Enhancing CO_2-Based Working Fluids for Low Enthalpy Closed-Loop System for multi-generation: Additive Preliminary Screening and Thermodynamic Evaluation

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Abstract

This work aims to find effective additives for improving heat extraction and performance in low-enthalpy closed-loop geothermal systems. Supercritical carbon dioxide (sCO_2) cycles have gained interest in the energy sector because of their high efficiency and compact design. In closed-loop Enhanced Geothermal Systems (EGS), buoyancy-driven natural circulation, known as the thermosyphon effect, serves as a promising way to transport fluid. This is especially useful for low-enthalpy resources, as it reduces or eliminates the need for mechanical pumping. However, using pure CO_2 has several drawbacks. These include insufficient density gradients, phase instability near the wellhead, and lower thermodynamic performance in low-temperature reservoir conditions. Using CO_2-based mixtures offers a way to adjust thermophysical properties and enhance buoyancy-driven circulation. By shifting the critical point and increasing the effective heat capacity of the working fluid, the right additives can improve circulation stability and prevent unwanted two-phase conditions in the loop. This study looks at the potential of selected CO_2-based mixtures through a preliminary thermodynamic screening. It focuses on their ability to enhance heat extraction and operational reliability in low-enthalpy closed-loop geothermal systems. The results provide insights into fluid property adjustment strategies for multigeneration geothermal applications and help identify promising working fluids for more detailed system-level analysis.

Keywords:

Carbon Dioxide, Carbon Dioxide mixtures, EGS, Buoyancy, Heat extraction, LCOEx

1. Introduction

A Closed-Loop Geothermal Systems (CLGSs) also referred as advanced geothermal systems (AGS) are proposed to resolve the problems associated with site specific geologic uncertainties such as issues associated with mineral dissolution in the working fluid, loss of working fluid and to minimize the risk of induced seismicity typically associated with hydraulic stimulation [1][2]. The main heat transfer mode of CLGS is conduction between reservoir and working fluid across well casing and cement and the fluid dose not permeate the reservoir [3]. Despite the advantages of CLGS, several challenges remain. Achieving an adequate heat transfer area along the wellbore is critical and largely dependent on the required energy output, which in turn dictates the number and length of wells needed. However, drilling deep and extended wells at economically viable costs continues to be a major technological and financial challenge for large-scale CLGS deployment[2].

The novel idea of using CO2 in EGS was proposed by Brown highlighting the advantages over water[4]. CO2 based energy technologies are getting more attraction as interesting options in the context of tackling climate change, as well as for their high efficiency and compactness [5]. However, interests in further improvement of CO2 performance in relevant applications by enhancing its favourable properties when blended with suitable additives are increasing consideration by many researchers [6]. The performance of CO2 in geothermal heat mining is advantageous compared to water, particularly for power production, mainly because of its higher buoyancy force caused by the larger density variation while getting heated, leading to natural thermosiphon effect and relevant pressure raise [7]. Nevertheless, the critical point of CO2 remains a significant constraint, often hindering its possible advantageous utilization in several applications, both underground and surface use conditions. One of the major obstacles of CO2 cycles is subcritical CO2 condensation, where it requires special techniques for liquefaction during the summer or in tropical zones. Many authors have suggested additives for lower the subcritical CO2 condensation difficulty[8]. In particular, shifting the critical point to ease condensation may introduce trade-offs, such as reducing the tendency for vaporization at the well bottom, which can negatively impact performance in low-enthalpy geothermal systems.

The selection of optimal additives for Closed-Loop Geothermal Systems (CLGS) is a multi-variable problem involving coupled thermodynamic and operational effects. Additives influence key properties such as density variation, phase behaviour, and heat transfer, thereby affecting both subsurface performance and surface cycle efficiency. Rath et al. showed that certain additives can enhance the efficiency of supercritical CO_2 (sCO_2) power cycles; however, their impact is strongly configuration dependent. These findings indicate that additive selection is inherently system-specific, requiring integrated evaluation across both the geothermal loop and the power cycle rather than relying on isolated performance metrics. [9]. Consequently, the screening and selection of additives must be performed in relation to the specific system under consideration.

