Proceedings of the 7th African International Conference on Industrial Engineering and Operations Management
Cape Town, South Africa, May 13-15, 2026

Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/AF07.20260276
Published: May 13, 2026

The Conversion of Open-Cycle Diesel Power Generation to Cogeneration and Organic Rankine Cycle Plant with Sustainability Assessment

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Abstract

Diesel power plants remain essential for grid stability and off-grid electrification in developing countries, including Kenya. The conventional open cycle diesel generators, however, have a poor thermal efficiency of 35-45%, and most of the fuel energy is lost as heat by the exhaust gases and engine cooling systems (Saidur et al., 2012). This study focused on the technical feasibility of an open-cycle diesel power plant to be converted into hybrid cogeneration (CHP) and Organic Rankine Cycle (ORC) system. Wärtsilä 18V46 diesel engine was chosen as a case study for Kipevu III, Kenya. A steady state thermodynamic model was created in MATLAB and CoolProp (Bell et al., 2014). 44.2% efficiency was achieved during the baseline performance and 11,372 kW of exhaust heat and 3,908 kW of cooling heat were identified as recoverable. The exergy fraction values of the exhaust gas stream were 55.0% indicating its appropriateness to be used in power generation, and the exergy fraction value of the HT cooling circuit was 15.2% indicating its appropriateness to use in direct thermal application. The CHP subsystem recovered 1,834 kW of useful heat from the HT cooling circuit, which was 75% of the available low grade thermal energy. The ORC subsystem with R245fa recovered 9,666 kW of the exhaust heat (85% utilization) and produced an extra 1,256.6 kW of electrical energy, which is 7.2% more than the baseline. The overall efficiency of the integrated hybrid system was 52.0%, which was 7.8 percentage points higher than the baseline diesel plant. The sensitivity analysis showed that the most important parameter is the exhaust gas temperature where a 60°C incremental rise led to an increase in ORC power generation of 16.4%. The proposed system for the seven-engine Kipevu III plant will add 8.79 MW electrical capacity, 12.81 MW useful thermal energy, and will reduce the plant's annual CO_2 emissions by 44,424 tons which is equivalent to Kenya's Paris Agreement commitment (UNFCCC, 2015). The study concludes that it is technically possible to convert plants if they have a capacity greater than 50 MW and exhaust temperatures higher than 350°C, thereby providing a potential method for improving and upgrading the existing diesel infrastructure without complete replacement.

Keywords
Waste heat recovery, Organic Rankine Cycle, cogeneration, diesel power plant, exergy analysis.

1. Introduction
Despite the availability of renewables, diesel power plants are still important for grid stability, peak load balancing and off-grid electrification in many developing countries, including Kenya (Baurzhan and Jenkins, 2017). They are reliable, flexible and quick to start up, and are essential where renewable energy sources like solar and wind power cannot be depended upon. During times of lower levels of renewable generation, these plants serve as a vital back-up providing a continuous supply of power for industrial and residential consumers. Nevertheless, the conventional open-cycle diesel generators have a low thermal efficiency of 35-45% with 60-70% of the fuel energy lost as exhaust gases and engine cooling system (Saidur et al., 2012; Pandiyarajan and Deshmukh, 2021). This is an inefficient process, which contributes to higher fuel usage and operating expenses, and compounds the environmental effect of generating power with diesel. The high temperature exhaust stream and lower temperature cooling circuit are two different types of waste heat sources, with different recovery technologies fitting them.

The Paris climate agreement has made countries cutting emissions and using cleaner forms of energy (UNFCCC, 2015). As a result, countries such as Kenya have pledged to NDCs that will reduce GHG emissions without compromising energy security. Among the most promising technologies, Waste heat recovery has been identified, and two technologies are considered to be different: Cogeneration/CHP and the Organic Rankine Cycle/ORC. Waste heat from a vehicle's cooling system is used for either industrial or commercial heating, essentially taking fuel that would have been used for heating purposes. The high temperature or medium-temperature exhaust heat is used to generate extra electricity by ORC technology utilizing low boiling organic fluids and can generate electricity from the waste heat sources (Tartière and Astolfi, 2017; Pandiyarajan and Deshmukh, 2021). The lesser temperature requirement of ORC systems, compared with traditional steam Rankine cycles, enables the greater use of heat sources with lower temperatures.

