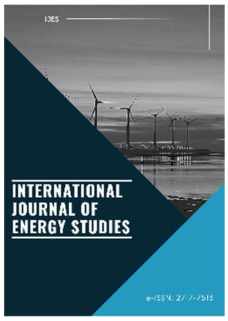
INTERNATIONAL JOURNAL OF ENERGY STUDIES

e-ISSN: 2717-7513 (ONLINE); homepage: https://dergipark.org.tr/en/pub/ijes



Research Article

Int J Energy Studies 2024; 9(2): 219-237

DOI: 10.58559/ijes.1449528

Received	:	09 Mar 2024
Revised	:	28 May 2024
Accepted	:	03 June 2024

Comparative analysis of Kalina and ORC cycles in renewable energy systems: exergo-environmental assessment and cost calculations with carbon emissions

Ahmet Elbir*

**Süleyman Demirel University, Renewable Energy Resources Research Center, Isparta, Turkey, ORCID: 0000-0001-8934-7665*
*(*Corresponding Author:ahmetelbir@sdu.edu.tr)*

Highlights

- Kalina and ORC cycles play a significant role in renewable energy systems, contributing to sustainable energy production, reducing dependency on fossil fuels, and minimizing environmental impacts.
- Comparing the two cycles reveals that ORC system outperforms Kalina in terms of electrical power generation, energy and exergy efficiency, exergetic sustainability index, and economic value of electricity produced.
- Despite generating higher electrical power output with the same heat transfer rate as Kalina, ORC exhibits superior energy and exergy efficiencies, exergetic sustainability, and economic value. However, Kalina system offers lower carbon emissions compared to ORC.

You can cite this article as: Elbir A. Comparative analysis of Kalina and ORC cycles in renewable energy systems: exergo-environmental assessment and cost calculations with carbon emissions. Int J Energy Studies 2024; 9(2): 219-237.

ABSTRACT

This study aims to compare the thermal energy conversion performances of Organic Rankine Cycle (ORC) and Kalina systems. By comparing the performances of ORC and Kalina systems, it aims to provide an analysis on carbon emissions and economic costs. The highlighted results of the study indicate that for the ORC (Organic Rankine Cycle), the electrical power is 16.93 kW, with a heat transfer rate of 100 kW for heat exchanger-I. The ORC energy efficiency is 16.86%, with an exergy efficiency of 57.92%. The exergetic sustainability index is 1.34, with a carbon emission of 6.61 kgCO_2 per hour and an economic value of electricity of $2.31 per hour. For the Kalina cycle, the electrical power is 11.60 kW, with a heat transfer rate of 100 kW for heat exchanger-I. The Kalina energy efficiency is 11.55%, with an exergy efficiency of 24.78%. The exergetic sustainability index is 0.60, with a carbon emission of 4.49 kg per hour and an economic value of electricity produced of $1.57 per hour. A comparison of both cycles is presented.

Keywords: Thermal energy conversion, Organic Rankine Cycle (ORC), Kalina cycle, Renewable energy systems

