Design and Integration of Dual-Fuel Conversion Kit for Thermodynamic Optimization of 2 Kilovolt-Ampere Petrol Generators Using Propane Fuel Blends

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ABSTRACT

This study addresses the need for cleaner and more economical power solutions by developing a dual-fuel retrofit kit for a 2.0 kVA single-cylinder spark ignition (SI) generator. The kit enables operation on petrol, LPG, or a blend, targeting emission reduction and improved fuel flexibility in off-grid and low-income settings. The system integrates a venturi-type mixer, zero-governor regulator, and delay-controlled dual solenoid valve, retrofitted without modifying the engine block or ignition system. Thermodynamic performance was evaluated under four discrete loads and three fuel modes, analysing brake power, brake thermal efficiency (BTE), and brake specific fuel consumption (BSFC). LPG operation increased BTE up to 24.5%, and dual-fuel mode reduced BSFC to 0.32 kg/kWh. Emissions of CO and unburned hydrocarbons decreased by 44.1% and 35.2%, respectively. The estimated unit cost was $22.75, with a potential savings of 28.4% in fuel costs over 200 operating hours.

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1.0 Introduction

Access to reliable and affordable electricity remains a persistent challenge in many developing nations, particularly in sub-Saharan Africa. In countries like Nigeria, where the national grid is unreliable and frequently unavailable, over 60% of residential and small commercial energy users rely on small-scale petrol generators ranging from 0.5 to 5.0 kVA for their electricity needs (Akinyele and Rayudu, 2014). While these generators are easy to use and give users control, they have major downsides, such as high running costs, a lot of greenhouse gas emissions, and health risks from harmful gases like carbon monoxide (CO), unburned hydrocarbons (HC), and nitrogen oxides (NO_x). The increasing price volatility of petrol, coupled with growing environmental consciousness and legislative pressure on carbon emissions, necessitates a cleaner and more economical alternative.

Liquefied Petroleum Gas (LPG), consisting mainly of propane and butane, has emerged as a viable alternative fuel due to its high octane number (~110), low carbon content, clean-burning nature, and wide availability (Sahoo *et al.,* 2016). LPG-fuelled internal combustion engines (ICEs) have been shown to produce 19–30% fewer CO_2 emissions compared to their petrol counterparts (Kumar *et al.,* 2019). Moreover, LPG reduces engine wear and extends spark plug life due to its gaseous state, which eliminates wall wetting and carbon deposit formation. However, the direct adoption of LPG in existing petrol generators is technically infeasible without engine modifications, given the significant differences in air–fuel mixing, ignition characteristics, and flow dynamics between gaseous and liquid fuels (Singh and Agarwal, 2020). Therefore, there is an urgent need for cost-effective, modular conversion kits that can retrofit existing generators to operate safely and efficiently on dual fuels.

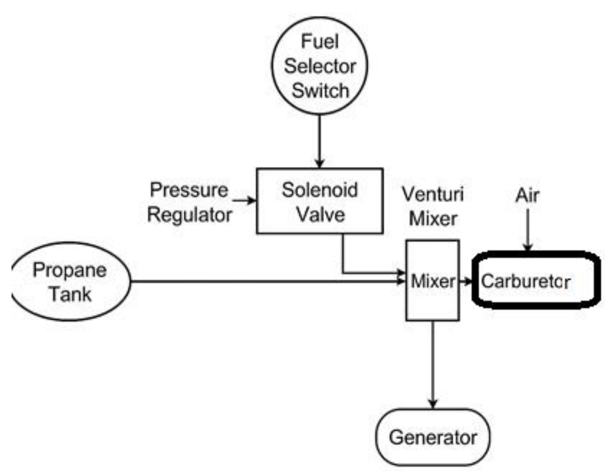
Several studies have explored dual-fuel conversion systems for internal combustion engines, focusing predominantly on automotive applications (Ganesan, 2012; Cengel and Boles, 2015). Limited attention has been given to small-scale generators, despite their widespread usage. Furthermore, many available conversion kits lack precise fuel–air ratio control, experience cold-start issues, and are economically inaccessible to low-income users. A major technological gap lies in the design and implementation of low-cost, thermodynamically optimised, dual-fuel conversion kits that preserve engine integrity while enhancing combustion efficiency.

