TECHNO-ECONOMIC ANALYSIS OF ORC *R245FA PARABOLIC DISH-IIR* CSP FOR 1 MWE PLANT IN KUPANG

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ABSTRAK

Energi surya terkonsentrasi berpeluang dikembangkan di Indonesia, khususnya pada wilayah dengan iradiasi tinggi dan biaya pokok pembangkitan yang relatif besar. Penelitian ini bertujuan mengevaluasi rancangan teknis dan kelayakan ekonomi pembangkit *Concentrating Solar Power* (CSP) tipe *parabolic dish* dengan *Indirect Illumination Receiver* (IIR) yang diintegrasikan dengan *Organic Rankine Cycle* (ORC) berfluida kerja R245fa untuk keluaran 1 MWe. Metode penelitian dilakukan melalui pemilihan lokasi berdasarkan *Global Tilted Irradiation* (GTI) dan BPP, simulasi termodinamika menggunakan Cycle Tempo 5.0, perencanaan alat penukar kalor menggunakan HTRI, serta analisis ekonomi berbasis proyeksi tarif listrik dan *EPC cost*. Hasil menunjukkan Kupang, NTT, menjadi lokasi paling potensial dengan GTI rata-rata 5,84 kWh/m²/hari. Kondisi operasi optimum diperoleh pada tekanan 6,95 bar, temperatur R245fa 74,99 °C, laju aliran R245fa 70,30 kg/s, efisiensi *gross* 24,08%, dan efisiensi *net* 20,39%. Kebutuhan area CSP untuk operasi 24 jam diperkirakan 21.941,24 m². Analisis ekonomi menunjukkan sistem layak dikembangkan terutama di Indonesia Timur dengan tarif listrik acuan Rp1.629/kWh dan *EPC cost* rata-rata USD2.075,95/kWe.

Kata kunci: *Concentrating Solar Power*; *Indirect Illumination Receiver*; *Organic Rankine Cycle*; R245fa; analisis tekno-ekonomi.

ABSTRACT

Concentrating solar power has strong potential in Indonesia, especially in regions with high irradiation and relatively high electricity generation costs. This study evaluates the technical design and economic feasibility of a parabolic-dish Concentrating Solar Power (CSP) system with an Indirect Illumination Receiver (IIR) integrated with an Organic Rankine Cycle (ORC) using R245fa as the working fluid for a 1 MWe output. The research procedure included site selection based on Global Tilted Irradiation (GTI) and generation cost, thermodynamic simulation using Cycle Tempo 5.0, heat-exchanger design using HTRI, and economic analysis based on electricity tariff projection and EPC cost. The results indicate that Kupang, East Nusa Tenggara, is the most promising location, with an average GTI of 5.84 kWh/m²/day. The optimum operating case was obtained at 6.95 bar, R245fa temperature of 74.99 °C, R245fa mass flow rate of 70.30 kg/s, gross efficiency of 24.08%, and net efficiency of 20.39%. The CSP field area required for 24-hour operation was estimated at 21,941.24 m². The economic analysis suggests that the system is feasible for further development, particularly in eastern Indonesia, with a reference electricity tariff of IDR 1,629/kWh and an average EPC cost of USD 2,075.95/kWe.

Keywords: *Concentrating Solar Power; Indirect Illumination Receiver; Organic Rankine Cycle; R245fa; techno-economic analysis.*

INTRODUCTION

The need for low-carbon electrification encourages the use of solar thermal energy as an alternative to power generation in areas that are difficult to reach by conventional systems. The specific issue examined in this article is how to design and assess the feasibility of a *parabolic dish-type CSP system* with an IIR that supplies heat to an R245fa fluidized ORC for an output of 1 MWe. This issue is important because Indonesia has the potential for solar radiation throughout the year, but the implementation of *CSP-ORC* is still limited to conceptual studies and has not been much directed at the selection of locations and economic feasibility based on regional BPP conditions [1], [2].