1. INTRODUCTION

With the rapid increase in population, the demand for energy is continuously rising, while existing fossil fuel resources are depleting at an alarming rate. This necessitates the exploration and utilization of alternative energy sources to meet energy needs. Renewable energy sources such as solar, geothermal, and wind, despite being considered as low-grade and low-temperature heat sources, hold significant energy potential at lower temperature ranges. Technologies like Organic Rankine Cycle (ORC) and Kalina cycle are employed to efficiently convert this low-grade energy into electricity. The utilization of these renewable energy sources aims to achieve important objectives such as reducing environmental impacts, enhancing economic opportunities, and ensuring secure operations. Several studies in the literature have addressed these aspects: Proposed and examined a new triple production system analyzed from energy, exergy, economic, and environmental perspectives. The exergy analysis indicated an exergy efficiency of 42.11%, with the Brayton cycle contributing the most to exergy destruction, accounting for 93.00% of annual exergy destruction [1]. Investigated the use of Kalina and organic Rankine cycles for electricity generation, incorporating a thermoelectric generator to enhance electricity production by harnessing cyclical heat losses. Additionally, water electrolysis and cooling cycles were integrated to produce clean hydrogen fuel and provide cooling loads. The performance of the presented multi-generation configuration was evaluated and discussed from thermodynamic, energetic, exergetic, and exergoeconomic perspectives, emphasizing an exergetic efficiency of 35.9% and a product unit cost of $36.95 per GJ [2]. Designed and evaluated a new tri-generation regional energy system (TDES) from various perspectives. The system incorporated a regenerative gas turbine cycle for heat recovery, a Kalina cycle for additional power generation, and an ejector refrigeration cycle for cold production, aiming to optimize primary energy ratio, exergy efficiency, exergoeconomic criterion, and exergo-environmental criterion, reaching optimum values of 76.9%, 30.8%, $58.4/GJ, and 42.7 kg/GJ, respectively [3]. Developed a mathematical model to evaluate the performance of a three-stage organic Rankine cycle, Kalina cycle, and liquefied natural gas direct expansion system for combined cooling, heating, and power generation. Thermodynamic analysis revealed a net output power, thermal efficiency, and exergy efficiency of 1257.708 kW, 43.43%, and 70.4%, respectively. Multi-objective optimization results indicated a maximum exergy efficiency of 80.49% and a minimum total product unit cost of $48.04/GJ for this integrated system [4]. In their study, a hybrid energy system that includes a renewable cycle based on geothermal and solar energy sources is proposed. In this system, one gas cycle, one vapor cycle, two organic Rankine cycles (ORC) and concentrated photovoltaic thermal panels (CPVT) are used. A detailed energy, efficiency, economy and environmental analysis was carried out on the proposed system. The analysis shows that the most suitable fluids for ORC are R123 and Ammonia, and the energy efficiency, exergy efficiency, exergy destruction rate for the entire cycle and the power produced in the base case are 50.59%. In addition, the annual capital cost amount and the amount of carbon dioxide emissions resulting from energy and exergy were determined as 107.034 dollars, 11.672 and 35.401 kg per month, respectively. The optimization results show a 0.25% improvement in exergy efficiency and a reduction in capital cost of $500 per year at the optimum point [5]. In their research, a Kalina cycle was examined from energy, exergy, economy and exergoeconomic aspects. In this cycle, water-ammonia solution was used as the working fluid. Parametric analysis was carried out in terms of energy, exergy and exergoeconomics to examine the effect of turbine inlet temperature and pressure and ammonia content on the cycle performance. The optimization results show that the exergy efficiency is 0.08824 and the total cost rate is 318.58 $/hour. This represented a 19.5% increase in exergy efficiency and a 12.95% decrease in the cost rate compared to the base case [6]. In this study, the performance of a new solar-powered combined cooling, heating and power (CCHP) Kalina system is proposed and optimized. The performance evaluation was made based on exergy, exergo-economic and exergo-environmental concepts. In summer, the optimum value of daily exergy efficiency, total product environmental impact ratio and total product cost ratio increased by 2.56%, 15.7% and 15.3%, respectively, and in winter months, it increased by 36.34%, 7.39% and 15.3% respectively. It achieved an improvement of 4.93 [7]. In their work, a new combined cooling and power system is proposed, which includes a Kalina cycle and a single-effect water-ammonia absorption chiller. In this system, two heat recovery systems (Kalina cycle and absorption cooler) together with the fuel cell were used in a new arrangement and analyzed from energy, exergy, exergoeconomic and environmental perspectives. The effects of current density, fuel price and carbon price on the system performance were examined and the net power and cooling load of the system were evaluated. The results, energy and exergy efficiencies, system unit cost and carbon dioxide emission penalty are 54.27%, 45.48%, $0.162 kW-1s-1 and $9.557 s-1, respectively. Additionally, it is seen that carbon dioxide emissions decrease by up to 147.6 g kW-1s-1 compared to the fuel cell operating alone, and energy and exergy efficiencies increase by 52.32% and 33.06%, respectively [8]. In their studies, an innovative hybrid system consisting of an organic Rankine unit, a carbon dioxide power plant, a Kalina power cycle based on sea water temperature difference and a multi-effective desalination system was developed. Part of the heat of the system is provided by solar collectors. Exergy analysis shows that the highest exergy destruction occurs in the combustion chamber and heat exchangers, and these account for more than 80% of the total exergy destruction. The exergy efficiency of the entire system was determined as 44.81% [9]. In this study, an integrated energy production system consisting of low-temperature organic Rankine cycle, gas and steam combined power plant and Kalina power generation unit was developed and examined. This integrated system can produce 158.5 MW of power, 9.498 MW of cooling and 46.02 kg/h of hot water. They determined the total electrical, thermal and exergy efficiencies as 48.62%, 55.18% and 67.74%, respectively [10]. Their work consists of a steam Rankine cycle, double-effect absorption cooler, proton exchange membrane electrolyzer, multi-effect desalination and parabolic slotted solar collector. It shows that for the multiple generation system, energy efficiency increases by 82.4%, exergy efficiency by 14%, total product cost rate by 0.84 $/h, and environmental impact improvement by 0.15 [11]. In this study, a new combined cooling and power (CCP) system based on organic Rankine cycle and absorption cooling cycle is proposed for waste heat recovery of natural gas-biomass dual fuel gas turbine. Comprehensive thermodynamic, exergo-economic