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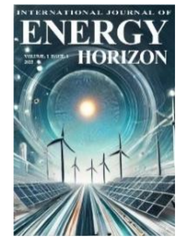

Research Article

Thermo-economic analysis of a pressurized-water-reactor cogeneration plant for electricity and water production

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A B S T R A C T

The high demand for stable electricity and freshwater has increased interest in nuclear cogeneration systems that can provide multiple outputs with high efficiency and minimal environmental impact. This study examines a cogeneration system utilizing a pressurized-water reactor (PWR) that concurrently produces electricity and freshwater through multi-effect distillation (MED). Electricity is produced by a regenerative Rankine cycle utilizing high-, intermediate-, and low-pressure turbines, and the MED unit is powered by low-pressure extraction steam. A detailed thermodynamic model, created in Engineering Equation Solver (EES), assesses mass, energy, and exergy balances across the integrated system, encompassing feedwater heating, moisture-separator-reheater, and MED coupling. The basic configuration produces a net electrical output of 1188 MW_e and generates freshwater at a rate of 200 kg/s (about 6.3 million m³ annually), with a thermal efficiency of 34.7% and a net levelized cost of electricity ($LCOE_{net}$) of 29.1 USD/MWh. Parametric optimization of turbine isentropic and pump efficiencies, feedwater heater terminal temperature differential, MED gain output ratio, and cooling water temperature rise showed an ideal design that reduces $LCOE_{net}$ to 28.7 USD/MWh while boosting net power to 1245 MW_e. The findings indicate that low-grade thermal energy can be utilized for desalination with no impact on electrical output, hence enhancing the plant's total energy efficiency. The proposed PWR-MED cogeneration system offers a technically feasible, economically viable, and thermodynamically consistent approach for tackling the energy-water nexus in water-scarce areas with existing or projected nuclear infrastructure.

1. INTRODUCTION

The dual generation of electricity and freshwater has been extensively studied as a strategic solution to rising global energy demands and water scarcity, especially in dry and coastal regions. Nuclear power plants (NPPs), due to their substantial thermal capacity, low carbon emission, and dependable baseload operation, have been recognized and accepted as appropriate for cogeneration uses beyond mere electricity generation [1–3]. Pressurized water reactors (PWRs) are the predominant technology in the global nuclear fleet and provide advantageous secondary-side steam conditions for integration with thermal desalination systems [4]. Many researchers have investigated nuclear-assisted desalination employing both membrane and thermal processes. Reverse osmosis (RO) systems powered by nuclear-generated electricity have been extensively proposed and evaluated, especially in hybrid configurations that integrate RO and thermal desalination [5]. Simultaneously, thermal desalination systems like multi-stage flash (MSF) and multi-effect distillation (MED) have been examined for direct integration with nuclear steam cycles, utilizing low-grade thermal energy derived from turbine stages [6–8]. Comparative studies consistently indicate that MED provides enhanced thermodynamic efficiency at reduced operating temperatures, rendering it particularly suitable for low-pressure steam extraction from Rankine cycles in PWR-based facilities [9].

Numerous researchers have performed thermodynamic, exergetic, and economic assessments of PWR–MED cogeneration systems. K Ansari et al. [10] optimized a pressurized water reactor (PWR) integrated with a multi-effect distillation and thermal vapor compression (MED-TVC) desalination unit, demonstrating that the adjustment of steam extraction pressure and mass flow can substantially decrease freshwater production costs with minimal effect on electrical output. Subsequent studies augmented this methodology by integrating exergy analysis and operational flexibility, underscoring the need for cohesive modeling of the power cycle and desalination unit [11–13]. Triki et al. [16] conducted energy and exergy analysis of a full-scale 1300 MWe PWR coupled with an ME-TVC-MED desalination plant based on real operational data from the Angra II nuclear power plant and the Al-Jubail desalination facility. Their component-level analysis showed that the reactor core accounts for 50.28% of total system exergy destruction, while turbines contribute 5.8% and the MED-TVC desalination subsystem exhibits a low exergetic efficiency of only 6.43%, with evaporators and the thermo-compressor being the dominant sources of irreversibility within the desalination unit. The overall plant thermal efficiency was reported as 35.38%, consistent with results from comparable PWR-MED configurations. These findings confirm the importance of component-level exergy breakdown in identifying thermodynamic bottlenecks — a methodology adopted and extended

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in the present study to quantify irreversibility in the secondary Rankine cycle and feedwater heating train.

