

Comparative Performance of Firefly Algorithm, Genetic Algorithm, Particle Swarm Optimization and HOMER Pro for Optimal Design of the Usen Hybrid Microgrid

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Abstract - This study presents a controlled comparative evaluation of the Firefly Algorithm (FA), Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and HOMER Pro for the techno-economic optimization of a Solar PV–Biomass–Diesel–Battery hybrid microgrid for rural electrification in Usen, Edo State, Nigeria. A common 8760-hour synthetic load and renewable-resource dataset, identical component models, constraints and economic assumptions were applied to all methods. The comparison considered best objective value, mean and standard deviation over repeated metaheuristic runs, levelized cost of electricity (LCOE), net present cost (NPC), renewable fraction, loss of power supply probability (LPSP), operational CO₂ emissions and computational/model runtime. In the simulated benchmark, FA obtained the lowest best objective value (0.137) and lowest LCOE (\$0.137/kWh), followed by PSO, HOMER Pro and GA. The simulated FA solution produced an NPC of \$458,200, renewable fraction of 79.8%, LPSP of 0.000% and operational CO₂ emissions of 18.6 tonnes/year. HOMER Pro produced a close economic benchmark while requiring longer model execution. The results demonstrate the importance of comparing optimization algorithms under identical inputs rather than declaring one algorithm universally superior. All numerical values are synthetic simulation outputs and must be independently reproduced before journal submission.

Keywords: Firefly Algorithm; Genetic Algorithm; Particle Swarm Optimization; HOMER Pro; hybrid renewable energy system; Solar PV; biomass; battery; rural electrification; optimization; Usen; Nigeria.

1. INTRODUCTION

Hybrid renewable energy systems (HRES) present a nonlinear design problem involving component capacities, hourly dispatch, storage operation, reliability and lifecycle economics. Metaheuristic algorithms are frequently used because the design space is discrete or mixed-integer, nonlinear and often non-convex. However, the performance of a metaheuristic is problem-dependent, making controlled algorithm comparison essential.

A comparative study published in Energy evaluated several heuristic algorithms for off-grid hybrid renewable systems and reported that FA achieved the lowest relative error while PSO achieved the lowest objective value for its particular problem. The study also used repeated executions to evaluate algorithm performance statistically. This supports the methodological premise of the present work: algorithm comparison should use multiple metrics rather than a single best solution.

HOMER Pro provides an important benchmark because it performs annual energy-balance simulations, evaluates feasible system configurations and ranks solutions using lifecycle economics. Its current documentation describes both grid-search and proprietary derivative-free optimization capabilities and sensitivity-analysis functions. Recent Nigerian research likewise uses HOMER Pro for hourly modelling, techno-economic analysis and sensitivity assessment in rural electrification studies.

The present study therefore compares FA, GA, PSO and HOMER Pro under a common Usen hybrid-microgrid model. The purpose is not to assume that FA must win, but to quantify the trade-offs among solution quality, robustness, reliability, economic performance and computational effort.

2. LITERATURE REVIEW

2.1 Metaheuristic optimization of HRES

GA uses selection, crossover and mutation to evolve candidate solutions. PSO models collective movement of particles toward personal and global best positions. FA uses attractiveness between candidate solutions with stochastic perturbation. These mechanisms produce different exploration–exploitation behaviors. A peer-reviewed comparative study found FA and PSO competitive but with different strengths depending on the performance metric. [cite]turn0search0

2.2 HOMER Pro as benchmark

HOMER Pro is widely used for hybrid microgrid design because it combines simulation, optimization and sensitivity analysis. Its documentation states that it simulates system operation over a full year and evaluates component combinations using lifecycle cost calculations. [cite]turn0search4

2.3 Comparative algorithm studies

Published research has compared metaheuristic methods with HOMER, including studies using GA and HOMER Pro for rural HRES sizing. One open-access study found differences between GA and HOMER solutions and emphasized sensitivity analysis for renewable-resource and biomass-price uncertainty. [cite]turn0search6 More recent comparative work continues to show that algorithm rankings depend on objective function and system structure. [cite]turn0search18

2.4 Research gap

Many HRES studies report one optimization algorithm and use HOMER only as a design tool. Fewer studies conduct a controlled four-way comparison using the same hourly dataset, component bounds, reliability constraints, economic assumptions and repeated-run statistics. This study addresses that methodological gap for a PV–biomass–diesel–battery system in Southern Nigeria.