State-of-the-art shows that *solar-ORC* is one of the relevant approaches for the conversion of low- to medium-temperature solar heat into electricity. The cutting-edge literature emphasizes the selection of ORC configurations, working fluids, heat source temperatures, *pinch points*, expanders, as well as the integration of thermal storage as the main factors that determine the efficiency and economics of the system [3]–[9]. On the collector side, *parabolic dishes have a higher* receiver concentration and temperature ratio than some other types of collectors, so they can provide more

intensive heat for thermal applications [10]–[12], [14]–[16].

The method that is currently most widely used for the pre-design stage is thermodynamic simulation based on mass and energy balance, followed by *heat exchanger design* and techno-economic assessment. This approach was chosen because it is able to connect cycle operating parameters, heat requirements, collector area requirements, and project costs in one analytical framework. Some *solar-ORC* studies also place *recuperative ORC* and thermal *energy storage integration* as configurations that are more adaptive to solar radiation fluctuations [3], [5], [13].

However, there is still a research gap on the technical integration between CSP *parabolic dish-IIR* and ORC for Indonesian conditions. Most studies focus on *parabolic trough*, *flat plate collector*, or ORC evaluation in general, while IIR-based designs require heat transfer fluids and heat exchangers that are able to separate the heat receiving system from the organic cycle. Another gap is the lack of studies that directly link the results of the Cycle Tempo simulation, the initial design *of the heat exchanger*, the needs of the CSP area, and the economic feasibility of the electricity tariff based in Indonesia.

This study aims to prepare a techno-economic design of a CSP *parabolic dish-IIR* integrated with ORC R245fa for a capacity of 1 MWe. The scientific contributions of this article are: (i) selection of potential locations based on a combination of GTI and BPP, (ii) identification of optimal operating conditions of ORC from several pressure and temperature variations, (iii) estimation of CSP and TES area requirements for 24-hour operation, and (iv) initial assessment of project economics through comparison of electricity tariff and *EPC cost*. Thus, this article not only presents a cycle simulation, but also shows the design consequences for the implementation of power plants in Eastern Indonesia.

METODOLOGI PENELITIAN

The research uses a quantitative approach based on thermodynamic simulation and techno-economic analysis. The object of the study is a CSP *parabolic dish* system with IIR that heats a heat transfer fluid in the form of water, then the heat is used to evaporate the ORC R245fa working fluid through *a pre-heater* and *evaporator*. The study location was selected from several regions of Indonesia based on the potential of GTI and BPP generation.

Preliminary data were obtained through literature studies, solar potential maps, regional BPP data, and ORC and CSP technical parameters. The main analysis equipment is Cycle Tempo 5.0 for mass and energy balance modeling, HTRI for the initial design of heat exchangers, and proforma worksheets for economic estimation. Fixed parameters used include ambient temperature 30 °C, *pinch temperature* 15 °C, condensation temperature 33.35 °C, turbine efficiency 70%, and gross output target of 1,000 kWe.

The research stage began with location selection, *CSP-ORC* configuration, working fluid determination, Cycle Tempo modeling, and simulation of six operating pressure cases. Each case was evaluated using R245fa temperature indicators, R245fa flow rate, heating water temperature, water flow rate, *gross efficiency,* net *efficiency,* auxiliary power, net power, *and* Qsol heat requirement. The optimum case was selected based on a combination of the highest *net* efficiency, controlled auxiliary power, and suitability of heating water temperature.

The optimal simulation results are the basis for calculating the thermal energy needs of CSP, TES volume, and collector area needs. Area estimation is calculated using the relationship $A = m \cdot Cp \cdot (T2 - T1)/I$ by taking into account the rate of water mass, difference in heating water temperature, heat type, CSP efficiency, and daily irradiation value. Economic analysis was carried out by estimating the cost of CSP, TES, and ORC *plants*, then comparing *EPC costs* with electricity tariffs in several regions and project IRR of 13%.