El-Ashmawy et al. [17] performed a thermo-economic comparison of five nuclear-coupled desalination configurations — RO, MED, MSF, MED+RO, and MSF+RO — using the IAEA's DE-TOP and DEEP-5 software tools applied to real Egyptian desalination plants. Their results showed that RO is the most cost-effective single technology at 1.01 USD/m³, while the MED+RO hybrid produced water at 1.192 USD/m³, outperforming MSF+RO by 0.36 USD/m³. Thermodynamic optimization identified the LP heater-2 extraction point as the optimal steam extraction location for MED operation. The study further demonstrated that replacing conventional oil-fired power with nuclear energy reduces CO_2 emissions from 0.8 to 0.029 kg/kWh. These findings reinforce the economic rationale for MED-based nuclear cogeneration and highlight the importance of optimizing steam extraction points — a consideration directly relevant to the design of the PWR-MED system presented in this work. Alessi and Al-Rabiah [18] investigated the economic feasibility of replacing fossil fuel boilers with a dedicated nuclear heating reactor (NHR170, 169 MWth) to power an existing MED-TVC desalination plant in Saudi Arabia, simulated in Aspen Plus and evaluated using the IAEA DEEP program. The nuclear option yielded a freshwater cost of 1.38 USD/m³ versus 0.95 USD/m³ for oil at the heavily subsidized domestic price of 4.4 USD/barrel. However, nuclear becomes cost-competitive when domestic oil prices exceed 15 USD/barrel or a carbon tax of 20 USD/ton is imposed — conditions increasingly plausible under current global energy policy trends. The analysis also quantified an annual GHG saving of 543,235 tons if nuclear energy replaces crude oil. These findings are directly relevant to the economic context of the PWR-MED system examined in this study, particularly regarding the sensitivity of water production cost to capital investment and financing conditions. These studies validate the technological viability of nuclear-driven MED desalination and highlight its capacity for extensive freshwater generation. Notwithstanding these advancements, the majority of current research addresses the power cycle and desalination unit in a rudimentary or loosely interconnected fashion, with insufficient focus on the intricate interplay of regenerative feedwater heating, flash tank dynamics, and desalination steam extraction. The impact of MED steam extraction on feedwater heater performance, condenser loading, and overall cycle efficiency is inadequately characterized in the existing literature.

This paper develops a thermodynamic model of a PWR-based cogeneration system that explicitly incorporates turbine steam extraction, regenerative feedwater heating, flash tank operation, and MED desalination integration. The methodology offers a cohesive framework for assessing electricity-water cogeneration performance using a consolidated mass, energy, and exergy balance formulation. The original contribution of this work lies in its explicit, fully-integrated thermodynamic treatment of regenerative feedwater heating, flash tank dynamics, MED steam extraction, and economic optimization within a single PWR-based cogeneration model—an approach that has not been comprehensively presented in prior literature.

2. MATERIALS AND METHODS

2.1. System Description

This system describes an integrated cogeneration plant designed for dual production of electricity and freshwater. The core power cycle is a regenerative steam turbine system. High-pressure (HP) steam from the steam generator expands through the HP turbine, subsequently undergoes drying and reheating in the Moisture Separator Reheater (MSR), and finally propels the intermediate-pressure (IP) turbine and low-pressure (LP) turbine. These turbines jointly operate a generator for power generation. Steam is extracted at multiple stages from the turbines to preheat the boiler feedwater. Extracts from the LP Turbine and IP Turbine provide the Low and Intermediate Pressure Heaters (LPH - IPH) and the deaerator, which eliminates dissolved gases. The boiler feed pump subsequently pressurizes the deaerated water through high-pressure heaters (HPH), which are heated by extraction from the HP turbine, before its return to the steam generator. The thermal desalination is conducted by a multi-effect distillation (MED) desalination unit. It utilizes extracted steam, generally from the IP turbine cycle, as its thermal energy source. The unit treats feedwater sourced from a seawater intake. The main product is distilled fresh water, while the remaining concentrate (brine) is discharged back into the sea through the concentrate return line. A condensate pump manages condensed steam from the system.