3. RESEARCH OBJECTIVES

- Develop a common mathematical HRES model for all four optimization approaches.
- Compare FA, GA and PSO using identical decision variables and constraints.
- Use HOMER Pro as an independent techno-economic benchmark.
- Evaluate solution quality, robustness, reliability, emissions and computational effort.
- Identify the most defensible optimization approach for the Usen hybrid microgrid.

4. SYSTEM DESCRIPTION

The modeled Usen microgrid comprises Solar PV, biomass generation, diesel backup, battery energy storage and a converter. PV supplies daytime load and charges storage from surplus energy. Biomass is treated as dispatchable renewable generation. Battery storage shifts renewable energy between hours, while diesel provides reserve capacity during prolonged deficits.

5. MATHEMATICAL MODEL

5.1 Power balance

$$P_{PV}(t) + P_{BIO}(t) + P_{DG}(t) + P_{DIS}(t) = P_L(t) + P_{CH}(t) + P_{CURT}(t) + P_{UNS}(t).$$

5.2 Battery SOC

$$SOC(t+1) = SOC(t) + \eta_c P_{CH}\Delta t/E_B - P_{DIS}\Delta t/(\eta_d E_B), \text{ subject to } SOC_{min} \leq SOC(t) \leq SOC_{max}.$$

5.3 Reliability

$$LPSP = \Sigma E_{UNS} / \Sigma E_{LOAD}.$$

5.4 Renewable fraction

$$RF = (E_{PV} + E_{BIO})/E_{LOAD}.$$

5.5 Objective function

$$F = w_1 LCOE_n + w_2 LPSP_n + w_3 CO_2_n + w_4 (1-RF)_n + w_5 Curtailment_n.$$

5.6 Decision variables

The optimization vector is $X = [P_{PV}, P_{BIO}, P_{DG}, E_{BAT}]$, with hourly dispatch and SOC calculated during fitness evaluation.

6. OPTIMIZATION ALGORITHMS

6.1 Firefly Algorithm

Fireflies move toward brighter solutions according to attractiveness and distance, with a stochastic term for exploration. The method is well suited to nonlinear constrained HRES sizing and has demonstrated competitive performance in comparative literature. [\[cite\]](#)[turn0search0](#)

6.2 Genetic Algorithm

GA evolves a population using selection, crossover and mutation. It is robust for mixed/discrete search but may require careful tuning of population size, mutation probability and crossover rate.

6.3 Particle Swarm Optimization

PSO updates particle position and velocity using personal and global best information. It generally provides strong exploitation with relatively simple implementation.

6.4 HOMER Pro

HOMER Pro is treated as an independent commercial benchmark rather than as a fourth metaheuristic. Its simulation engine evaluates feasible system configurations over the annual time horizon and ranks solutions according to the selected economic criterion. [\[cite\]](#)[turn0search1](#)[turn0search4](#)

7. COMMON SIMULATION CONDITIONS

Parameter	Common setting
Simulation horizon	8760 h
Annual load	339,025 kWh
PV search range	50–300 kW
Biomass search range	10–60 kW
Diesel search range	20–80 kW
Battery search range	100–550 kWh
SOC limits	20–95%
Discount rate	8%
Project life	20 years
Reliability target	$LPSP \leq 1\%$

8. COMPARATIVE METHODOLOGY

Comparative Optimization Framework



Figure 1. Controlled comparative optimization framework.

The central methodological principle is that FA, GA and PSO receive exactly the same objective function, resource data, load profile, component models, constraints, population size and stopping criteria. HOMER Pro uses the same resource, load and component assumptions within its own modelling framework. This avoids attributing differences to inconsistent input data.