and exergo-environmental performance and parametric analysis of this system have been carried out. The results show that under the design condition, the thermal efficiency of the system is 68.88%, the exergy efficiency is 42.10%, and the levelized exergy cost is 21.16 $/GJ, while the environmental impact of levelized exergy is 5208.82 mPts/GJ [12]. In this study, thermodynamic simulation, exergy, exergoeconomics and exergoenvironmental analyzes were carried out. In addition, emergoeconomic and emergoenvironmental evaluations, which are emergency unit-based concepts, were made based on Life Cycle Assessment (LCA). According to the results obtained, the thermal efficiency in the system was determined as 48.25% and the net power production was determined as 419600 kW [13]. In their proposed study, it consists of a Kalina cycle integrated with a solar-powered organic Rankine cycle and a double-effect absorption refrigeration cycle. Life cycle analyzes were conducted to assess environmental impacts, and algebraic thermodynamic mathematical programming was used for more in-depth evaluations. Under intelligent management, a suitable optimal system and fluid distribution is realized by hybrid deterministic decision-making technique. Optimization results show that total exergy risk, system reliability and environmental impact can be simultaneously improved by using different working fluids. While the system provided the lowest cost rate with R113 (4.17 USD·s−1), the highest energy efficiency (46.3%) and system reliability (91.2%) were associated with R365mfc. Finally, comparative analysis reveals annual CO_2 saving potential of 6646, 4883 and 2878 tons compared to coal, fuel oil and natural gas-based energy systems [14]. In this study, a research was conducted on the evaluation of waste heat from the solar gas turbine power plant in different scenarios. In these scenarios, waste heat was used as a Kalina cycle, multiple effect water demarcation (MED) unit, and combined Kalina/MED. Thermodynamic modeling was done to analyze the scenarios, and then emergo-economic and emergo-environmental analyzes were carried out. The results show that both the Kalina cycle and the marineization unit can increase the energy and exergy efficiency of the plant by 11.4% and 6.02%, respectively. However, it was determined that the scenario in which only the demarcation unit was used had the highest monetary and ecological performance. These values increased from 87.25% and 88.11% to 90.3% and 97.8%, respectively, after optimization, indicating a significant improvement compared to the base cycle [15]. In its work, the article deals with the analysis of both the first and second laws of thermodynamics by examining the thermodynamics of the ORC and Kalina cycle. 15 different working fluids were evaluated for ORC and three different ammonia-water mixtures for the Kalina cycle. It was determined that a mixture consisting of R-290 for ORC and 84% ammonia mass fraction and 16% water mass fraction for the Kalina cycle offered the best performance. Under these conditions, the Kalina cycle produces 18% more net power than the ORC. A levelized electricity cost of 0.22 €/kWh for the ORC and 0.18 €/kWh for the Kalina cycle was achieved [16]. In his study, waste heat from solid waste facilities was evaluated using the Rankine cycle. Later, the Organic Rankine Cycle (ORC) system was integrated into the lower cycle of the steam Rankine cycle. The integrated system is completed by using waste heat from the Rankine steam cycle in the carbon dioxide cycle. The highest mass flow requirement in the ORC system is observed when R123 fluid is used. Energy efficiency for the entire system was calculated as 22.4% and exergy efficiency as 60.7%. According to the results of Exergo Environmental Analysis, the exergy stability factor was determined as 60.7% and the exergetic sustainability index was determined as 2.66 [17]. In his study, he discussed how geothermal resources can be used efficiently and cost effectively with binary cycle technology by making economic analysis and comparison between the organic Rankine cycle and Kalina cycle. The study states that potential source temperatures vary between 90°C and 140°C and the mass of the geothermal fluid varies between 20 kg/s and 80 kg/s. Organic Rankine cycle and Kalina cycle models were analyzed. The results obtained show that a binary cycle-based power plant is possible in various geothermal field conditions [18].In their study, they compare the organic Rankine cycle (ORC) using isopentane and the Kalina cycle systems using ammonia-water mixture for power generation. It shows that the ORC system has the highest efficiency with an exergy efficiency of 82.12%, produces a unit energy cost of 8.19 US cents/kWh, and has a total environmental impact of 282.29 mPt/h [19]. A new cogeneration system based on a combination of a gas turbine cycle, supercritical CO_2 cycle and Kalina cycle has been developed for heating and power generation. Energy, exergy and exergo-economic analyzes were performed to evaluate the performance and suitability of the system. According to the findings, system energy and exergy efficiencies were obtained as 78.15% and 40.97%, respectively [20]. The article states that the ideal performance of the system is achieved by optimizing the ammonia-water mixture and the compression temperature of the heat exchangers. However, heat exchanger installations (evaporators and reclaimers) were designed in detail and examined to analyze the feasibility of the system. The designed system can produce 1660.30 kW of electricity with 13.20% thermal efficiency. These findings show that the system can operate in an optimized manner and produce significant amounts of electrical energy [21]. In his work, he introduces a new configuration of a triple cycle that includes gas and vapor cycles and also includes the organic Rankine cycle (ORC) for energy recovery from hot exhaust gas. Energy, exergy, economic, exergo-economic and exergo-environmental (5E) evaluations of the system were carried out. The results show that adding steam and ORC cycles to the gas cycle in this system increases the energy and exergy efficiencies by 71.8% and 73.7%, respectively. However, the integration of the CCS unit into this system reduces the energy and exergy efficiencies to 50.5% and 51.9%. The economic results of the proposed system show that SPP and PP both last 1.5 years. Moreover, NPV and IRR are found to be 3.13×09 and 0.68 respectively. Additionally, it has been determined that the carbon capture system (CCS) unit can prevent the release of 627,000 metric tons of CO_2 per year [22]. In their work, considering the important role of combination cooling, heating and power (KSHG) systems in improving the performance of power plants, two new micro-KSHG systems based on organic Rankine cycle (ORC) and Kalina cycle (KC) are presented. It was determined that the KC-based micro-KSHG system had higher optimum thermal efficiency and total unit product cost (TUM) than the ORC-based micro-KSHG system, but had lower exergy efficiency. In this context, the optimum thermal efficiency for ORC and KC-based micro-KSHG systems was calculated as 76.54% and 77.32%, respectively, while the optimum exergy efficiency was calculated as 48.37% and 31.2%, respectively [23].

