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Original Article

Multiaspect analysis and optimization of a power and cooling cogeneration plant integrated with a multilevel waste heat recovery system

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Abstract

This study focuses on the development and improvement of a new combined power and cooling system called the power-cooling cogeneration system (PCCS). The PCCS incorporates a tri-tier waste heat recovery system that includes an organic Rankine cycle (ORC) system and an ejector-driven refrigeration mechanism. The cogeneration system design incorporates a thorough assessment of thermodynamic efficiency, cost-efficiency, and environmental consequences. A dual-objective optimization technique is developed to decrease expenses while simultaneously improving exergy efficiency. In addition, the complex behavior of PCCS is compared to a standard system that uses a one-stage recovery-ORC system and a compressor-based refrigeration approach. Also, the effectiveness of the PCCS was evaluated through the utilization of several environmentally friendly refrigerants. Environmental evaluations employ two metrics: total equivalent-warming impact (TE-WI) and life cycle-climate performance (LC-CP), emphasizing substantial reductions in environmental harm through improved waste heat recovery. The results demonstrate that the R1234-yf refrigerant achieves the best possible performance in both configurations, resulting in a significant increase of roughly 10.1% in exergetic efficiency compared to the standard system. Simultaneously, the PCCS experiences a decrease in exergy loss and annual costs of around 7.25% and 21.16%, respectively, as compared to the baseline. Incorporating an ejector into the refrigeration cycle has the potential to reduce carbon dioxide emissions by up to 11.41×10^6 kg.

Keywords: power and cooling; cogeneration system; multilevel waste heat recovery system; environmental analysis; optimization

1 Introduction

The increasing worldwide need for energy, fueled by improved quality of life and continuous progress in industry and society, has heightened the difficulties in maintaining a dependable and environmentally benign energy source [1, 2]. Researchers strongly recommend implementing cutting-edge energy systems with traditional power facilities [3–5]. In order to be successfully implemented at either the power plant or distributed generation scale, these innovative systems need to show strong financial feasibility and exceptional thermodynamic efficiency [6, 7]. Furthermore, given the pressing environmental concerns, it is necessary for these systems to be sustainable and in accordance with worldwide carbon standards [8–10].

Carbon neutrality has been acknowledged as a crucial objective for sustainable development in modern society by international treaties [11, 12]. However, fossil-fueled power stations, which significantly contribute to atmospheric carbon pollution, still account for more than 80% of energy consumption [13]. In 2020, the burning of fossil fuels was responsible for almost 70% of these emissions [14, 15]. The uncontrolled release of waste heat from exhaust systems causes substantial harm to public health and ecosystems [16, 17]. The significance of heat recovery processes (HRPs) in

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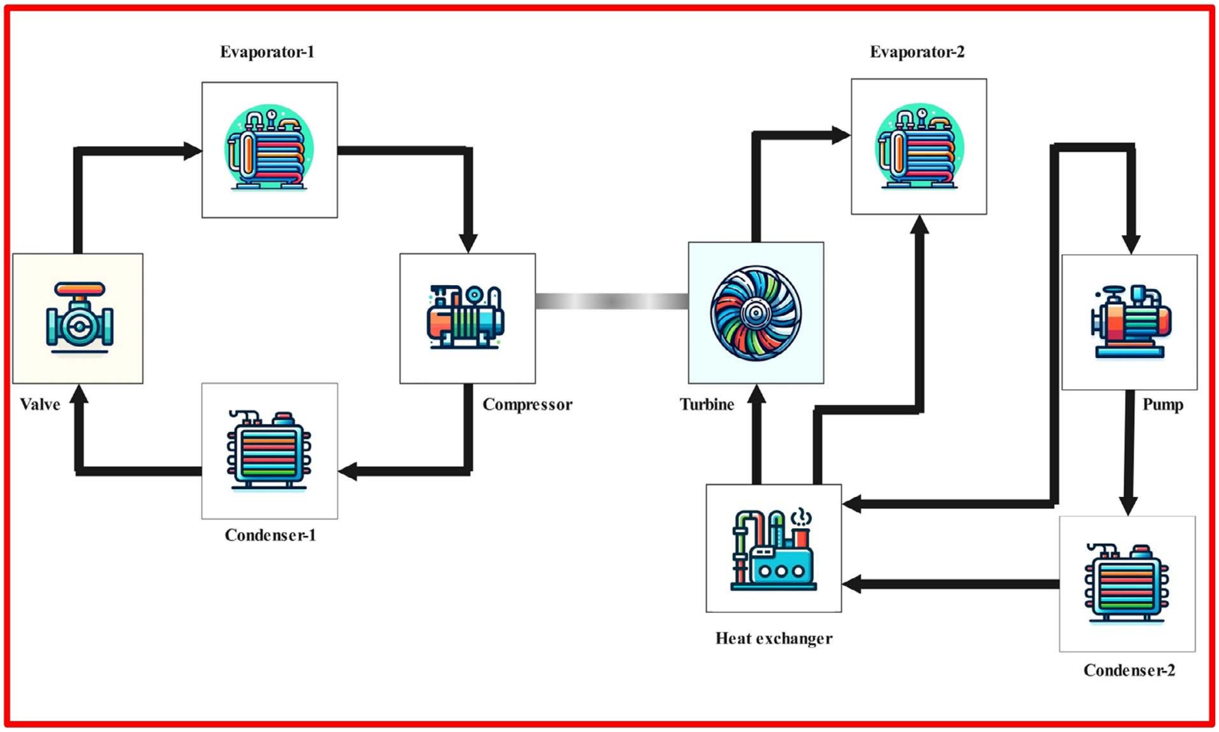

Figure 1. The arrangement and flow diagram of the reference system (RS).

capturing and utilizing exhaust heat that would otherwise be wasted is emphasized [18].

HRPs can be used in conjunction with organic Rankine cycle (ORC) systems, Kalina cycles, other refrigeration methods, thermoelectric and thermionic generators, as well as water electrolysis processes to convert waste heat into useful energy [19, 20]. ORCs are highly preferred for their capacity to operate efficiently using low-grade heat sources, thanks to the lower boiling point of organic fluids in comparison to water [21]. These systems have the ability to combine with a wide range of heat sources such as geothermal well [22], solar collectors [23], biomass gasification system [24], exhaust gas of industrial processes, fossil power emissions, and various fuel cells [25, 26]. Reshaeel *et al.* [27] and Lan *et al.* [28] conducted studies that demonstrated notable improvements in waste heat recovery by the utilization of particular organic fluids and the incorporation of thermoelectric generators. While fossil-based power plants play a vital role in maintaining grid stability, they also contribute significantly to the release of CO_2 emissions. Thus, incorporating waste heat recovery methods in these plants not only decreases carbon emissions but also enhances both environmental and thermodynamic efficiency [29]. In [30], the possibility of integrating a plant under an organic Rankine cycle-system to provide extra thermal energy for greenhouse applications was investigated. They showed that using multi-stage heat exchangers in ORCs can improve waste heat recovery, leading to better thermodynamic performance and reduced environmental impact [31, 32].

The refrigeration process utilizes waste heat recovery to efficiently generate cooling, making it a viable thermodynamic cycle [33]. The ejection-based refrigeration technology utilizes an ejector instead of a typical compressor, thus obviating the requirement for electrical power. This modification greatly decreases the amount of electricity used during the cycle, hence improving the total thermodynamic efficiency [34]. In contrast, conventional compressor-driven refrigeration systems employ an expansion valve, where leads to cooling capacity losses under the expansion cycle [35]. The ejector-driven system is recognized for its exceptional efficiency, streamlined operation, and decreased thermodynamic losses [36]. The work conducted by Yang *et al.* [37] found that the coefficient of performance (COP) for a transcritical-CO_2 system and a refrigeration mechanism driven by a dual-stage compressor was roughly 2.2 times greater than that of typical ones. Cogeneration methods that integrate electricity and cooling demand are becoming recognized as efficient, contemporary, and promising technologies [38].

However, in light of the increasing commercialization and globalization of these technologies, it becomes imperative to undertake thorough and all-encompassing comparative evaluations to underscore their benefits. Algharbawi *et al.* [39] investigated a hybrid solar ejector cooling system that was combined with an ORC unit. The shape of the ejector was modified to enhance heat absorption, leading to a significant 80% increase in the coefficient of performance. In a study by Yu *et al.* [40], perfluoropropane was determined to be the most effective working fluid for a combined power cycle and refrigeration system that uses both an ORC system and an ejector-driven system.