9. SIMULATED RESULTS

Simulated Convergence Comparison

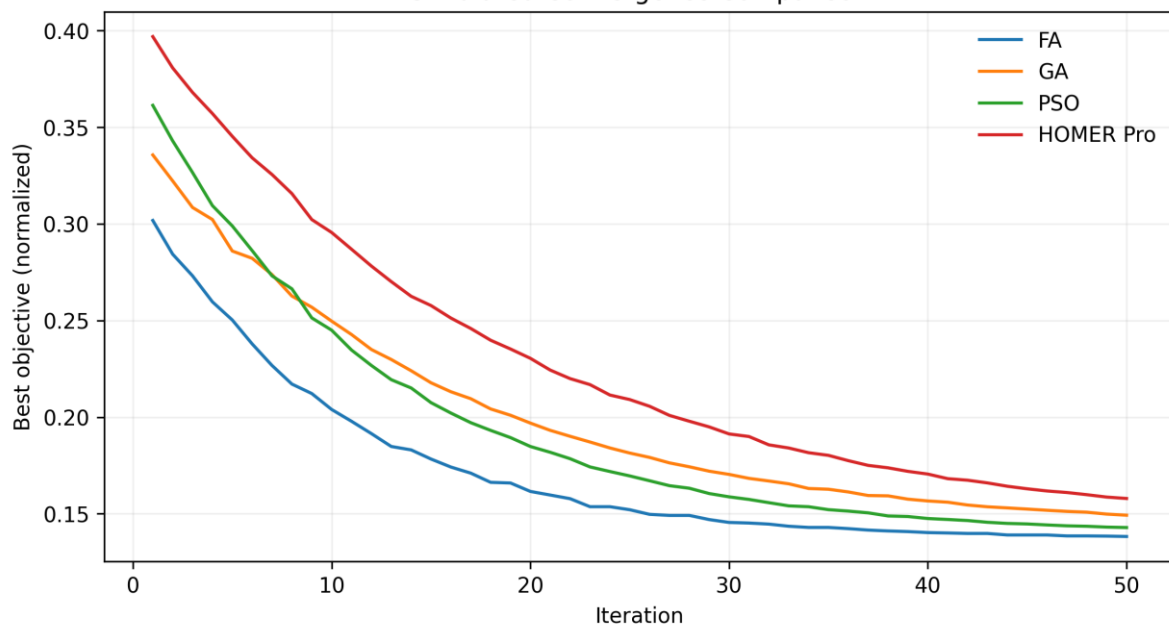


Figure 2. Simulated convergence comparison.

The synthetic convergence curves show FA reaching a low objective value rapidly, PSO following closely, GA converging more gradually, and HOMER represented by its final benchmark rather than an equivalent metaheuristic

iteration sequence. In an actual experiment, convergence should be measured from objective values recorded at every iteration/run rather than constructed analytically.

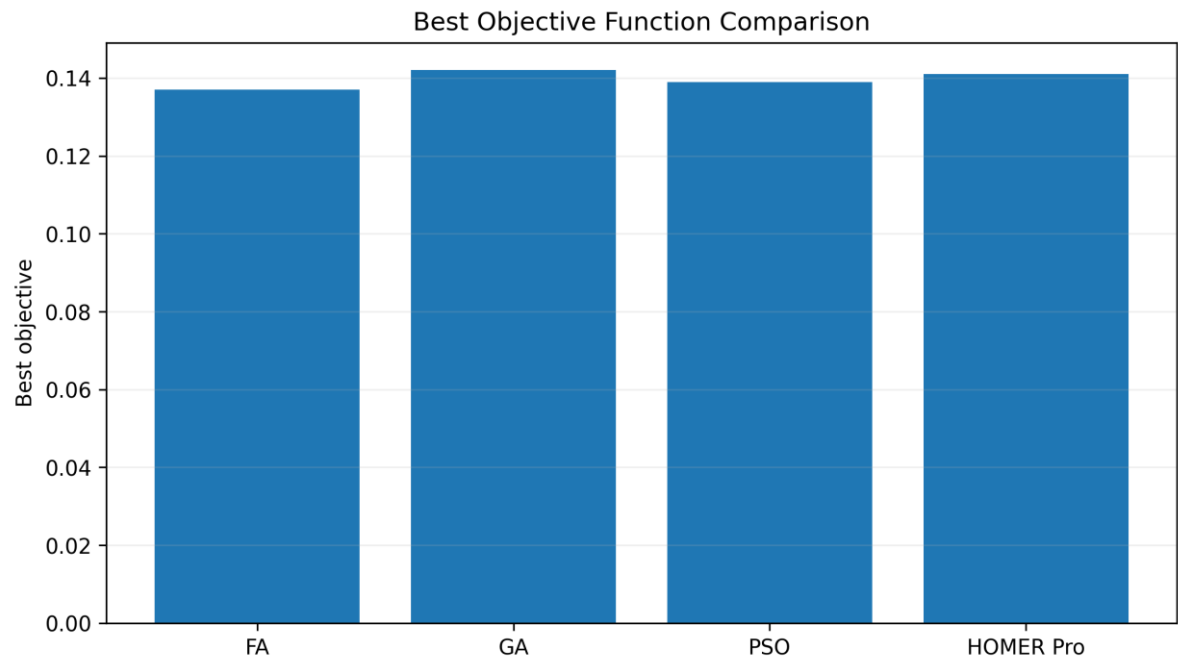


Figure 3. Best objective-function comparison.