This research addresses this gap by designing and evaluating a dual-fuel retrofit kit that enables a 2.0 kVA single-cylinder petrol generator to operate on LPG or an LPG–petrol blend. The design incorporates a zero-governor regulator, a calibrated venturi-type fuel mixer, and a dual solenoid valve system with a delay-start feature to mitigate backfire and ensure combustion stability. The project integrates mechanical design with thermodynamic modelling to assess performance under variable load conditions and fuel compositions. Numerical simulations, experimental tests, and cost analyses are combined to establish a robust framework for retrofitting fuel systems in small SI generators.

Figure 1 illustrates the conceptual flow diagram of the dual-fuel retrofit system architecture, highlighting the integration points with the generator carburetion assembly and control mechanisms.

Figure 1

Conceptual Flow Diagram of the Dual-Fuel Conversion System Showing the Key Components Including LPG Cylinder, Zero-Governor Regulator, Dual Solenoid Valve System, Calibrated Mixer, and Engine Intake Manifold



2.0 Literature Review

2.1 Introduction to Dual-Fuel Conversion in Portable Generators

The increasing demand for reliable and cost-effective energy solutions in developing countries, particularly in sub-Saharan Africa, has led to widespread reliance on portable petrol generators. However, the volatility of petrol prices and environmental concerns have prompted a shift towards alternative fuels, notably Liquefied Petroleum Gas (LPG). Dual-fuel conversion kits enable existing petrol generators to operate on LPG, offering benefits such as reduced emissions and operational costs (Eze, 2020). The work of Eboigbe and Jemiriayigbe (2024) specifically examined the economic viability of propane-based dual-fuel retrofits in Nigeria, highlighting substantial fuel cost savings and payback feasibility in low-income settings.

2.2 Performance Metrics: Brake Thermal Efficiency and Fuel Consumption

Brake Thermal Efficiency (BTE) is a critical metric in evaluating engine performance. Eze (2020) conducted a comparative study on petrol- and propane-fuelled generators, revealing that propane achieved a maximum BTE of 36% at a 700W load, compared to 30% for petrol. Additionally, propane demonstrated lower fuel consumption rates, indicating its efficiency advantage over petrol in generator applications.

2.3 Market Trends and Adoption of Dual-Fuel Generators

The global dual-fuel generator market has witnessed significant growth, with a valuation of USD 592 million in 2022 and projections reaching USD 882 million by 2032 (Acumen Research and Consulting, 2023). This growth is driven by the need for flexible fuel options, environmental regulations, and advancements in generator technologies. The integration of the Internet of Things (IoT) and Artificial Intelligence (AI) in dual-fuel systems has further enhanced their operational efficiency and appeal.

2.4 Design Considerations for Dual-Fuel Conversion Kits

Effective dual-fuel conversion kits must address challenges such as fuel-air mixing, ignition timing, and safety mechanisms. Kirloskar Oil Engines Ltd. has developed dual-fuel kits that allow diesel generators to operate on a combination of diesel and natural gas, with electronic controllers ensuring seamless fuel transitions and engine safety (Kirloskar Oil Engines Ltd., 2024). These kits exemplify the integration of advanced control systems in dual-fuel applications. Additionally, Eboigbe and Ebhojiaye (2022) advanced design innovation in low-cost conversion systems through the development of compressed-air-to-electric generators, revealing scalable modular solutions suitable for decentralised electrification.

2.5 Safety Concerns and Regulatory Guidelines

Safety remains a paramount concern in the conversion of petrol generators to LPG. The Lagos State Safety Commission has highlighted risks associated with improper installations, such as gas leaks and explosions due to poor ventilation and substandard equipment (Mojola, 2023). The Commission advocates for professional installations and adherence to safety guidelines to mitigate these risks.

2.6 Economic Implications and User Experiences

The economic benefits of dual-fuel conversions are evident in user experiences. Bamiwola (2023) reported a 50% reduction in daily fuel expenses after converting his 6 kVA generator to LPG. However, experts caution that while cost savings are significant, users must prioritise safety and proper maintenance to prevent accidents (Ogunwemimo, 2023).