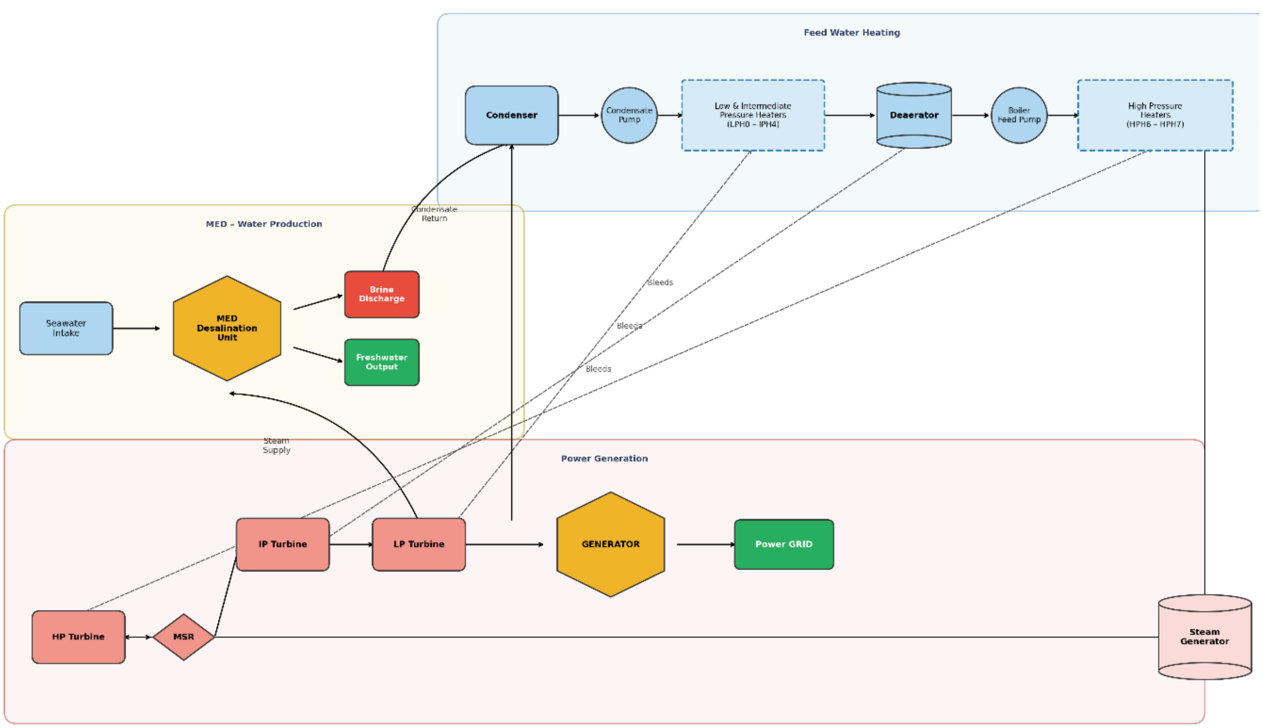


Figure 1. Process flow diagram (PFD) of the PWR-MED cogeneration system

2.2. Model Assumptions

The entire system is modeled in Engineering Equation Solver (EES) using component-wise mass, energy, and exergy balance equations. The principal boundary conditions are: reactor thermal output $\dot{Q}_{RX}$ = 3200 MW_{th}; main steam pressure p_{main} = 7000 kPa; main steam temperature T0 = 285.9 °C; MED freshwater production rate $\dot{m}_{fw}$ = 200 kg/s; dead-state temperature T_0 = 25 °C and pressure p_0 = 101.325 kPa (for exergy calculations). The following assumptions were made for the thermodynamic modeling of the system:

i. The thermodynamic model is developed under steady-state conditions
ii. Pressure drop in pipes and heat exchangers is neglected.
iii. Turbines and pumps operate with constant isentropic efficiencies.
iv. Heat losses to the environment are neglected
v. MED unit operates at constant gain output ratio (GOR)

2.3. Thermodynamic Modeling

Mass and energy conservation equations are applied to all major components of the cogeneration system as:

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \quad (1)$$

$$\sum \dot{m}_{in} h_{in} + \dot{Q} - \dot{W} = \sum \dot{m}_{out} h_{out} \quad (2)$$

