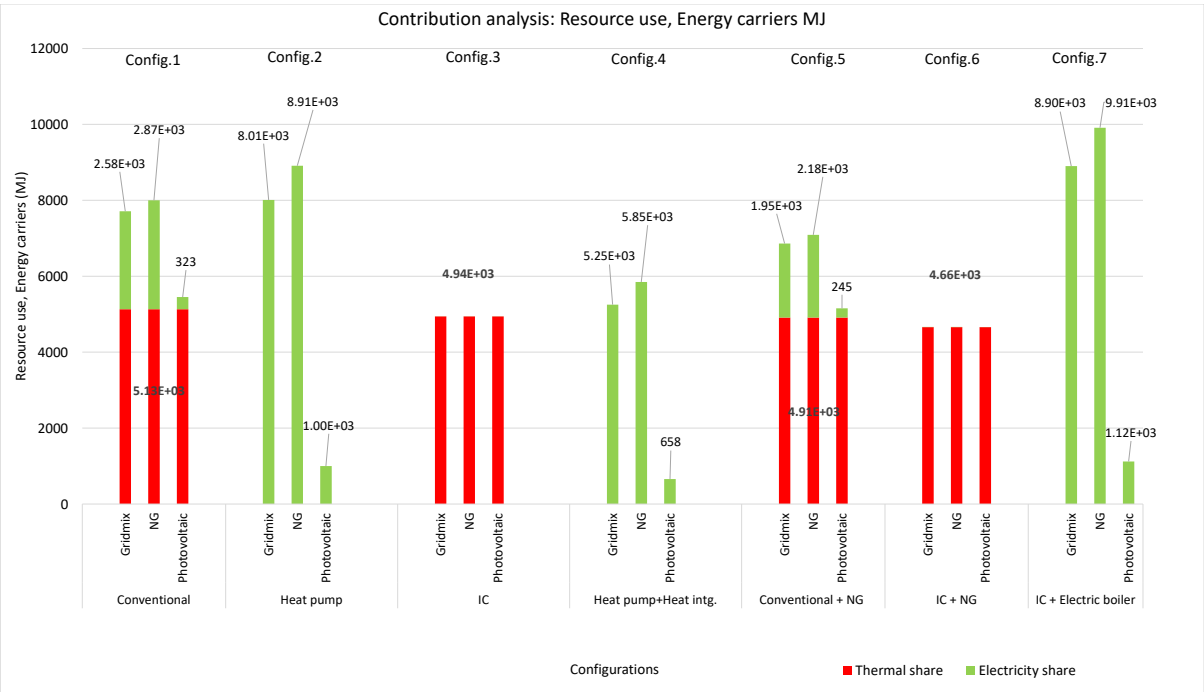
In conclusion, this thesis underscores the importance of the energy source in CO_2 capture sustainability. Heat pump technology and the conventional method employing electrode boilers are both seen as a viable option, especially when operated with renewable electricity, as opposed to the traditional practice of directly burning fossil fuels to generate thermal energy for reboilers. Future investigations could explore the comparison of ammonia based CO_2 capture systems or alternatively, investigate the potential of chilled ammonia-based processes, comparing its environmental impacts with the amine-based approach. This study contributes valuable insights to the development of more sustainable and effective strategies in the global effort to reduce climate change.