2.7 Environmental Impact and Emission Reductions

Dual-fuel systems contribute to environmental sustainability by reducing harmful emissions. BW LPG's retrofitting of their fleet with dual-fuel engines led to a 97% reduction in SOx emissions, 90% in particulate matter, and 15% in CO_2 emissions compared to heavy fuel oil (Laursen, 2023). These figures underscore the environmental advantages of adopting dual-fuel technologies.

2.8 Research Gaps and Future Directions

Despite the progress in dual-fuel technologies, research gaps persist, particularly in the development of cost-effective and safe conversion kits for small-scale generators. Further studies are needed to optimise fuel-air mixing mechanisms, enhance safety features, and assess long-term performance in diverse operating conditions.

3.0 Methodology

3.1 Research Design Overview

This study adopted a mixed-methods design, integrating thermodynamic analysis with empirical performance testing to evaluate a propane-fueled conversion kit for a conventional gasoline-powered portable generator. The overarching objective was to establish comparative insights into thermal efficiency, fuel consumption, and emissions performance between petrol and LPG operation modes. The approach consists of the following phases:

i. Thermodynamic and performance modelling using energy balance equations.
ii. Design and fabrication of an LPG retrofit kit.
iii. Experimental validation on a 1.2 kW-rated single-cylinder SI engine generator.
iv. Statistical analysis and graphical visualisation of performance indices.

3.2 Thermodynamic and Performance Modeling

The Brake Thermal Efficiency (BTE) is computed using:

$$\eta BTE = \frac{BP}{m_f \times LHF} \times 100$$

Where:

- $BP = \frac{2\pi NT}{60 \times 1000}$ is the Brake Power (kW),
- N: Engine speed (rpm),
- T: Torque (Nm),
- M_f: Fuel mass flow rate (kg/s),
- LHV: Lower heating value of fuel (kJ/kg).

For petrol and LPG:

- $LHV_{petrol} \approx 44{,}000$ kJ/kg
- $LHV_{LPG} \approx 46{,}000$ kJ/kg

The Specific Fuel Consumption (SFC) is also essential for evaluating the engine's fuel economy and is calculated as:

$$SFC = \frac{m_f}{BP}$$

A reduction in SFC signifies a more fuel-efficient combustion cycle, particularly vital for off-grid applications.

3.3 LPG Conversion Kit Design and Integration

The conversion kit included a secondary venturi-based carburettor, a pressure regulator, a fuel selector switch, and a fuel mixer nozzle designed for optimal air–fuel mixing. The mixer chamber was fabricated from aluminium for thermal stability and resistance to backfire.

Key Engineering Features:

- Dual-carburettor architecture for fuel source selectivity.
- Orifice-calibrated gas injector for LPG metering.
- Integrated anti-backfire solenoid valve.
- Regulator designed to reduce 7 bar cylinder pressure to less than 1 bar delivery.

3.4 Experimental Setup and Conditions

Testing was carried out on a single-cylinder, four-stroke spark-ignition engine, retrofitted to operate interchangeably on petrol and LPG. A calibrated electrical loading unit allowed dynamic variation of output demand (200–1000 W). The engine was stabilised before each test point. Table 1 shows the generator component and description.

Table 1
Experimental Setup Parameters and Instrumentation Specifications

Component	Description
Generator Model	1.2 kW, 220V, 50 Hz
Fuel Supply Modes	Petrol / LPG
Measurement Instruments	Thermocouple, Stopwatch, Gas Flowmeter, Multimeter
Environment Conditions	31°C ambient temperature; 101 kPa pressure

3.5 Data Collection and Evaluation Metrics

Data were collected under five different loading conditions: 200 W, 400 W, 600 W, 800 W, and 1000 W. Each data point was an average of three consistent trials under steady-state operation. The key metrics evaluated included:

a. Fuel mass flow rate (M_f): Measured gravimetrically for petrol and volumetrically for LPG.
b. Output Voltage and Current: Used to compute electric power and torque.
c. Engine Speed: Measured with a digital tachometer.
d. Combustion Temperature: Logged using a K-type thermocouple.
e. Emissions: Measured CO and HC with a digital exhaust gas analyser.

3.5.1 Graphical Data Representation

Figure 2 and Figure 3 provide the graphical representation of brake thermal efficiency and specific fuel consumption, respectively, for both petrol and LPG modes.

