in this equation, n denotes the molar coefficient of the reactants and products.

As previously stated, the combustion chamber is assumed to operate under adiabatic conditions. Applying the principles of energy conservation to the contemplated combustion process, the following equation can be derived [29]:

$$\sum_j X_j\left[\overline{h}^0_{f_j}+\Delta\overline{h}\right]_{generated\ gas}+\sum_j X_j\left[\overline{h}^0_{f_j}+\Delta\overline{h}\right]_{Air,1}=\sum_j X_j\left[\overline{h}^0_{f_j}+\Delta\overline{h}\right]_{products} \tag{4}$$

3.2. Exergy balance

In a steady-state condition, the exergy balance is expressed as [30]:

$$\dot{E}x_Q-\dot{W}=\sum\dot{E}x_{out}-\sum\dot{E}x_{in}+\dot{E}x_D \tag{5}$$

Here, $\dot{E}_D$ represents the exergy destruction rate. Also, $\dot{E}_Q$ is the exergy rate related to heat transfer, which can be calculated as follows [31]:

$$\dot{E}x_Q=\sum\dot{Q}\left(1-\frac{T_0}{T}\right) \tag{6}$$

here, T denotes the temperature and subscript 0 stands for the standard condition. The exergy flow consists of the physical and chemical exergy that is defined as follows [31]:

$$\dot{E}x_i=\dot{E}x_{ph,i}+\dot{E}x_{ch,i} \tag{7}$$

The chemical and physical exergy rates are estimated from the following equations [31]:

$$\dot{E}x_{ch,i}=\dot{n}_i\left[\sum y_m\overline{e}_m^{ch,o}+\overline{R}T_0\sum y_m\ ln(y_m)\right] \tag{8}$$

$$\dot{E}x_{ph,i}=\dot{m}_i\left[\left(h_i-h_{0,i}\right)-T_0\left(s_i-s_{0,i}\right)\right] \tag{9}$$

here, $\dot{n}_i$ and y_m are the molar flow rate and molar fraction, and s demonstrates the specific entropy. It's worth noting that chemical exergy analysis is applied specifically to the combustion chamber due to its chemical reactions.

Since energy and exergy analyses involve multiple equations, their application to different components is summarized in Table 2 for reference.

3.3. Exergoeconomic analysis

This study assesses economic indices using an exergoeconomic analysis method known as Specific Exergy Costing (SPECO). This approach incorporates exergy rates into the economic evaluation, and the cost balance of components is expressed as follows: [31]:

$$\dot{C}_{q,k}+\sum\dot{C}_{in,k}+\dot{Z}_k=\dot{C}_{w,k}+\sum\dot{C}_{out,k} \tag{10}$$

where;

- $\dot{C}_{q,k}$ represents the cost rate associated with the heat transfer within component k.
- $\sum\dot{C}_{in,k}$ represents the sum of cost rates associated with the inflow of exergy to component k.
- $\dot{Z}_k$ represents the cost rate associated with the investment or capital cost of component k.
- $\dot{C}_{w,k}$ represents the cost rate associated with the work transfer within component k.
- $\sum\dot{C}_{out,k}$ represents the sum of cost rates associated with the outflow of exergy from component k.

Moreover;

Table 2
Mass, energy, and exergy balance equations for different components of the proposed system.