Turbines

$$\dot{W}_t = \dot{m}\left(h_{in} - h_{out,act}\right) \quad (3)$$

$$h_{out,act} = h_{in} - \eta_t\left(h_{in} - h_{out,s}\right) \quad (4)$$

Feedwater Heaters

$$\dot{m}_{fw}\left(h_{fw,out} - h_{fw,in}\right) = \dot{m}_{ext}\left(h_{ext} - h_{drain}\right) \quad (5)$$

$$T_{fw,out} = T_{sat,ext} - TTD \quad (6)$$

Flash Tank

$$\dot{m}_d = \dot{m}_v + \dot{m}_l \quad (7)$$

$$\dot{m}_d h_d = \dot{m}_v h_g + \dot{m}_l h_f \quad (8)$$

MED desalination

The MED unit was modeled as a thermal desalination process driven by low-pressure extraction steam from the turbine. Freshwater production was calculated based on the thermal energy supplied to the MED unit and the corresponding latent heat of vaporization, consistent with reported MED performance by [9].

$$\dot{Q}_{MED} = \dot{m}_{MED}\left(h_{steam} - h_{cond}\right) \quad (9)$$

$$\dot{m}_{fw,MED} = \frac{\dot{Q}_{MED}}{h_{fw,eff}} \quad (10)$$

The $h_{fw,eff}$ in Equation 10 represents the effective specific enthalpy of evaporation of feedwater in the MED unit, defined as $h_{fw,eff} = h_{fg}$ / GOR, where h_{fg} is the latent heat of vaporization at the MED operating temperature, and GOR is the gain output ratio. The constant GOR assumption is a simplification; in a real MED system, GOR varies with the number of effects and operating conditions. This limitation is acknowledged and discussed further in Section 3.3.

Net power is calculated as the difference between turbine output and pump consumption:

$$\dot{W}_{net} = \dot{W}_t - \dot{W}_P \quad (11)$$

The overall thermal efficiency

$$\eta_{th} = \frac{\dot{W}_{net}}{\dot{Q}_{RH} + \dot{Q}_{SG}} \quad (12)$$

Where Q_{SG} and Q_{RH} are the steam generator and reheater thermal duties, respectively. The net electrical output reported in this study is the power delivered to the grid after subtracting all internal parasitic loads. These parasitic loads include the boiler feed pump (BFP), condensate pump (CP), and cooling water pump.

Specific exergy:

$$ex = (h_i - h_0) - T_0(s_i - s_0) \quad (13)$$

Exergy efficiency

$$\eta_{ex} = \frac{\dot{W}_{net}}{\dot{Ex}_{in}}$$

2.3. Thermo-Economic Model and Validation

The levelized cost of electricity net of water revenue ($LCOE_{net}$) is considered the primary economic metric. Capital costs for turbines, pumps, heat exchanges, and the MED unit are scaled using power-law functions referenced to known equipment costs [14,15]. The MED capital cost is correlated with GOR and capacity, given as:

$$MED_{cost} = MED_{cost,ref}\left(\left(\frac{GOR_{ref}}{GOR}\right)^{0.6}\right)\left(\left(\frac{\dot{m}_{water}}{200}\right)^{0.8}\right) \quad (15)$$

Where $MED_{cost,ref}$ = 5 x 10^6 USD at GOR = 10 and $\dot{m} = 200 kg/s$. Annual costs include capital recovery factor (CRF = 0.08386, corresponding to 8% discount rate and 40-year plant life), fixed and variable operation and maintenance (O&M), and fuel cost. Water revenue is calculated at a scale of 1.5 USD/m^3.

The presented model results are validated by comparison with El-Nashar and Al-Mansoori [9] under equivalent steam-extraction conditions yields a thermal efficiency of 34.7% versus their 34.2%, and an $LCOE_{net}$ of 29.1 USD/MWh within 3% of their 30.2 USD/MWh. As a secondary validation, the model was run at the reactor conditions of Triki et al. [16] (3855 MWth), yielding a thermal efficiency of 34.68% against their reported 35.38% — a deviation of 2%, within acceptable modeling uncertainty.

3. RESULTS AND DISCUSSION

3.1. Baseline System Performance

The baseline cogeneration system was modeled under the design conditions specified in Table 1. The net electrical output was 1188 MW_e, with a thermal efficiency of 34.7% and an exergy efficiency of 45.2%. Freshwater production was fixed at 200 kg/s (≈6.3×10^6 m^3/yr), corresponding to a gain output ratio (GOR) of 10. The total heat exchanger area reached 185200 m^2, of which the condenser accounted for approximately 81%. The levelized cost of electricity before accounting for water revenue (LCOE) was 30.1 USD/MWh. After deducting the annual water revenue (9.46 million USD/yr), the net LCOE ($LCOE_{net}$) was 29.1 USD/MWh.