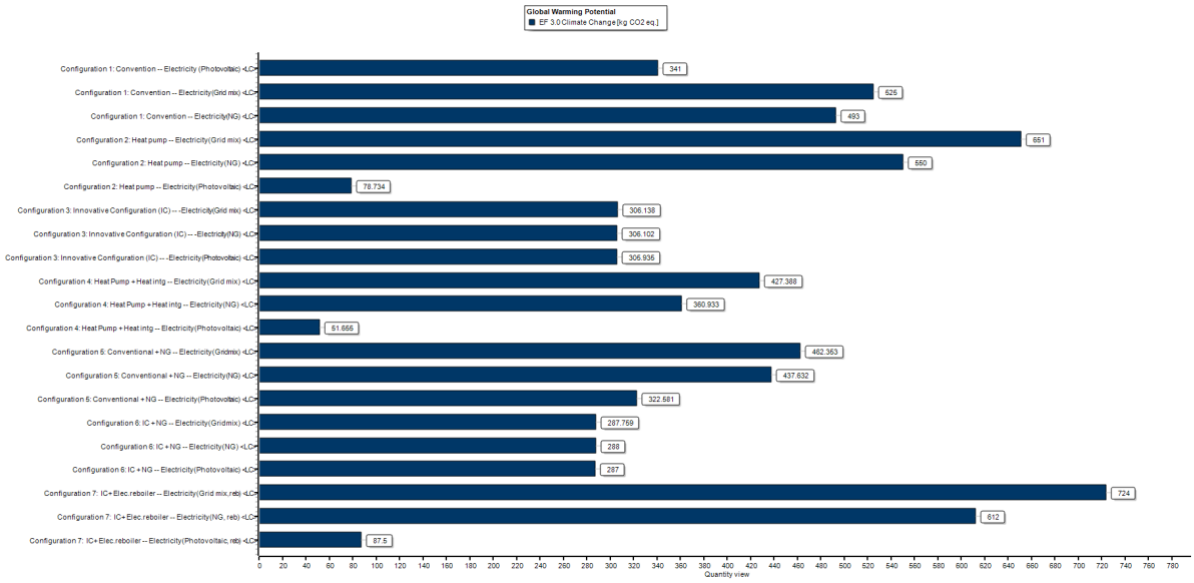
Results:

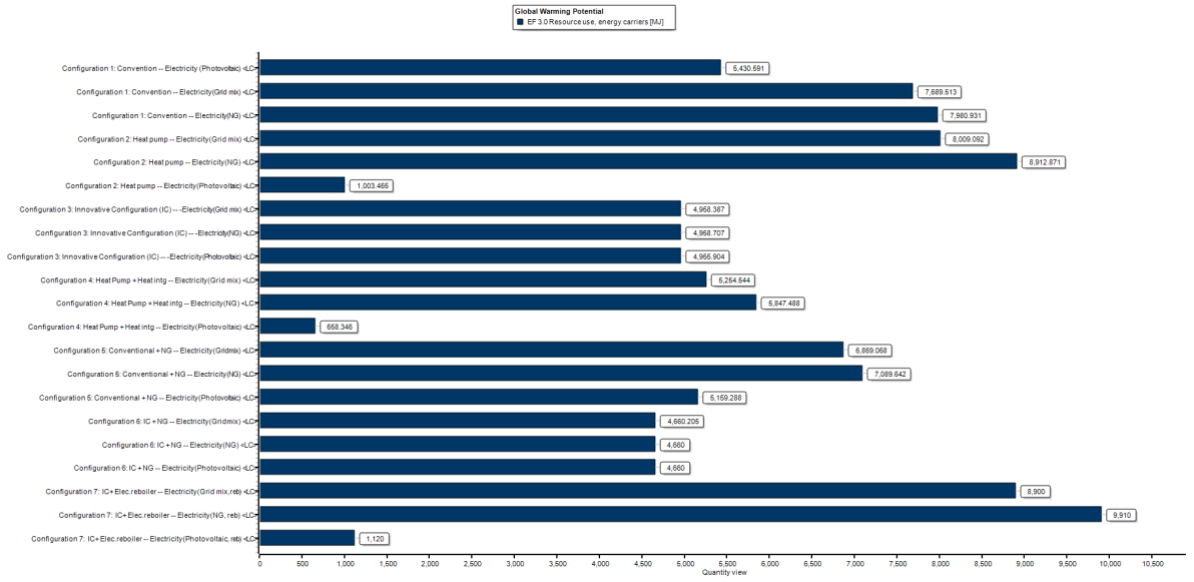

Regeneration duty
Regeneration duty (MJ/kg)
4.80
4.70
4.60
4.50
4.40
4.30
4.20
4.10
4.00
4.69
4.68
4.53
4.52
4.50
4.27
4.53
1.Conventional
2.Heat pump
3.IC
4.Heat pump + Heat intg.
5.Conventional + NG
6.IC + NG
7.IC +Electric Boiler
Configurations