Component	Mass and energy rates	Exergy destruction rate ($\dot{E}x_D^i$)
Combustion Chamber	$\dot{m}_1+\dot{m}_7=\dot{m}_8$ $\dot{m}_1h_1+\dot{m}_7h_7=\dot{m}_8h_8$	$(\dot{E}x_{10}+\dot{E}x_4)-(\dot{E}x_{11})$
Inter Cooler	$\dot{Q}_{IC}=\dot{m}_3[h_4-h_3]=\dot{m}_{12}[h_{13}-h_{12}]$ $\dot{m}_3=\dot{m}_4$, $\dot{m}_{12}=\dot{m}_{13}$	$(\dot{E}x_{12}+\dot{E}x_3)-(\dot{E}x_{13}+\dot{E}x_4)$
Air Preheater	$\dot{Q}_{AP}=\dot{m}_5[h_6-h_5]=\dot{m}_9[h_9-h_{10}]$ $\dot{m}_5=\dot{m}_6$, $\dot{m}_9=\dot{m}_{10}$	$(\dot{E}x_5+\dot{E}x_9)-(\dot{E}x_6+\dot{E}x_{10})$
Heat exchanger 1	$\dot{m}_{10}=\dot{m}_{11}$, $\dot{m}_{28}=\dot{m}_{36}$ $\dot{Q}_{Hx1}=\dot{m}_{10}[h_{10}-h_{11}]=\dot{m}_{28}[h_{28}-h_{36}]$	$(\dot{E}x_{10}+\dot{E}x_{36})-(\dot{E}x_{11}+\dot{E}x_{28})$
Heat exchanger 2	$\dot{m}_{10}=\dot{m}_{11}$, $\dot{m}_{28}=\dot{m}_{36}$ $\dot{Q}_{Hx2}=\dot{m}_{37}[h_{38}-h_{37}]=\dot{m}_{45}[h_{45}-h_{46}]$	$(\dot{E}x_{37}+\dot{E}x_{45})-(\dot{E}x_{38}+\dot{E}x_{46})$
Condenser 1	$\dot{m}_{22}=\dot{m}_{23}$, $\dot{m}_{26}=\dot{m}_{27}$ $\dot{Q}_{Cond1}=\dot{m}_{22}[h_{22}-h_{23}]=\dot{m}_{26}[h_{27}-h_{26}]$	$(\dot{E}x_{22}+\dot{E}x_{26})-(\dot{E}x_{23}+\dot{E}x_{27})$
Condenser 2	$\dot{m}_{34}=\dot{m}_{35}$, $\dot{m}_{41}=\dot{m}_{42}$ $\dot{Q}_{Cond2}=\dot{m}_{34}[h_{34}-h_{34}]=\dot{m}_{41}[h_{42}-h_{41}]$	$(\dot{E}x_{34}+\dot{E}x_{41})-(\dot{E}x_{35}+\dot{E}x_{42})$
Condenser 3	$\dot{m}_{39}=\dot{m}_{40}$, $\dot{m}_{43}=\dot{m}_{44}$ $\dot{Q}_{Cond3}=\dot{m}_{39}[h_{40}-h_{39}]=\dot{m}_{43}[h_{43}-h_{44}]$	$(\dot{E}x_{39}+\dot{E}x_{43})-(\dot{E}x_{40}+\dot{E}x_{44})$
Turbine 1	$\dot{m}_6=\dot{m}_7$ $\dot{W}_{Tur1}=\dot{m}_6[h_6-h_7]$, $\eta_{is,Tur1}=\frac{h_6-h_7}{h_6-h_{7,is}}$	$(\dot{E}x_6-\dot{E}x_7)-\dot{W}_{Tur1}$
Turbine 2	$\dot{m}_8=\dot{m}_9$ $\dot{W}_{Tur2}=\dot{m}_8[h_8-h_9]$, $\eta_{is,Tur2}=\frac{h_8-h_9}{h_8-h_{9,is}}$	$(\dot{E}x_8-\dot{E}x_9)-\dot{W}_{Tur2}$
Turbine 3	$\dot{m}_{15}=\dot{m}_{16}$ $\dot{W}_{Tur3}=\dot{m}_{15}[h_{15}-h_{16}]$, $\eta_{is,Tur3}=\frac{h_{15}-h_{16}}{h_{15}-h_{16,is}}$	$(\dot{E}x_{15}-\dot{E}x_{16})-\dot{W}_{Tur3}$
Turbine 4	$\dot{m}_{20}=\dot{m}_{22}$ $\dot{W}_{Tur4}=\dot{m}_{20}[h_{20}-h_{22}]$, $\eta_{is,Tur4}=\frac{h_{20}-h_{22}}{h_{20}-h_{22,is}}$	$(\dot{E}x_{20}-\dot{E}x_{22})-\dot{W}_{Tur4}$
Turbine 5	$\dot{m}_{28}=\dot{m}_{29}$ $\dot{W}_{Tur5}=\dot{m}_{28}[h_{28}-h_{29}]$, $\eta_{is,Tur5}=\frac{h_8-h_{29}}{h_{28}-h_{29,is}}$	$(\dot{E}x_{28}-\dot{E}x_{29})-\dot{W}_{Tur5}$
Turbine 6	$\dot{m}_{30}=\dot{m}_{33}$ $\dot{W}_{Tur6}=\dot{m}_{30}[h_{30}-h_{33}]$, $\eta_{is,Tur6}=\frac{h_{30}-h_{33}}{h_{30}-h_{33,is}}$	$(\dot{E}x_{30}-\dot{E}x_{33})-\dot{W}_{Tur6}$
Compressor 1	$\dot{m}_2=\dot{m}_3$ $\dot{W}_{Comp1}=\dot{m}_1[h_3-h_2]$, $\eta_{is,Comp1}=\frac{h_{3,is}-h_2}{h_3-h_2}$	$\dot{W}_{Comp1}-(\dot{E}x_3-\dot{E}x_2)$
Compressor 2	$\dot{m}_4=\dot{m}_5$ $\dot{W}_{Comp2}=\dot{m}_4[h_5-h_4]$, $\eta_{is,Comp2}=\frac{h_{5,is}-h_4}{h_5-h_4}$	$\dot{W}_{Comp2}-(\dot{E}x_5-\dot{E}x_4)$
Pump 1	$\dot{m}_{23}=\dot{m}_{24}$ $\dot{W}_{Pump1}=\dot{m}_{23}[h_{24}-h_{23}]$, $\eta_{is,Pump}=\frac{h_{24,is}-h_{23}}{h_{24}-h_{23}}$	$\dot{W}_{Pump1}-(\dot{E}x_{24}-\dot{E}x_{23})$
Pump 2	$\dot{m}_{12}=\dot{m}_{25}$ $\dot{W}_{Pump2}=\dot{m}_{25}[h_{12}-h_{25}]$, $\eta_{is,Pump2}=\frac{h_{12,is}-h_{25}}{h_{12}-h_{25}}$	$\dot{W}_{Pump2}-(\dot{E}x_{12}-\dot{E}x_{25})$
Pump 3	$\dot{m}_{35}=\dot{m}_{36}$ $\dot{W}_{Pump3}=\dot{m}_{35}[h_{36}-h_{35}]$, $\eta_{is,Pump3}=\frac{h_{36,is}-h_{35}}{h_{36}-h_{35}}$	$\dot{W}_{Pump2}-(\dot{E}x_{12}-\dot{E}x_{25})$
Separator 1	$\dot{m}_{15}+\dot{m}_{17}=\dot{m}_{14}$ $\dot{m}_{15}h_{15}+\dot{m}_{17}h_{17}=\dot{m}_{14}h_{14}$	$\dot{E}x_{14}-(\dot{E}x_{15}+\dot{E}x_{17})$
Separator 2	$\dot{m}_{20}+\dot{m}_{21}=\dot{m}_{19}$ $\dot{m}_{20}h_{20}+\dot{m}_{21}h_{21}=\dot{m}_{19}h_{19}$	$\dot{E}x_{19}-(\dot{E}x_{20}+\dot{E}x_{21})$
Separator 3	$\dot{m}_{30}+\dot{m}_{31}=\dot{m}_{29}$ $\dot{m}_{30}h_{30}+\dot{m}_{31}h_{31}=\dot{m}_{29}h_{29}$	$\dot{E}x_{29}-(\dot{E}x_{30}+\dot{E}x_{31})$
Separation Vessel	$\dot{m}_{43}+\dot{m}_{45}=\dot{m}_{42}$ $\dot{m}_{43}h_{43}+\dot{m}_{45}h_{45}=\dot{m}_{42}h_{42}$	$\dot{E}x_{42}-(\dot{E}x_{43}+\dot{E}x_{45})$