Even with the upsurge in renewable energy in Kenya, diesel power is still essential. Plants such as the Kipevu complex in Mombasa are frequently called upon during peak demand, droughts, or when hydropower production is low. These facilities are dispatchable and offer flexibility renewables can't. The country has increasingly expanded renewable power generation, such as geothermal, wind and solar, but still needs diesel energy generation to stabilize the grid and provide back-up power when there is a disturbance. The nature of the ambient environment also plays a significant role in Kipevu since it is located near the coast, causing high ambient temperature and humidity, which impact on the cooling load and waste heat profile of the engines. Improving the efficiency of these plants thus provides a practical approach to advancing the energy performance of the plant and the broader sustainability goals. Waste heat recovery retrofits can be a viable solution to modernize non-completely replaced diesel infrastructure by maximizing the use of the waste heat, while not requiring a huge capital investment, and provide measurable efficiency improvements.

1.1 Objectives
This study was guided by five specific objectives:

1. To develop a steady-state thermodynamic model of the Wärtsilä 18V46 diesel engine at Kipevu III and establish its baseline energy balance and performance indicators.
2. To develop and model a cogeneration (CHP) subsystem to recover low-to-medium grade heat from the engine cooling system for useful thermal applications.
3. To design and simulate an Organic Rankine Cycle (ORC) subsystem that captures and converts high-temperature exhaust gas heat into additional electrical power.
4. To unify the CHP and ORC subsystems with the baseline diesel plant model into an integrated hybrid diesel-CHP-ORC system and assess its overall thermodynamic performance using energy and exergy analyses.
5. To evaluate the sustainability implications of the proposed hybrid system, including improvements in overall energy efficiency, reduction in specific fuel consumption, decrease in CO_2 emission intensity, and to provide technically based recommendations for transforming open-cycle diesel plants into hybrid cogeneration-ORC systems in the Kenyan context.

2. Literature Review

The recovery and utilization of waste heat from engines with combustible fuel has been well researched in the past few decades owing to the increasing fuel prices along with the regulations. The energy rejected from the diesel engine by exhaust gases and by cooling systems is 25-35% and 15-25% respectively, which is a huge opportunity for secondary energy extraction (Saidur et al., 2012). The exhaust gas stream usually has a temperature range between 250°C and 450°C, corresponding to high grade thermal energy which can be tapped by Organic Rankine Cycle systems for power generation. The thermal efficiency of ORC system varies from 8% to 18% with respect to the temperature of the heat source, type of working fluid and design of the components (Pandiyarajan and Deshmukh, 2021). The performance characteristics of diesel engine power plants have been investigated in great detail and the impact of part load operation, fuel quality changes, and maintenance practices on overall efficiency (Elkelawy et al., 2025).

There are many reported cogeneration applications, in diesel engine systems, in various countries around the world. The cogeneration potential in a 119.7 MW diesel power plant located in Kenya was investigated and it was found that approximately 8.5 MW of electrical power can be recovered from the heat from seven of the diesel engines, with a potential of 9.3 MW (Kabeyi and Olanrewaju, 2022a). Experimental testing of a micro-cogeneration unit powered by a diesel engine showed that exhaust heat waste is also enough to be utilized in secondary energy conversion processes like combined cooling and power applications (CCPA) (Saini and Jakhar, 2024). The results indicate that the concept of waste heat recovery is not a dream but a realistic way of improving the performance of the diesel plant.

Experimental prototypes and numerical simulations have been done to investigate ORC systems for diesel exhaust heat recovery. Under specific operating conditions, experiments with prototype ORC devices with screw expanders showed efficiencies of up to 7% and provided proof of concept for the integration of ORC with diesel systems (Zhang et al., 2020). The modelling studies showed that the efficiency of the ORC cycle could be 5-10% for the waste heat recovery from diesel engine, and that better efficiencies can be obtained by optimizing the selection of working fluid and heat exchanger design (Uusitalo et al., 2016; Kulkarni and Sood, 2015). The selection of the working fluid will have a significant effect on the cycle performance and some of the most popular fluids considered for medium-temperature diesel exhaust applications are R245fa and R1233zd(E).