Unlike previous studies, this research presents a detailed exergo-environmental analysis that combines exergy efficiency with environmental impact assessments. By focusing specifically on carbon emissions and cost calculations, it provides a more holistic understanding of the sustainability of renewable energy systems. The study offers an in-depth comparative analysis of the Kalina and ORC cycles under various operating conditions. This comparison is based not only on energy and exergy efficiencies but also on environmental and economic factors, providing a more comprehensive evaluation than typically seen in the literature. New insights into the design parameters specific to the Kalina and ORC cycles are provided. The study examines how these parameters affect system performance, a topic that has not been thoroughly addressed in previous research. The research includes case studies or simulations that mimic real-world operating scenarios. These scenarios help understand the practical implications of adopting Kalina and ORC cycles in different renewable energy applications.

2. MATERIAL METHOD

2.1. Organic Rankine Cycle

The Organic Rankine Cycle (ORC) system consists of a turbine, a pump and two heat exchangers. The working principle of the system is as follows: The heat coming from the heat source heats the ORC working fluid and evaporates it. The resulting steam is directed to the turbine, expands in the turbine and produces mechanical energy. The steam coming out of the turbine turns into a liquid by cooling and is pumped back to the first heat exchanger by the pump to rejoin the cycle. In this way, the ORC system can operate at low temperature and produce electrical energy. Figure 1 presents the ORC flow chart we used in our study.

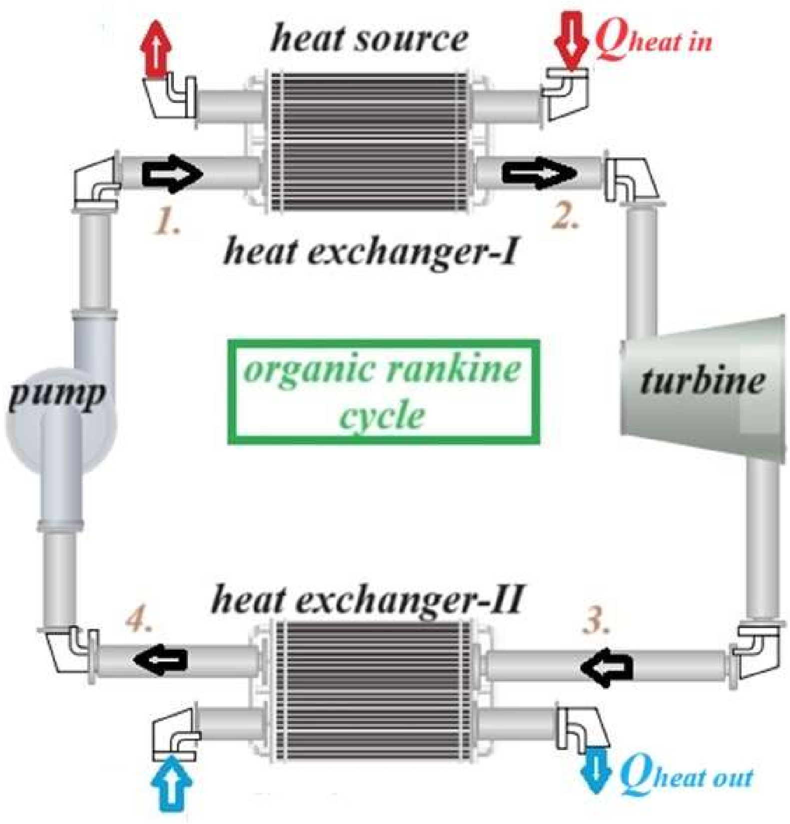


Figure 1. ORC flow chart

Thermodynamic properties of the ORC system in Figure 1 according to their positions in the flow chart are given in Table 1.

Table 1. The table' caption Thermodynamic properties of the ORC

Location	T [K]	s [kJ/kg.K]	P [bar]	h [kJ/kg]	ex [kj/kg]	m [kg/s]	Fluid
1.	293.8	1.075	10.86	222	0.7333	0.43763	R123
2.	388.2	1.7	10.86	450.5	48.99	0.43763	R123
3.	316.9	1.722	0.7586	411.8	4.047	0.43763	R123
4.	293.2	1.074	0.7586	221.1	0.0433	0.43763	R123
T0.	288.2	1.057	1	215.9	0	-------	R123

2.2. Kalina Cycle

The Kalina cycle consists of a generator, valves, turbine, pump and two heat exchangers. Steam and liquid coming from the heat source are separated in the generator, then the steam is directed to the high pressure area and converted into kinetic energy in the turbine. The liquid is pumped into the low-pressure area through the pump, then passes through two heat exchangers, where it is heated and evaporated. As a result, the low-temperature Kalina cycle is designed to produce electrical energy more efficiently from low-quality heat sources. Figure 2 presents the flow chart of the Kalina cycle we used in our study.