Despite the vast global geothermal potential, approximately 70% of geothermal resources are classified as low enthalpy[10]. Buoyancy-driven natural circulation is attractive feature of CO_2 as a working fluid as already mentioned. Natural circulation of the working fluid plays a crucial role in maximizing energy efficiency, particularly for low-temperature geothermal resources, where the available thermal energy is limited and active pumping can significantly reduce net power output. By enabling buoyancy-driven flow based on temperature and density gradients, natural circulation eliminates or minimizes the need for active pumping. This not only improves net power output but also simplifies system design, reduces maintenance, and enhances long-term sustainability. Therefore, promoting stable and efficient natural circulation becomes particularly important when evaluating working fluids or fluid mixtures for use in low enthalpy GS. For systems with natural circulation the phase control at the wellhead is crucial as the phase can directly impact the flow stability and pressure buildup at the wellhead.

The novelty of this work lies in identifying suitable additives specifically for HOCLOOP systems operating under low-enthalpy conditions. Unlike conventional sCO_2 cycles, HOCLOOP systems exhibit self-pressurization due to vertical fluid columns. Therefore, an integrated evaluation considering thermodynamic performance, pressurization effect, and economic feasibility (LCOEx) is required. This study proposes a targeted screening approach to identify additives that satisfy these coupled constraints.

2. Methodology

2.1. Theoretical framework and thermodynamic modelling

Thermophysical Properties

All thermodynamic properties were evaluated using the CoolProp library with the REFPROP backend. The simulations were performed within a Python-based computational environment. Only predefined binary mixtures available in CoolProp were considered in this study.

The well model adopted in this study is based on the simplified framework proposed by Ungar et al.[11]. The ascending and descending well sections are assumed to be isentropic, with heat transfer occurring only along the horizontal section. A detailed description of the thermodynamic modelling can be found in [12]. System performance is evaluated considering only the well section, coupled with a simplified surface configuration comprising a turbine with 80% isentropic efficiency and a heat recuperator. A simplified surface configuration is adopted to isolate the impact of fluid properties on subsurface performance. Therefore, the results should be interpreted in a relative sense, focusing on performance trends rather than absolute system performance. More detailed cycle configurations may lead to different optimal additive selections. The corresponding schematic is presented in Figure 1.This study aims to assess the heat-mining performance of low-enthalpy geothermal systems using an exergy-based approach, comparing pure CO_2 with CO_2-based mixtures under consistent geometric and subsurface conditions.

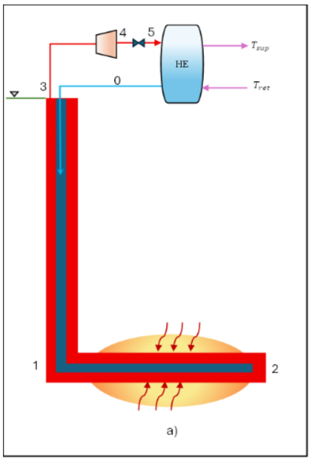

Figure 1:Schematic diagrams of system considered

Performance Parameters

In contrast to pure fluids, mixtures introduce additional complexity due to the increased number of evaluation parameters. To reduce the scope of variability and ensure comparability, the well performance is evaluated at 3 fixed depths of 1,2 and 3 km and from corresponding limiting thermal gradients of 0.05,0.04 and 0.034 °C/m and above. As reported by Ungar et al a depth of 1000 meters is the minimum at which cooling losses are minimized, and the chosen thermal gradient (0.05 °C/m) represents the critical lower bound beyond which natural circulation cannot be sustained [11] [13]. These limiting cases are selected to enable a consistent assessment of performance improvements achieved by CO_2-based mixtures relative to pure CO_2.

Geometric parameters, particularly the lateral length and wellbore diameter, play a key role in determining the LCOEx through their influence on capital costs. Increasing the wellbore diameter generally leads to higher drilling and completion costs. Previous techno-economic studies have considered diameters in the range of 0.1–0.5 m. While larger diameters can enhance power output, they also increase capital expenditure; conversely, smaller diameters combined with higher mass flow rates may result in significant frictional losses [2], [14] ,[15]. In this study, a wellbore diameter of 0.2286 m is adopted following Beckers et al. [16]. as a reference case. The mass flow rate and lateral length are determined through system optimisation aimed at minimising LCOEx. For each vertical depth, the optimal horizontal (lateral) length and corresponding mass flow rate are identified.