(continued on next page)

Table 2 (*continued*)

Component	Mass and energy rates	Exergy destruction rate ($\dot{E}x_D^i$)
Mixer 1	$\dot{m}_{21}+\dot{m}_{24}=\dot{m}_{25}$ $\dot{m}_{21}h_{21}+\dot{m}_{24}h_{24}=\dot{m}_{25}h_{25}$	$(\dot{E}x_{21}+\dot{E}x_{24})-(\dot{E}x_{25})$
Mixer 2	$\dot{m}_{18}+\dot{m}_{16}=\dot{m}_{19}$ $\dot{m}_{18}h_{18}+\dot{m}_{16}h_{16}=\dot{m}_{19}h_{19}$	$(\dot{E}x_{18}+\dot{E}x_{16})-(\dot{E}x_{19})$
Mixer 3	$\dot{m}_{32}+\dot{m}_{33}=\dot{m}_{34}$ $\dot{m}_{32}h_{32}+\dot{m}_{33}h_{33}=\dot{m}_{34}h_{34}$	$(\dot{E}x_{32}+\dot{E}x_{32})-(\dot{E}x_{34})$
Mixer 4	$\dot{m}_{38}+\dot{m}_{40}=\dot{m}_{41}$ $\dot{m}_{38}h_{38}+\dot{m}_{40}h_{40}=\dot{m}_{41}h_{41}$	$(\dot{E}x_{38}+\dot{E}x_{40})-(\dot{E}x_{41})$
Valve 1	$\dot{m}_{13}=\dot{m}_{14}$ $\dot{m}_{13}h_{13}=\dot{m}_{14}h_{14}$	$\dot{E}x_{13}-\dot{E}x_{14}$
Valve 2	$\dot{m}_{17}=\dot{m}_{18}$ $\dot{m}_{17}h_{17}=\dot{m}_{18}h_{18}$	$\dot{E}x_{17}-\dot{E}x_{18}$
Valve 3	$\dot{m}_{31}=\dot{m}_{32}$ $\dot{m}_{31}h_{31}=\dot{m}_{32}h_{32}$	$\dot{E}x_{31}-\dot{E}x_{32}$

$$\dot{C}=c\dot{E}_{in}=c(\dot{m}e_{in}) \tag{11}$$

where $\dot{C}$ and c are the cost rate and cost per unit of exergy. Term $\dot{Z}_k$ is calculated as [31]:

$$\dot{Z}_i=\frac{CRF\times\varphi}{N\times3600}\times Z_i \tag{12}$$

where Z_i is the purchase fixed cost of component i, N depicts the annual operation time, φ and CRF refer to the maintenance factor and capital recovery factor, respectively. The term CRF is estimated considering the system's lifetime (n) and interest rate (K) as [31]:

$$CRF=\frac{K(1+K)^n}{(1+K)^n-1} \tag{13}$$

The components' purchase costs are reported for the reference years, and they need to be updated to the recent year by the following [31]:

$$\text{Cost of target year}=Z_i\times\frac{\text{cost index of the target year}}{\text{cost index of the reference year}} \tag{14}$$

in this regard, the components' purchase fixed costs and cost indexes are listed in Table 3.

The estimation of total capital investment costs (TCI) encompasses both fixed-capital investment costs (FCI) and other outlay costs. These additional expenses comprise working capital, research and development costs, construction allowances for funds, start-up expenses, and licensing fees. Since the value of other outlays in cost evaluation is negligible compared to other values, it can be neglected. Consequently, there are two categories of costs: direct and indirect. The TCI term is calculated using the following equation [31]:

$$TCI=FCI+other\ outlays=DC+IC \tag{15}$$

The direct costs and indirect costs of the designed system are presented in Table 4.

As previously mentioned, Net Present Value (NPV) and Payback Period (PP) serve as essential economic performance indicators. These metrics provide insights into the system's economic returns and aid in shaping the economic strategy for the designed system. The NPV index quantifies the net profit accumulated at the conclusion of the system's operational lifespan and is calculated as follows [31]:

Table 3
The components' purchase costs and cost indexes.