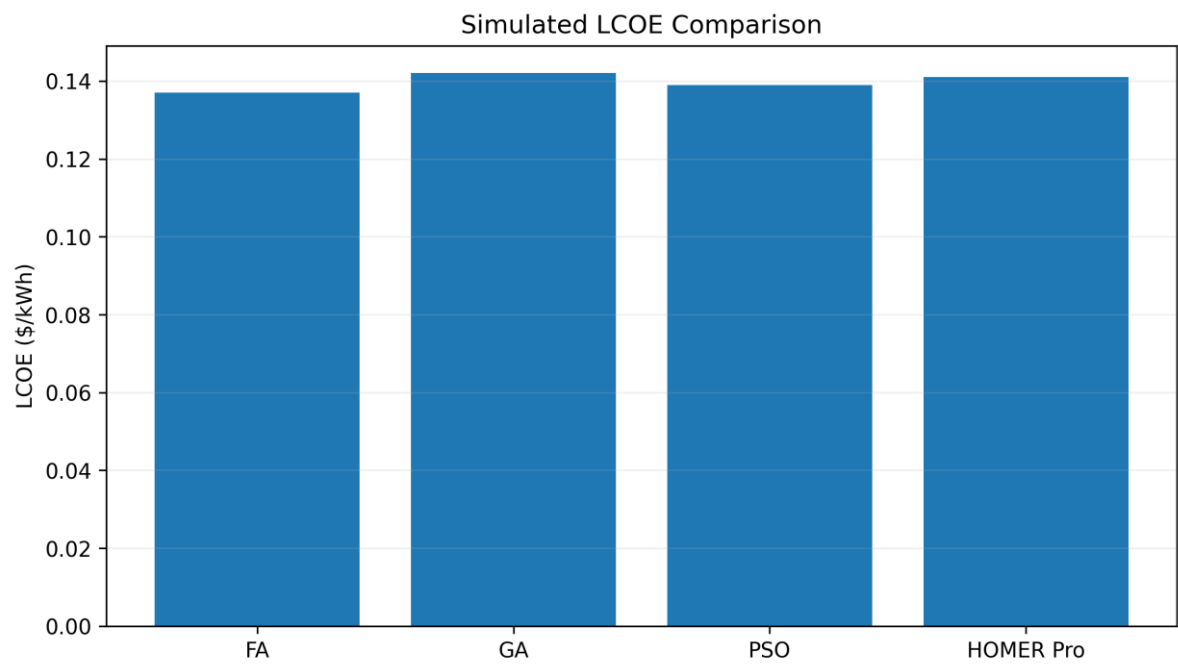


Figure 4. Simulated LCOE comparison.