The maximum temperature that the working fluid can theoretically reach is the rock temperature. However, this condition is impractical, as it would require an excessively long well and a large heat transfer area to achieve thermal equilibrium with the surrounding rock. According to the work of Fiaschi et al, lateral length of the well can be determined as in Eq.1 and detailed derivations for heat extraction can be find here [11].

$$L = R_{rocks} \frac{\dot{m}\Delta h_{max}}{\pi \phi_{well}} \int_0^{\Delta h_{\%}} \frac{dh'}{\Delta T(h')} \qquad \text{Eq. 1}$$

R_{rocks}- is rock resistance which is depends on subsurface conditions. Unless the diameter of the well and well sounding is not change it would be remained constant. The values used in this study are obtained from in-house data.

For selected horizontal extension lengths (1–5 km), the heat transfer rate is evaluated, followed by the calculation of the corresponding net power output, exergy gain, and second-law efficiency. In the exergy analysis, a maximum exergy destruction is assumed in the heat recuperator. This assumption reduces the number of variables by decoupling the results from the specific configuration of the secondary system integrated via the recuperator. Consequently, the analysis represents a conservative (worst-case) scenario, enabling the identification of the most robust additives under unfavourable operating conditions. Exergy destruction in the gas cooler, or heat recuperator, is evaluated following the methodology proposed by Rauch et al. [17], who developed a non-dimensional framework to quantify exergy destruction in heat exchangers.
Exergy is defined as the maximum amount of energy that can be converted into useful work as a system comes into equilibrium with a specified reference environment.

$$ex = \left(h - h_{ref}\right) - T_{ref}(s - s_{ref}) \quad \text{Eq. 2}$$

In this work the reference pressure is set to saturation pressure of CO2 at the reference temperature, that temperature is taken as the ambient temperature of the system under consideration. However, variations in the dead-state (reference state) conditions have only a minor impact on the calculated energy and exergy values of the system [18] [19].

Amount of Heat transferred to the system:

$$\dot{Q}_f = \dot{m}_f(\Delta h) = \dot{m}_f(h_2 - h_1) \quad \text{Eq. 3}$$

Heat exergy into the system:

$$\dot{E}x_{BHE,f} = \dot{Q}_f(1 - \frac{T_{ref}}{T_{rock}}) \quad \text{Eq. 4}$$

Work exergy:

$$\dot{E}x_{w,f} = \dot{W}_T = \dot{m}_f(h_3 - h_4) \quad \text{Eq. 5}$$

For any HE, maximum exergy destruction occurs at $\pi_1 = \varepsilon = 0.5$,:

$$\left(\frac{\Delta\dot{E}x_D}{\dot{C}_f T_{ref}}\right)_{co,max,\pi_3=1} = \ln\frac{(1+\pi_T)^2}{4\pi_T} \quad \text{Eq. 6}$$

$$\pi_T = \frac{T_{ret}}{T_5}\ , \varepsilon = \frac{T_5 - T_0}{T_5 - T_{ret}}$$

Second law efficiency of the system:

$$\eta_{Ex,f} = \frac{\dot{W}_{net,f} + \dot{m}_{sec}(ex_{sup} - ex_{ret})}{\dot{E}x_{BHE,f}} \quad \text{Eq. 7}$$

Exergy balance to the HE:

$$\dot{m}_{sec}(ex_{sup} - ex_{ret}) = \dot{m}(ex_5 - ex_0) - \Delta\dot{E}x_D \quad \text{Eq. 8}$$

Levelized Cost of Exergy

The surface plant configuration considered in geothermal systems typically produces both electricity and thermal energy. For such combined output systems, conventional economic indicators such as the Levelized Cost of Electricity (LCOE) or the Levelized Cost of Heat (LCOH) are not suitable, because heat and work are fundamentally different forms of energy and cannot be directly compared. To address this limitation, Kocher et al. proposed a unified evaluation framework based on the Levelized Cost of Exergy (LCOEx), which enables consistent comparison of systems driven by both work(electricity) and heat. The LCOEx metric evaluates the cost per unit of useful exergy delivered by the system, accounting for both thermal and mechanical outputs within a single thermodynamic framework [20]. Economic model adapted in this work is which has previously been presented by Fiaschi et al [21]. At this stage of the study, conducting a comprehensive economic analysis is not feasible. Depending on the type of additive used, additional requirements such as high-technology sealing systems may further increase the overall cost. Therefore, in the present work, LCOEx is used as a relative economic indicator to compare the performance of different working fluids under consistent assumptions. A simplified cost model based primarily on drilling costs is adopted; therefore, the results do not represent absolute economic values but rather enable a consistent comparative assessment between fluids.