Indicators of the success of the research are the achievement of the 1 MWe ORC design with the highest net efficiency from the simulation alternative, the fulfillment of daily heat needs through the estimation of CSP and TES areas, and the obtaining of initial economic feasibility indications in areas that have solar potential and supporting electricity tariffs.

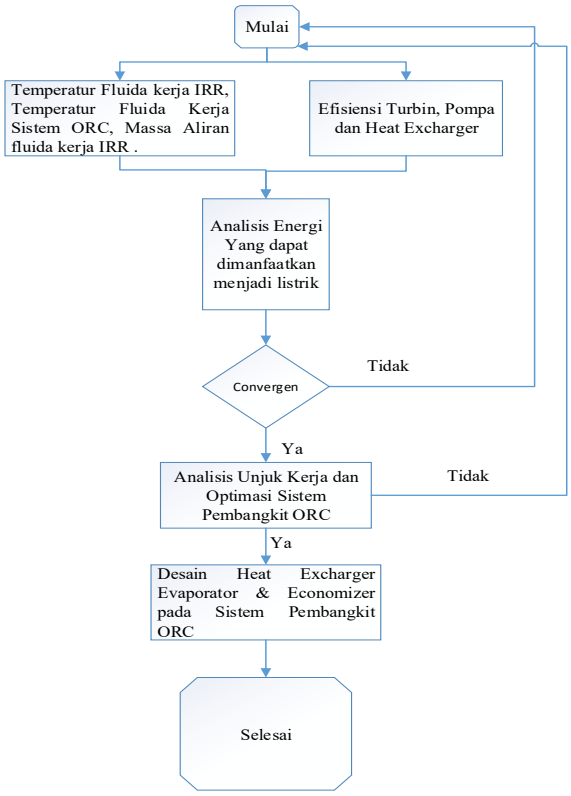


Figure 1. Research methodology flowchart.

The calculation of the mass and energy balance in the Cycle Tempo is carried out on the principle of mass conservation in *evaporators*, *pre-heaters*, turbines, condensers, and pumps. For each component, the incoming mass is assumed to be equal to the outgoing mass under the constant condition, while the energy change is calculated from the difference in the enthalpy of the working fluid. The turbine power is assessed from the decrease in the enthalpy of R245fa after expansion, the pump power is calculated from the increase in the pressure of the liquid fluid, and the *efficiency of the plant* is calculated as the ratio of net electrical power to the thermal heat entering the cycle.

In the *heat exchanger design*, the pressure, temperature, mass rate, and enthalpy data from the simulation are used as *boundary conditions*. The *pre-heater* raises the temperature of R245fa before entering *the evaporator*, while *the evaporator* converts R245fa into dry steam suitable for turbine expansion. Parameters that need to be verified in HTRI include heat transfer area, *shell* and *tube side flow rate*, *pressure drop*, *baffle configuration*, and safe operating temperature limits.

Inferential statistical methods were not used because this study was in the form of pre-design deterministic modeling. The validity of the results was strengthened through the consistency of the mass-energy balance, the convergence of the simulation, the comparison between the operation cases, and the conformity of the result trends with the ORC theory and *the solar-ORC literature*. The initial sensitivity analysis was carried out through the variation of operating pressure and the comparison of electricity tariff to *EPC cost*.

Methodological limitations include the use of daily average irradiation data, CSP efficiency assumptions, and estimated cost-based estimates. Therefore, the results of this article are positioned as *a basic design* and initial feasibility study, rather than *a detailed engineering design*. The advanced stage needs to include hourly DNI/GTI data, receiver optical models, collector degradation, weather variations, and experimental *heat exchanger validation*.

RESULTS AND DISCUSSION

CSP-IIR and ORC R245fa System Configuration

The configuration analyzed uses an indirect heat transfer path. Solar radiation is concentrated by a *parabolic dish* to the *receiver*, then the heat is transferred to the water as *a heat transfer fluid*. The hot water does not mix with the ORC working fluid, but rather releases heat to the *pre-heater* and *evaporator*. R245fa was chosen because it has a relatively low boiling point making it suitable for heat sources of 70–100 °C. This scheme is relevant for tropical regions that have high daily irradiation, but require heat storage flexibility in order for the plant to operate more stably.