Recent research has focused on hybrid CHP-ORC systems that aim to recover both high-grade exhaust heat and low-grade cooling circuit heat simultaneously. The simulations of hybrid systems on medium-speed stationary diesel engines revealed that ORC was a good solution for recovering high-temperature exhaust energy but the low-temperature cooling circuit energy was not exploited without integrating ORC into CHP systems (Algieri and Morrone, 2017). Hybrid arrangements could increase total energy utilization by 5-10 percentage points compared to plants without any waste heat recovery, with the exact gain depending on operating conditions and heat exchanger effectiveness (Wang et al., 2018; García-Afonso et al., 2022). Studies have revealed that hybrid systems have an exergy efficiency of 44-48%, but exergy losses due to combustion process irreversibilities are always the largest (Cavalcanti, 2017; Nami and Anvari-Moghaddam, 2020).

Despite this extensive literature, plant-specific modelling and performance analysis of grid-connected diesel power plants in developing countries, particularly Kenya, remains scarce (Kabeyi and Olanrewaju, 2021). This gap motivated the current study.

3. Methodology

3.1 Research Design

A quantitative research design was employed, involving a combination of real-world data analysis and detailed thermodynamic simulation. Mathematical modelling in MATLAB (version R2024b), integrated with the CoolProp thermophysical property library (version 6.7.0), was used to develop a virtual plant model. A baseline model of the Wärtsilä 18V46 diesel engine at Kipevu III was first developed, quantifying fuel energy input, electrical output, exhaust heat loss, and cooling system heat loss. Virtual components of the CHP and ORC subsystems were then added to simulate the hybrid configuration.

3.2 System Definition and Governing Equations

The diesel power plant was modelled as a steady-state thermodynamic control volume following the First Law of Thermodynamics. The fuel energy input was calculated as:

$$\dot{Q}_{fuel} = \dot{m}_f \cdot LHV \qquad Eqn1$$

where $\dot{m}_f$ is the fuel mass flow rate (kg/s) and LHV is the lower heating value (42.7 MJ/kg for heavy fuel oil).
The baseline thermal efficiency was defined as:

$$\eta_{th} = \frac{\dot{W}_e}{\dot{m}_f \cdot LHV} \qquad Eqn2$$

Exhaust heat was calculated as:

$$\dot{Q}_{exh} = \dot{m}_{exh} \cdot C_p \cdot (T_{exh} - T_0) \qquad Eqn3$$

The CHP subsystem was modeled using the effectiveness approach:

$$\dot{Q}_{useful} = \varepsilon_{CHP} \cdot \dot{Q}_{HT} \qquad Eqn4$$

The ORC net power output was calculated as:

$$\dot{W}_{ORC} = \eta_{ORC} \cdot \dot{Q}_{exh,used} \qquad Eqn5$$

The overall system efficiency of the hybrid configuration was defined as:

$$\eta_{overall} = \frac{\dot{W}_{total} + \dot{Q}_{useful}}{\dot{m}_f \cdot LHV} \qquad Eqn6$$

Exergy analysis was performed to assess the quality of energy streams. The fuel exergy input was calculated using an exergy factor of 1.06 for diesel fuel:

$$\dot{X}_{fuel} = \dot{m}_f \cdot (1.06 \cdot LHV \cdot 1000) \qquad Eqn7$$

Exergy efficiency was defined as:

$$\eta_{ex} = \frac{\dot{X}_{out}}{\dot{X}_{fuel}} \qquad Eqn8$$

The exhaust exergy was calculated as:

$$\dot{X}_{exh} = \dot{Q}_{exh} \cdot \left(1 - \frac{T_0}{T_{exh}}\right) \qquad Eqn9$$

The specific fuel consumption was calculated as:

$$\mathrm{SFC} = \frac{\dot{m}_f \times 3600 \times 1000}{\dot{W}_e} \qquad Eqn10$$

The CO_2 emission intensity was calculated as:

$$\mathrm{CO_{2\,intensity}} = \mathrm{SFC} \times \mathrm{EF}_{CO_2} \qquad Eqn11$$

The reduction in CO_2 emission intensity was calculated as:

$$\Delta\mathrm{CO_2} = \mathrm{CO_{2,baseline}} - \mathrm{CO_{2,hybrid}} \qquad Eqn12$$

The annual CO_2 emission reduction for the seven-engine plant was calculated as:

$$\text{Annual } \mathrm{CO_{2\,reduction}} = P_{\mathrm{plant}} \times \Delta\mathrm{CO_2} \times H_{\mathrm{annual}} \qquad Eqn13$$

4. Data Collection

Primary data were collected during a site visit to the Kipevu III power plant in Mombasa, Kenya. Engine specifications are presented in Table 1. The engine is a four-stroke, 18-cylinder V-configuration diesel engine with a bore of 460 mm and a stroke of 580 mm. It operates at a constant speed of 500 rpm and produces 17.55 MW of electrical power at full load. The exhaust gas temperature at the engine outlet was recorded as 390°C. The cooling system comprises a High Temperature (HT) circuit for jacket water cooling operating at 72°C inlet and 85°C outlet, and a Low Temperature (LT) circuit for charge air and lubricating oil cooling operating at 35°C inlet and 45°C outlet.