The turbine outlet temperature - is an important parameter, as it indicates the suitability of downstream integration with secondary systems and potential applications, including power production, thermal uses, cascade utilisation, and hybrid system configurations.

Base Case Selection

The mass flow rate and horizontal length are selected based on four key performance parameters: LCOEx, second-law efficiency, exergy gain, and turbine outlet temperature (T_5). By analysing system performance across different horizontal lengths and mass flow rates, the parameters listed in are defined as the base case for mixture evaluation. Although LCOEx exhibits only weak sensitivity to mass flow rate within the considered range (as shown in Figure), selecting excessively low mass flow rates is undesirable due to reduced power output. Conversely, higher mass flow rates increase net power production but may lead to significant frictional losses, which are not accounted for in the present simulations.

Table 1:BHE parameters

Case 1		***Case 2***		***Case 3***	
Depth	1000m	Depth	2000m	Depth	3000m
H-Length	1000m	H-Length	2000m	H-Length	2000m
Thermal gradient	0.05°C/m	Thermal gradient	0.04°C/m	Thermal gradient	0.034°C/m
D-well	0.229m	D-well	0.229m	D-well	0.229m
R_{rocks}	0.3392	R_{rocks}	0.3392	R_{rocks}	0.3392
Depletion time	20 Years	Depletion time	20 Years	Depletion time	20 Years
Mass flowrate	10kg/s	Mass flowrate	10kg/s	Mass flowrate	10kg/s
T_{in}	30°C	T_{in}	30°C	T_{in}	30°C

System Evaluation with mixtures

Based on the defined base cases (i.e. identical geometric and subsurface conditions), both systems are evaluated using mixtures while maintaining the same energy input as the corresponding pure CO_2 case. A reference mass flow rate is adopted for consistent comparison of mixtures. The system performance is assessed over additive mole fractions ranging from 50% to 90%.

$$\dot{m}_s = \frac{\Delta h_{max,CO_2}}{\Delta h_{max,s}} \dot{m}_{CO_2} \quad \text{Eq. 9}$$

The surface configuration considered in this study is highly simplified. In practical applications, the surface plant would be more complex and potentially more efficient. Therefore, evaluating subsurface performance alongside selected key performance indicators provides more meaningful guidance for additive selection, particularly for integration with advanced surface plant configurations.

Accordingly, this part of the study investigates the influence of additives on LCOEx, pressurisation behaviour, power production, and turbine outlet temperature (T_5) of the CO_2-based loop, with the aim of assessing whether overall performance is enhanced or degraded. All mixture performance metrics are normalised against the pure CO_2 baseline and presented using radial plots to enable clear visual comparison.

$$PE = P_3 - P_0 \qquad \text{Eq. 10}$$

Normalized Performance Metrics

$$X_{rel} = \frac{X_s}{X_{CO_2}} \qquad \text{Eq. 11}$$

Phase Check at turbine inlet

The present study focuses solely on sCO_2 turbine expansion. Unlike pure fluids, phase identification for mixtures is more complex due to modified critical properties. As a result, the thermodynamic state at point 3 may correspond to a supercritical liquid, supercritical gas, gas, or two-phase region. The CoolProp framework identifies two-phase conditions but does not explicitly distinguish between supercritical liquid and supercritical gas states. Due to the complexity of phase behavior in mixtures, particularly the presence of multiple critical points, this study considers only operating conditions corresponding to the supercritical gas region at the turbine inlet. This simplification is adopted to enable consistent screening; however, it represents a limitation, and a more detailed phase analysis is required in future work.