Comparison : Net CO2 eq. footprint (ton CO2 eq. / 1 ton of CO2 captured)
Net CO2 eq. footprint (ton CO2 eq. / 1 ton of CO2 captured)
Gridmix
NG
Photovoltaic
Conventional
-0.559
-0.592
-0.744
Heat pump
-0.435
-0.536
-1.007
IC
-0.787
Heat pump + Heat intg.
-0.666
-0.732
-1.041
Conventional + NG
-0.589
-0.614
-0.729
IC + NG
-0.780
IC + Electric boiler
-0.368
-0.480
-1.005
Config: 1
Config: 2
Config: 3
Config: 4
Config: 5
Config: 6
Config: 7
Configurations


Contribution analysis: Climate change
Climate change (kg CO2 eq.)
800
700
600
500
400
300
200
100
0
Config.1
Config.2
Config.3
Config.4
Config.5
Config.6
Config.7
210
177
25.4
316
651
550
78.7
305
427
361
51.7
159
134
19.2
303
287
724
612
87.5
Gridmix
NG
Photovoltaic
Conventional
Heat pump
IC
Heat pump+Heat intg.
Conventional + NG
IC + NG
IC + Elec. reboiler
Configurations
Thermal share
Electricity share


Contribution analysis: Resource use, Energy carriers MJ
Resource use, Energy carriers (MJ)
12000
10000
8000
6000
4000
2000
0
Config.1
Config.2
Config.3
Config.4
Config.5
Config.6
Config.7
2.58E+03
2.87E+03
323
8.01E+03
8.91E+03
1.00E+03
4.94E+03
5.25E+03
5.85E+03
658
1.95E+03
2.18E+03
245
4.66E+03
8.90E+03
9.91E+03
1.12E+03
Gridmix
NG
Photovoltaic
Conventional
Heat pump
IC
Heat pump+Heat intg.
Conventional + NG
IC + NG
IC + Electric boiler
Configurations
Thermal share
Electricity share


Global Warming Potential
EF 3.0 Climate Change [kg CO2 eq.]
Configuration 1: Convention -- Electricity (Photovoltaic) <LCI>
341
Configuration 1: Convention -- Electricity (Grid mix) <LCI>
525
Configuration 1: Convention -- Electricity(NG) <LCI>
493
Configuration 2: Heat pump -- Electricity(Grid mix) <LCI>
651
Configuration 2: Heat pump -- Electricity(NG) <LCI>
560
Configuration 2: Heat pump -- Electricity(Photovoltaic) <LCI>
78.734
Configuration 3: Innovative Configuration (IC) -- -Electricity(Grid mix) <LCI>
306.138
Configuration 3: Innovative Configuration (IC) -- -Electricity(NG) <LCI>
306.102
Configuration 3: Innovative Configuration (IC) -- -Electricity(Photovoltaic) <LCI>
306.936
Configuration 4: Heat Pump + Heat intg -- Electricity(Grid mix) <LCI>
427.388
Configuration 4: Heat Pump + Heat intg -- Electricity(NG) <LCI>
360.933
Configuration 4: Heat Pump + Heat intg -- Electricity(Photovoltaic) <LCI>
61.666
Configuration 5: Conventional + NG -- Electricity(Gridmix) <LCI>
462.363
Configuration 5: Conventional + NG -- Electricity(NG) <LCI>
437.632
Configuration 5: Conventional + NG -- Electricity(Photovoltaic) <LCI>
322.681
Configuration 6: IC + NG -- Electricity(Gridmix) <LCI>
287.759
Configuration 6: IC + NG -- Electricity(NG) <LCI>
288
Configuration 6: IC + NG -- Electricity(Photovoltaic) <LCI>
287
Configuration 7: IC+ Elec.reboiler -- Electricity(Grid mix,reb) <LCI>
724
Configuration 7: IC+ Elec.reboiler -- Electricity(NG, reb) <LCI>
612
Configuration 7: IC+ Elec.reboiler -- Electricity(Photovoltaic, reb) <LCI>
87.5
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380 400 420 440 460 480 500 520 540 560 580 600 620 640 660 680 700 720 740 760 780
Quantity view