This study examines the comprehensive evaluation and improvement of a combined power and cooling system, which generates both electricity and cooling. The system contains a tri-tier waste HRP, incorporating of an ORC system and an ejector-driven refrigeration mechanism. We thoroughly assess and analyze the thermodynamic efficiency, cost-efficiency, and environmental consequences of the suggested procedure. A framework for dual-objective optimization is designed with

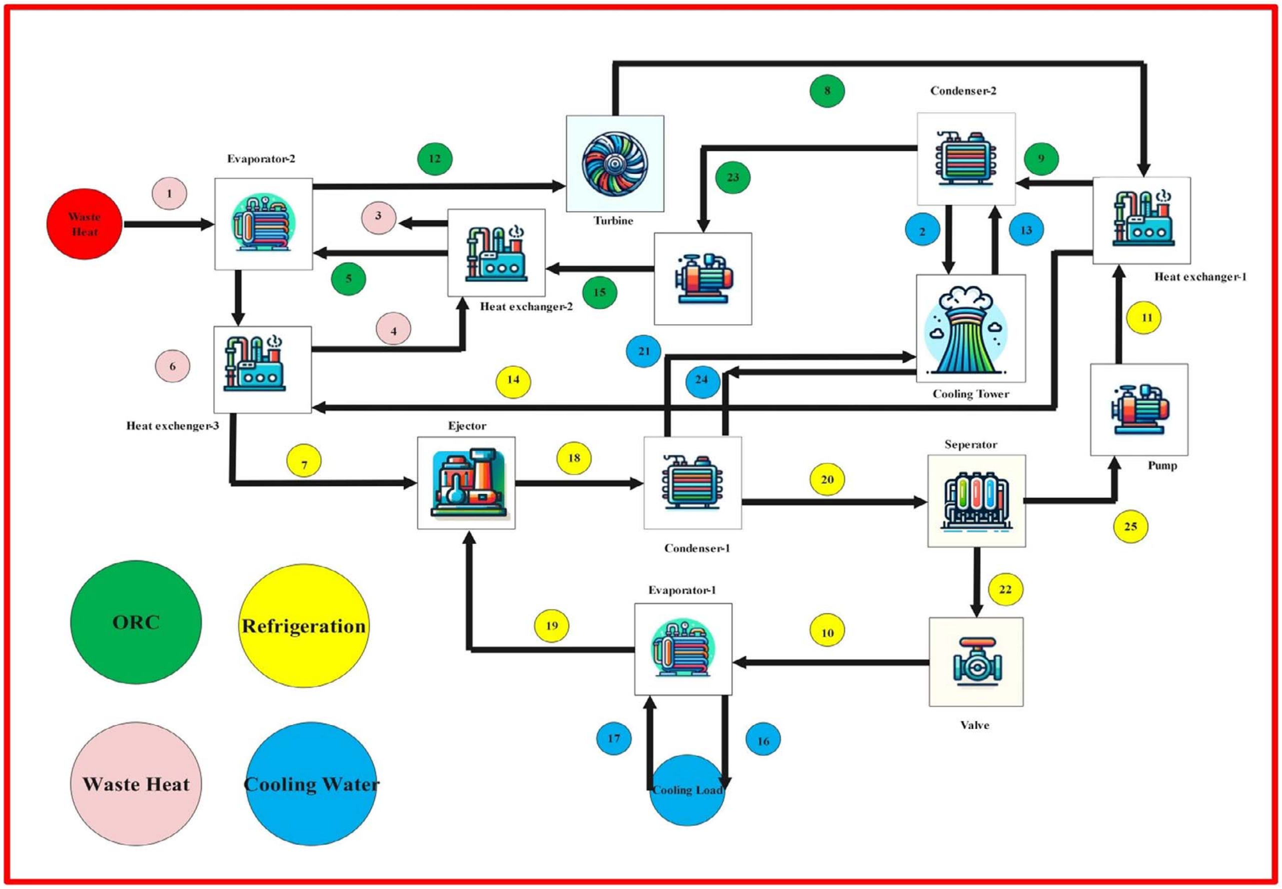

Figure 2. The arrangement and flow diagram of the proposed PCCS.

the aim of minimizing the overall cost while simultaneously maximizing the exergy efficiency. In addition, we analyze the complex behaviors of the power-cooling cogeneration system (PCCS) in comparison to a traditional system that consists of a one-stage recovery-ORC system and a compressor-driven refrigeration approach. The PCCS's behavior is evaluated using environmentally friendly refrigerants that have no-ozone depletion potential and low-global warming potential (GWP). The environmental assessment we do utilizes two metrics: TE-WI and LC-CP. These metrics are widely acknowledged as good tools for evaluating the environmental impact of novel energy systems [41]. To summarize, the suggested procedure presents numerous significant benefits and novel ideas:

i) Improved thermodynamic efficiency and minimized environmental harm achieved by implementing multitiered waste heat recovery systems.
ii) Achieving energy self-sufficiency to power electrical equipment, consequently reducing electricity expenses.
iii) Enhanced cooling efficiency achieved by minimizing energy losses in the refrigeration cycle, resulting in reduced operational expenses.

In the next section, the methodology of the article and mathematical modeling are presented. Section 3 introduces the optimization algorithm. In Section 4, the results are discussed. The final conclusion of the research is stated in Section 5.

2 Methodology

The aim of this study is to perform a comprehensive assessment of a novel waste heat recovery system that produces both power and cooling through a multicriteria evaluation. For the purpose of this analysis, we will consider that there is waste heat available at a temperature of 125°C. The PCCS's performance was assessed using diverse refrigerants, and a wide comparative analysis with traditional cycles mentioned in existing literature is also presented. Figures 1 and 2 demonstrate the arrangement and flow diagram of both the standard and the proposed PCCS systems. In addition, the modeling equations used were based on the Peng–Robinson equation of state, as described in reference [42].

Figure 2 illustrates the proposed PCCS, which has four major elements: a waste HRP, electricity generating system, a refrigeration mechanism, and a cooling capacity generation system. The refrigeration and electricity generation sectors employ a vapor-ejector and an ORC system, respectively. Further, a cooling tower was used in the cooling capacity generation system to return condensed-H_2O to the electricity generating system.

In this design, the conventional use of expansion valves and compressors is substituted with an ejector, which improves the thermodynamic efficiency and minimizes the environmental consequences by utilizing multilevel heat recovery. The effectiveness of the PCCS is also assessed using other refrigerants with low-GWP, specifically R1336-mzz-E, R1216, R1234-yf, R1354-mzy-E, and R1225-zc. The GWP values of various refrigerants are methodically displayed in

Table 1. The global warming potential values of various refrigerants [13, 59].

Refrigerant	Boiling point	Global warming potential	Chemical abstracts service
R1336-mzz-E	7.5 °C	18.00	66711-86-2
R1216	−29.6°C	8.70	116-15-4
R1234-yf	−29.0°C	4.00	754-12-1
R1354-mzy-E	14.36°C	-	791616-87-0
R1225-zc	−21.03°C	4.30	690-27-7

Table 1, with R1336-mzz-E exhibiting the greatest GWP among them.

2.1 Thermodynamic assessment

This study is established under the thermodynamic framework, which utilizes the principles of the first and second laws of thermodynamics. The first law pertains to the balance of mass and energy, while the second law specifically deals with the balance of exergy for each component [20]:

$$\begin{cases} \sum \dot{m}_i = \sum \dot{m}_o \\ \sum \dot{m}_i h_i - \dot{W} = \sum \dot{m}_o h_o - \dot{Q} \\ \sum \dot{E}_i - \dot{E}_D + \dot{E}_q = \sum \dot{E}_o + \dot{E}_w \end{cases} \tag{1}$$

These concepts facilitate the computation of power generation and consumption levels, overall power production, and the overall PCCS's thermodynamic efficiency. In addition, the exergy study of the second law assists in identifying irreversibilities and inefficiencies, offering opportunities for optimizing thermodynamic performance. The exergy rates for each flow at the inlet and outflow are precisely determined according to reference [43]:

$$\dot{E}_j = \dot{m}_j.\left(\left(h - h_0\right) - T_0.(s - s_0)\right) \tag{2}$$

The PCCS utilizes an ejection-based technology instead of the traditional compression refrigeration method in order to improve performance. An essential aspect of this approach is the accurate representation of the ejector, which involves considering the mass entrainment ratio (MER). This ratio relies on specific characteristics, including ejector geometry, operating refrigerant, and cooling demands, which are fundamental for accurately simulating the ejector-driven mechanism. The geometric characteristics of the ejector are specified in the diagrams provided, and the MER values are based on optimized findings of Galindo *et al.* [44]:

$$\text{MER} = \frac{\dot{m}_{\text{se}}}{\dot{m}_{\text{pr}}} \tag{3}$$

The performance of the refrigeration system is evaluated quantitatively using the coefficient of performance, as defined in [29], for the PCCS.

$$\text{COP} = \frac{\dot{Q}_{\text{evaporator}}}{\dot{W}_{\text{pump}} + \dot{Q}_{\text{genrator}}} \tag{4}$$

Table 2. The initial capital cost breakdown for different components [48, 60, 61].

Component	Initial capital expenses
Evaporator	$Z = 30000 + 750.A_{\text{evaporator}}^{0.81}$
Condenser	$Z = 30000 + 750.A_{\text{condenser}}^{0.81}$
Turbine	$Z = 4405.\dot{W}_{\text{turbine}}^{0.89}$
Heat exchanger	$Z = 30000 + 750.A_{\text{heat exchanger}}^{0.81}$

2.2 Financial analysis

The financial sustainability of the PCCS includes both the expenses related to operations and the costs associated with equipment. The total expense is determined by the capital recovery factor (CRF), which is influenced by i_r (interest rate) and $\overline{N}$ (the PCCS's lifespan duration of the project). The element plays a crucial role in calculating the PCCS's overall cost rate [45, 46]. Table 2 presents the initial capital cost breakdown for different components.

$$\begin{cases} \dot{Z}_{\text{tot}} = \sum \frac{Z.\phi}{tt} \times \text{CRF} \\ \text{CRF} = \frac{i_r.(i_r+1)^{\overline{N}}}{(i_r+1)^{\overline{N}}-1} \end{cases} \tag{5}$$

It is important to consider that the initial expenses associated with the valve and ejector can be disregarded due to their minimal impact on the overall expense [13].