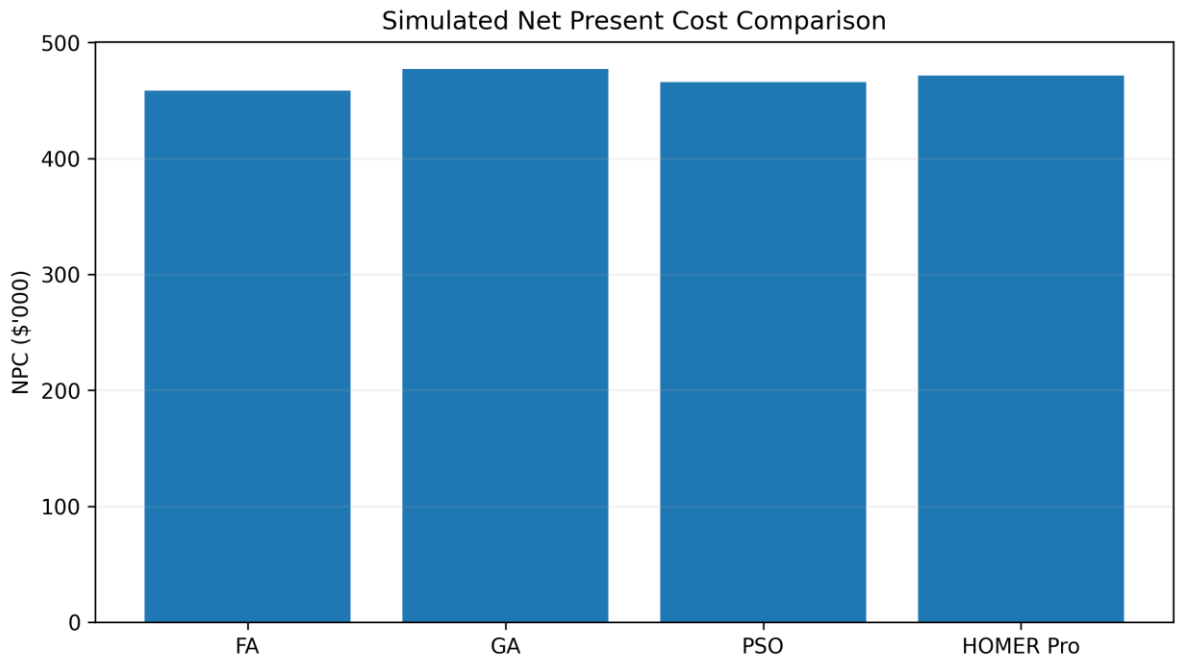


Figure 5. Simulated NPC comparison.

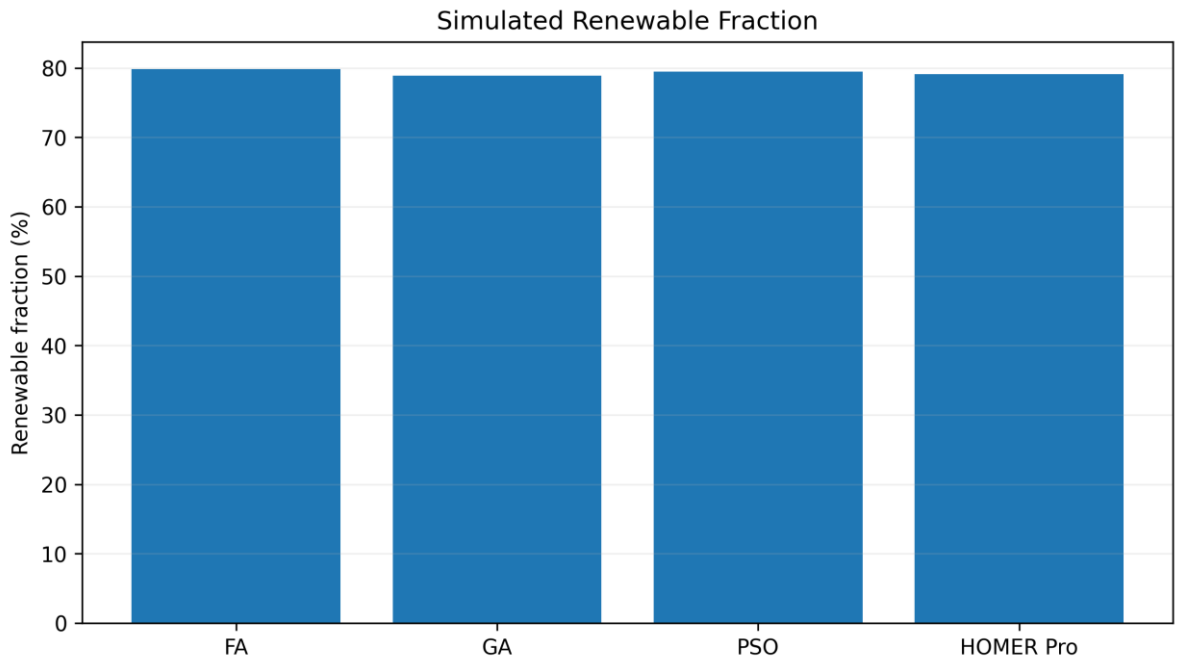


Figure 6. Simulated renewable fraction.