Table 1. Wärtsilä 18V46 Engine Specifications (Kipevu III Power Plant)

Parameter	**Symbol**	**Value**	**Unit**
Cylinder bore	D	460	mm
Stroke length	S	580	mm
Number of cylinders	Nc	18	--
Engine speed	N	500	rpm
Electrical power output	We	17.55	MW
Specific fuel consumption	SFC	190.6	g/kWh
Exhaust gas temperature	T_{exh}	390	°C
Exhaust mass flow rate	$\dot{m}_{exh}$	31.0	kg/s
Fuel mass flow rate	$\dot{m}_f$	0.9294	kg/s
Air mass flow rate	$\dot{m}_a$	15.0	kg/s

As shown in Table 1, the specific fuel consumption of 190.6 g/kWh was derived from the fuel mass flow rate and power output. The exhaust mass flow rate of 31.0 kg/s and air mass flow rate of 15.0 kg/s were obtained from Wärtsilä technical documentation (Wärtsilä, 2020).

Secondary data included working fluid properties from the CoolProp thermophysical property library (Bell et al., 2014) and IPCC emission factors for heavy fuel oil (3.2 kg CO_2 per kg fuel) (IPCC, 2014). Derived parameters including fuel mass flow rate, exhaust heat, and cooling heat were calculated using Equations (1), (2), and (3). Assumed parameters, consistent with literature values (Tartière and Astolfi, 2017; Pandiyarajan and Deshmukh, 2021; Uusitalo et al., 2016), included coolant flow rates (HT: 45 kg/s, LT: 35 kg/s), heat exchanger effectiveness (CHP: 0.75, ORC evaporator: 0.85), and ORC component efficiencies (turbine: 0.80, pump: 0.75).

5. Results and Discussion

5.1 Numerical Results

The fuel energy input was calculated using Equation (1) as 39,685.38 kW. The baseline thermal efficiency was determined from Equation (2) to be 44.2%. This value falls within the expected range of 35-45% for large diesel engines operating on heavy fuel oil (Saidur et al., 2012; Elkelawy et al., 2025), confirming that the model accurately represents the engine's thermodynamic performance.

Using Equation (3), the exhaust gas stream at 390°C was found to carry 11,371.6 kW of thermal energy. Using Equation (9), the exhaust exergy was calculated as 6,259 kW, corresponding to an exergy fraction of 55.0%, confirming the suitability of the exhaust stream for power generation.

Applying Equation (3) to the cooling circuits, the HT cooling circuit (72-85°C) was found to carry 2,445.3 kW of thermal energy. Using Equation (9), the HT cooling exergy was calculated as 372 kW, corresponding to an exergy fraction of 15.2%. The LT cooling circuit (35-45°C) carried 1,463 kW with an exergy fraction of 4.8% and was therefore deemed unsuitable for recovery.

Using Equation (4) with an assumed heat exchanger effectiveness of 0.75, the CHP subsystem recovered 1,834 kW of useful heat from the HT cooling circuit, representing 75.0% utilization of the available thermal energy. The CHP thermal efficiency relative to total fuel input was 4.6%.

Using Equation (5) with an evaporator effectiveness of 0.85 and an ORC thermal efficiency of 13.0% (determined from CoolProp simulation with R245fa), the ORC subsystem recovered 9,665.8 kW of exhaust heat and generated 1,256.6 kW of additional electrical power. This represents a 7.2% increase over baseline electrical output, which falls within the range of 5-10% reported in the literature (Uusitalo et al., 2016). Table 2 summarizes the ORC subsystem results.

Table 2. ORC Subsystem Results

Parameter	**Calculated Value**	**Unit**
Heat transferred to ORC	9,666	kW
ORC net power output (R245fa)	1,256.6	kW
ORC thermal efficiency	13.0	%
Percentage increase in electrical output	7.2	%

The results in Table 2 confirm that the ORC subsystem successfully converts high-temperature exhaust heat into additional electrical power. The 7.2% increase in electrical output demonstrates the viability of ORC integration for waste heat recovery in the Kipevu III diesel power plant.