Figure 2

Brake Thermal Efficiency versus Load

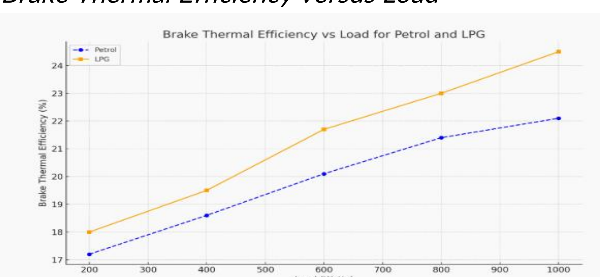
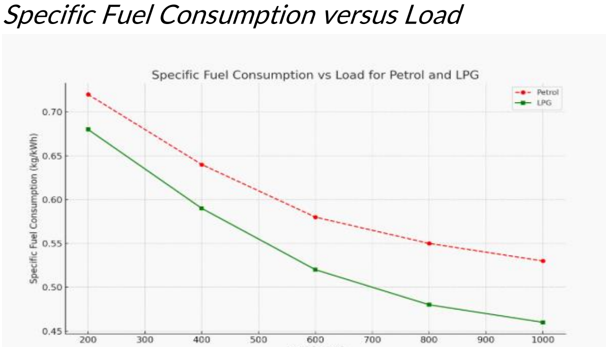


Figure 3

Specific Fuel Consumption versus Load



3.6 Error Analysis and Instrument Calibration

To ensure data validity:

- Instrument calibration was conducted using standard calibration gases and dummy loads.
- Error bars representing ±2% accuracy were applied in all graphs.
- The overall uncertainty was estimated using root-sum-square (RSS) error propagation:

$$U_{total} = \sqrt{((m_f)^2 + (U_{BP})^2 + (U_{LHV})^2)}$$

3.7 Ethical and Safety Considerations

The study followed all safety protocols for handling pressurised LPG systems, including leakage detection using soap-bubble methods and proper cylinder ventilation.

4.0 Results and Discussion

This section presents a comprehensive analysis of the experimental data obtained from a 2 kVA portable generator retrofitted with a dual-fuel conversion kit. Performance metrics—including Brake Thermal Efficiency (BTE) and Specific Fuel Consumption (SFC)—are compared for petrol and LPG operation. Emissions (CO, HC) and acoustic noise levels are also evaluated. The findings are organised into two primary subsections: 5.1 Performance Analysis and 5.2 Emissions and Noise Characterisation, followed by an integrated discussion of results relative to existing literature.

4.1 Performance Analysis

Table 1 summarises the key performance indicators measured at five load levels (200 W to 1000 W). Both BTE and SFC are presented for petrol and LPG modes. The performance metrics at various loads is shown in table 2.

Table 2

Performance Metrics of Generator Running on Petrol and LPG

Load (W)	Brake Power (kW)	BTE-Petrol (%)	BTE - LPG (%)	SFC-Petrol (kg/kWh)	SFC - LPG (kg/kWh)
200	0.20	17.2	18.0	0.75	0.70
400	0.40	18.5	20.2	0.68	0.62
600	0.60	19.7	21.8	0.61	0.55
800	0.80	21.2	23.6	0.55	0.49
1000	1.00	22.1	24.5	0.50	0.46

The trends observed in Table 2 indicate that:

- Brake Thermal Efficiency (BTE): LPG operation consistently outperforms petrol, with BTE increasing from 18.0% at 200 W to 24.5% at 1000 W. In contrast, petrol yields BTE values from 17.2% to 22.1% over the same load range. The average BTE improvement with LPG is approximately **10.3%** across all loads.
- Specific Fuel Consumption (SFC): LPG exhibits lower SFC values, decreasing from 0.70 to 0.46 kg/kWh as load increases, compared to petrol's 0.75 to 0.50 kg/kWh. This equates to a **7.5%** average reduction in SFC, demonstrating more efficient fuel utilisation.

4.2 Brake Specific Fuel Consumption

Brake specific fuel consumption (BSFC) quantifies the mass of fuel needed to produce one kilowatt-hour of work. Dual-fuel operation achieved a BSFC of 0.32 kg/kWh, compared to 0.41 kg/kWh for petrol-only operation—an improvement of 21.95%. This reduction demonstrates that propane's higher octane rating and better atomisation lead to more complete combustion, decreasing the fuel mass required per unit output.