2.3 Environmental analysis

The long-term viability of an inventive energy system such as the PCCS depends not only on its thermodynamic and economic efficiency but also on its ecological footprint [47]. Although the system uses refrigerants with low global warming potential and zero ozone depletion potential, there remains a chance of refrigerant escaping while the system is in operation [36]. The environmental assessment in this work employs two primary indicators: TE-WI and LC-CP. These indicators are crucial for quantifying the effects on climate change and carbon emissions [48–50]. TE-WI measures the extent of refrigerant escaping into the atmosphere, is determined using the following calculation:

$$\text{TE}-\text{WI} = \text{GWP}\times\dot{m}_{rf}\times\left((1-\alpha) + \left(n \times Lkg\right)\right)+(n \times E_{\text{tot}} \times \beta) \tag{6}$$

The equation TE-WI is equal to the product of the recovery coefficient alpha and the beta coefficient. The variable (α) represents the rate at which refrigerant is recovered, while (β)

Table 3. The model validation of the ORC system.

Item	Inlet temperature	Inlet pressure	Efficiency thermal	Efficiency exergy
Simulation	523 K	0.1 MPa	0.168	0.518
White *et al*. [61]	523 K	0.1 MPa	0.165	0.526
Error	0.00%	0.00%	1.82%	1.54%

Table 4. The model validation of the ejector system.

Item	Evaporator temperature	Mixed stream pressure	Primary stream pressure	Secondary stream pressure
Simulation	286 K	1.02 MPa	3.77 MPa	0.48 MPa
Galindo *et al*. [45]	286 K	1.00 MPa	3.72 MPa	0.472 MPa
Error	0.00%	2.00%	1.34%	1.69%

represents the carbon intensity factor. The TE-WI value rises proportionally with increased electricity utilization.

Besides that, LC-CP considers the wider environmental impacts of using refrigerants over the entire life cycle of the energy production [51]:

$$\mathrm{LC-CP} = \mathrm{LC-CP}_{\mathrm{direct}} + \mathrm{LC-CP}_{\mathrm{indirect}} \tag{7}$$

Direct emissions include those resulting from refrigerant leakage, servicing operations, end-of-life handling, by-products, production, and transportation. Indirect emissions comprise the transportation of machinery, energy usage throughout the PCCS's duration, and the energy utilized in the manufacturing of refrigerants and equipment construction.

The PCCS's performance is evaluated by considering its exergy efficiency (η_{ex}), overall exergy destroyed ($\dot{E}_{D,\mathrm{tot}}$), and total system cost (C_{tot}). This assessment provides a thorough understanding of the PCCS's operational and environmental effect.

$$\begin{cases} \eta_{\mathrm{ex}} = \frac{\dot{W}_{\mathrm{net}}+\dot{E}_o}{\dot{E}_i+\dot{E}_{\mathrm{W}}+\dot{E}_{\mathrm{Q}}} \\ \dot{E}_{D,\mathrm{tot}} = \sum \dot{E}_{\mathrm{D}} \\ C_{\mathrm{tot}} = C_{\mathrm{capital}} + C_{\mathrm{O\&M}} \end{cases} \tag{8}$$

3 Optimization algorithm

In order to achieve the highest degree of performance for the PCCS, optimization methods are employed to identify the most effective operational parameters [52]. The primary purpose of this study is to optimize the exergy efficiency and minimize the total expenses by employing a bi-objective optimization approach. The genetic algorithm, renowned for its effectiveness in improving energy systems, functions based on ideas derived from evolutionary biology [53]. This strategy emulates the process of natural selection, in which the most adapted individuals thrive, amplifying their traits over successive generations, while the less adapted individuals are progressively removed [54, 55]. The Pareto frontier is used to identify optimal solutions that represent the most favorable tradeoffs between conflicting objectives [56].

The process of selecting the most appropriate solution from the Pareto frontier requires a methodical decision-making procedure. This study utilizes the LINMAP decision-making model to aid in this selection [57]. The optimization variables that are crucial for the system's performance are well described, including their respective boundaries, and are presented in Equation (9):

$$\begin{cases} 62^{\circ}\mathrm{C} \le T_{o,\mathrm{turbine}} \le 125^{\circ}\mathrm{C}\& \quad 6.0^{\circ}\mathrm{C} \le T_{\mathrm{cold}} \le 12.0^{\circ}\mathrm{C} \\ 1.1\ \mathrm{kg/s} \le \dot{m}_{rf} \le 3.3\ \ \mathrm{kg/s}\& \quad 1.1\ \mathrm{MPa} \le P_{i,\mathrm{turbine}} \le 1.8\ \mathrm{MPa} \end{cases} \tag{9}$$

4 Model validation

The validity of the simulation models for the PCCS's primary units—ORC system, refrigeration mechanism, and ejector—was confirmed by comparing them to established literature. The validation of the ORC model was performed using process conditions documented in the literature [58], and a comparative analysis is shown in Table 3.

Furthermore, the refrigeration mechanism's model, which depends on the ejection process, was verified by comparing it to reported process conditions [44]. The pressure measurements for mixed, primary, and secondary flows were consistent with the values reported in the literature, hence supporting the accuracy of the model (refer to Table 4). Additional validation was conducted on the ejector's numerical modeling created in Aspen by comparing it with computational fluid dynamics simulation results. The little inconsistencies discovered emphasize the accuracy of the model, indicating that the simulations are reliable for evaluating the performance of the proposed PCCS. This validation highlights the strength and reliability of the models and simulation technique in accurately representing the dynamics of the PCCS.

5 Results and discussion

When comparing the PCCS and the reference system (RS), notable distinctions arise primarily as a result of their refrigeration methods—specifically, the PCCS utilizes ejection-based refrigeration whereas the reference system employs compression-based refrigeration. In addition, the RS employs a one-stage heat exchange to recover wasted thermal energy, while the PCCS utilizes a more intricate three-level cycle. The procedure of selecting the most efficient refrigerant includes assessing the ORC system's efficiency and the refrigeration system's COP using different refrigerants.

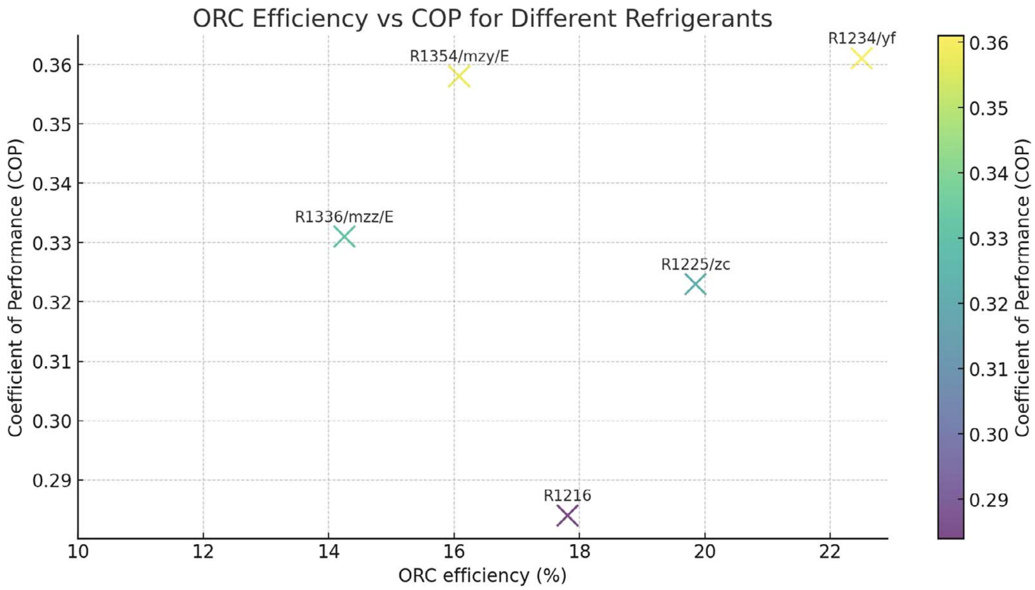

Figure 3. Criteria for choosing the most suitable refrigerant.

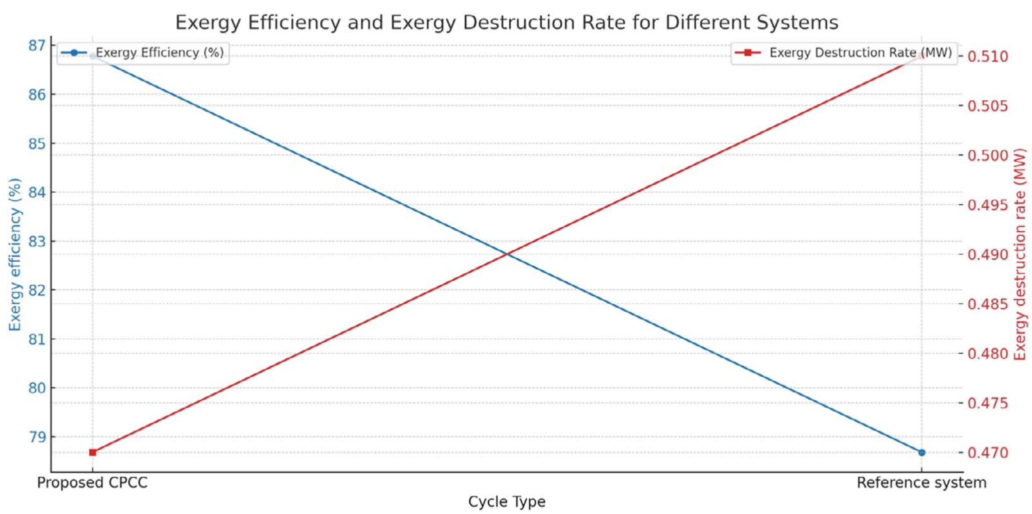

Figure 4. Analysis and comparison of exergy behaviors of the PCCS and RS.