$$P_c - P_3 < 0, T_c - T_3 < 0$$
$$P_c - P_3 > 0, T_c - T_3 < 0$$

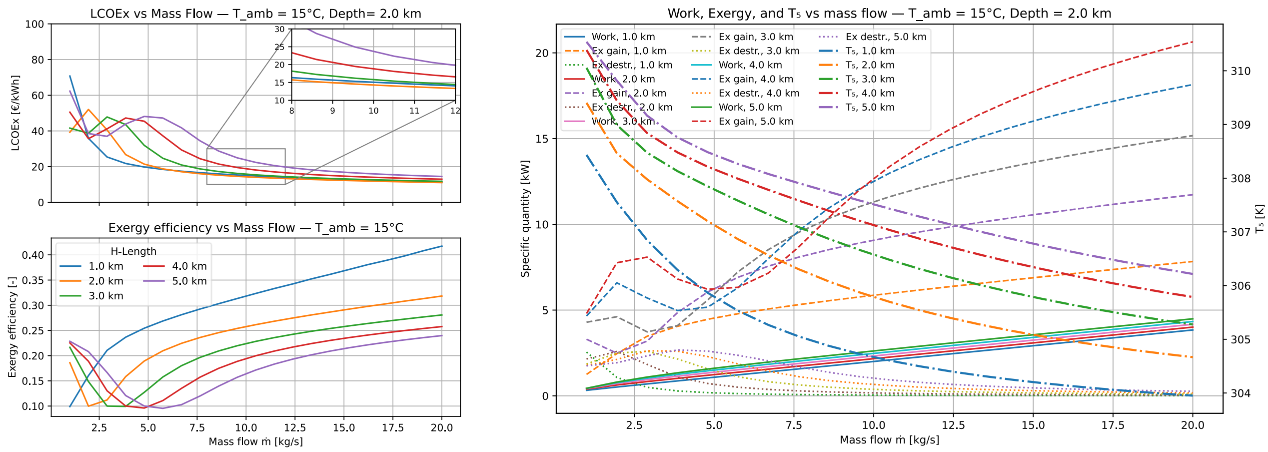

Figure 2: Work, Exergy vs mass flowrate, Performance of Case 2

2.2. TOPSIS Sort

Since the screening involves multiple evaluation parameters, the TOPSIS [8] ,[22] method is employed to rank additive performance. As the primary objective of introducing additives is to enhance favourable fluid properties and overall system performance while maintaining a low LCOEx, a multi-criteria decision-making approach is appropriate. Net power output, pressurisation effect, LCOEx, and turbine outlet temperature (T_5) are selected as the evaluation criteria, with a predefined weighting reflecting their relative importance. Within the TOPSIS framework, criteria are classified as either benefit or cost indicators, where higher values are desirable for benefit criteria (e.g. net power, pressurisation effect, T_5) and lower values are preferred for cost criteria (e.g.

LCOEx). The ideal solutions are defined accordingly, with the positive ideal representing the best attainable performance and the negative ideal representing the worst.

1. LCOEx - 0
2. Pressurization Effect - 1
3. Net power - 1
4. T5 - 1

Pure CO_2 performance parameters were adopted as the reference baseline for normalizing the decision matrix. The weighted normalized matrix was then obtained by applying predefined weighting factors to each criterion. Higher weights were assigned to LCOEx and net power, given their direct impact on system economic viability and energy output. Conversely, a lower weight was assigned to the pressurization effect, as mechanical pumping can be implemented to compensate for insufficient natural circulation. Detailed procedure can be found in the work of Sabokbar et al [23].

Weight matrix - [0.30, 0.15, 0.30, 0.20]

Assumptions made

- Frictional losses in wellbore are neglected to simplify the analysis.
- The thermal properties adopted in the heat transfer calculations correspond to stabilized conditions after 20 years of operation.
- The system is assumed to operate under steady-state conditions.

assessment of overall system performance. Relative values greater than 2 are filtered out to avoid distortion arising from possible numerical discrepancies or non-physical results.

3. Results.

Additives were ranked both according to their minimum LCOEx values and using the TOPSIS method. Although the lowest LCOEx criterion identifies economically favourable options, it does not account for trade-offs with other performance indicators. The TOPSIS approach, however, enables the identification of additives that achieve a balanced improvement across multiple parameters, thereby providing a more comprehensive assessment of overall system performance. Relative values greater than 2 are filtered out to avoid distortion arising from possible numerical discrepancies or non-physical results