Component	Purchase fixed cost	Reference year	Cost index
Combustion Chamber	$Z_{CC}=\left(\dfrac{46.08\times\dot{m}_7}{0.995-\left(\frac{P_8}{P_7}\right)}\right)[1+\exp(0.018\times T_8-26.4)]$	1994	368
Inter Cooler	$Z_{IC}=8000\left(\dfrac{A_{IC}}{100}\right)^{0.6}$	2000	394.1
Air Preheater	$Z_{AP}=4112\left(\dfrac{\dot{m}_9(h_9-h_{10})}{U_{AP}\ \Delta T_{lm,AP}}\right)^{0.6}$	1994	368
Heat exchanger 1	$Z_{Hx1}=2681\ (A_{Hx1})^{0.59}$	1994	368
Heat exchanger 2	$Z_{Hx2}=2681\ (A_{Hx2})^{0.59}$	1994	368
Condenser 1	$Z_{Cond1}=2143\ (A_{Cond1})^{0.514}$	2003	402
Condenser 2	$Z_{Cond2}=2143\ (A_{Cond2})^{0.514}$	2003	402
Condenser 3	$Z_{Cond3}=2143\ (A_{Cond3})^{0.514}$	2003	402
Turbine 1	$Z_{Turb1}=479.34\times\left(\dfrac{\dot{m}_6}{0.93-\eta_{Turb1}}\right)ln\left(\dfrac{P_6}{P_7}\right)\times(1+exp(0.036\times T_6-54.4))$	1994	368
Turbine 2	$Z_{Turb2}=479.34\times\left(\dfrac{\dot{m}_8}{0.93-\eta_{Turb2}}\right)ln\left(\dfrac{P_8}{P_9}\right)\times(1+exp(0.036\times T_8-54.4))$	1994	368
Turbine 3	$Z_{Turb3}=479.34\times\left(\dfrac{\dot{m}_{15}}{0.93-\eta_{Turb3}}\right)ln\left(\dfrac{P_{15}}{P_{16}}\right)\times(1+exp(0.036\times T_{15}-54.4))$	1994	368
Turbine 4	$Z_{Turb4}=479.34\times\left(\dfrac{\dot{m}_{20}}{0.93-\eta_{Turb4}}\right)ln\left(\dfrac{P_{20}}{P_{22}}\right)\times(1+exp(0.036\times T_{20}-54.4))$	1994	368
Turbine 5	$Z_{Turb5}=479.34\times\left(\dfrac{\dot{m}_{28}}{0.93-\eta_{Turb5}}\right)ln\left(\dfrac{P_{28}}{P_{29}}\right)\times(1+exp(0.036\times T_{28}-54.4))$	1994	368
Turbine 6	$Z_{Turb6}=479.34\times\left(\dfrac{\dot{m}_{30}}{0.93-\eta_{Turb6}}\right)ln\left(\dfrac{P_{30}}{P_{33}}\right)\times(1+exp(0.036\times T_{30}-54.4))$	1994	368
Compressor 1	$Z_{Comp1}=\left(\dfrac{71.1\times\dot{m}_2}{0.9-\eta_{is,Comp}}\right)\left(\dfrac{P_3}{P_2}\right)\left[\ln\left(\dfrac{P_3}{P_2}\right)\right]$	1994	368
Compressor 2	$Z_{Comp2}=\left(\dfrac{71.1\times\dot{m}_4}{0.9-\eta_{is,Comp}}\right)\left(\dfrac{P_5}{P_4}\right)\left[\ln\left(\dfrac{P_5}{P_4}\right)\right]$	1994	368
Pump 1	$Z_{Pump1}=2100\left(\dfrac{\dot{W}_{Pump1}}{10}\right)^{0.26}\left(\dfrac{1-\eta_{is,Pump}}{\eta_{is,Pump}}\right)^{0.5}$	2000	394.1
Pump 2	$Z_{Pump2}=2100\left(\dfrac{\dot{W}_{Pump2}}{10}\right)^{0.26}\left(\dfrac{1-\eta_{is,Pump}}{\eta_{is,Pump}}\right)^{0.5}$	2000	394.1
Pump 3	$Z_{Pump3}=2100\left(\dfrac{\dot{W}_{Pump3}}{10}\right)^{0.26}\left(\dfrac{1-\eta_{is,Pump}}{\eta_{is,Pump}}\right)^{0.5}$	2000	394.1

Table 4
The direct and indirect costs.

Term	Equation
Direct costs	Onsite costs + Offsite costs
Onsite costs	
Purchased-equipment cost (PEC)	$\sum Z_i$
Purchased-equipment installation (PEI)	$0.33 \times PEC$
Piping	$0.35 \times PEC$
Electrical equipment and materials	$0.13 \times PEC$
Offsite costs	
Land	$0.05 \times PEC$
Civil, structural, and architectural work	$0.21 \times PEC$
Service facilities	$0.35 \times PEC$
Indirect costs	
Engineering and supervision	$0.08 \times DC$
Construction costs, including contractor's profit	$0.15 \times DC$
Contingencies	$0.15 \times (1.23 \times DC)$

$$NPV_n = -TCI + \sum_{n=0}^{N} Y(1+K)^{-n} \tag{16}$$

Here, 'Y' represents the net cash flow at the conclusion of each year, and its calculation is defined as follows [31]:

$$Y = AI - \left(C^{O\&M} + C_f\right) \tag{17}$$

where AI, $C^{O\&M}$, and C_f are the annual income, operation and maintenance costs, and input fuel cost, which are obtained as [31]:

$$AI = c_{elec} \times t_{year} \times \dot{W}_{net} + c_{fw} \times t_{year} \times \dot{m}_{fw} \tag{18}$$

$$C^{O\&M} = 0.06 \times PEC \tag{19}$$

$$C_f = \dot{C}_1 \tag{20}$$

The evaluation of the PP is conducted using the following equation [31]:

$$PP = min\ \{n : NPV(n) > 0\} \tag{21}$$

Another significant economic performance index is the Sum Unit Cost of Products (SUCP), and its calculation is as follows:

$$SUCP = \frac{\dot{C}_{w,net} + \dot{C}_{44}}{\dot{W}_{net} + \dot{E}x_{44}} \tag{22}$$

The economic analysis necessitates specific input data, which are detailed in Table 5. Additionally, the components' cost balance and corresponding auxiliary equations are provided in Table 6.

4. Results and discussions

This section pertains to the obtained results, which encompass various aspects, including the verification of the simulation procedure, presentation of the primary findings, exergy analysis, sensitivity analysis, and an economic assessment. Within the economic analysis, both the PP and NPV are evaluated under different economic strategies.

Table 5
The economic analysis input data.

Parameter	Value
Plant expected life, n (years)	20
Annual number of hours, t_{year} (hours)	7446
Interest rate, i_r (%)	15
Fuel price, c_F (\$/GJ)	4.57
Electricity price, c_{ele} (\$/ kWh)	0.10
Freshwater price, c_{fw} (\$/ m^3)	1.8
CEPCI for 2020	668
Maintenance factor, φ_r	1.06

Table 6
The components cost balance equations and corresponded auxiliary equations.