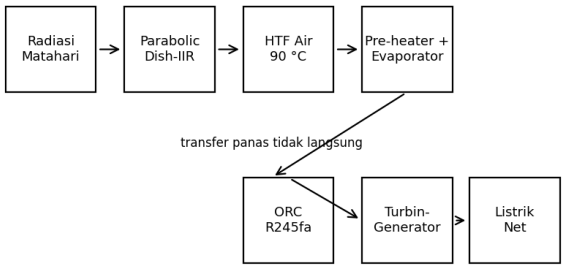


Figure 2. Schematic of the energy flow on the CSP-IIR supplying heat to the ORC R245fa.

The advantage of the indirect configuration is the ability to separate the optical-heat receiver system from the power cycle. This separation makes the selection of ORC working fluids more flexible, facilitates the integration of TES, and reduces the risk of direct exposure of organic fluids to *the receiver* temperature. The disadvantage is the added irreversibility of the heat exchanger, so that the *design of the pre-heater* and *evaporator* is an important determinant of *plant efficiency*.

Location Selection Based on GTI and BPP

The selection of the location was carried out by combining the potential of solar radiation and the economic attractiveness of the region. The recapitulation results showed that Kupang has the highest GTI value, which is 5.84 kWh/m²/day, as well as a relatively high BPP of Rp2,588/kWh. This combination makes Kupang more attractive than areas with fairly high GTI but low BPP. From an investment perspective, areas with high BPP provide tariff space that is closer to the cost of generating *CSP-ORC technology*.

Table 1. Summary of potential locations based on GTI and BPP.

Location	Region	GTI	BPP
Kupang	NTT	5,84	2.588
Surabaya	Jawa Timur	5,42	989
Pontianak	Kalbar	5,41	1.525
Manado	Sulut	5,06	1.918
Jayapura	Papua	4,88	2.162
Jakarta	DKI	4,69	985

These findings reinforce the argument that the location *of the CSP-ORC* is not sufficiently selected based solely on solar intensity. Regional economic indicators need to be included because the energy costs of the CSP are relatively sensitive to the initial investment, *the size of the solar field*, and the availability of thermal storage. Therefore, Kupang was chosen as a case study because it meets two conditions at once: high irradiation potential and a more supportive reference rate.

Thermodynamic Performance of ORC R245fa

Cycle Tempo simulations were performed at six operating pressure variations. The results showed that *the net* efficiency increased from *Case* 01 to *Case* 03, then decreased at lower pressures. This pattern showed a compromise point between an increase in thermal performance and an increase in auxiliary power requirements. *Case* 03 was the optimum condition with a pressure of 6.95 bar, a temperature of R245fa of 74.99 °C, a flow of R245fa of 70.30 kg/s, and a *net efficiency* of 20.39%.

Table 2. Summary of ORC operation parameters from the Cycle Tempo simulation.

Case	P (bar)	T R245fa	Flow R245fa	η *net*
01	8,20	89,74	61,40	20,16
02	7,89	79,98	63,25	20,37
03	6,95	74,99	70,30	20,39
04	6,09	69,96	79,49	20,21
05	5,32	64,98	91,69	19,79
06	4,62	59,96	109,04	18,90

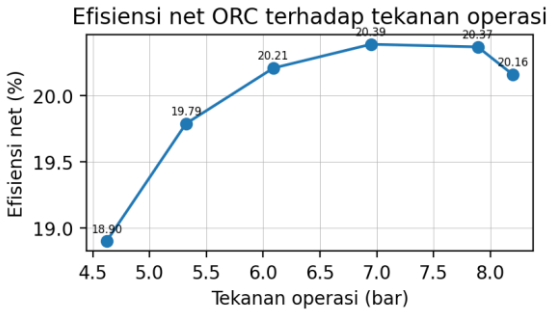


Figure 3. Graph of ORC's *net* efficiency against operating pressure.