Figure 3 illustrates that R1234-yf and R1336-mzz-E fluids have the maximum and lowest ORC efficiencies, respectively. Similarly, R1216 and R1234-yf exhibit the minimum and maximum COP values, respectively. Therefore, R1234-yf was recognized as the most appropriate fluid, providing superior performance for both the ORC and refrigeration processes.

An exergy study was conducted to evaluate the efficiency and destructiveness of several components in the PCCS. The PCCS attained an exergetic efficiency of around 85.1%, accompanied by an overall destructed exergy of approximately 460.6 kW. The PCCS's exergetic performance, as shown in Fig. 4, demonstrates notable enhancements compared to the RS. More precisely, the PCCS's exergetic efficiency increased by around 10%, while its destructed exergy declined by around 7.2%. The PCCS's improved tri-stage heat recovery is primarily responsible for this improvement, as it effectively reduces process losses, decreases power consumption, and thus enhances thermodynamic behavior.

Figure 5 provides a detailed breakdown of the exergy destruction contributions of different components in both systems. The heat exchangers, which consist of condensers and evaporators, play a significant role in the loss of exergy in both systems. According to Fig. 5, the evaporators in both systems, evaporator-1 and evaporator-2, contribute to ∼42.1% and 51.2% of the overall exergy destruction, respectively. The turbines in PCCS and RS dissipate roughly the identical amount of exergy (5.6% and 5.4%) due to their operation under comparable thermodynamic conditions. The destructed exergy in the entire refrigeration system of the PCCS was significantly lowered by 24.9% compared to the RS. The reduction results in a 6.8% decrease in the proportion of exergy destruction in the PCCS's refrigeration process compared to the reference. This highlights the efficiency improvements achieved by replacing compressors with ejectors in the cogeneration plant's architecture.

Using a tri-stage HRP and replacing the ejection process with a compressor reduces power usage and improves economic efficiency, as stated earlier. A comprehensive economic evaluation of the PCCS and the RS indicates that the PCCS has an annual overall expense of $\$263.62 \times 10^3$. The majority

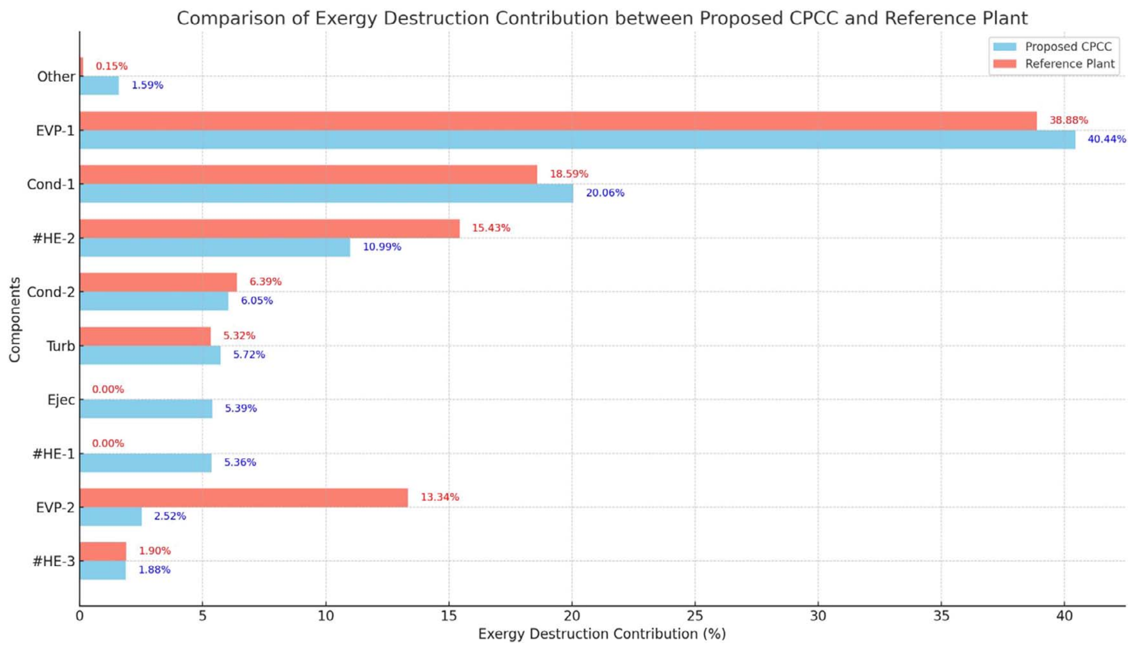

Figure 5. A detailed breakdown of the exergy destruction contributions of different components in both systems.

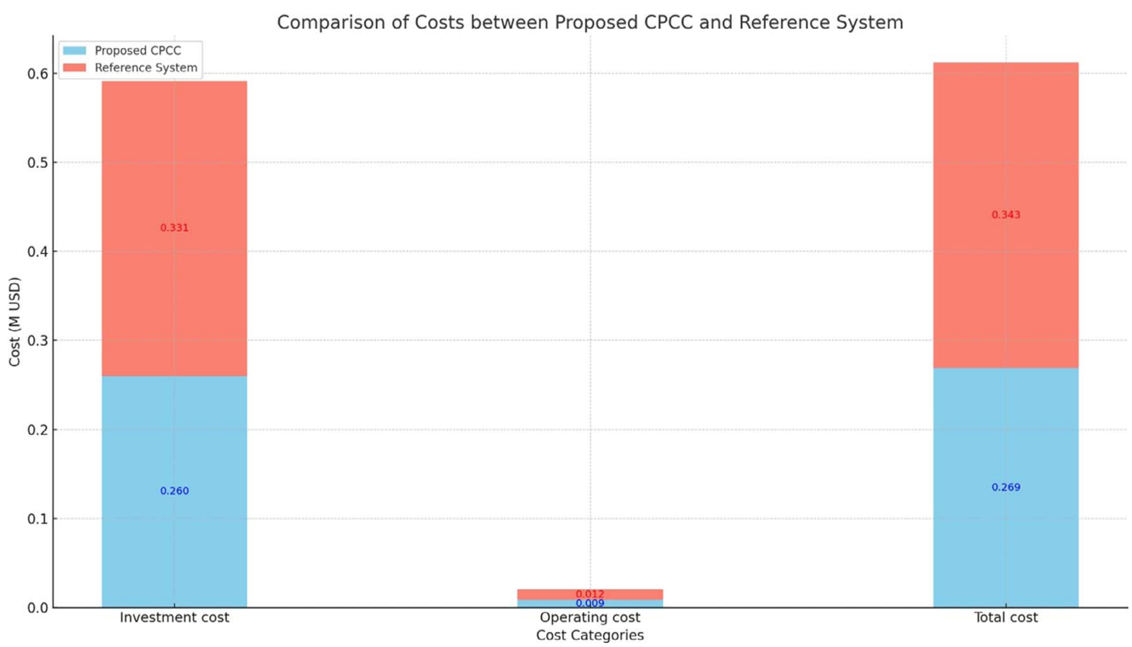

Figure 6. Analysis and comparison of financial behaviors of the PCCS and RS.

of this cost, approximately 95%, is due to capital charges, while the remaining 5% is attributed to operational costs. The graph in Fig. 6 shows that the PCCS could potentially reduce its annual total costs by around 21% compared to the RS. This reduction is mainly due to lower losses and improved waste heat recovery, resulting in a decrease in equipment investment costs of ∼20.9%. In addition, the PCCS's yearly operational expenses are ∼24.6% less than those of the comparison system.

An analysis of the initial capital contributions of each component, as shown in Fig. 7, indicates that the compressor accounts for more than 31.3% of the investment in the reference system, whereas the ejector represents less than 0.9% of the entire capital expenses in the PCCS. This change results in a drop of ∼4.4% in condenser investment expenses in the PCCS compared to the RS. This is due to the lower usage of cooled water and decreased thermal responsibilities. Although there have been improvements, the investment costs for turbines are still comparable across both systems. However, the three-level heat exchange requires a considerably higher investment than the one-stage system. In the end, the PCCS's overall investment cost is cheaper than that of the reference system mainly because of the expensive compression procedure.