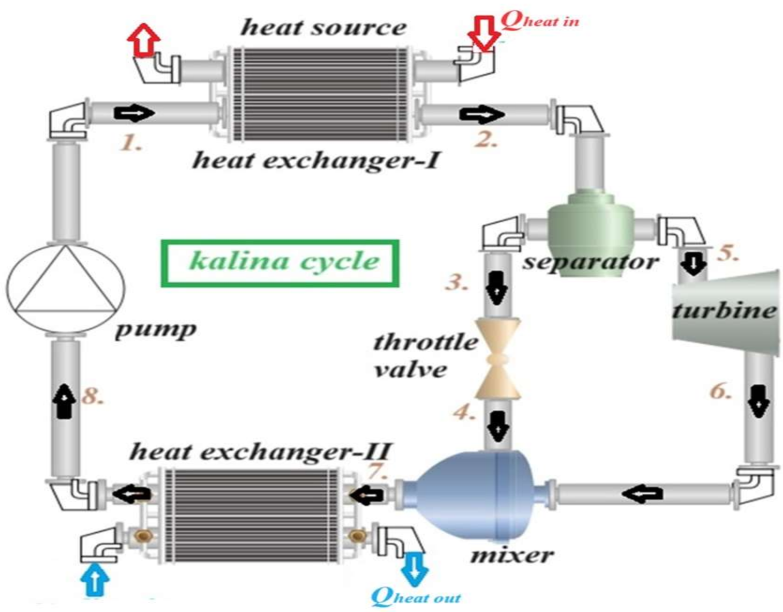


Figure 2. Flow chart of Kalina cycle

Table 2. Thermodynamic properties of the Kalina cycle

Location	T [K]	h [kJ/kg]	s [kJ/kg.K]	P [bar]	Qu [quality]	ex [kj/kg]	m [kg/s]	X [%NH3]	Fluid
1.	293,8	54.84	0.337	40	-0.001	-2.141	0.07891	0.94	NH_3H_2O
2.	388.2	1322	3.933	40	0.8967	228.7	0.07891	0.94	NH_3H_2O
3.	388.2	313.8	1.469	40	0	-69.42	0.00815	0.5848	NH_3H_2O
4.	338.8	313.8	1.541	10	0.1902	-90.17	0.00815	0.5848	NH_3H_2O
5.	388.2	1438	4.216	40	1	263.1	0.07076	0.9809	NH_3H_2O
6.	324	1274	4	10	0.9492	72.58	0.07076	0.9809	NH_3H_2O
7.	326.2	1175	4.025	10	0.8607	55.14	0.07891	0.94	NH_3H_2O
8.	293.2	50.14	0.338	10	0	-7.129	0.07891	0.94	NH_3H_2O
T[0].	288.2	-207.5	-0.581	1	---------	--------	----------	0.94	NH_3H_2O

Thermodynamic properties of the Kalina cycle system in Figure 2 according to their positions in the flow chart are given in Table 2.

2.3. Energy and Exergy Analysis

For steady state in thermodynamic analysis, the basic mass balance equation can be given as follows [24-25];

$$\sum \dot{m}_{in} = \sum \dot{m}_{ex} \tag{1}$$

where $\dot{m}$ is the mass flow rate, the in and ex indices represent the inlet and outlet states, respectively. The energy balance is given as:

$$\dot{Q}_{in} + \dot{W}_{in} + \sum_{in} \dot{m}\left(h + \frac{V^2}{2} + gz\right) = \dot{Q}_{ex} + \dot{W}_{ex} + \sum_{ex} \dot{m}\left(h + \frac{V^2}{2} + gz\right) \tag{2}$$

Here, $\dot{Q}$ is the heat transfer rate, $\dot{W}$ is the power, h is the specific enthalpy, v is the velocity, z is the height, and g is the gravitational acceleration. The entropy balance equation for steady-state conditions is written as:

$$\sum_{in} \dot{m}_{in} s_{in} + \sum_{k} \frac{\dot{Q}}{T_k} + \dot{S}_{gen} = \sum_{ex} \dot{m}_{ex} s_{ex} \tag{3}$$

where s is the specific entropy and $\dot{S}_{gen}$ is the entropy generation rate. The exergy balance equation can be written as:

$$\sum \dot{m}_{in}\, ex_{in} + \sum \dot{E}\, x_{Q,in} + \sum \dot{E}x_{W,in} = \sum \dot{m}_{ex} ex_{ex} + \sum \dot{E}x_{Q,ex} + \sum \dot{E}x_{W,ex} + \dot{E}x_D \tag{4}$$

The specific flow exergy can be written as:

$$ex = x_{ph} + ex_{ch} + ex_{pt} + ex_{kn} \tag{5}$$

The kinetic and potential parts of the exergy are assumed to be negligible. Also, the chemical exergy is assumed to be negligible. The physical or flow exergy (ex_{ph}) is defined as:

$$ex_{ph} = (h - h_o) - T_o(s - s_o) \tag{6}$$

where h and s represent specific enthalpy and entropy, respectively, in the real case. h_o and s_o are enthalpy and entropy at reference medium states, respectively.

Exergy destruction is equal to specific exergy times mass;

$$\dot{E}x_D = ex * m \tag{7}$$

$\dot{E}x_D$, are work-related exergy ratios and are given as:

$$\dot{E}x_D = T_0 \dot{S}_{gen} \tag{8}$$

$\dot{E}x_W$, are work-related exergy ratios and are given as:

$$\dot{E}x_W = \dot{W} \tag{9}$$

$\dot{E}x_Q$, are the exergy rates related to heat transfer and are given as below.

$$\dot{E}x_Q = \left(1 - \frac{T_0}{T}\right)\dot{Q} \tag{10}$$

$\dot{E}x_{D,syst.}$ Exergy destruction in the system;

$$\dot{E}x_{D,syst.} = \dot{E}x_{in} - \dot{E}x_{aut} \tag{11}$$

What work comes out of the system;

$$\dot{W}net_{out} = \dot{Q}_{in} - \dot{Q}_{out} \tag{12}$$

system thermal efficiency (η);

$$\eta = \frac{energy\ in\ exit\ outputs}{total\ energy\ inlets} \tag{13}$$

The exergy efficiency (ψ) can be defined as follows;

$$\psi = \frac{exergy\ in\ exit\ outputs}{total\ exergy\ inlets} \tag{14}$$

2.4. Exergoenvironmental Analysis

fei shows exergoenvironmental impact factor, $\dot{E}x_{D,tot.}$ is total exergy destruction rate, $\dot{E}x_{D,in.}$ is input exergy rate [26],

$$fei = \frac{\dot{E}x_{D,tot.}}{\dot{E}x_{D,in.}} \tag{15}$$

Cei is exergoenvironmental impact coefficient, ψ_{ex} represents exergy efficiency of the system,

$$Cei = \frac{1}{\psi_{ex}/_{100}} \tag{16}$$

Φei is exergoenvironmental impact index,

$$\Phi ei = fei \times Cei \tag{17}$$

Φeii represents exergoenvironmental impact improvement,

$$\Phi eii = \frac{1}{\Phi ei} \tag{18}$$

fes is the exergy stability factor,

$$fes = \frac{\dot{E}x_{D,out.}}{\dot{E}x_{D,out.} + \dot{E}x_{D,tot.}} \tag{19}$$