Figure 3. shows that *the net* efficiency does not increase linearly with respect to pressure. Too high a pressure requires a higher heating temperature, while too low a pressure demands a larger fluid flow rate and increases the need for the pump. Therefore, the technical optimum is in Case 03, not at the highest or lowest pressure. This result is in line with the ORC theory that the selection of evaporative pressure and working fluid must be adjusted to the quality of the heat source so that the irreversibility of the *evaporator* and condenser can be suppressed.

CSP, TES, and *Heat Exchanger Energy Needs*

Under optimal conditions, the system requires approximately 27.30 kg/s of heating water in the simulation model and 31.76 kg/s is used in the calculation of daily energy requirements for the 24-hour operating scenario. The water is heated from 50 °C to 90 °C, with a Kupang irradiation value of 5.84 kWh/m²/day. The calculation results in a daily thermal energy requirement of approximately

128,136.81 kWhth/day and a solar *field area* requirement of approximately 21,941.24 m². The demand for a hot water tank-based TES *is* estimated at 2,744.07 m³ to support daily operations.

Table 3. Summary of the optimal conditions of the *CSP-ORC design*.

Parameter optimum	Value
Inlet turbine pressure	6,95 bar
Turbine inlet temperature R245fa	74,99 °C
Flow rate R245fa	70,30 kg/s
Gross/net *efficiency*	24,08% / 20,39%
Daya *gross* / *net*	1.000 kW / 846,58 kW
Qsol heat needs	4.152,82 kW
CSP area needs	21.941,24 m²
TES *hot water tank*	±2.744,07 m³

The heat *exchanger design* is a critical part because the IIR system does not heat the R245fa directly with solar radiation. The heat is transferred from the water as HTF to the R245fa through a *pre-heater* and *evaporator*. This separation provides operational flexibility and allows for TES integration, but adds heat transfer resistance. Thus, *the heat exchanger's performance* determines the magnitude of the effective temperature difference, the need for the heat transfer area, and the total efficiency of *the plant*. In the initial design, HTRI was used as a design validation so that *the configuration* of shells, *tubes*, *baffles*, and operating limits could meet technical criteria.

Early Economic Qualification

Economic analysis was carried out by combining the cost *of solar field*, TES, and ORC *plant* based on the reference of renewable plant costs and ORC techno-economic studies [17]–[19]. The cost estimate shows that *the EPC cost* is in a wide range, which is around USD1,395.25/kWe to USD6,158.50/kWe, depending on the assumption of *solar field costs*, TES, and ORC packages. In the projection of regional electricity tariffs referring to the BPP data of the Ministry of Energy and Mineral Resources [20], *the average EPC cost* used is USD2,075.95/kWe with a reference electricity tariff of IDR 1,629.33/kWh. For NTT, the reference tariff of IDR 2,588/kWh provides a higher *EPC cost* limit, which is around USD3,381.80/kWe.

Table 4. Summary of project economic indicators.

Indicator	Value
Capacity *gross* / *net*	1 MW / 0,85 MW
Capacity factor	80%
Project lifespan	25 tahun
IRR target	13%
Average reference electricity tariff	Rp1.629,33/kWh
EPC cost average	USD2.075,95/kWe
EPC cost limits NTT	USD3.381,80/kWe
Initial conclusion	More feasible for Eastern Indonesia

Critically, the economics of the system are still highly dependent on the reduction of *solar field* and TES costs. Although the *net* efficiency of 20.39% is promising for *small-scale solar-ORC*, the initial investment cost can be a major obstacle. The results of this study support the literature that says that *solar-ORC* is more competitive in small-medium systems, remote locations, areas with high electricity costs, or systems that require thermal storage to improve supply reliability [3], [6], [13].