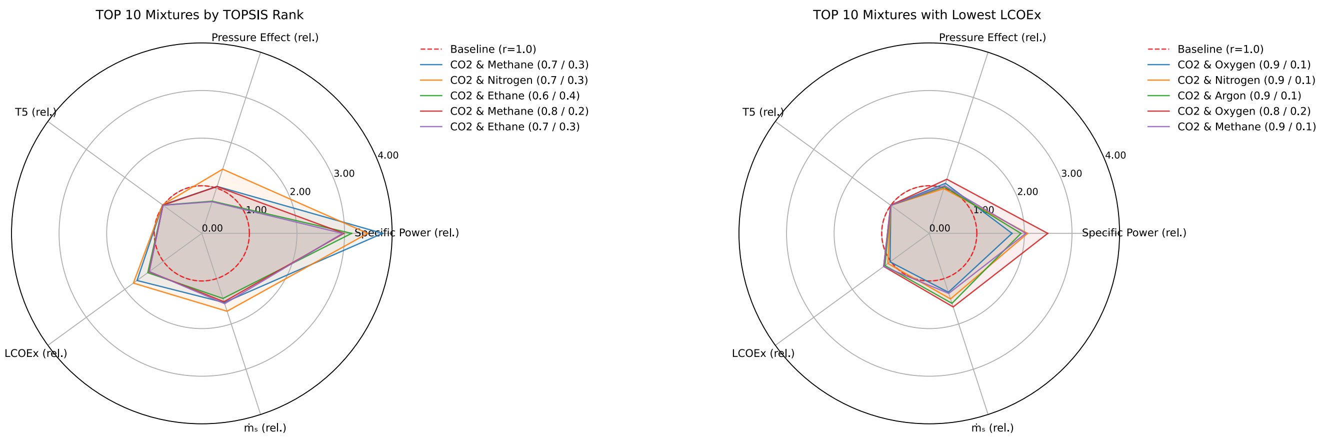

Figure 3: Comparison of TOPSIS-selected mixtures and lowest-LCOEx mixtures for Case 1.

Case 1

Table 2:TOPSIS sorted additive list case 1

Mixture	Composition	T_c (K)	P_c (MPa)	$\dot{m}_s$ (kg/s)	$\dot{W}_{net}$ (kW)	$\dot{E}x_{net}$ (kW)	LCOEx (€/kWh)	T_5 (K)
CO2 & Methane	0.7 / 0.3	276.99	8.89	15.27	0.74	22.44	23.94	309.88
CO2 & Nitrogen	0.7 / 0.3	272.57	12.18	17.2	0.68	23.09	25.28	310.47
CO2 & Ethane	0.6 / 0.4	290.25	5.83	14.38	0.61	17.51	19.97	306.84
CO2 & Methane	0.8 / 0.2	287.23	8.56	15.1	0.58	17.5	19.49	306.66
CO2 & Ethane	0.7 / 0.3	291.23	6.06	15.53	0.58	17.04	19.4	306.17

Table 3:Lowest LCOEx additives case 1

Mixture	Composition	T_c (K)	P_c (MPa)	$\dot{m}_s$ (kg/s)	$\dot{W}_{net}$ (kW)	$\dot{E}x_{net}$ (kW)	LCOEx (€/kWh)	T_5 (K)
CO2 & Oxygen	0.9 / 0.1	299.84	9.15	13	0.34	9.07	14.48	304.24
CO2 & Nitrogen	0.9 / 0.1	294.9	8.78	14.48	0.4	11.2	15.29	304.53
CO2 & Argon	0.9 / 0.1	296.59	8.72	15.46	0.37	11.21	16.38	304.33
CO2 & Oxygen	0.8 / 0.2	292.28	10.66	16.25	0.48	15.28	16.81	305.84
CO2 & Methane	0.9 / 0.1	296.52	8.08	13.26	0.39	10.71	16.84	304.19

Case 2

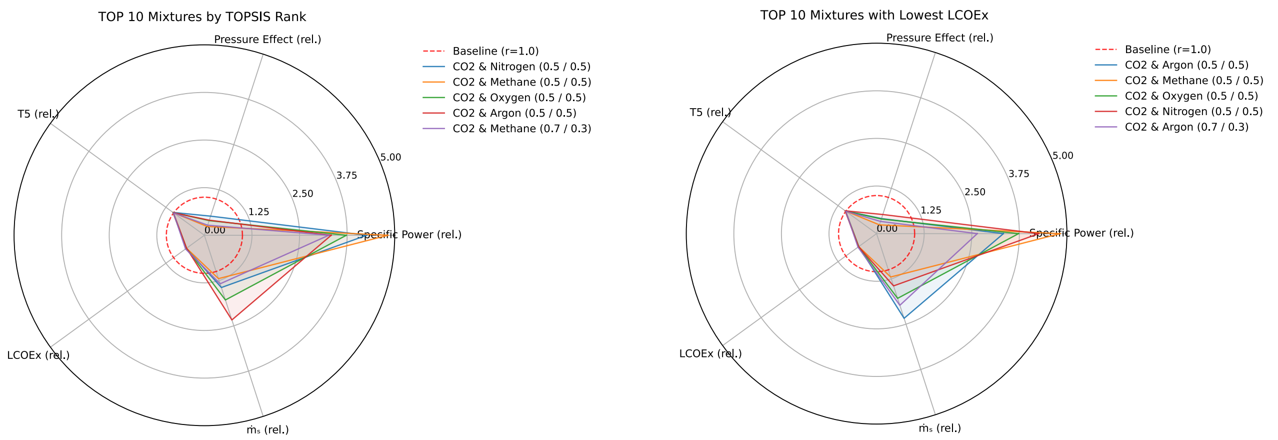

Figure 4: Comparison of TOPSIS-selected mixtures and lowest-LCOEx mixtures for Case 2.