Component	Cost balance	Auxiliary equations
Combustion Chamber	$\dot{C}_1 + \dot{C}_7 + \dot{Z}_{CC} = \dot{C}_8$	–
Inter Cooler	$\dot{C}_{12} + \dot{C}_3 + \dot{Z}_{IC} = \dot{C}_{13} + \dot{C}_4$	$c_{12} = c_{13}$
Air Preheater	$\dot{C}_5 + \dot{C}_9 + \dot{Z}_{AP} = \dot{C}_6 + \dot{C}_{10}$	$c_9 = c_{10}$
Heat exchanger 1	$\dot{C}_{10} + \dot{C}_{36} + \dot{Z}_{Hx1} = \dot{C}_{11} + \dot{C}_{28}$	$c_{10} = c_{11}$
Heat exchanger 2	$\dot{C}_{37} + \dot{C}_{45} + \dot{Z}_{Hx2} = \dot{C}_{38} + \dot{C}_{46}$	$c_{45} = c_{46}$
Condenser 1	$\dot{C}_{22} + \dot{C}_{26} + \dot{Z}_{Cond1} = \dot{C}_{23} + \dot{C}_{27}$	$c_{22} = c_{23}$
Condenser 2	$\dot{C}_{34} + \dot{C}_{41} + \dot{Z}_{Cond2} = \dot{C}_{35} + \dot{C}_{42}$	$c_{34} = c_{35}$
Condenser 3	$\dot{C}_{39} + \dot{C}_{43} + \dot{Z}_{Cond3} = \dot{C}_{40} + \dot{C}_{44}$	$c_{43} = c_{44}$
Turbine 1	$\dot{C}_6 + \dot{Z}_{Tur1} = \dot{C}_7 + \dot{C}_{W,Tur1}$	$c_6 = c_7$
Turbine 2	$\dot{C}_8 + \dot{Z}_{Tur2} = \dot{C}_9 + \dot{C}_{W,Tur2}$	$c_8 = c_9$
Turbine 3	$\dot{C}_{15} + \dot{Z}_{Tur3} = \dot{C}_{16} + \dot{C}_{W,Tur3}$	$c_{15} = c_{16}$
Turbine 4	$\dot{C}_{20} + \dot{Z}_{Tur4} = \dot{C}_{22} + \dot{C}_{W,Tur4}$	$c_{20} = c_{22}$
Turbine 5	$\dot{C}_{28} + \dot{Z}_{Tur5} = \dot{C}_{29} + \dot{C}_{W,Tur5}$	$c_{28} = c_{29}$
Turbine 6	$\dot{C}_{30} + \dot{Z}_{Tur6} = \dot{C}_{33} + \dot{C}_{W,Tur6}$	$c_{30} = c_{33}$
Compressor 1	$\dot{C}_2 + \dot{C}_{W,Comp1} + \dot{Z}_{Comp1} = \dot{C}_3$	$c_{W,Comp1} = c_{W,Tur3}$
Compressor 2	$\dot{C}_4 + \dot{C}_{W,Comp2} + \dot{Z}_{Comp2} = \dot{C}_5$	$c_{W,Comp2} = c_{W,Tur1}$
Pump 1	$\dot{C}_{23} + \dot{C}_{W,Pump1} + \dot{Z}_{Pump1} = \dot{C}_{24}$	$c_{W,Pump1} = c_{W,Tur4}$
Pump 2	$\dot{C}_{25} + \dot{C}_{W,Pump2} + \dot{Z}_{Pump2} = \dot{C}_{12}$	$c_{W,Pump2} = c_{W,Tur4}$
Pump 3	$\dot{C}_{35} + \dot{C}_{W,Pump3} + \dot{Z}_{Pump3} = \dot{C}_{36}$	$c_{W,Pump3} = c_{W,Tur5}$
Separator 1	$\dot{C}_{14} + \dot{Z}_{Sep} = \dot{C}_{15} + \dot{C}_{17}$	$c_{15} = c_{17}$
Separator 2	$\dot{C}_{19} + \dot{Z}_{Sep} = \dot{C}_{20} + \dot{C}_{21}$	$c_{20} = c_{21}$
Separator 3	$\dot{C}_{29} + \dot{Z}_{Sep} = \dot{C}_{30} + \dot{C}_{31}$	$c_{30} = c_{31}$
Separation Vessel	$\dot{C}_{42} + \dot{Z}_{SV} = \dot{C}_{43} + \dot{C}_{45}$	$c_{43} = c_{45}$
Mixer 1	$\dot{C}_{21} + \dot{C}_{24} + \dot{Z}_{Mixer} = \dot{C}_{25}$	–
Mixer 2	$\dot{C}_{16} + \dot{C}_{18} + \dot{Z}_{Mixer} = \dot{C}_{19}$	–
Mixer 3	$\dot{C}_{32} + \dot{C}_{33} + \dot{Z}_{Mixer} = \dot{C}_{34}$	–
Mixer 4	$\dot{C}_{38} + \dot{C}_{40} + \dot{Z}_{Mixer} = \dot{C}_{41}$	–
Valves		
Valve 1	$\dot{C}_{14} + \dot{Z}_{E.V} = \dot{C}_{14}$	–
Valve 2	$\dot{C}_{17} + \dot{Z}_{E.V} = \dot{C}_{18}$	–
Valve 3	$\dot{C}_{31} + \dot{Z}_{E.V} = \dot{C}_{32}$	–

Table 7
The Kalina cycle's simulation verification.

Parameter	unit	Reference value	Simulated value	Error (%)
$\dot{W}_{net}$	kW	285.6	274.3	3.95
$\dot{Q}_{VG}$	kW	3906	3936	0.76
η_{th}	%	7.17	6.95	3.06
X_{KT}	%	99.97	99.97	0.00

Table 8
The simulation procedure input data.