The novelty of this article lies in the integration of the design flow that connects the selection of Indonesian locations, the ORC R245fa simulation, the need *for heat exchangers* for IIR configurations, the estimation of the CSP area, and the economic feasibility in one compact study. The results not only show the value of efficiency, but also show the practical implications that *the CSP-ORC* design is more relevant for the Eastern Indonesia region than for the low-tariff area.

Analysis of Operating Parameters

The operating pressure affects the evaporation temperature, the flow rate of the working fluid, and the auxiliary power of the pump. In *Case* 01 and *Case* 02, the temperature of R245fa is higher, but the increase in efficiency is not too great. In *Case*

04 to *Case* 06, the lower pressure causes the flow rate of R245fa and water to increase sharply. The increase in flow rate has an impact on increasing pump size, potential *pressure drop*, and auxiliary power requirements. This explains why *net* efficiency drops at low pressures even though operating temperatures seem more achievable.

Auxiliary power is an important component in the evaluation *of net* power. In *Case* 03, auxiliary power is 153.42 kW or 15.34% of *gross* power. This value is still better than *Case* 06 which requires 204.77 kW or 20.48%. If the pump and condenser design is not optimized, the thermal gain from the ORC can be lost due to auxiliary power consumption. Therefore, the advanced design needs to lower *the pressure drop* in *the heat exchanger* and choose a pump with high efficiency.

The Qsol requirement in all cases is around 4.1–4.2 MWth. This difference is relatively small, but the impact on *the solar field area* is significant when calculated for daily operations. With a GTI of 5.84 kWh/m²/day, the area requirement of 21,941.24 m² indicates that the project requires a considerable amount of land. Therefore, land selection, collector reflectivity, tracking efficiency, *fouling*, and mirror cleaning strategies need to be part of a detailed feasibility study.

Heat Exchanger *and TES* Design Implications

In an IIR system, *the heat exchanger* is the meeting point between the solar domain and the power cycle domain. If the *direct illumination* approach is used, the solar energy directly heats the engine or fluid in the *receiver*. In contrast, IIR requires an additional heat transfer path. This additional path provides operational advantages, but it also increases the chance of heat loss. Therefore, *the heat exchanger* design needs to balance heat transfer area, *pressure drop*, material cost, and ease of maintenance.

Hot water *tank-based TES* was chosen because it is simple and suitable for an operating temperature of 50–90 °C. The advantages of this technology are the relatively low cost and ease of implementation. However, the volumetric capacity of hot water is lower than that of some other storage materials, resulting in large tank volumes. To increase storage density, advanced research can evaluate *phase change materials*, *thermochemical storage*, or other hot fluids that are compatible with *receiver* and ORC temperatures.

In terms of operational reliability, TES functions to dampen radiation fluctuations and maintain heat supply to *the evaporator*. Without TES, ORC turbines are at risk of repetitive partial operations that can decrease efficiency and accelerate component wear. With TES, the system is more likely to supply night loads or peak loads. However, these advantages must be compared to additional investment costs, storage heat loss, and tank maintenance costs.

Economic Sensitivity and Implementation Readiness

Economic results show that the *range of EPC costs* is still wide. This range indicates that investment decisions are very sensitive to collector prices, *receivers*, TES, ORC packages, construction costs, and site logistics costs. For remote areas in Eastern Indonesia, logistics costs may be higher than in Java, but BPP and local electrification needs are also more supportive. Therefore, further studies need to calculate *the Levelized Cost of Electricity* (LCOE) with optimistic, moderate, and conservative scenarios.

Implementation readiness is also influenced by the operation and maintenance aspects. CSP systems require reflector surface cleanliness, accurate sun tracking, receiver calibration, corrosion protection, and working fluid management. For the ORC R245fa, environmental issues and refrigerant regulation also need to be considered. If the working fluid is replaced with an alternative that has a lower GWP, the cycle configuration and *heat exchanger design* need to be recalculated due to the different thermophysical properties of the fluid.