Φest represents exergetic sustainability index.

$$\Phi est = fes \times \Phi eii \tag{20}$$

2.5. Carbon Emission and Cost Value

The equation mentioned indicates that the total emissions ("E") can be calculated by multiplying the direct energy consumed ("E") by the carbon intensity ("eCO_2"). It seems that in this study, the direct energy consumed is determined by subtracting the net power of the subcycle from the net power, suggesting a specific method for quantifying the direct energy consumption and subsequently estimating the associated carbon emissions [27].

$$Carbon\ Emissions = E \times eCO_2 \tag{21}$$

To calculate the reduction in the cost of power production within the integrated system, one subtracts the net power derived from waste heat from the initial net power, divides this figure by the system's efficiency, and then multiplies the result by the electricity price per unit, considering a carbon intensity of 0.40 kg [28]. CO_2/kWh and a unit electricity price of $0.14/kW.h [29].

$$electricitycost = \frac{power\ gained}{cycle\ efficiency} * electricityprice \tag{22}$$

2.6. Assumptions in Calculations

- System performance is assumed to be stable and regular.
- A pure substance is used in the system.
- Compression in compressors is assumed to be adiabatic.
- Heat transfer through pressure drops in system components and pipes is neglected.
- In heat source heat exchangers, counter flow heat exchangers are used and heat losses are neglected.
- ORC circulation fluids (R123) and Kalina cycle (NH_3H_2O) fluids are used. Dead state is taken as 288.2K temperature and 1 bar atmospheric pressure.
- Gravitational potential energy and kinetic energy are not taken into account.
- Heat exchanger-I (evaporator = 100 kW, 388.2K) and heat exchanger-II (condenser = 293.2K) are compiled according to the constant thermal source into ORC and Kalina cycles.
- Heat transfers in heat exchangers are equal. Heat inputs are supplied from renewable energy sources (solar, geothermal, etc.).
- Carbon density is taken as 0.40 kg.CO_2/kWh.
- The unit electricity price is taken as 0.14 $/kW.hour.

3. RESULTS AND DISCUSSION

The results in Table 3 were obtained in the context of ORC. Electrical power is 16.93 kW, ORC heat transfer rate with heat exchanger-I is 100 kW. ORC energy efficiency is 16.86%, ORC exergy efficiency is 57.92%. The exergic sustainability index was determined as 1.34, carbon emission was determined as 6.61 kgCO_2 per hour and the economic value of electricity was determined as 2.31 $ per hour.

Table 3. Results obtained in the context of ORC

Parameters	Values
Electric power ($\dot{W}_{ORC}$)	16.93 kW
ORC heat transfer rate with heat exchanger-I ($\dot{Q}_{ORC}$)	100 kW
ORC energy efficiency (η ORC)	% 16.86
ORC exergy efficiency (ψ ORC)	% 57.92
exergetic sustainability index	1.34
Carbon emission	6.61 $kgCO_2/h$
Economic value of electricity	2.31 $/h

The results in Table 4 were obtained in the context of Kalina. The electrical power is 11.60 kW and the heat transfer rate of Kalina with heat exchanger-I is 100 kW. Kalina energy efficiency is 11.55%, Kalina exergy efficiency is 24.78%. The exergic sustainability index was determined as 0.60, carbon emission was determined as 4.49 kg per hour and the economic value of the electricity produced was determined as 1.57 $ per hour.

Table 4. Results obtained in the context of Kalina

Parameters	Values
Electric power ($\dot{W}_{kalina}$)	11.60 kW
Kalina heat transfer rate with heat exchanger-I ($\dot{Q}_{kalina}$)	100 kW
Kalina energy efficiency (η kalina)	11.55 %
Kalina exergy efficiency (ψ kalina)	24.78 %
exergetic sustainability index	0.60
Carbon emission	4.49 kg/h
Economic value of the electricity produced	1.57 $/h

In comparison with the literature, in terms of Electric Power and Energy Efficiency, the ORC System has been designed with an electric power of 16.93 kW and an energy efficiency of 16.86%. The Kalina System, on the other hand, has an electric power of 11.60 kW and an energy efficiency of 11.55%. In other studies, energy efficiencies and performances of Kalina and ORC cycles have been investigated, with an exergy efficiency of 35.9% found for the Kalina system [2]. For an integrated energy system, the total electrical efficiency is 48.62%, thermal efficiency is 55.18%, and exergy efficiency is 67.74% [10]. The ORC system exhibits the highest exergy efficiency of 82.12% [19]. System energy and exergy efficiencies are 78.15% and 40.97%, respectively [20].

Optimum thermal efficiencies for ORC and Kalina cycles are 76.54% and 77.32%, with exergy efficiencies of 48.37% and 31.2%, respectively [23]. Regarding Exergy Efficiency and Sustainability, the ORC System has an exergy efficiency of 57.92% and an exergetic sustainability index of 1.34. The Kalina System has an exergy efficiency of 24.78% and an exergetic sustainability index of 0.60. In other studies, the exergy efficiency is 42.11%, with the Brayton cycle contributing 93.00% to exergy destruction [1]. The net power output for a three-stage system is 1257.708 kW, with a thermal efficiency of 43.43% and an exergy efficiency of 70.4% [4]. The exergy efficiency is 50.59% [5]. For the Kalina cycle, energy and exergy efficiencies are 54.27% and 45.48% [8]. The integrated system's exergy efficiency is 60.7%, with an exergetic sustainability index of 2.66 [17]. In terms of Environmental Impact, the ORC System produces carbon emissions of 6.61 kgCO_2 per hour, while the Kalina System produces 4.49 kgCO_2 per hour. In other studies, annual CO_2 emissions are 11.672 and 35.401 kg [5], with CO_2 emissions reduced by 6646, 4883, and 2878 tons per year under optimal conditions [23]. For Economic Value, the ORC System's economic value of electricity is $2.31 per hour, while the Kalina System's is $1.57 per hour. In other studies, the unit product cost is $36.95/GJ [2], the system unit cost is $0.162 kW/s [8], and the lowest cost rate is $4.17/s with R113 [14]. The unit energy cost is 8.19 cents/kWh [19]. In terms of Energy Efficiency and Economic Value, the ORC cycle is more advantageous in terms of energy efficiency and economic gain. The Kalina cycle has lower energy and exergy efficiencies but is advantageous in terms of environmental sustainability. Regarding Environmental Sustainability, the Kalina cycle performs better with lower carbon emissions.