The environmental evaluation of the PCCS takes into accounts its LC-CP and TE-WI indicators to determine its environmental friendliness and sustainability. The environmental evaluations, utilizing TE-WI, conduct a comparative

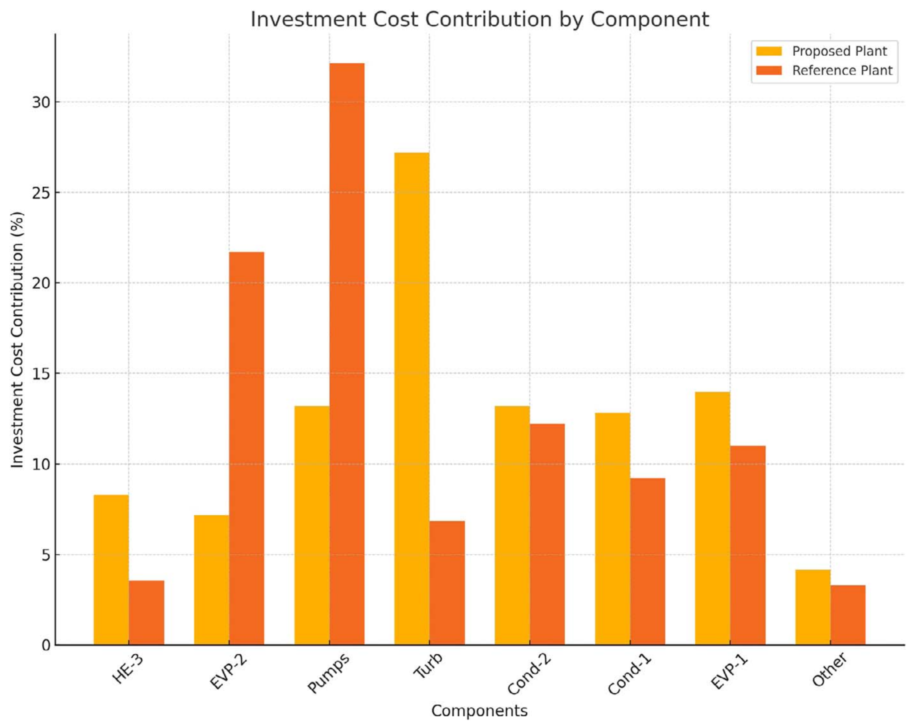

Figure 7. Analysis and comparison of financial behaviors of the PCCS and RS: capital expenses distributions.

assessment between the PCCS and the RS, subject to identical conditions, employing R1234-yf refrigerant. The results, depicted in Fig. 8(A, B), demonstrate a significant decrease in CO_2 emissions in the PCCS, mostly due to the substitution of the compressor with an ejector. Figure 8(A) provides a comprehensive analysis that reveals the compressor is responsible for more than 96% of the CO_2 equivalent emissions in the reference system. However, the PCCS effectively mitigates this impact. In addition, improving the efficiency of electrical energy-generating equipment not only boosts energy production but also decreases electricity usage within the system, resulting in reduced CO_2 emissions. The enhancement is measured in Fig. 8(A), which estimates that almost 11.41×10^6 kg of CO_2 might be reduced each year by implementing an ejector, showcasing the PCCS's exceptional environmental efficiency. Finally, the environmental study based on LC-CP, as shown in Fig. 9, reveals that although the PCCS and the RS have similar total amounts of CO_2 emissions, the PCCS emits a substantially lower proportion of CO_2 directly (0.078% vs. 1.68%).

The difference in the amount of CO_2 emitted by the two systems is due to the replacement of a compressor with an ejector, which remarkably declines the amount of electric power used. As explained in the TE-WI-based environmental evaluation, this adjustment allows the PCCS to decline the emitted CO_2 relative to the RS. The environmental study based on LC-CP provides additional clarification that the reference system's indirect CO_2 emissions make up more than 97.7% of its total emissions. On the other hand, the PCCS not only prevents indirect CO_2 emissions but also significantly reduces the overall CO_2 output. As a result, the PCCS provides more environmental advantages compared to the conventional cycle. The decrease in indirect carbon dioxide emissions in the PCSS can be ascribed to its production of electrical energy surpassing its usage. The findings of the LC-CP highlight the advantages of reducing the utilization of power-intensive components, which leads to a decrease in overall electricity consumption and enhances environmental performance.

Figure 10 demonstrates the influence of alterations in turbine pressure and temperature on the energy efficiency of the ORC system. Increasing the pressure at which the turbine receives air, while keeping the pressure at which the air leaves the turbine constant, increases the difference in pressure across the turbine. This improves the thermodynamic characteristics of the air entering the turbine, resulting in higher output of work and electrical production from the turbine. Consequently, raising the pressure at the turbine's entrance or lowering the temperature at the exit enhances electricity generation, potentially enhancing the thermal efficiency of the ORC, assuming the set evaporator's heat duty remains constant.

5.1 Findings of an optimization analysis

This part presents the findings of an optimization analysis that used a genetic algorithm to maximize exergy efficiency and minimize overall expenses. The optimization analysis shows that the exergy efficiency of the PCCS may be improved by 1.98%, while also reducing overall expenses by ~4.2%. To get these optimal outcomes, it is necessary to increase the flow rate of the refrigerant by 9%, raise the cold temperature by 32.9%, and increase the turbine inlet pressure by 28.3%. At the same time, the turbine's exit temperature should be declined by 6.9 K. These modifications are crucial in maximizing the efficiency of the PCCS (see Table 5).

5.2 Comparison of results

The power expenses for the planned PCCS are significantly decreased due to its ability to generate enough electricity to meet the needs of the electric equipment. Furthermore,

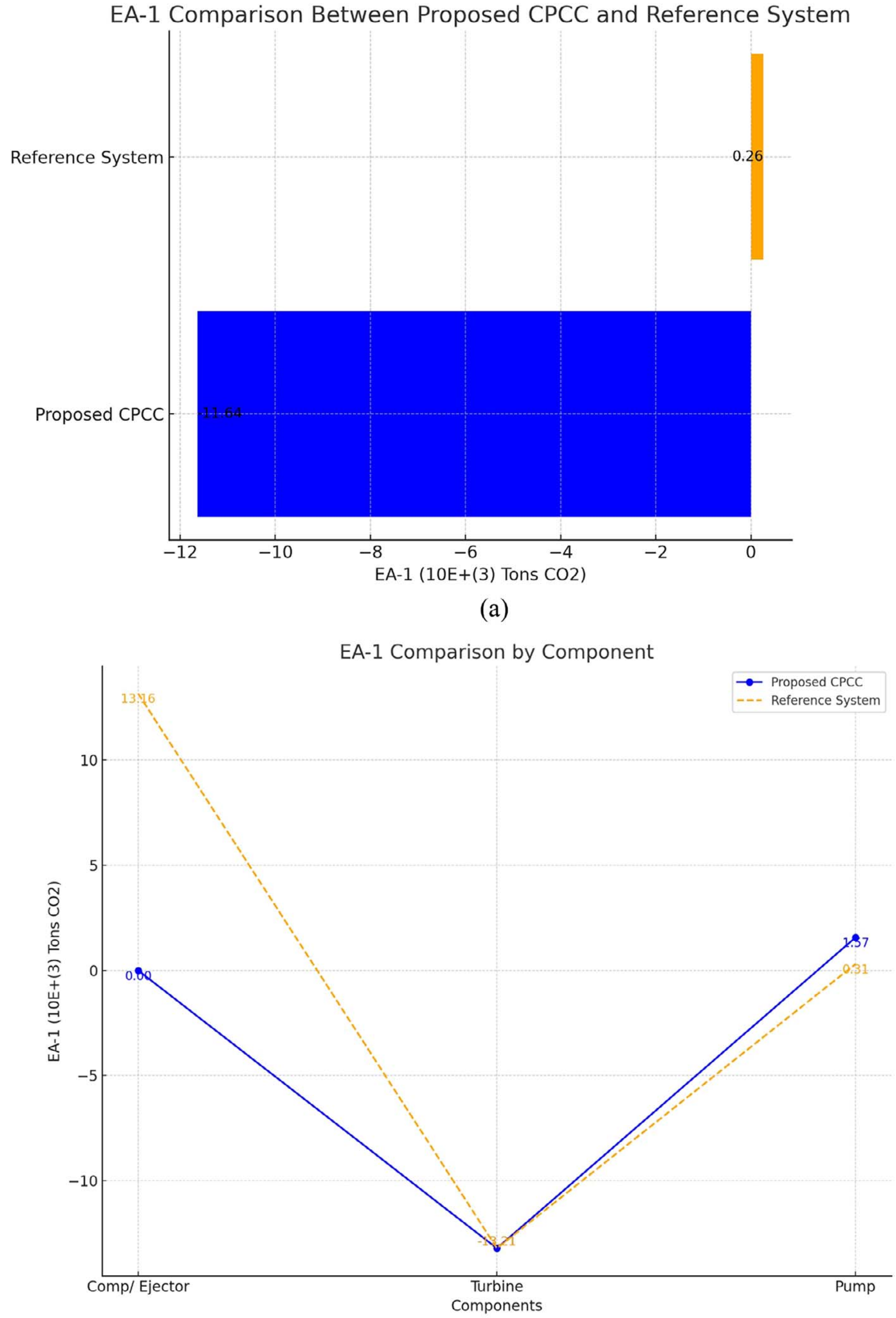

Figure 8. Analysis and comparison of environmental behaviors of the PCCS and RS (under TE-WI).

there has been a significant enhancement in the cooling yield, resulting from the decrease in energy wastage throughout the refrigeration process. This, in turn, leads to lower operating expenses. Based on the information provided in Table 6 and supported by a review of relevant literature, it is clear that the PCCS offers a distinct advantage in terms of thermodynamic efficiency, cost-effectiveness, and environmental impact when compared to other similar processes.