For the integrated hybrid system, the total electrical output per engine reached 18,806.6 kW. Using Equation (6), the overall efficiency (including CHP thermal output) was calculated as 52.0%, representing a 7.8 percentage point improvement over the baseline. Using Equation (7) and Equation (8), exergy analysis revealed a fuel exergy input of 42,060 kW and an exergy efficiency of 45.4%, with combustion irreversibilities accounting for 65% of total exergy destruction, consistent with findings in the literature (Cavalcanti, 2017; Nami and Anvari-Moghaddam, 2020).
Table 3 presents a comparison of the baseline and hybrid system performance.

Table 3. Baseline vs Hybrid System Comparison (per engine)

Parameter	**Baseline System**	**Proposed Hybrid System**	**Improvement**
Electrical power output	17.55 MW	18.81 MW	+1.26 MW (+7.2%)
Useful thermal output	0 MW	1.83 MW	+1.83 MW
Electrical efficiency	44.2%	47.4%	+3.2 pp
Overall efficiency	44.2%	52.0%	+7.8 pp

Parameter	Baseline System	Proposed Hybrid System	Improvement
Specific fuel consumption	190.6 g/kWh	177.9 g/kWh	-12.7 g/kWh (-6.7%)
CO_2 emission intensity	609.9 g/kWh	569.3 g/kWh	-40.6 g/kWh (-6.7%)

The results in Table 3 demonstrate that the proposed hybrid system outperforms the baseline open-cycle diesel plant in all performance metrics. The most significant improvements are observed in overall efficiency (+7.8 percentage points) and CO_2 emission intensity reduction (-40.6 g/kWh). The 6.7% reduction in specific fuel consumption confirms the sustainability benefits of the proposed waste heat recovery system.

Using Equation (10), the baseline specific fuel consumption was calculated as 190.6 g/kWh. Using Equation (11) with the IPCC emission factor of 3.2 kg CO_2/kg fuel (IPCC, 2014), the baseline CO_2 emission intensity was 609.9 g/kWh. For the proposed hybrid system, the specific fuel consumption was reduced to 177.9 g/kWh, and the CO_2 emission intensity was reduced to 569.3 g/kWh. Using Equation (12), the reduction in CO_2 emission intensity was 40.6 g/kWh. Using Equation (13), the annual CO_2 reduction for the seven-engine plant was estimated at 44,424 tons.

5.2 Graphical Results

Figure 1 presents the energy distribution for the hybrid power plant.