Table 4: TOPSIS sorted additive list case 2

Mixture	Composition	T_c (K)	P_c (MPa)	$\dot{m}_s$ (kg/s)	$\dot{W}_{net}$ (kW)	$\dot{E}x_{net}$ (kW)	LCOEx (€/kWh)	T_5 (K)
CO2 & Nitrogen	0.5 / 0.5	239.31	19.17	14.43	0.92	21.58	8.37	312.07

CO2 & Methane	0.5 / 0.5	252.6	8.68	11.97	1.05	20.26	8.29	311.19
CO2 & Oxygen	0.5 / 0.5	251.16	13.96	17.87	0.81	22.53	8.34	309.8
CO2 & Argon	0.5 / 0.5	239.98	14.99	23.38	0.72	25.17	8.26	308.84
CO2 & Methane	0.7 / 0.3	276.99	8.89	13.4	0.71	15.54	8.75	306.79

Table 5:Lowest LCOEx additives case 2

Mixture	Composition	T_c (K)	P_c (MPa)	$\dot{m}_s$ (kg/s)	$\dot{W}_{net}$ (kW)	$\dot{E}x_{net}$ (kW)	LCOEx (€/kWh)	T_5 (K)
CO2 & Argon	0.5 / 0.5	239.98	14.99	23.38	0.72	25.17	8.26	308.84
CO2 & Methane	0.5 / 0.5	252.6	8.68	11.97	1.05	20.26	8.29	311.19
CO2 & Oxygen	0.5 / 0.5	251.16	13.96	17.87	0.81	22.53	8.34	309.8
CO2 & Nitrogen	0.5 / 0.5	239.31	19.17	14.43	0.92	21.58	8.37	312.07
CO2 & Argon	0.7 / 0.3	276.42	11.44	19.78	0.57	17.42	8.63	306.13

Case 3

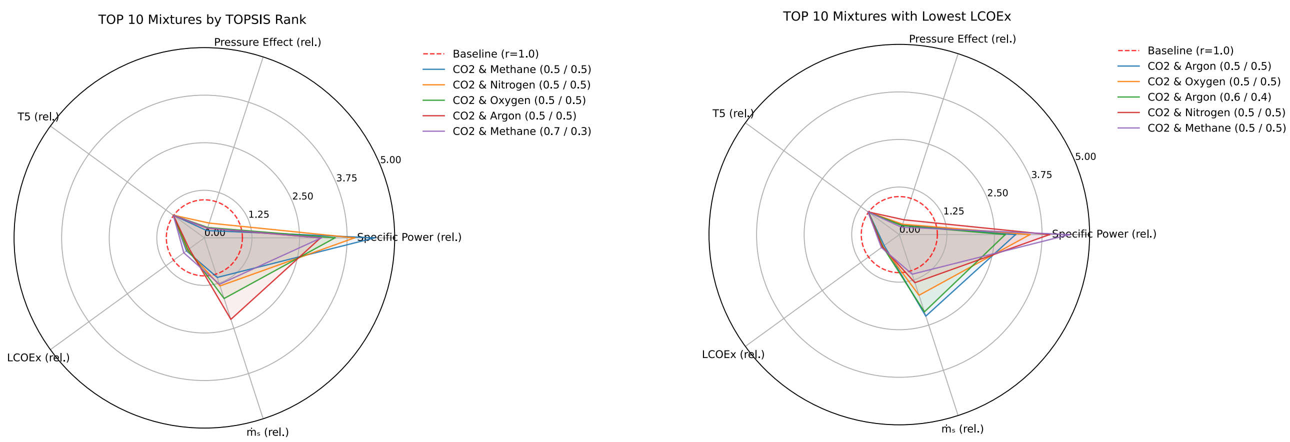

Figure 5: Comparison of TOPSIS-selected mixtures and lowest-LCOEx mixtures for Case 3.