Table 1. Baseline thermodynamic and economic performance of the cogeneration system

Parameter	Value	Unit
Thermal input [$\dot{Q}RX$]	3200	MW_{th}
Main steam pressure	7000	kPa
Main steam temperature	285.9	°C
Main steam mass flow rate	1773	Kg/s
Net electric output	1188	MW_e
Thermal efficiency η_{th}	34.68	%
Exergy efficiency η_{ex}	45.2	%
MED freshwater production	200	Kg/s
Annual freshwater production	6.307e6	M^3/yr
Gain output ratio (GOR)	10	-
Total heat exchanger area (A_{total})	185198	m^2
Total capital cost (CAPEX)	2.317e9	USD
Annual water revenue	9.461e6	USD/yr
Levelized cost of electricity (LCOE)	30.1	USD/MWh
LCOE net of water revenue ($LCOE_{net}$)	29.1	USD/MWh

The system exergy efficiency of 45.2% reflects the ratio of net power output to the total exergy input from the reactor. A component-level exergy destruction breakdown and the rate derived from the thermodynamic model is presented in Table 2 and Figure 2. The LP turbine is the single largest source of exergy destruction at 81,927 kW, followed closely by the deaerator (81,003 kW) and the HP turbine (53,167 kW). The condenser accounts for 44,016 kW, while the IP turbine contributes 24,355 kW. Among the feedwater heaters, LPH2 (7,961 kW) and IPH3 (7,207 kW) are the most significant, while the MSR exhibits negligible exergy destruction (~0 kW), confirming its near-ideal separation and reheating performance. These results indicate that turbine irreversibilities (combined HP + IP + LP = 159,449 kW) and the deaerator are the dominant targets for thermodynamic improvement. The high deaerator destruction arises from the large enthalpy difference between incoming streams mixing at different temperatures and pressures. Future design improvements should therefore prioritize advanced turbine blade profiles to reduce moisture losses in the LP stages, and staged deaeration or improved mixing to reduce irreversibility in the deaerator.

Table 2. Component-level exergy destruction in the PWR-MED cogeneration system under baseline conditions

Component	Exergy Destruction (kW)
LP Turbine	81,927
Deaerator	81,003
HP Turbine	53,167
Boiler Feed Pump	33,557
Condenser	44,016
IP Turbine	24,355
LPH2 (FWH)	7,961
IPH3 (FWH)	7,207
Other FWHs + CP	~2,900
MSR	≈ 0

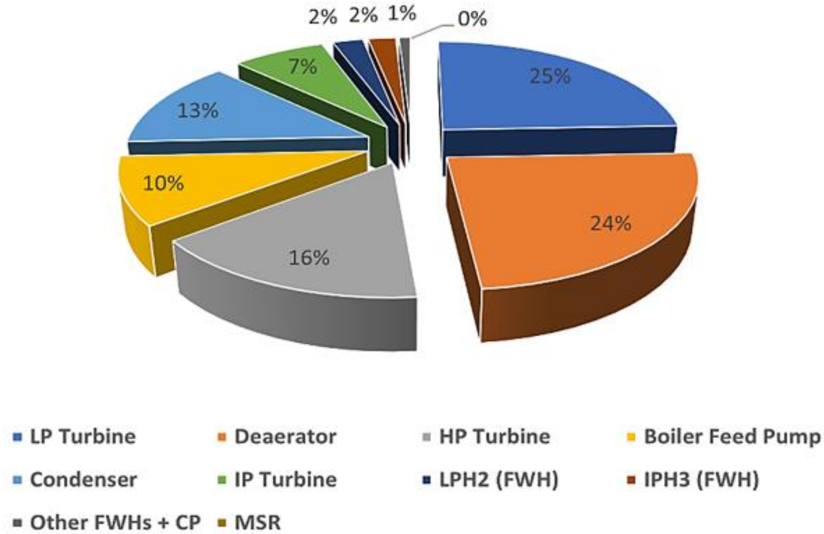
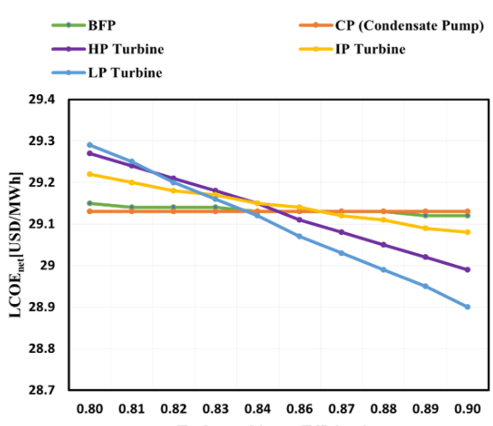