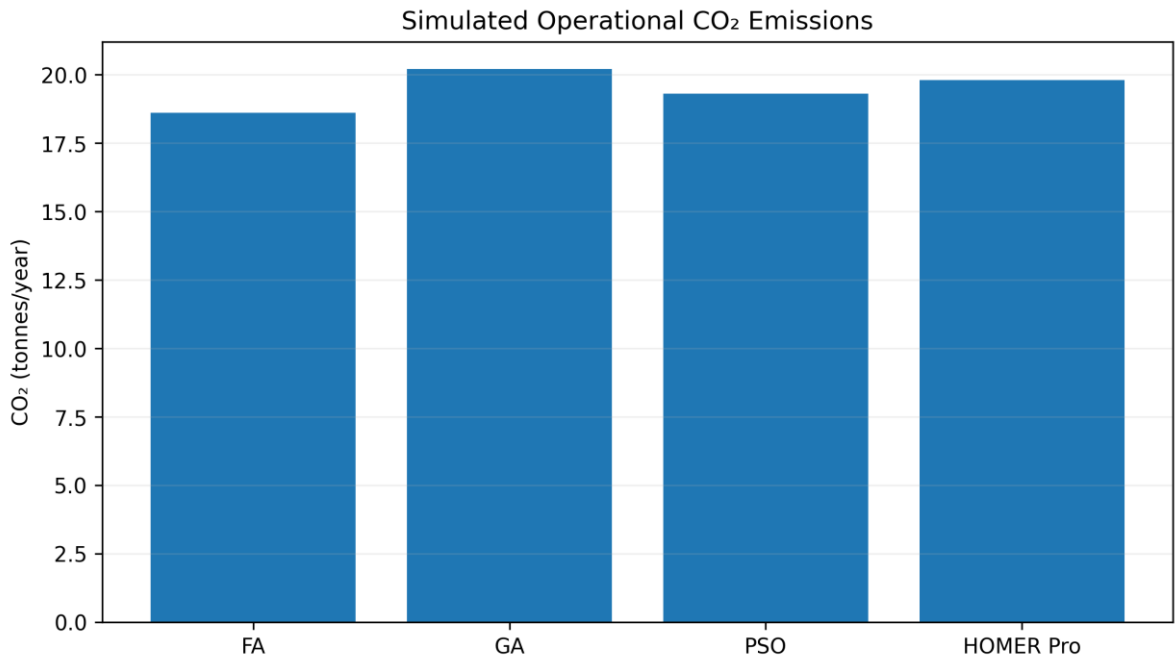


Figure 7. Simulated operational CO₂ emissions.