Table 5. Findings of an optimization analysis.

Variable	Not optimized	Optimized
$T_{o,\text{turbine}}$	373.1 K	366.2 K
T_{cold}	280.9 K	373.3 K
$\dot{m}_{rf}$	9100 kg/h	9918 kg/s
$P_{i,\text{turbine}}$	1.58 MPa	2.03 MPa
Total expenses	263.62×10^3 \$	252.54×10^3 \$
Exergetic efficiency	85.1%	86.8%

6 Conclusions

An extensive evaluation and improvement of a new combined power and cooling system called the PCCS. The investigated method utilized a waste heat recovery system consisting of three levels, which was integrated with an ORC system and an ejector-driven refrigeration system. An exhaustive assessment

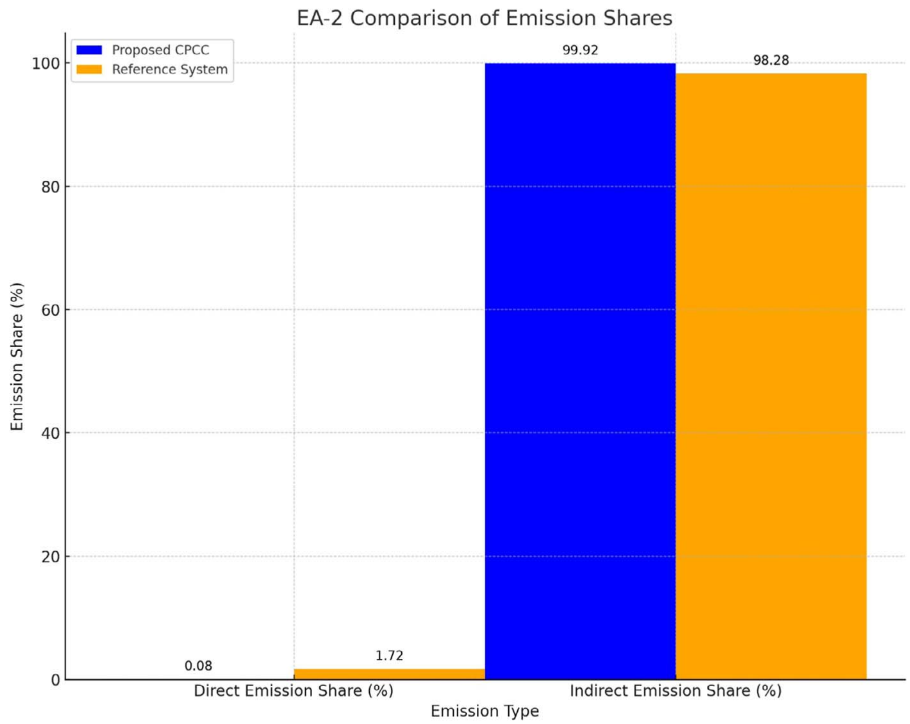

Figure 9. Analysis and comparison of environmental behaviors of the PCCS and RS (under LC-CP).

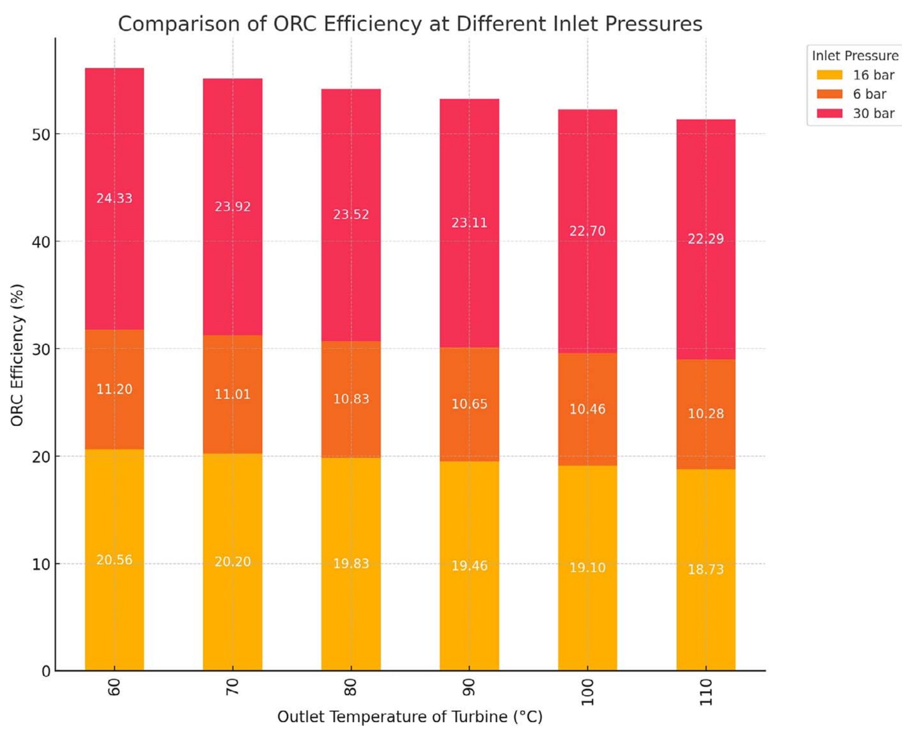

Figure 10. The influence of alterations in turbine pressure and temperature on the energy efficiency of the ORC system.

and analysis were conducted to analyze and explain the thermodynamic efficiency, economic viability, and environmental consequences of the proposed system. A dual-function optimization technique was utilized to decrease the overall expenses while simultaneously maximizing the exergy efficiency. In addition, the PCCS's performance was compared to a RS that consisted of a one-stage HRP-ORC system and a compressor-driven refrigeration approach. The PCCS's performance was evaluated by employing different refrigerants with low global warming potential and zero ozone depletion potential.

The environmental evaluations utilized two main indicators: TE-WI and LC-CP. The suggested PCCS demonstrated an exergetic efficiency of around 85.1%, which corresponds to a 10.1% enhancement compared to the RS. The PCCS's exergetic efficiency may be improved by an additional 1.98% under ideal circumstances, while also reducing the overall cost by around 4.2%. The refrigerant R1234-yf was determined to

Table 6. Comparison of results [62–66]

Reference	System configuration	Refrigerant	COP	Efficiency (energy/exergy)
This work	Tri-stage HRP, ejector-driven refrigeration system, and ORC system	R1234-yf	0.353	Exergy: 85.1%
[62]	Ejector-driven transcritical refrigeration system and ORC system	-	2.05	Exergy: 28.8%
[63]	Ejector-driven refrigeration system and ORC system	R134a-R141b	1.12	Energy: 4.2%
[64]	Ejector-driven refrigeration system and ORC system	-	0.33	Thermal: 26.2%
[65]	Compressor-driven refrigeration system and ORC system	R1234ze(Z)-R141b	4.6	Exergy: 33%
[66]	Compressor-driven refrigeration system and ORC system	-	0.425	Exergy: 31.1%

be the most efficient option, resulting in optimal performance for both systems. The PCCS's annual total cost estimate was calculated to be $\$263.62 \times 10^3$.

By removing the compressor and making improvements to energy and thermal demands, HRP yield, and electrical self-sufficiency, the PCCS achieved a 21.16% reduction in investment costs compared to the RS. The utilization of an ejector had the potential to reduce about 11.41×10^6 kg of CO_2 emissions each year. This highlights the PCCS's exceptional environmental performance, which is achieved by its low electricity consumption and efficient design.

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Author contributions

Tao Hai (Data curation [equal], Software [equal], Writing—original draft [equal]), Ihab Omar (Data curation [equal], Supervision [equal], Writing—review and editing [equal]), Mohamed El-Sharkawy (Investigation [equal], Resources [equal], Validation [equal]), Murizah Kassim (Investigation [equal], Methodology [equal], Validation [equal], Writing—review and editing [equal]), Husam Rajab (Data curation [equal], Formal analysis [equal], Resources [equal], Writing—review and editing [equal]), Esraa Said (Formal analysis [equal], Software [equal], Writing—original draft [equal]), Abbas Abdul Hussein (Formal analysis [equal], Resources [equal], Software [equal], Writing—review and editing [equal]), Wesam Hassan Alhaidry (Investigation [equal], Validation [equal], Writing—review and editing [equal]), Ameer Idan (Methodology [equal], Software [equal], Writing—original draft [equal]), and Mehrsam Alizadeh (Formal analysis [equal], Methodology [equal], Project administration [equal], Writing—original draft [equal]).