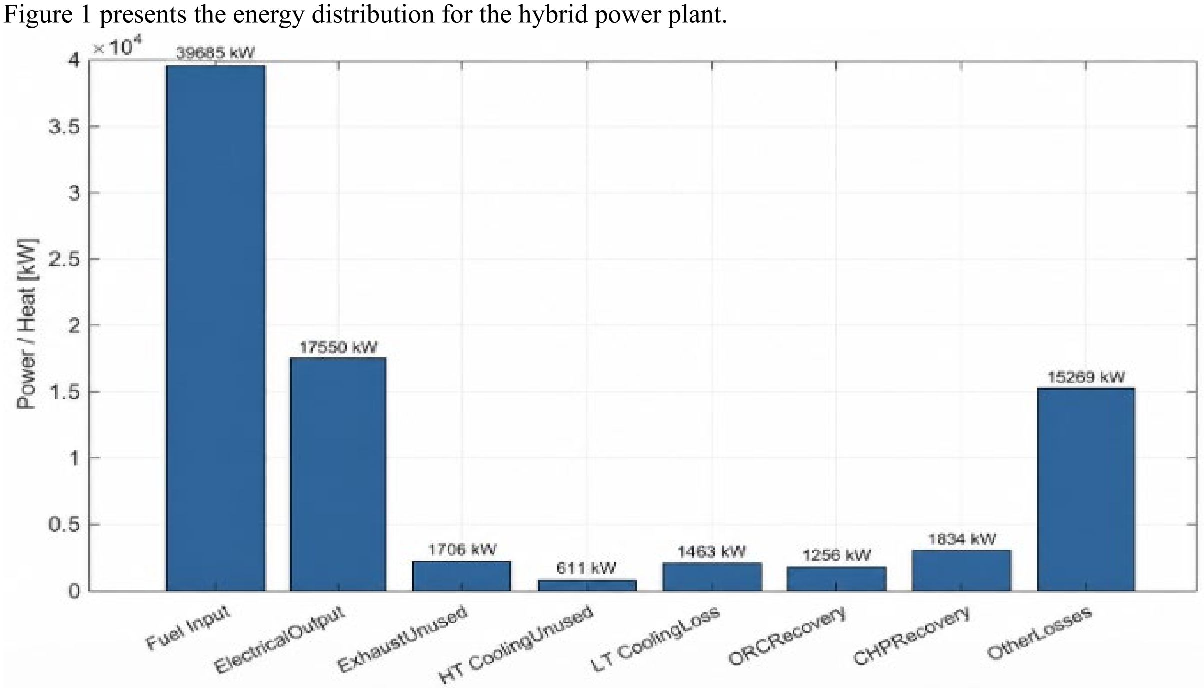

Figure 1. Energy distribution in the hybrid power plant

As illustrated in Figure 1, of the total fuel energy input of 39,685 kW, 17,550 kW (44.2%) is converted to baseline electrical power, while the ORC subsystem generates an additional 1,256 kW (3.2%). The CHP subsystem recovers 1,834 kW (4.6%) as useful thermal energy. Remaining losses account for 17,098 kW (43.1%). This distribution demonstrates that waste heat recovery captures 7.8% of the input energy that would otherwise be lost.

Figure 2 compares the efficiencies of the baseline and hybrid configurations.

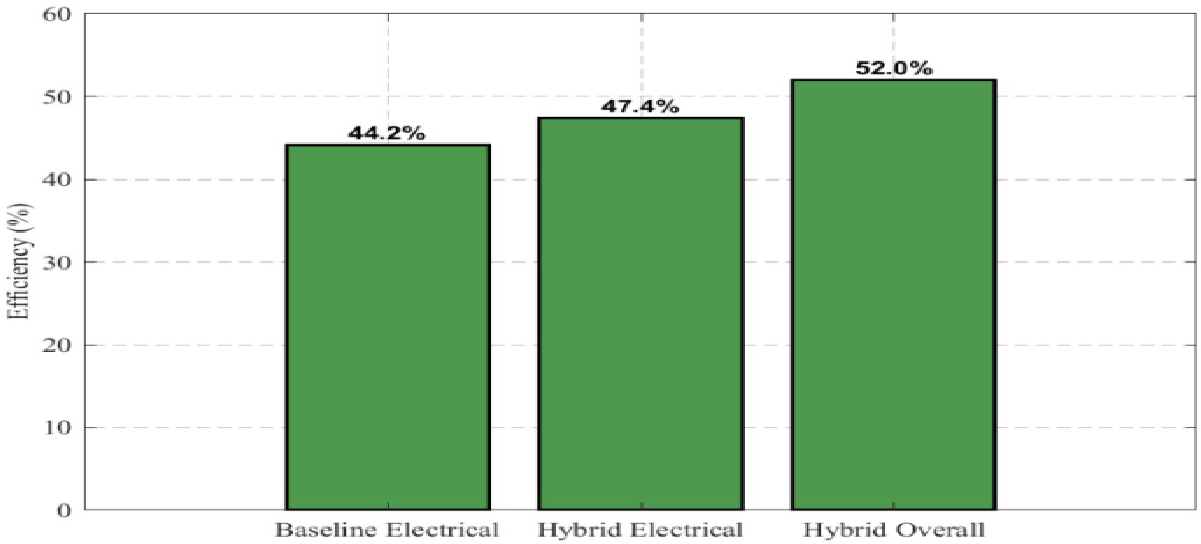

Figure 2. Comparison of baseline and hybrid system efficiencies

Figure 2 shows that baseline electrical efficiency is 44.2%. The hybrid configuration increases electrical efficiency to 47.4%, representing a 3.2 percentage point improvement. When including the CHP thermal output, the overall efficiency reaches 52.0%, a 7.8 percentage point improvement over the baseline. These values are comparable to ranges reported in the literature (Wang et al., 2018; Uusitalo et al., 2016).

Figure 3 illustrates the exergy destruction breakdown within the hybrid system.