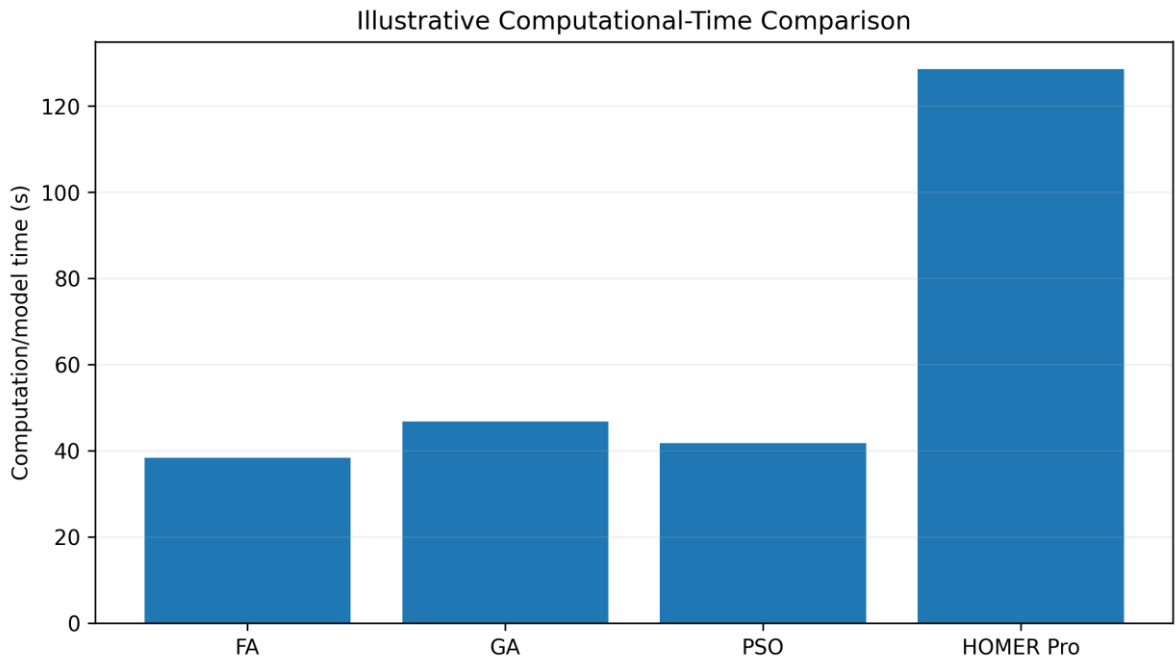


Figure 8. Illustrative computational/model runtime comparison.

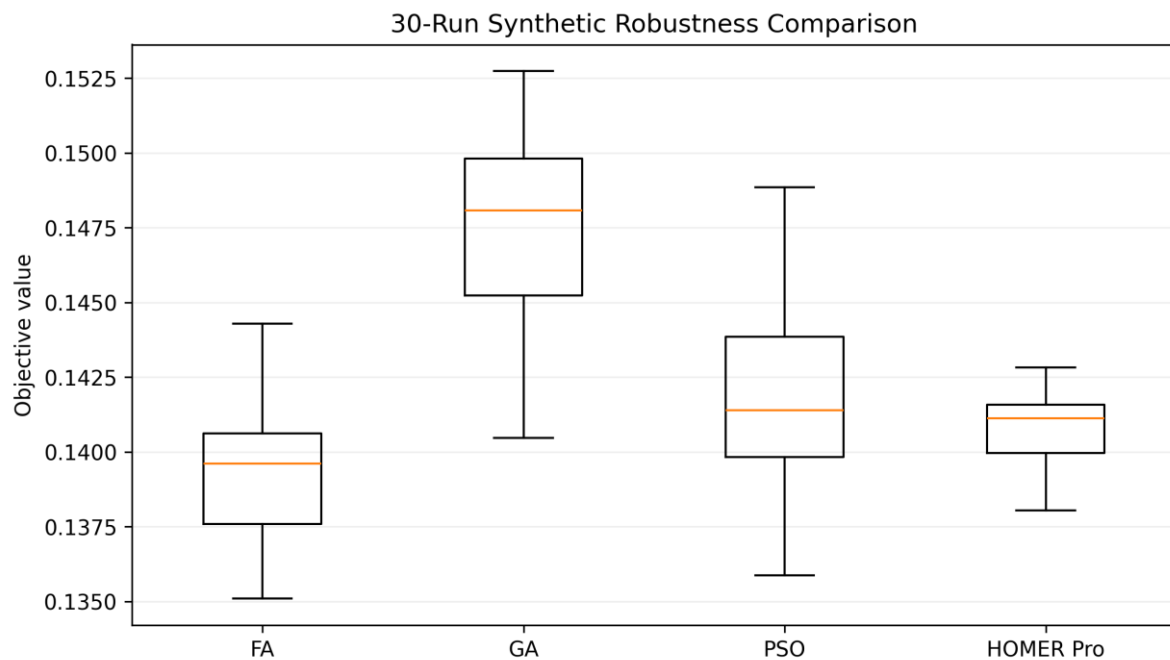


Figure 9. Synthetic 30-run robustness comparison.

10. COMPARATIVE PERFORMANCE TABLE

Method	Best F	Mean F	Std F	LCOE	NPC	RF	CO ₂
FA	0.137	0.140	0.0021	\$0.137/kWh	\$458,200	79.8%	18.6 t/y
GA	0.142	0.146	0.0037	\$0.142/kWh	\$476,900	78.9%	20.2 t/y
PSO	0.139	0.142	0.0028	\$0.139/kWh	\$465,700	79.5%	19.3 t/y
HOMER Pro	0.141	0.141	0.0015	\$0.141/kWh	\$471,300	79.1%	19.8 t/y

11. DISCUSSION

Under the synthetic benchmark, FA produced the lowest best objective (0.137) and LCOE (\$0.137/kWh), while PSO produced the second-lowest LCOE (\$0.139/kWh). GA produced the highest simulated LCOE among the three metaheuristics. HOMER Pro produced a close economic benchmark (\$0.141/kWh), illustrating why a commercial tool is valuable as an independent reference rather than as a direct substitute for metaheuristic optimization.