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References

1. Yanto DTP, Akhmadeev R, Hamad HS. *et al.* Development and investigation of a pollutants emission reduction process from a coal-gasification power plant integrated with fuel cell and solar energy. *Int J Low-Carbon Technol* 2023;**18**:1120–33. https://doi.org/10.1093/ijlct/ctad093.
2. Demir N, Shadjou AM, Abdulameer MK. *et al.* A low-carbon multigeneration system based on a solar collector unit, a bio waste gasification process and a water harvesting unit. *Int J Low-Carbon Technol* 2024;**19**:1204–14. https://doi.org/10.1093/ijlct/ctae045.
3. Nejati MG, Kamali SE, Zoqi MJ. *et al.* Life cycle analysis (cost and environmental) of different renewable natural gas from waste procedures based on a multivariate decision-making approach: a comprehensive comparative analysis. *Int J Low-Carbon Technol* 2024;**19**:339–50. https://doi.org/10.1093/ijlct/ctae008.
4. Zhang D, Ma T, Fooladi H. Evaluation of carbon dioxide emission reduction in an energy cycle based on biomass gasification and molten carbonate fuel cell; Exergoeconomic and environmental analysis. *Int J Low-Carbon Technol* 2023;**18**:283–94. https://doi.org/10.1093/ijlct/ctad006.
5. Wang H, Song M, Taghavi M. Comprehensive analysis and optimization of a low-carbon multi-generation system driven by municipal solid waste and solar thermal energy integrated with a microbial fuel cell. *Int J Low-Carbon Technol* 2024;**19**:455–67. https://doi.org/10.1093/ijlct/ctae006.
6. Zhang X, Li H, Taghavi M. Exergoeconomic evaluation of a new carbon-free hydrogen and freshwater production system based on biomass gasification process. *Int J Low-Carbon Technol* 2023;**18**:589–99. https://doi.org/10.1093/ijlct/ctad012.
7. Fang Q, Li S, Fooladi H. Parametric layout and performance examination of a novel energy process based on the renewable energies and thermodynamic cycles. *Int J Low-Carbon Technol* 2022;**17**:1000–11. https://doi.org/10.1093/ijlct/ctac082.
8. DJ, Al-Rubaye AH, Kolsi L. *et al.* A fuel gas waste heat recovery-based multigeneration plant integrated with a LNG cold energy process, a water desalination unit, and a CO2 separation process. *Heliyon* 2024;**10**:e26692. https://doi.org/10.1016/j.heliyon.2024.e26692.
9. Ayadi B, Jasim DJ, Anqi AE. *et al.* Multi-criteria/comparative analysis and multi-objective optimization of a hybrid solar/geothermal source system integrated with a Carnot battery. *Case Stud Therm Eng* 2024;**54**:104031. https://doi.org/10.1016/j.csite.2024.104031.
10. Lu Z, Wang J, Shahidehpour M. *et al.* Cooperative operation of distributed energy resources and thermal power plant with a carbon-capture-utilization-and-storage system. *IEEE Trans Power Syst* 2024;**39**:1850–66. https://doi.org/10.1109/TPWRS.2023.3253809.
11. Ghasemi A, Nikafshan Rad H, Akrami M. *et al.* Exergoeconomic and exergoenvironmental analyzes of a new biomass/solar-driven multigeneration energy system: an effort to maximum utilization of the waste heat of gasification process. *Therm Sci Eng Prog* 2024;**48**:102407. https://doi.org/10.1016/j.tsep.2024.102407.
12. Ghasemi A, Rad HN, Izadyar N. *et al.* Optimizing industrial energy: an eco-efficient system for integrated power, oxygen, and methanol production using coke plant waste heat and electrolysis. *Energy Convers Manag: X* 2024;**22**:100571. https://doi.org/10.1016/j.ecmx.2024.100571.
13. Rad HN, Ghasemi A, Marefati M. Cost and environmental analysis and optimization of a new and green three-level waste heat recovery-based cogeneration cycle: a comparative study. *Heliyon* 2024;**10**:e29087. https://doi.org/10.1016/j.heliyon.2024.e29087.
14. Ghasemi A, Rad HN, Golizadeh F. A low-carbon polygeneration system based on a waste heat recovery system, a LNG cold energy process, and a CO2 liquefaction and separation unit. *Int J Low-Carbon Technol* 2024;**19**:654–66. https://doi.org/10.1093/ijlct/ctad146.
15. Rad HN, Ghasemi A, Akrami M. *et al.* Evaluating energy, exergy and economic aspects of a CO 2-free Kalina cycle cogeneration

system with various solar collectors. *Int J Low-Carbon Technol* 2024;**19**:892–907. https://doi.org/10.1093/ijlct/ctae035.

16. Bai L, Asadollahzadeh M, Chauhan BS. *et al.* A new biomass-natural gas dual fuel hybrid cooling and power process integrated with waste heat recovery process: exergoenvironmental and exergoeconomic assessments. *Process Saf Environ Prot* 2023;**176**: 867–88. https://doi.org/10.1016/j.psep.2023.06.037.
17. Yi S, Lin H, Abed AM. *et al.* Sustainability and exergoeconomic assessments of a new MSW-to-energy incineration multi-generation process integrated with the concentrating solar collector, alkaline electrolyzer, and a reverse osmosis unit. *Sustain Cities Soc* 2023;**91**:104412. https://doi.org/10.1016/j.scs.2023.104412.
18. Zhang Z, Altalbawy FMA, Al-Bahrani M. *et al.* Regret-based multi-objective optimization of carbon capture facility in CHP-based microgrid with carbon dioxide cycling. *J Clean Prod* 2023;**384**:135632. https://doi.org/10.1016/j.jclepro.2022.135632.
19. Mehrpooya M, Hosseini SS. A novel integration of plasma gasification melting process with direct carbon fuel cell. *Int J Hydrog Energy* 2024;**50**:388–401. https://doi.org/10.1016/j.ijhydene.2023.08.183.
20. Rezaie K, Mehrpooya M, Delpisheh M. *et al.* Solar-driven chemisorption cogeneration system integrated with thermal energy storage. *J Energy Storage* 2024;**76**:109705. https://doi.org/10.1016/j.est.2023.109705.
21. Mahmoud M, Naher S, Ramadan M. *et al.* Investigation of a ground-cooled organic Rankine cycle for waste heat recovery. *Int J Thermofluids* 2023;**18**:100348. https://doi.org/10.1016/j.ijft.2023.100348.
22. Xiao D, Liu M, Li L. *et al.* Model for economic evaluation of closed-loop geothermal systems based on net present value. *Appl Therm Eng* 2023;**231**:121008. https://doi.org/10.1016/j.applthermaleng.2023.121008.
23. Zhu C, Wang M, Guo M. *et al.* Optimizing solar-driven multi-generation systems: a cascade heat recovery approach for power, cooling, and freshwater production. *Appl Therm Eng* 2024;**240**: 122214. https://doi.org/10.1016/j.applthermaleng.2023.122214.
24. Zhu C, Wang M, Guo M. *et al.* An innovative process design and multi-criteria study/optimization of a biomass digestion-supercritical carbon dioxide scenario toward boosting a geothermal-driven cogeneration system for power and heat. *Energy* 2024;**292**:130408. https://doi.org/10.1016/j.energy.2024.130408.
25. Arslan AE, Arslan O, Genc MS. Hybrid modeling for the multi-criteria decision making of energy systems: an application for geothermal district heating system. *Energy* 2024;**286**:129590. https://doi.org/10.1016/j.energy.2023.129590.
26. Arslan O, Arslan AE. Multi-criteria optimization of a new geothermal driven integrated power and hydrogen production system via a new index: economic sustainability (EcoSI). *Fuel* 2024;**358**:130160. https://doi.org/10.1016/j.fuel.2023.130160.
27. Reshaeel M, Javed A, Jamil A. *et al.* Multiparametric optimization of a reheated organic Rankine cycle for waste heat recovery based repowering of a degraded combined cycle gas turbine power plant. *Energy Convers Manag* 2022;**254**:115237. https://doi.org/10.1016/j.enconman.2022.115237.
28. Lan S, Li Q, Guo X. *et al.* Fuel saving potential analysis of bifunctional vehicular waste heat recovery system using thermoelectric generator and organic Rankine cycle. *Energy* 2023;**263**:125717. https://doi.org/10.1016/j.energy.2022.125717.
29. Musharavati F, Khanmohammadi S, Tariq R. Comparative exergy, multi-objective optimization, and extended environmental assessment of geothermal combined power and refrigeration systems. *Process Saf Environ Prot* 2021;**156**:438–56. https://doi.org/10.1016/j.psep.2021.10.018.
30. Saedi A, Jahangiri A, Ameri M. *et al.* Feasibility study and 3E analysis of blowdown heat recovery in a combined cycle power plant for utilization in organic Rankine cycle and greenhouse heating. *Energy* 2022;**260**:125065. https://doi.org/10.1016/j.energy.2022.125065.
31. Huang W, Marefati M. Development, exergoeconomic assessment and optimization of a novel municipal solid waste-incineration and solar thermal energy based integrated power plant: an effort to improve the performance of the power plant. *Process Saf Environ Prot* 2023;**172**:562–78. https://doi.org/10.1016/j.psep.2023.02.016.
32. Ma T, Lan L, Marefati M. Assessment of a new multigeneration system based on geothermal plant and a linear Fresnel reflector-based solar unit: an effort to improve performance. *Process Saf Environ Prot* 2023;**171**:896–913. https://doi.org/10.1016/j.psep.2023.01.071.
33. Cao Y, Zoghi M, Habibi H. *et al.* Waste heat recovery of a combined solid oxide fuel cell - gas turbine system for multi-generation purposes. *Appl Therm Eng* 2021;**198**:117463. https://doi.org/10.1016/j.applthermaleng.2021.117463.
34. Bai T, Shi R, Yu J. Thermodynamic performance evaluation of an ejector-enhanced transcritical CO2 parallel compression refrigeration cycle. *Int J Refrig* 2023;**149**:49–61. https://doi.org/10.1016/j.ijrefrig.2022.12.014.
35. Li H, Cao F, Bu X. *et al.* Performance characteristics of R1234yf ejector-expansion refrigeration cycle. *Appl Energy* 2014;**121**: 96–103. https://doi.org/10.1016/j.apenergy.2014.01.079.
36. Hai T, Ali MA, Dhahad HA. *et al.* A novel bi-evaporator cooling system via integration of absorption refrigeration cycle for waste energy recovery from an ejector-expansion trans-critical CO2 (EETRCC) cycle: proposal and optimization with environmental considerations. *Sustain Energy Technol Assess* 2023;**57**:103118. https://doi.org/10.1016/j.seta.2023.103118.
37. Yang D, Zhu J, Wang N. *et al.* Experimental study on the performance of trans-critical CO2 two-stage compression refrigeration system with and without an ejector at low temperatures. *Int J Refrig* 2022;**154**:231–42. https://doi.org/10.1016/j.ijrefrig.2022.11.019.
38. Ghamari V, Hajabdollahi H, Dehaj MS. Comparison of gas turbine and diesel engine in optimal design of CCHP plant integrated with multi-effect and reverse osmosis desalinations. *Process Saf Environ Prot* 2021;**154**:505–18. https://doi.org/10.1016/j.psep.2021.07.030.
39. Tashtoush B, Algharbawi ABR. Parametric study of a novel hybrid solar variable geometry ejector cooling with organic Rankine cycles. *Energy Convers Manag* 2019;**198**:111910. https://doi.org/10.1016/j.enconman.2019.111910.
40. Yu W, Wang H, Ge Z. Comprehensive analysis of a novel power and cooling cogeneration system based on organic Rankine cycle and ejector refrigeration cycle. *Energy Convers Manag* 2021;**232**:113898. https://doi.org/10.1016/j.enconman.2021.113898.
41. Mota-Babiloni A, Barbosa JR Jr, Makhnatch P. *et al.* Assessment of the utilization of equivalent warming impact metrics in refrigeration, air conditioning and heat pump systems. *Renew Sust Energ Rev* 2020;**129**:109929. https://doi.org/10.1016/j.rser.2020.109929.
42. Kim J-K, Son H, Yun S. Heat integration of power-to-heat technologies: case studies on heat recovery systems subject to electrified heating. *J Clean Prod* 2022;**331**:130002. https://doi.org/10.1016/j.jclepro.2021.130002.
43. Mousavi SA, Mehrpooya M, Delpisheh M. Development and life cycle assessment of a novel solar-based cogeneration configuration comprised of diffusion-absorption refrigeration and organic Rankine cycle in remote areas. *Process Saf Environ Prot* 2022;**159**:1019–38. https://doi.org/10.1016/j.psep.2022.01.067.
44. Galindo J, Dolz V, García-Cuevas LM. *et al.* Numerical evaluation of a solar-assisted jet-ejector refrigeration system: screening of environmentally friendly refrigerants. *Energy Convers Manag* 2020;**210**:112681. https://doi.org/10.1016/j.enconman.2020.112681.