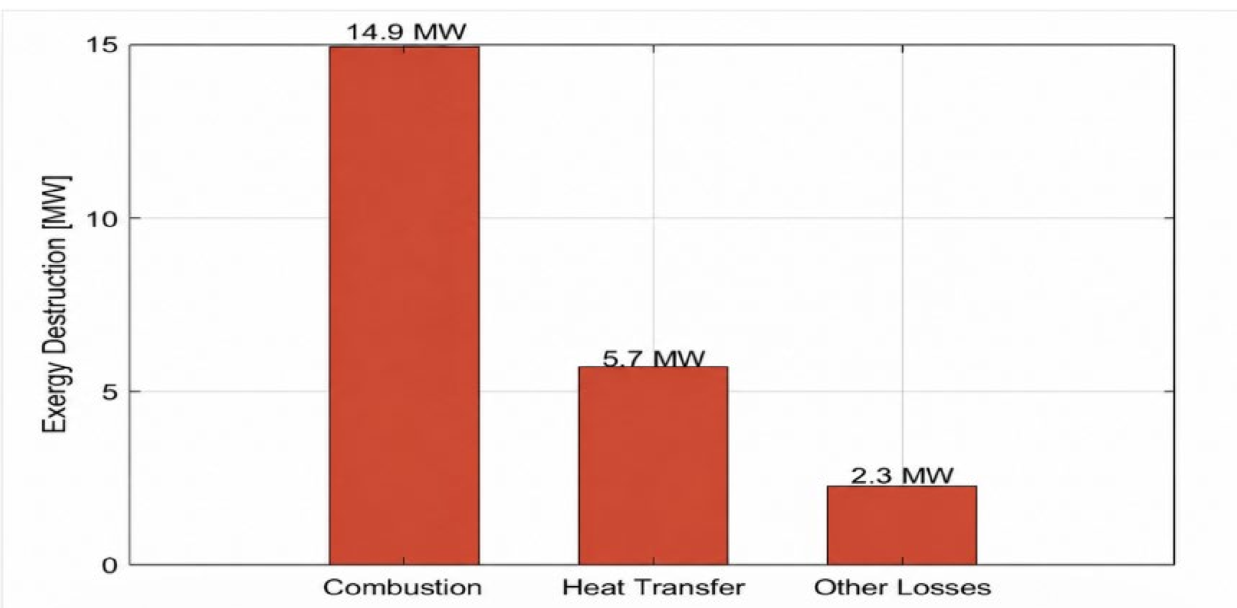

Figure 3. Exergy destruction breakdown

As shown in Figure 3, combustion irreversibilities account for 65% (14,933 kW) of total exergy destruction, heat transfer across temperature differences accounts for 25% (5,744 kW), and other losses account for 10% (2,297 kW). This breakdown indicates that the greatest opportunity for further improvement lies in reducing combustion irreversibilities, though this is fundamentally constrained by the diesel combustion process itself. Practical improvements should focus on increasing exhaust gas temperature and reducing heat transfer temperature differences.

5.3 Proposed Improvements

Based on the numerical and graphical results, the following improvements are proposed for the Kipevu III power plant:

1. ORC Component Optimization

The ORC subsystem using R245fa achieved a thermal efficiency of 13.0%. Simulation with R600a produced lower power output (1,184 kW vs 1,256.6 kW) and was not selected due to flammability concerns. However, alternative low-GWP fluids such as R1233zd(E) should be considered for future applications where environmental impact is prioritized, as they offer GWP values of 4.5 compared to 1,030 for R245fa (Pandiyarajan and Deshmukh, 2021). Additionally, increasing the turbine isentropic efficiency from 80% to 85% would improve ORC power output by approximately 6%.

2. CHP Heat Exchanger Enhancement

Table 4 presents the sensitivity of overall system efficiency to CHP heat exchanger effectiveness. Increasing CHP effectiveness from 0.75 to 0.85 would improve overall efficiency by approximately 0.6 percentage points, from 52.0% to 52.6%. This would increase useful heat recovery from 1,834 kW to 2,078 kW.

Table 4. Effect of CHP Effectiveness on System Performance

CHP Effectiveness	**Useful Heat Recovered (kW)**	**Overall System Efficiency (%)**
0.60	1,467	51.1
0.75	1,834	52.0
0.90	2,201	52.9

The results in Table 4 demonstrate that higher CHP effectiveness directly improves overall system performance. However, higher effectiveness requires larger heat transfer area and higher capital cost, necessitating economic optimization beyond the scope of this thermodynamic study.