Global Warming Potential
EF 3.0 Resource use, energy carriers [MJ]
Configuration 1: Convention -- Electricity (Photovoltaic) <LCI>
5,430.691
Configuration 1: Convention -- Electricity(Grid mix) <LCI>
7,689.513
Configuration 1: Convention -- Electricity(NG) <LCI>
7,980.931
Configuration 2: Heat pump -- Electricity(Grid mix) <LCI>
8,009.092
Configuration 2: Heat pump -- Electricity(NG) <LCI>
8,912.871
Configuration 2: Heat pump -- Electricity(Photovoltaic) <LCI>
1,003.466
Configuration 3: Innovative Configuration (IC) -- -Electricity(Grid mix) <LCI>
4,968.387
Configuration 3: Innovative Configuration (IC) -- -Electricity(NG) <LCI>
4,968.707
Configuration 3: Innovative Configuration (IC) -- -Electricity(Photovoltaic) <LCI>
4,966.904
Configuration 4: Heat Pump + Heat intg -- Electricity(Grid mix) <LCI>
5,254.544
Configuration 4: Heat Pump + Heat intg -- Electricity(NG) <LCI>
5,847.488
Configuration 4: Heat Pump + Heat intg -- Electricity(Photovoltaic) <LCI>
658.346
Configuration 5: Conventional + NG -- Electricity(Gridmix) <LCI>
6,869.068
Configuration 5: Conventional + NG -- Electricity(NG) <LCI>
7,089.642
Configuration 5: Conventional + NG -- Electricity(Photovoltaic) <LCI>
5,159.288
Configuration 6: IC + NG -- Electricity(Gridmix) <LCI>
4,660.206
Configuration 6: IC + NG -- Electricity(NG) <LCI>
4,660
Configuration 6: IC + NG -- Electricity(Photovoltaic) <LCI>
4,660
Configuration 7: IC+ Elec.reboiler -- Electricity(Grid mix,reb) <LCI>
8,900
Configuration 7: IC+ Elec.reboiler -- Electricity(NG, reb) <LCI>
9,910
Configuration 7: IC+ Elec.reboiler -- Electricity(Photovoltaic, reb) <LCI>
1,120
0 500 1,000 1,500 2,000 2,500 3,000 3,500 4,000 4,500 5,000 5,500 6,000 6,500 7,000 7,500 8,000 8,500 9,000 9,500 10,000 10,500
Quantity view

Conclusion and Future works

Configuration 2 (heat pump) and Configuration 7 (IC + Electric boilers), produces high emissions compared to all other configurations due to carbon intensity in gridmix and natural gas. Configurations 3 to 6 have lower emissions compared to Configuration 1 due to the heat integration strategy(Configuration 3,4) or burning natural gas(Configuration 5,6) directly to produce thermal energy. Configuration 2 exhibits fewer emissions compared to all other configurations when the source of energy supply is renewable, such as photovoltaic. The contribution analysis of climate change and fossil resource use is correlated because resource consumption is necessary for energy production.

Configuration 2 and Configuration 7 are viable choices when the energy source comes from renewables. Configuration 4, which includes a heat pump and heat integration, presents a feasible alternative showing lower emissions compared to other configurations. Configuration 3 is also a wise choice when applying the heat integration strategy.

The simulation in this study uses parameters from Chikezie Nwaoha et al. In all scenarios, these parameters remain unchanged. However, adjustments to parameters could be studied in future work, including variations in the composition of the flue gas, operating conditions, and the use of different solvents or combinations of solvents. Furthermore, the life cycle assessment (LCA) in this study only accounts for a limited number of energy sources, namely grid mix, natural gas, photovoltaics, and thermal energy from natural gas, while the future study could also investigate the use of alternative energy sources such as hydropower, wind, ocean energy, and more.

In addition, this research focuses on the capture of CO_2 from cement production and uses amine solvent for absorption, but the capture of CO_2 from ammonia production or the absorption of CO_2 with chilled ammonia process could be explored to compare the distinctions between the two solvents and their life cycle assessment(LCA).