In the literature, higher energy and exergy efficiencies are generally achieved, and comprehensive environmental and economic analyses are conducted. ORC and Kalina cycles have been specifically compared, and their advantages under certain conditions have been identified. If high energy efficiency and economic gain are prioritized, the ORC system should be preferred. If environmental sustainability and lower carbon emissions are prioritized, the Kalina system should be chosen.

4. CONCLUSION

Kalina and ORC cycles play an important role in renewable energy systems. These cycles contribute to sustainable energy production, reducing dependence on fossil fuels and minimizing environmental impacts. In addition, it increases the efficiency of energy conversion by ensuring more efficient use of renewable energy resources. Therefore, Kalina and ORC cycles have important strategic value in terms of transformation and sustainability in the energy sector. Results of the study;

In consideration of Electric Power and Energy Efficiency: The ORC system provides higher electric power (16.93 kW) and energy efficiency (16.86%) compared to the Kalina system, indicating that the ORC system is more effective in energy conversion. The Kalina system, on the other hand, offers lower electric power (11.60 kW) and energy efficiency (11.55%).

Considering Exergy Efficiency and Sustainability: The ORC system has higher exergy efficiency (57.92%) and exergetic sustainability index (1.34) compared to the Kalina system, indicating that the ORC system experiences less energy loss and is more sustainable. The Kalina system's exergy efficiency (24.78%) and exergetic sustainability index (0.60) are lower, implying more energy loss and less sustainability.

Assessing Environmental Impacts: The Kalina system produces lower carbon emissions (4.49 $kgCO_2/h$) compared to the ORC system, indicating that environmentally, the Kalina system is more advantageous. The carbon emissions of the ORC system (6.61 $kgCO_2/h$) are higher, thus its environmental impacts are more adverse compared to the Kalina system.

Considering Economic Values: The ORC system is more advantageous in terms of the economic value of the generated electricity (2.31 $/h). The economic value of the electricity produced by the Kalina system (1.57 $/h) is lower.

The ORC cycle is superior in terms of energy efficiency, exergy efficiency, and economic value, but disadvantaged in terms of environmental sustainability due to higher carbon emissions. Although the Kalina cycle has lower energy and exergy efficiencies, it is advantageous in terms of environmental sustainability due to lower carbon emissions. If high energy efficiency and economic gain are prioritized, the ORC system should be preferred. If environmental sustainability and lower carbon emissions are prioritized, the Kalina system should be chosen.

ACKNOWLEDGMENT

This research did not receive any specific grant from funding agencies in public or not-for-profit sectors.

DECLARATION OF ETHICAL STANDARDS

The author of the paper submitted declares that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Ahmet Elbir: Performed the whole processes.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

REFERENCES

[1] Alrobaian AA. Energy, exergy, economy, and environmental (4E) analysis of a multi-generation system composed of solar-assisted Brayton cycle, Kalina cycle, and absorption chiller. Applied Thermal Engineering 2022; 204: 117988.

[2] Ding GC, Peng JI, Mei-Yun GENG. Technical assessment of Multi-generation energy system driven by integrated renewable energy Sources: Energetic, exergetic and optimization approaches. Fuel 2023; 331: 125689.

[3] Ebrahimi-Moghadam A, Farzaneh-Gord M, Moghadam AJ, Abu-Hamdeh NH, Lasemi MA, Arabkoohsar A, Alimoradi A. Design and multi-criteria optimisation of a trigeneration district energy system based on gas turbine, Kalina, and ejector cycles: Exergoeconomic and exergoenvironmental evaluation. Energy conversion and management 2021; 227: 113581.

[4] Fang Z, Shang L, Pan Z, Yao X, Ma G, Zhang Z. 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 Conversion and Management 2021; 238: 114148.

[5] Shoaei M, Hajinezhad A, Moosavian SF. Design, energy, exergy, economy, and environment (4E) analysis, and multi-objective optimization of a novel integrated energy system based on solar and geothermal resources. Energy 2023; 280: 128162.

[6] Rahmatian M, Ahmadi Boyaghchi F. Exergo-environmental and exergo-economic analyses and multi-criteria optimization of a novel solar-driven CCHP based on Kalina cycle. Energy Equipment and Systems 2016; 4(2): 225-244.

[7] Rahmatian M, Ahmadi Boyaghchi F. Exergo-environmental and exergo-economic analyses and multi-criteria optimization of a novel solar-driven CCHP based on Kalina cycle. Energy Equipment and Systems 2016; 4(2): 225-244.