Figure 2. Rate of exergy destruction in the cogeneration plant component

2.3. Thermo-Economic Model and Validation

Figure 3 illustrates the effect of simultaneously varying the isentropic efficiencies of all turbines and pumps from 0.80 to 0.90. As efficiency increased, $LCOE_{net}$ decreased linearly from 29.57 USD/MWh to 28.7 USD/MWh, while net power ($\dot{W}_{net}$)i) increased from 1135 MW_e to 1245 MW_e. This trend is expected, as higher isentropic efficiency directly reduces irreversibility in turbomachinery, thereby increasing work output per unit mass of steam. The corresponding improvement in $\dot{W}_{net}$ (≈110 MW_e over the range) is attributable to both increased turbine work and reduced pump consumption. The economic benefit, however, is contingent upon the cost premium associated with high-efficiency equipment. In the present model, the capital cost of turbines and pumps scales only with size (via the scaling exponent n_{TG} = 0.75), not explicitly with efficiency. In practice, achieving η = 0.90 would likely entail advanced blade designs, tighter tolerances, and superior materials, all of which increase capital cost. Future work should incorporate a cost–efficiency correlation to identify the true economic optimum. Nevertheless, the strong sensitivity of $LCOE_{net}$ to η underscores that turbomachinery performance is a critical lever for improving the economics of nuclear cogeneration plants.



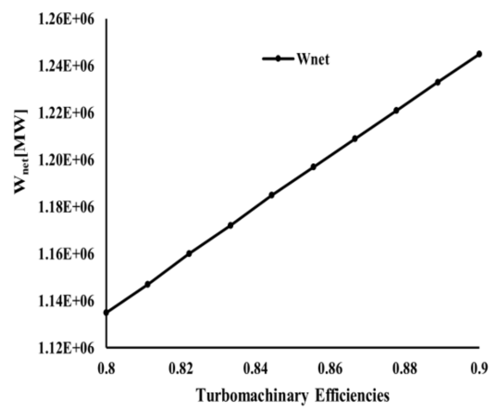


Figure 3. Effect of turbine isentropic and pump efficiencies on the (a) levelized cost of electricity net of water revenue (b) net power

The terminal temperature difference (TTD) of all feedwater heaters was varied from 3 °C to 10 °C (Figure 4). Larger TTD values reduce the required heat-transfer area (and hence capital cost) but degrade cycle efficiency due to poorer thermal recovery. The minimum $LCOE_{net}$ occurred at TTD ≈ 9°C –10 °C, where the capital-cost reduction outweighed the efficiency penalty. At TTD = 10 °C, the total heat-exchanger area decreased by ~6% compared to the 3 °C case, while thermal efficiency dropped only 0.9 percentage points (from 34.76% to 34.42%). This relatively modest efficiency loss explains why $LCOE_{net}$ is only marginally sensitive to TTD (a change of <0.5% across the range). The optimum TTD found here is higher than the typical design value of 3°C –5 °C often assumed in textbook cycles [14], highlighting that in capital-intensive nuclear plants, accepting a slightly larger TTD can yield a better economic outcome without significantly compromising performance. This finding aligns with the work of Nafey et al. [8], who reported that in combined power-desalination plants, the optimum TTD tends to shift to higher values when heat-exchanger costs are explicitly considered.

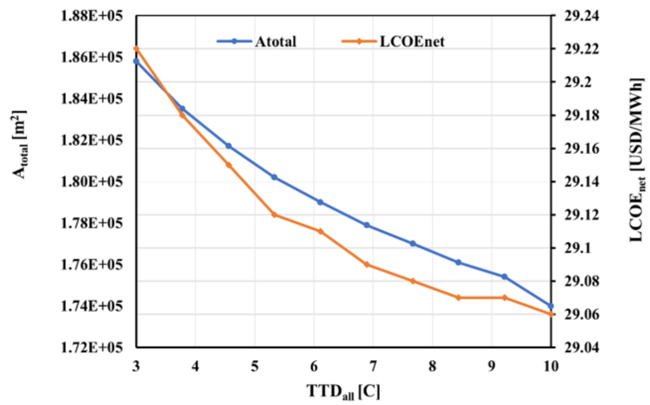


Figure 4. Influence of feedwater-heater TTD on $LCOE_{net}$ and total heat exchanger area