Parameter	Value	Unit
Standard condition pressure, P_0	1.013	bar
Standard condition temperature, T_0	298.15	K
Gas turbines' isentropic efficiency, $\eta_{is,GT}$	86	%
Steam turbine's isentropic efficiency, $\eta_{is,ST}$	88	%
OFC turbine's isentropic efficiency, $\eta_{is,OFC,Tur}$	80	%
Compressor's isentropic efficiency, $\eta_{is,Comp}$	80	%
Pumps' isentropic efficiency of, $\eta_{is,Pump}$	86	%
Pressure ratio of Compressor 1, r_{P1}	14	[−]
Pressure ratio of Compressor 2, r_{P2}	5	[−]
Combustion temperature, T_8	1500	K
Combustion chamber pressure drop, ΔP_{CC}	5	%
Gasification temperature, T_g	1073.15	K
Gasification pressure, P_g	4	bar
Intercooler's cold end temperature difference $CETD_{IC}$	20	[K]
Air preheater effectiveness, ε_{AP}	0.85	[−]
Hot end temperature difference of heat exchanger 1 $HETD_{HX1}$	100	[K]

4.1. Simulation verification

The simulation of the designed system is executed using an ESS code, applying mass, energy, exergy, and exergoeconomic analyses to various system components. To ensure the accuracy of the simulation procedure, a verification step is essential. In this context, a simulation of the Kalina cycle is conducted, utilizing the assumptions outlined by Wang et al. [29], and the results obtained are compared with their findings. Table 7

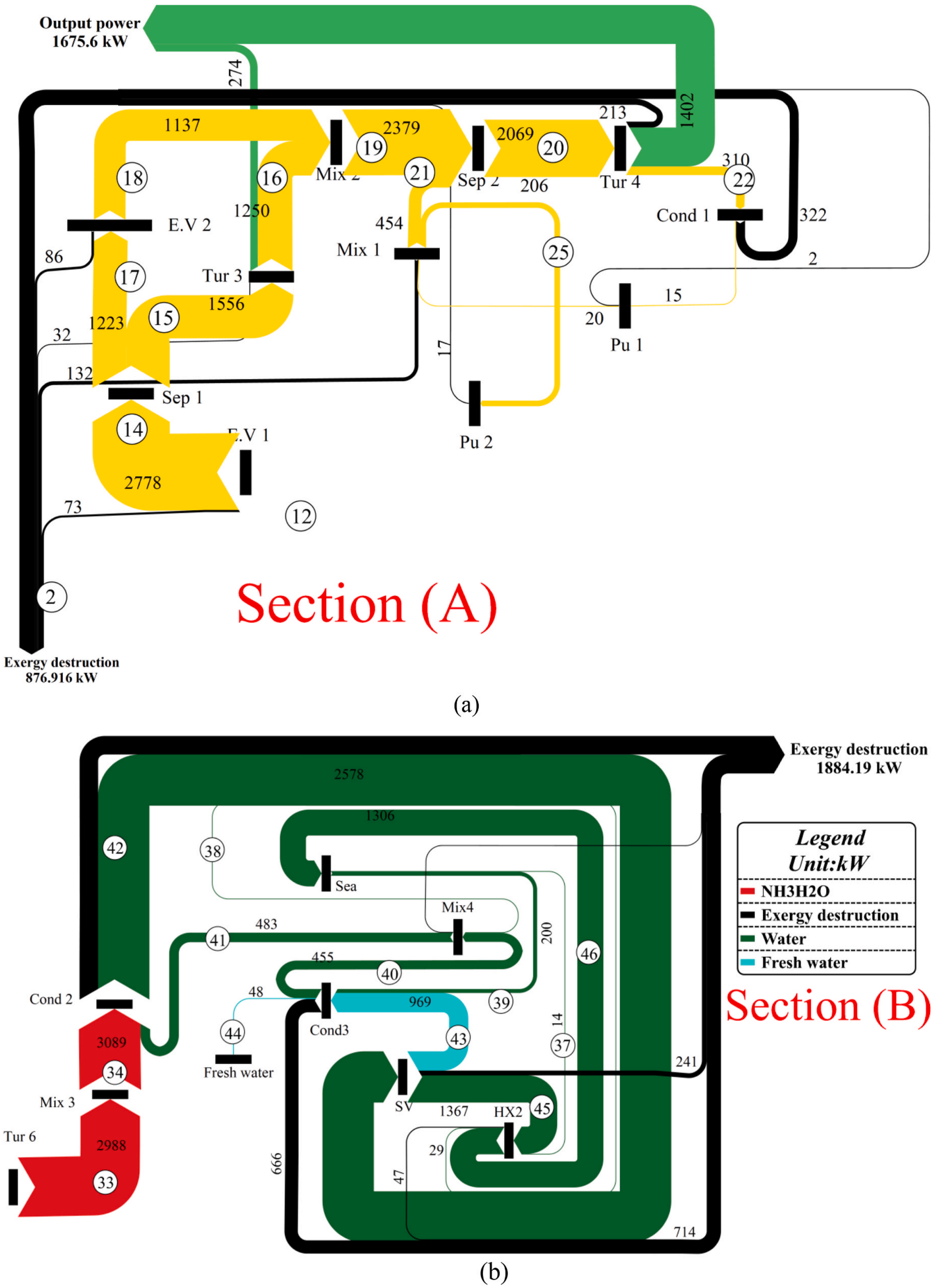
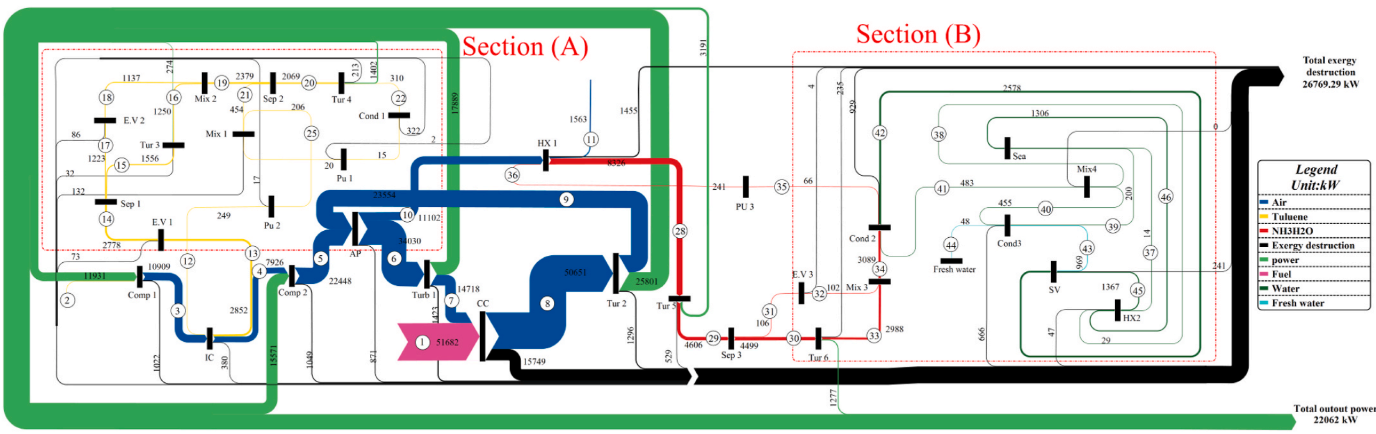