[8] Einanlou M, Mehregan M, Hashemian SM. Energy, exergy, exergoeconomic, and environmental (4E) analyses of a novel combined cooling and power system with phosphoric acid fuel cell and Kalina cycle. Applied Thermal Engineering 2023; 221: 119877.
[9] Ghorbani B, Ebrahimi A, Moradi M. Exergy, pinch, and reliability analyses of an innovative hybrid system consisting of solar flat plate collectors, Rankine/CO_2/Kalina power cycles, and multi-effect desalination system. Process Safety and Environmental Protection 2021; 156: 160-183.
[10] Ghorbani B, Ebrahimi A, Rooholamini S, Ziabasharhagh M. Pinch and exergy evaluation of Kalina/Rankine/gas/steam combined power cycles for tri-generation of power, cooling and hot water using liquefied natural gas regasification. Energy Conversion and Management 2020; 223: 113328.
[11] Hashemian N, Noorpoor A. Assessment and multi-criteria optimization of a solar and biomass-based multi-generation system: Thermodynamic, exergoeconomic and exergoenvironmental aspects. Energy conversion and management 2019; 195: 788-797.
[12] Ren J, Qian Z, Fei C, Lu D, Zou Y, Xu C, Liu L. Thermodynamic, exergoeconomic, and exergoenvironmental analysis of a combined cooling and power system for natural gas-biomass dual fuel gas turbine waste heat recovery. Energy 2023; 269: 126676.
[13] Nourpour M, Khoshgoftar Manesh MH, Pirozfar A, Delpisheh M. Exergy, exergoeconomic, exergoenvironmental, emergy-based assessment and advanced exergy-based analysis of an integrated solar combined cycle power plant. Energy & Environment 2023; 34(2): 379-406.
[14] Tariq S, Safder U, Yoo C. Exergy-based weighted optimization and smart decision-making for renewable energy systems considering economics, reliability, risk, and environmental assessments. Renewable and Sustainable Energy Reviews 2022; 162: 112445.
[15] Rafat E, Babaelahi M. Recovering waste heat of a solar hybrid power plant using a Kalina cycle and desalination unit: A sustainability (emergo-economic and emergo-environmenal) approach. Energy conversion and management 2020; 224: 113394.
[16] Rodríguez CEC, Palacio JCE, Venturini OJ, Lora EES, Cobas VM, Dos Santos DM, Gialluca V. Exergetic and economic comparison of ORC and Kalina cycle for low temperature enhanced geothermal system in Brazil. Applied Thermal Engineering 2013: 52(1): 109-119.
[17] Elbir A. Thermodynamic Analysis of the Integrated System that Produces Energy by Gradual Expansion from the Waste Heat of the Solid Waste Facility. Hittite Journal of Science and Engineering 2023; 10(4): 339-348.

[18] Wakana F, Omarsdottir M, Haraldsson IG, Georgsson LS. Preliminary Study of Binary PowerPlant Feasibility Comparing ORC and Kalina for Low-Temperature Resources in Rusizi Valley, Burundi. Geothermal Training Programme, Reykjavik, 2013.

[19] Nasruddin N, Saputra ID, Mentari T, Bardow A, Marcelina O, Berlin S. Exergy, exergoeconomic, and exergoenvironmental optimization of the geothermal binary cycle power plant at Ampallas, West Sulawesi, Indonesia. Thermal Science and Engineering Progress 2020; 19: 100625.

[20] Ji-chao Y, Sobhani B. Integration of biomass gasification with a supercritical CO_2 and Kalina cycles in a combined heating and power system: a thermodynamic and exergoeconomic analysis. Energy 2021; 222: 119980.

[21] Prananto LA, Zaini IN, Mahendranata BI, Juangsa FB, Aziz M, Soelaiman TAF. Use of the Kalina cycle as a bottoming cycle in a geothermal power plant: Case study of the Wayang Windu geothermal power plant. Applied Thermal Engineering 2018; 132: 686-696.

[22] Talebizadehsardari P, Ehyaei MA, Ahmadi A, Jamali DH, Shirmohammadi R, Eyvazian A, Rosen MA. Energy, exergy, economic, exergoeconomic, and exergoenvironmental (5E) analyses of a triple cycle with carbon capture. Journal of CO_2 Utilization 2020; 41: 101258.

[23] Rostamzadeh H, Ebadollahi M, Ghaebi H, Shokri A. Comparative study of two novel micro-CCHP systems based on organic Rankine cycle and Kalina cycle. Energy conversion and management 2019; 183: 210-229.

[24] Dinçer İ, Rosen MA. Ekserji: enerji, çevre ve sürdürülebilir kalkınma . Newnes, 2012.

[25] Bejan A, Tsatsaronis G, Moran MJ. Thermal design and optimization. John Wiley & Sons, 1995.

[26] Sharifishourabi M. Energetic and Exergetic Analysis of a Solar Organic Rankine Cycle with Triple Effect Absorption System (Master's thesis, Eastern Mediterranean University (EMU)-Doğu Akdeniz Üniversitesi (DAÜ)), 2016.

[27] Jeswiet J. Kara S. Carbon emissions and CES™ in manufacturing. CIRP annals 2008; 57(1): 17-20.

[28] International Energy Agency (IEA). Global Energy & CO_2 Data. 2018 [cited 2023 August]; Available from: https://www.iea.org/countries.

[29] İRENA REmap 2030 commodity prices, [cited 2023 August]; Available from: https://www.irena.org/media/Files/IRENA/REmap/Methodology/IRENA_REmap_2030_commodity_prices.xlsx?la=en&hash=505B546E4EE80A557363781E83EA1AE83D9FB256

[30] Klein SA. Engineering Equation Solver(EES) F-Chart Software, Version 10.835-3D 2020.