Figure 5 presents the influence of the MED gain output ratio (GOR) on $LCOE_{net}$ and MED capital cost. Increasing GOR from 8 to 12 reduced the specific steam consumption for a fixed water output, thereby increasing net power by ≈1 MW_e per unit GOR. Concurrently, the MED capital cost decreased from 5.7 million USD to 4.5 million USD due to the reduced specific heat-transfer area. Despite these opposing effects, $LCOE_{net}$ remained nearly constant (29.14 USD/MWh – 29.11 USD/MWh). This insensitivity arises because the reduction in MED capital cost is almost entirely offset by the slightly lower water revenue (due to the fixed water price) and the minimal change in power revenue. The result implies that, within the typical MED design range (GOR = 8–12), the selection of GOR is not a decisive economic factor for the overall plant, provided the MED cost scales as modeled. This finding is consistent with El-Nashar & Al-Mansoori [9], who noted that beyond GOR ≈ 8, further increases yield diminishing returns in overall system economics. However, it should be noted that higher GOR typically requires more effects and/or advanced heat-recovery designs, which may introduce operational complexities not captured in the present steady-state model.

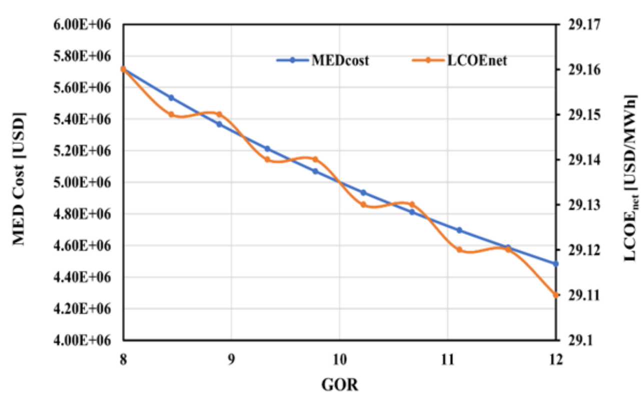


Figure 5. Impact of MED GOR on $LCOE_{net}$ and MED capital cost

With the cooling-water pump now included in the model, optimization of cooling water temperature (ΔT_{cw}) was varied from 5 °C to 12 °C (Figure 6). A higher ΔT_cw reduces the cooling-water mass flow and hence pumping power, but it raises the condenser pressure, which lowers the turbine exhaust efficiency. The optimum ΔT_{cw} was found to be 6°C –7 °C, yielding an $LCOE_{net}$ of 28.98 USD/MWh. Beyond this point, the power-cycle penalty (≈0.5 MW_e per °C increase in ΔT_{cw}) outweighs the pumping-power savings (≈0.3 MW_e per °C). This optimum is lower than the typical design value of 8 °C –10 °C often used in conventional power plants [15], because the present analysis includes the cooling-water pump work explicitly. The result emphasizes the importance of integrated modeling of the cooling system in cogeneration plants, where the condenser operates at a higher pressure due to the extraction of steam for desalination, making the cycle more sensitive to condenser back-pressure variations.

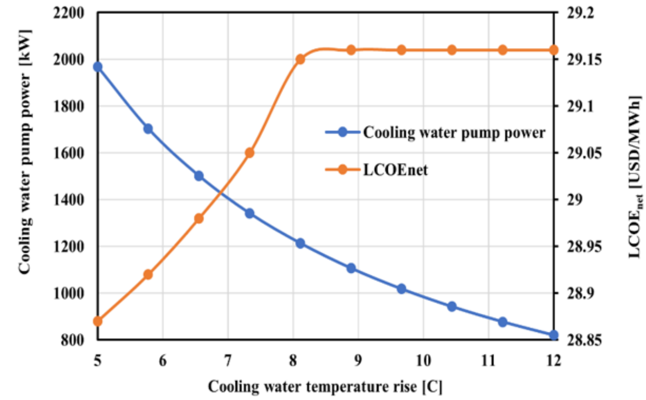


Figure 6. The effect of optimized cooling water temperature on LCOEnet and pumping power

Based on the parametric study, the following design values minimize $LCOE_{net}$:

- Turbine/pump isentropic efficiency: 0.90
- Feedwater-heater TTD: 9–10 °C
- MED GOR: 12
- Cooling-water ΔT: 6–7 °C