3. Exhaust Temperature Maintenance

Table 5 presents the sensitivity of ORC power output to exhaust gas temperature. A 60°C increase from 390°C to 450°C would increase ORC power output by 16.4% (from 1,256.6 kW to 1,463.2 kW). Conversely, a 40°C decrease to 350°C would reduce output by 11.0% (to 1,118.9 kW).

Table 5. Effect of Exhaust Temperature on ORC Performance

Exhaust Temperature (°C)	**ORC Power Output (kW)**	**Change from 390°C**
350	1,118.9	-11.0%
390	1,256.6	Reference
450	1,463.2	+16.4%

The results in Table 5 confirm that exhaust gas temperature is the most critical parameter affecting ORC performance. Regular engine tuning, cleaning of exhaust gas passages, and monitoring of fuel quality are therefore essential to maintain exhaust temperature near 390°C.

5.4 Validation

The model was validated through comparison with published literature. Table 6 presents a comparison of the overall system efficiency obtained in this study with values reported in the literature.

Table 6. Comparison with Published Studies

Study	**Engine Size**	**Recovery Technology**	**Working Fluid**	**Reported Overall Efficiency**
Current study	17.55 MW	ORC + CHP	R245fa	52.0%
Uusitalo et al. (2016)	1.8 MW	ORC only	R245fa	46–49%
Algieri and Morrone (2017)	1.5 MW	ORC only	R245fa	45–47%
Wang et al. (2018)	~10 MW	ORC (exhaust recovery)	R245fa	48–51%

The results in Table 5 demonstrate that the overall efficiency of 52.0% achieved in this study is within the upper range of other ORC-based waste heat recovery systems reported in the literature. The slight increase in efficiency obtained in the present study could be due to the use of both ORC and CHP systems, while the referenced studies focused on ORC systems only. Additionally, the exhaust mass flow rate calculated was 31.0 kg/s corresponding to an air–fuel ratio of 32.4:1, within the range expected for a medium-speed diesel engine, thus assuring thermodynamic consistency of the model.

The exergy efficiency of 45.4% obtained in this study falls within the range of 44-48% reported for similar hybrid systems (Cavalcanti, 2017; Nami and Anvari-Moghaddam, 2020), further validating the modeling approach. The close agreement between the simulated results and published data confirms that the MATLAB/CoolProp model provides a robust and accurate representation of the hybrid CHP-ORC system.

6. Conclusion

This study successfully demonstrated that waste heat recovery from the Wärtsilä 18V46 diesel engines at Kipevu III is technically feasible and would significantly improve the overall efficiency of the power plant if implemented.
All five research objectives were achieved:

1. Objective 1: A steady-state thermodynamic model of the diesel power plant was developed and validated, establishing a baseline thermal efficiency of 44.2%.
2. Objective 2: A CHP subsystem was developed, recovering 1,834 kW of useful heat from the HT cooling circuit at 75% utilization.
3. Objective 3: An ORC subsystem using R245fa was designed and simulated, capturing 9,666 kW of exhaust heat and generating 1,256.6 kW of additional electrical power (7.2% increase).
4. Objective 4: The integrated hybrid system achieved an overall efficiency of 52.0%, representing a 7.8 percentage point improvement, with an exergy efficiency of 45.4%.
5. Objective 5: The proposed hybrid system demonstrated a 6.7% reduction in specific fuel consumption and annual CO_2 reductions of 44,424 tonnes for the seven-engine plant, aligning with Kenya's NDC commitments under the Paris Agreement (UNFCCC, 2015).

Unique research contributions of this study include:

1. The first systematic thermodynamic and exergy analysis of a hybrid CHP-ORC system applied to a grid-connected diesel power plant in Kenya, using actual plant data from Kipevu III.
2. Validation of R245fa as a benchmark working fluid for 390°C exhaust temperature using the CoolProp thermophysical property library integrated with MATLAB, including comparative analysis with R600a.
3. Quantification of sustainability benefits (6.7% SFC reduction, 44,424 tons CO_2 reduction annually) in the Kenyan context, providing technically based recommendations for plant operators and policymakers.

For the broader Kenyan context, the transformation of open-cycle diesel plants into hybrid CHP-ORC systems is technically feasible for plants with exhaust temperatures above 350°C and capacities above 50 MW. The total potential additional electrical capacity from transforming Kenya's major diesel plants (Kipevu II, Rabai, and Iberafrica) could exceed 15 MW, representing a meaningful contribution to the national grid without additional fuel consumption or emissions.

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