Fig. 3. The designed system exergy flow as a Sankey diagram.



(c)

Fig. 3. (*continued*).

presents this comparative analysis, where different performance indices are juxtaposed. The data presented in this table serve as a validation of the concepts employed in simulating the designed system and reaffirm the accuracy of the obtained results.

4.2. Main results

The simulation of the designed system was performed, taking into account the input data provided in Table 8. The system's products, namely, the net power and freshwater production rates, were determined to be approximately 22.06 MW and 2.87 kg/s, respectively. These product values correspond to an exergetic efficiency of 42.60 % and a SUCP of 22.67 \$/GJ. As a result, the system's payback period is estimated to be approximately 4.86 years, leading to a net profit of 38.53 million dollars over its operational lifetime.

4.3. Exergy analysis

Exergy is a vital parameter for evaluating energy systems as it quantifies the quality of processes within system components. To visually represent the exergy flow within the designed system, a Sankey diagram, depicted in Fig. 3, has been constructed. The Sankey diagram consists of three sections: Section A corresponds to the Double-Flash Organic Flash Cycle (DF-OFC) subsystem, Section B represents the Modified Single-Flash Desalination Unit (SSF) subsystem's exergy flow, and the overall system.

Fig. 3a presents the exergy flow within the DF-OFC subsystem. The inlet stream of Separator 1 carries an exergy rate of 2778 kW, with 1556 kW of it entering Turbine 3, resulting in Turbine 3 generating 274 kW of power. The primary power generation in the DF-OFC subsystem, approximately 1402 kW, is provided by Turbine 4 due to its higher inlet mass flow rate. Additionally, the total exergy destruction within this subsystem is calculated at approximately 876.92 kW.

Fig. 3b illustrates the exergy flow within the SSF subsystem. Notably, the main preheating process of the input seawater occurs in Condenser 2, while Heat Exchanger 2 contributes a smaller portion. The total exergy destruction within the SSF subsystem is estimated to be approximately 1884.19 kW.

Fig. 3c depicts the exergy flow for the entire system. Compressor 1 consumes 11931 kW for air compression, and Compressor 2 requires 15571 kW to reach the desired pressure. Consequently, the inlet stream of Turbine 1 carries 34030 kW of exergy, generating 17889 kW of power. The input fuel possesses an exergy rate of 51682 kW, and after the combustion process, the input exergy rate of Turbine 2 reaches 50651 kW, resulting in 25801 kW of power generation. Additionally, the combustion flue gas transfers 8084 kW of exergy to the Kalina cycle,

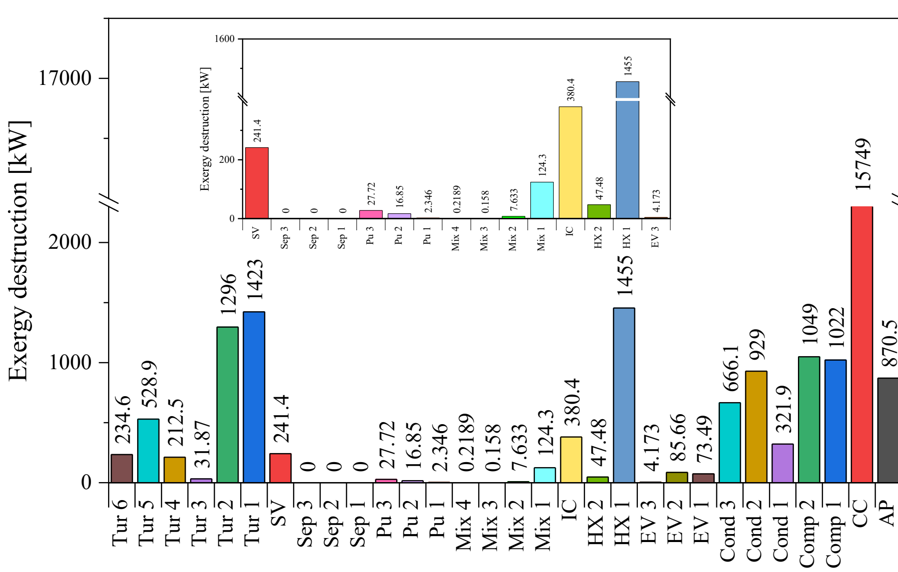


Fig. 4. The components' exergy destruction values.