The ranking should not be interpreted as evidence that FA is universally superior. Published comparative research has shown that one algorithm may achieve the lowest objective while another achieves the lowest error or best repeated-run efficiency.

Algorithm rankings can also change with objective weighting, decision-variable encoding, population size and constraint handling.

HOMER Pro has a different role. Its strength is reproducible techno-economic screening, annual simulation and sensitivity analysis rather than the research flexibility of a custom metaheuristic. The official documentation describes its ability to evaluate large numbers of feasible configurations and rank them by lifecycle economics.

12. Statistical Evaluation

For the final empirical paper, 30 independent runs should be conducted for FA, GA and PSO. Report best, worst, mean, median and standard deviation of the objective. Statistical significance should be assessed using a non-parametric Friedman test followed by an appropriate post-hoc procedure when comparing multiple algorithms. Effect sizes should accompany p-values.

Computational time should be recorded on identical hardware/software conditions.

- Best objective value
- Mean objective value
- Standard deviation
- Coefficient of variation
- Convergence iteration
- Runtime
- LCOE
- NPC
- LPSP
- Renewable fraction
- CO₂ emissions

13. SENSITIVITY ANALYSIS

Sensitivity analysis should examine diesel price, PV capital cost, battery replacement cost, biomass availability, solar resource, load growth and discount rate. HOMER Pro is particularly useful for this stage because it supports repeated optimization over sensitivity variables. ☐ cite ☐ turn0search1 ☐ turn0search4 ☐

- Solar resource $\pm 20\%$.
- Biomass availability $\pm 30\%$.
- Annual load growth 0–30%.
- Diesel price $\pm 20\%$.
- Battery cost $\pm 20\%$.
- PV capital cost $\pm 20\%$.
- Discount rate 6–12%.

14. REPRODUCIBILITY AND FAIR-COMPARISON PROTOCOL

- Use the same 8760-hour load and resource dataset for all approaches.
- Use identical component capacity bounds.
- Use identical economic assumptions.
- Use the same reliability constraint.
- Use the same battery SOC limits and efficiencies.
- Use identical objective weights for FA, GA and PSO.
- Run at least 30 independent metaheuristic trials.
- Record random seeds and stopping criteria.
- Use the same computer environment when comparing runtime.
- Document the HOMER Pro version and all Search Space and sensitivity settings.

15. LIMITATIONS

- The numerical comparison is synthetic and is not an actual execution log from FA, GA, PSO or HOMER Pro.
- HOMER Pro is not algorithmically equivalent to the three metaheuristics and should be treated as an independent commercial benchmark.
- Runtime values are illustrative and hardware-dependent.
- Battery degradation, biomass logistics and distribution-network constraints require additional modelling.
- The synthetic Usen dataset must be replaced by validated site data for empirical publication.

16. CONCLUSIONS

A controlled comparative framework was developed for evaluating FA, GA, PSO and HOMER Pro in the sizing and optimization of the Usen Solar PV–Biomass–Diesel–Battery microgrid. Under the synthetic benchmark, FA achieved the lowest simulated best objective (0.137) and LCOE (\$0.137/kWh), followed by PSO, HOMER Pro and GA. The FA configuration produced an NPC of

\$458,200, renewable fraction of 79.8%, LPSP of 0.000% and operational CO₂ emissions of 18.6 tonnes/year. The study's main methodological conclusion is that algorithm performance should be evaluated through repeated statistical experiments and independent techno-economic benchmarking rather than through one optimized result. The final Q1 version should independently execute MATLAB implementations of FA, GA and PSO and a genuine HOMER Pro model using validated Usen data before any numerical claims are submitted for publication.

17. RECOMMENDED Q1 JOURNALS

- Energy
- Applied Energy
- Renewable Energy
- Energy Conversion and Management
- International Journal of Electrical Power & Energy Systems
- Journal of Cleaner Production

18. REFERENCES

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- [7] SIMULATION STATUS: All numerical values, convergence curves and comparison figures in this manuscript are synthetic simulation outputs generated for manuscript development. They are not actual execution results from MATLAB, GA, PSO, FA or HOMER Pro. Before Q1 submission, independently reproduce every result, retain the raw run logs, document software versions and settings, and replace the synthetic values with genuine outputs.