At this optimum, the system achieves an $LCOE_{net}$ of 28.7 USD/MWh, a net power output of 1245 MW_e, and an annual freshwater production of 6.3 million m³. Compared to the baseline, the optimized design reduces $LCOE_{net}$ by 1.4% while increasing net power by 4.8%. The resulting $LCOE_{net}$ is competitive with reported values for conventional single-purpose nuclear power plants (typically 25 USD/MWh – 35 USD/MWh [2,3]) and significantly lower than that of fossil-fueled cogeneration plants with carbon-capture. Moreover, the freshwater production cost, implicit in the model, is approximately 1.5 USD/m³, which is within the range reported for large-scale MED plants (1.2–2.0 USD/m³) [9,13]. These figures confirm that PWR-MED cogeneration is not only technically feasible but also economically attractive, especially in regions where freshwater scarcity elevates the value of water.

3.3. Model System Limitation

The present analysis is based on steady-state modeling, and pressure drops in piping and heat exchangers were neglected as stated in the model assumptions. This may slightly overestimate turbine work and underestimate pump consumption. The MED unit was modeled using a constant GOR, whereas in reality, GOR varies with operating conditions and the number of effects. The capital-cost scaling, while based on established correlations, does not account for regional differences in labor and material. The model is validated against two independent references [9, 16]; however, the comparison remains limited to thermal efficiency and LCOE. Future work should broaden this to include feedwater heater outlet temperatures and pump power consumption. Despite these simplifications, the model captures the essential thermodynamic and economic trade-offs and provides a robust basis for preliminary design optimization.

4. CONCLUSION AND DISCUSSION

This study presented a thermo-economic analysis of a pressurized water reactor (PWR)-based cogeneration plant for dual generation of electricity and freshwater. A comprehensive thermodynamic model was created in Engineering Equation Solver (EES) and evaluated against existing data, demonstrating its accuracy within 3% for critical performance indicators. Under the baseline conditions, the system produces 1188 MW_e of net electricity and 200 kg/s of freshwater, achieving a thermal efficiency of 34.7% and a net levelized cost of electricity ($LCOE_{net}$) of 29.1 USD/MWh. Additionally, a detailed parametric analysis demonstrated that the turbine isentropic and pump efficiencies have the most significant impact on $LCOE_{net}$, followed by the cooling-water temperature rise, feedwater-heater terminal temperature difference, and MED gain output ratio. The ideal design configuration—defined by turbomachinery efficiencies of 0.90, a TTD of 9–10 °C, a GOR of 12, and a ΔT_{cw} of 6 °C – 7 °C—lowers $LCOE_{net}$ to 28.7 USD/MWh while enhancing net power output to 1245 MW_e. The results indicate that PWR-MED cogeneration is both thermodynamically feasible and economically competitive, providing a potential solution for regions experiencing scarcity of electricity and freshwater. The minimal sensitivity of $LCOE_{net}$ to MED GOR further suggests that the desalination subsystem can be engineered for operational flexibility without jeopardizing the economic efficiency of the entire plant. Furthermore, the component-level exergy destruction analysis presented revealed that the LP turbine (81,927 kW), deaerator (81,003 kW), and HP turbine (53,167 kW) are the three dominant sources of irreversibility, collectively accounting for over 60% of total system exergy destruction. These findings provide specific, actionable targets: reducing LP turbine moisture losses through improved blade design or moisture extraction, and minimizing deaerator mixing irreversibilities through staged preheating, offer the greatest potential for improving the overall second-law efficiency of the plant. Future research should expand the current steady-state analysis to encompass dynamic operations under unsteady load and seasonal conditions, which will reflect real-world operating profiles and augment the practical significance of the results. An enhanced MED cost model that explicitly incorporates the quantity of effects, material selection, and site-specific variables would augment economic precision. The exploration of thermal storage integration may facilitate the decoupling of power and water production, thereby enhancing operational flexibility and grid compatibility. A comprehensive environmental life-cycle assessment—covering carbon emissions, water usage, and resource consumption—would offer an integrated sustainability viewpoint and facilitate the implementation of nuclear cogeneration within a low-carbon energy-water nexus. These enhancements would fortify the decision-support framework for policymakers and plant designers contemplating nuclear-driven cogeneration in regions with water shortage, such as the Middle East and West Africa.

DATA AVAILABILITY STATEMENT

The data presented in this study can be provided upon request.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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