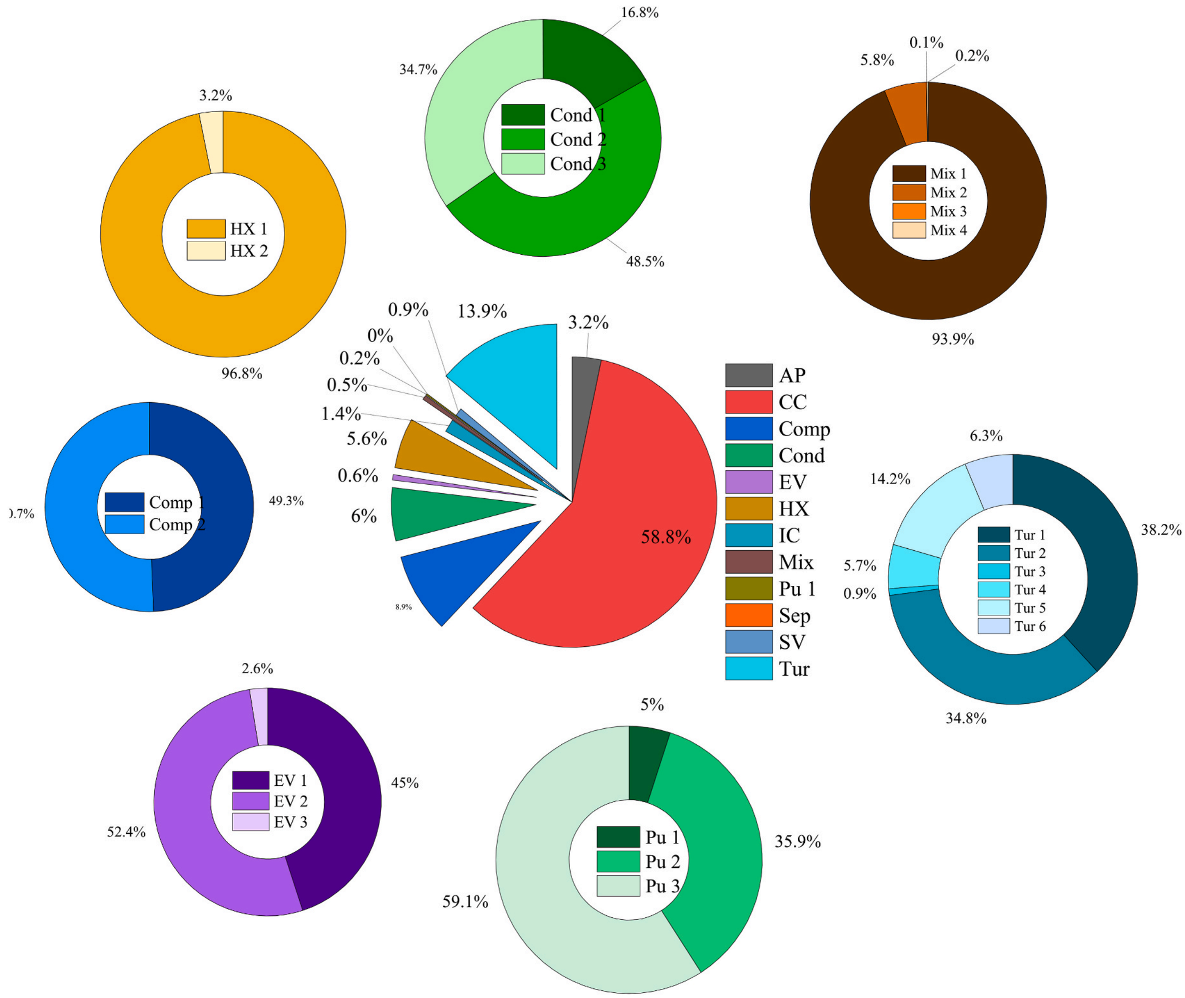


Fig. 5. The distribution of the exergy destruction in the components.

with 1563 kW of exergy being transferred to the ambient. The total exergy destruction rate for the entire system is calculated to be approximately 26769.29 kW.

The value of exergy destruction within various components is specified in Fig. 4, and their distributions are further detailed in Fig. 5. Notably, the combustion chamber, owing to the chemical reactions and higher exergy flows in its input streams, accounts for the highest exergy destruction at approximately 15749 kW, comprising 58 % of the total exergy destruction. Following the combustion chamber, the turbines contribute significantly to exergy destruction, with the second highest being approximately 1423 kW. Turbines collectively account for about 13.9 % of the total exergy destruction. Among the heat exchanger-based components, Heat Exchanger 1 has the highest exergy destruction at about 1455 kW. Furthermore, among the condensers, Condenser 2

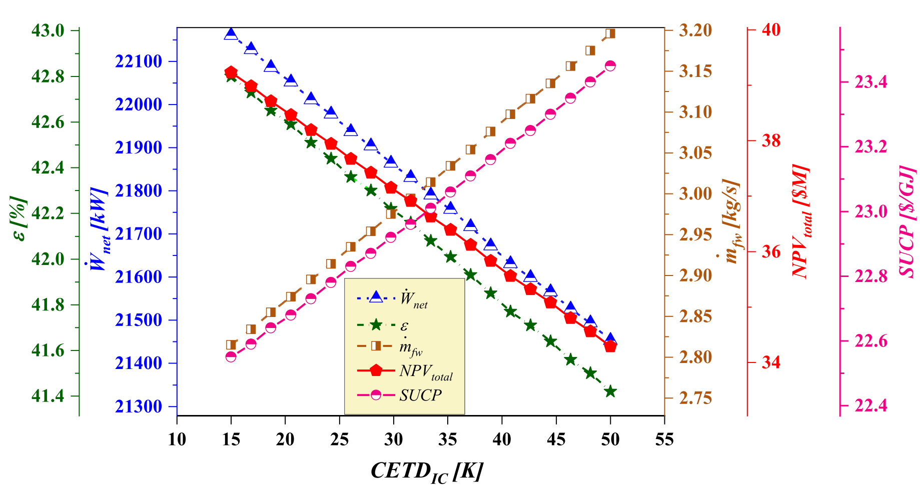


Fig. 6. The intercooler cold end temperature's effect on the performance indexes.