In the context of energy policy, this technology is more appropriately positioned as a distributed plant or a remote area support plant rather than a large-scale base load plant. The added value lies in the ability to harness solar heat, potential *storage integration*, and suitability for high-irradiated areas. However, to be competitive, EPC costs must be reduced through design standardization, local manufacturing of structural components, *solar field optimization*, and control system integration.

Limitations, Technical Risks, and Validation Agenda

The first limitation is the use of daily average GTI values as *the sizing input*. For detailed design, hourly data is required so that the model can capture morning, noon, evening, cloud cover, and seasonal variations. Without hourly data, TES capacity and *dispatch* strategies can only be roughly estimated. This is important because ORCs are sensitive to heat source temperature

drops, especially when solar radiation drops suddenly.

The second limitation is that detailed optical *modeling of the receiver* has not been carried out. In *the parabolic dish*, optical losses can come from reflector imperfections, tracking errors, structure *shading*, receiver absorpivity, hot surface emissivity, and convection loss. If the actual optical losses are greater than assumed, then the collector's extensive requirements and *solar field costs* will increase. Therefore, optical simulation and receiver prototype tests are an important agenda before the *detailed engineering design* stage.

The third limitation is the use of R245fa which is technically suitable for low-medium temperatures, but needs to be reviewed from an environmental regulatory perspective. Further studies need to compare R245fa with alternative fluids that have zero ODP, lower GWP, good thermal stability, and acceptable safety characteristics. Changes in the working fluid will change the operating pressure, flow rate, *heat exchanger size*, and cycle efficiency.

Table 5. Further validation agenda before implementation.

Validation aspects	Required data	Purpose
Irradiation	DNI/GTI per hour for at least 1 year	Sizing *solar field* dan TES
Receiver	Optical efficiency and heat loss	IIR model validation
Heat exchanger	U, *pressure drop*, *fouling factor*	Validasi *pre-heater*/*evaporator*
ORC	Curve turbine, pomp, condenser	Actual *net* power prediction
Economy	CAPEX, OPEX, LCOE, Tariff Scenario	Investment decisions

Considering these limitations, this article should be understood as an academic pre-design manuscript. Its main strength is to present a logical chain from solar energy problems, technology selection, thermodynamic simulations, system sizing, to economic implications. The weaknesses that still need to be completed are experimental validation, dynamic models, and updates of actual cost data. The combination of these three agendas will determine whether the design can rise from concept to construction-ready design.

CONCLUSION

This study compiled a techno-economic analysis of CSP *parabolic dish-IIR* integrated with ORC R245fa for a capacity of 1 MWe. The research approach was carried out through GTI and BPP-based location selection, Cycle Tempo thermodynamic simulation, initial design *of heat exchanger* with HTRI, as well as economic analysis based on *EPC cost*, electricity tariff, and IRR. The main findings show that Kupang, NTT, is the most potential location with a GTI of 5.84 kWh/m²/day and a BPP of Rp2,588/kWh. Optimum operating conditions were obtained in *Case* 03 with a pressure of 6.95 bar, temperature of R245fa of 74.99 °C, flow rate of R245fa of 70.30 kg/s, *gross* efficiency of 24.08%, *net* efficiency of 20.39%, *net power* of 846.58 kW, and heat requirement of 4,152.82 kW. For 24-hour operation, the system requires a CSP area of around 21,941.24 m² and a hot *water tank TES* of around 2,744.07 m³. Economic analysis shows that the implementation of the system is more feasible to be directed to Eastern Indonesia because electricity tariffs and solar potential are more supportive. The novelty of the research lies in the combination of ORC simulations, *IIR* heat exchanger designs, *solar field* estimates, and economic evaluation of Indonesian regions in one pre-design framework. Further research is recommended to optimize alternative working fluids with lower GWP, component exergy analysis, experimental *heat exchanger* design validation, dynamic simulation of daily radiation, and LCOE studies that include financing schemes, component degradation, and TES operating strategies.

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