Table 6: TOPSIS sorted additive list case 3

Mixture	Composition	Tc (K)	Pc (MPa)	$\dot{m}_s$ (kg/s)	Ẇ_net (kW)	Ėx_net (kW)	LCOEx (€/kWh)	T_5 (K)
CO2 & Methane	0.5 / 0.5	252.6	8.68	10.95	1.05	18.61	9.61	311.31
CO2 & Nitrogen	0.5 / 0.5	239.31	19.17	13.29	0.92	19.61	9.12	311.59
CO2 & Oxygen	0.5 / 0.5	251.16	13.96	16.77	0.8	20.26	8.83	308.88
CO2 & Argon	0.5 / 0.5	239.98	14.99	22.53	0.71	22.56	8.13	307.52
CO2 & Methane	0.7 / 0.3	276.99	8.89	12.84	0.72	16.17	11.06	307.68

Table 7: Lowest LCOEx additives case 3

Mixture	Composition	Tc (K)	Pc (MPa)	$\dot{m}_s$ (kg/s)	$\dot{W}$_net (kW)	$\dot{E}$x_net (kW)	LCOEx (€/kWh)	T_5 (K)
CO2 & Argon	0.5 / 0.5	239.98	14.99	22.53	0.71	22.56	8.13	307.52
CO2 & Oxygen	0.5 / 0.5	251.16	13.96	16.77	0.8	20.26	8.83	308.88
CO2 & Argon	0.6 / 0.4	260.46	12.71	21.36	0.65	20.05	8.92	306.78
CO2 & Nitrogen	0.5 / 0.5	239.31	19.17	13.29	0.92	19.61	9.12	311.59
CO2 & Methane	0.5 / 0.5	252.6	8.68	10.95	1.05	18.61	9.61	311.31

The results indicate that selecting additives solely based on minimum LCOEx does not necessarily lead to optimal thermodynamic performance. While low-LCOEx mixtures are economically favourable, they often exhibit limited improvements in power output and pressurization effect. In contrast, the TOPSIS-based selection identifies mixtures that achieve a balanced enhancement across multiple performance indicators, demonstrating the importance of multi-criteria optimization in additive screening.

3. Conclusions

This study presents a preliminary screening of CO_2-based mixtures for low-enthalpy closed-loop geothermal systems using an exergy-based and multi-criteria evaluation framework. The results demonstrate that several additives can improve system performance compared to pure CO_2 by enhancing thermophysical properties and system pressurization. However no single additive can be identified as universally optimal, as performance depends on the trade-off between thermodynamic and economic parameters. The TOPSIS method proved effective in identifying mixtures that provide a balanced improvement across multiple criteria. The findings highlight the strong potential of fluid property tailoring in geothermal applications, while also emphasizing the need for further investigation, including detailed phase behaviour analysis, improved thermodynamic modelling, and integration with more realistic surface plant configurations.

Future work

A sensitivity analysis on mass flow rate and thermal gradient is recommended as part of future work to assess robustness of additive ranking.

Acknowledgements

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Nomenclature

sCO2	Supercritical Carbon dioxide
AGS	Advanced geothermal Systems
EGS	Enhanced Geothermal systems
LCOEx	Levelized cost of Exergy
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
BHE	Borehole heat exchanger
HE	Heat exchanger
PE	Pressurization effect
sCO2	Supercritical Carbon dioxide
AGS	Advanced geothermal Systems
EGS	Enhanced Geothermal systems

LCOEx Levelized cost of Exergy
TOPSIS Technique for Order Preference by Similarity to Ideal Solution

$\dot{E}x_{D,HE}$	Exergy destruction rate, (W)
ex	Exergy, (J/kg)
$\dot{m}$	Mass flowrate, (kg/s)
$\dot{W}_{net}$	Net power (W)
$\dot{Q}$	Heat flowrate, (W)
R_{rocks}	Thermal resistance of the thermal rocks
T	Temperature, (K)
P	Pressure, (Pa)
s_0	Entropy, (J/kgK)
h_i	Enthalpy, (J/kg)
g	Gravitational acceleration, (m/s2)
z	Depth, (m)
D-well	Well diameter, (m)

Subscripts and superscripts

s	mixture
c	Critical property
sec	secondary fluid
ref	reference

Greek Symbols

$\eta_{Ex,f}$	Second law efficiency
π_i	Non-dimensional parameter

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