45. Allahyarzadeh-Bidgoli A, Mehrpooya M, Yanagihara JI. Geometric optimization of thermo-hydraulic performance of multistream plate fin heat exchangers in two-stage condensation cycle: thermodynamic and operating cost analyses. *Process Saf Environ Prot* 2022;**162**:631–48. https://doi.org/10.1016/j.psep.2022.03.088.
46. Bahnamiri FK, Khalili M, Pakzad P. *et al.* Techno-economic assessment of a novel power-to-liquid system for synthesis of formic acid and ammonia, based on CO2 electroreduction and alkaline water electrolysis cells. *Renew Energy* 2022;**187**:1224–40. https://doi.org/10.1016/j.renene.2022.01.085.
47. Chen M, Cheng W, Zhao L. *et al.* Circulating oil-immersed battery thermal management system for cylindrical lithium-ion battery module. *Process Saf Environ Prot* 2024;**186**:200–12. https://doi.org/10.1016/j.psep.2024.04.015.
48. Fang Z, Shang L, Pan Z. *et al.* Exergoeconomic analysis and optimization of a combined cooling, heating and power system based on organic Rankine and Kalina cycles using liquified natural gas cold energy. *Energy Convers Manag* 2021;**238**:114148. https://doi.org/10.1016/j.enconman.2021.114148.
49. Jing D, Mohammed AA, Kadi A. *et al.* Wastewater treatment to improve energy and water nexus with hydrogen fuel production option: techno-economic and process analysis. *Process Saf Environ Prot* 2023;**172**:437–50. https://doi.org/10.1016/j.psep.2023.02.032.
50. Tian L, Zhang Z, Salah B. *et al.* Multi-variable assessment/optimization of a new two-source multigeneration system integrated with a solid oxide fuel cell. *Process Saf Environ Prot* 2023;**179**: 754–73. https://doi.org/10.1016/j.psep.2023.08.003.
51. Montazerinejad H, Ahmadi P, Montazerinejad Z. Advanced exergy, exergo-economic and exrgo-environmental analyses of a solar based trigeneration energy system. *Appl Therm Eng* 2019; **152**:666–85. https://doi.org/10.1016/j.applthermaleng.2019.01.040.
52. Mousavi SA, Toopshekan A, Mehrpooya M. *et al.* Comprehensive exergetic performance assessment and techno-financial optimization of off-grid hybrid renewable configurations with various dispatch strategies and solar tracking systems. *Renew Energy* 2023;**210**:40–63. https://doi.org/10.1016/j.renene.2023.04.018.
53. Wang C, Wang Y, Wang K. *et al.* An improved hybrid algorithm based on biogeography/complex and metropolis for many-objective optimization. *Math Probl Eng* 2017;**2017**:1–14. https://doi.org/10.1155/2017/2462891.
54. Cao J, Gao J, Nikafshan Rad H. *et al.* A novel systematic and evolved approach based on XGBoost-firefly algorithm to predict Young's modulus and unconfined compressive strength of rock. *Eng Comput* 2022;**38**:3829–45. https://doi.org/10.1007/s00366-020-01241-2.
55. Cao Y, Dhahad H, Alsharif S. *et al.* Predication of the sensitivity of a novel daily triple-periodic solar-based electricity/hydrogen cogeneration system with storage units: dual parametric analysis and NSGA-II optimization. *Renew Energy* 2022;**192**:340–60. https://doi.org/10.1016/j.renene.2022.04.067.
56. Suriapparao DV, Gupta AA, Nagababu G. *et al.* Production of aromatic hydrocarbons from microwave-assisted pyrolysis of municipal solid waste (MSW). *Process Saf Environ Prot* 2022;**159**: 382–92. https://doi.org/10.1016/j.psep.2022.01.014.
57. Li R, Xu D, Tian H. *et al.* Multi-objective study and optimization of a solar-boosted geothermal flash cycle integrated into an innovative combined power and desalinated water production process: application of a case study. *Energy* 2023;**282**:128706. https://doi.org/10.1016/j.energy.2023.128706.
58. White MT, Read MG, Sayma AI. Making the case for cascaded organic Rankine cycles for waste-heat recovery. *Energy* 2020;**211**:118912. https://doi.org/10.1016/j.energy.2020.118912.
59. Li C, Wang L, Chen C. *et al.* Exergy, economic, and climate performance evaluation of an efficient clean cogeneration system driven by low-temperature waste-heat. *J Clean Prod* 2023;**403**:136773. https://doi.org/10.1016/j.jclepro.2023.136773.
60. Fang Z, Pan Z, Ma G. *et al.* Exergoeconomic, exergoenvironmental analysis and multi-objective optimization of a novel combined cooling, heating and power system for liquefied natural gas cold energy recovery. *Energy* 2023;**269**:126752. https://doi.org/10.1016/j.energy.2023.126752.
61. Li T, Gao H, Gao X. Synergetic mechanism of organic Rankine flash cycle with ejector for geothermal power generation enhancement. *J Clean Prod* 2022;**375**:134174. https://doi.org/10.1016/j.jclepro.2022.134174.
62. Nemati A, Mohseni R, Yari M. A comprehensive comparison between CO2 and ethane as a refrigerant in a two-stage ejector-expansion transcritical refrigeration cycle integrated with an organic Rankine cycle (ORC). *J Supercrit Fluids* 2018;**133**: 494–502. https://doi.org/10.1016/j.supflu.2017.11.024.
63. Zhu Y, Li W, Wang Y. *et al.* Thermodynamic analysis and parametric optimization of ejector heat pump integrated with organic Rankine cycle combined cooling, heating and power system using zeotropic mixtures. *Appl Therm Eng* 2021;**194**:117097. https://doi.org/10.1016/j.applthermaleng.2021.117097.
64. Sanaye S, Refahi A. A novel configuration of ejector refrigeration cycle coupled with organic Rankine cycle for transformer and space cooling applications. *Int J Refrig* 2020;**115**:191–208. https://doi.org/10.1016/j.ijrefrig.2020.02.005.
65. Malwe PD, Shaikh J, Gawali BS. *et al.* Dynamic simulation and exergy analysis of an organic Rankine cycle integrated with vapor compression refrigeration system. *Sustain Energy Technol Assess* 2022;**53**:102684. https://doi.org/10.1016/j.seta.2022.102684.
66. Sherwani AF. Analysis of organic Rankine cycle integrated multi evaporator vapor-compression refrigeration (ORC-mVCR) system. *Int J Refrig* 2022;**138**:233–43. https://doi.org/10.1016/j.ijrefrig.2022.03.014.