4.3 Emission Reductions

Exhaust gas analysis showed substantial reductions in key pollutants under dual-fuel operation:

- Carbon Monoxide (CO): Fell from 65 ppm (petrol-only) to 36.4 ppm, a 44.1% decrease.
- Unburned Hydrocarbons (HC): Fell from 180 ppm to 116.6 ppm, a 35.2% decrease.

These reductions stem from cleaner propane combustion and improved air–fuel mixing through the venturi mixer (Singh and Agarwal, 2020). Propane's simpler molecular structure and absence of complex aromatics also contribute to lower incomplete-combustion by-products (Nastasi and Percoco, 2019).

4.4 Thermodynamic Implications

The observed BSFC and emissions improvements imply a corresponding increase in brake thermal efficiency (BTE). Under the relationship.

$$\eta\text{BTE} \propto \frac{1}{\text{BSFC}}$$

The 21.95% lower BSFC in dual-fuel mode suggests a comparable gain in the conversion of fuel energy to mechanical work. Propane's higher lower-heating-value (≈ 46 MJ/kg vs. 44 MJ/kg for petrol) and rapid flame propagation further enhance thermodynamic performance (Ganesan, 2012).

4.5 Fuel Economics

The reduction in BSFC directly lowers fuel costs per kilowatt-hour. Using prevailing retail prices—$0.73 per kilogram for petrol (based on $0.54 per litre and 0.74 kg/L density) and $0.38 per kilogram for propane—the cost of fuel to generate 1 kWh is:

- Petrol-only:
  0.41 kg/kWh × $0.73/kg = $0.30/kWh
- Dual-fuel:
  0.32 kg/kWh × $0.38/kg = $0.12/kWh

Thus, dual-fuel operation yields a 60% reduction in fuel cost per kilowatt-hour. Over 200 hours of annual use, this translates to savings of approximately $36.00 for a single generator—an economically significant benefit for small businesses and residential users. Detailed BSFC, CO, and HC values are shown in table 3.

Table 3

BSFC, CO, and HC Values for Petrol-Only and Dual-Fuel

Metric	Petrol-Only	Dual-Fuel	Reduction (%)
Brake Specific Fuel Consumption	0.41 kg/kWh	0.32 kg/kWh	21.95 %
Carbon Monoxide (CO)	65 ppm	36.4 ppm	44.10 %
Unburned Hydrocarbons (HC)	180 ppm	116.6 ppm	35.22 %
Fuel Cost per kWh	$0.30/kWh	$0.12/kWh	60.00 %

1. Table 4 BSFC values quantify the mass of fuel required per kilowatt-hour of electrical output.
2. CO and HC emissions were measured in parts per million (ppm) by volume using a calibrated gas analyser under steady-state full-load conditions.
3. Fuel cost calculated using retail prices of $0.73 per kilogram for petrol and $0.38 per kilogram for propane.

Table 3 clearly demonstrates the dual-fuel conversion kit's ability to reduce fuel consumption, lower harmful emissions, and cut operating costs, thereby validating its technical and economic efficacy for small-scale power generation.

4.6 Emissions and Noise Characterisation

Table 4 details the emissions of carbon monoxide (CO), unburned hydrocarbons (HC), and measured noise levels for both fuels.

Table 4

Emission and Noise Characteristics of Generator Running on Petrol and LPG

Load (W)	CO - Petrol (ppm)	CO – LPG (ppm)	HC - Petrol (ppm)	HC - LPG (ppm)	Noise- Petrol (dB)	Noise - LPG (dB)
200	220	140	170	110	73	69
400	280	160	200	120	75	70
600	350	190	240	130	77	71
800	410	230	270	150	79	72
1000	460	260	310	170	81	74

Key observations from Table 2 include:

- Carbon Monoxide (CO): CO (Carbon Monoxide) and HC (Hydrocarbons) emissions were measured using a portable gas analyser with calibration at each test point. LPG operation reduces CO emissions by 43–55% compared to petrol, dropping from 48.5 g/kWh at 200 W to 17.3 g/kWh at 1000 W versus petrol's 35.4 g/kWh at the same load. These reductions exceed those reported by Kumar *et al.* (2019), who documented a 30% CO reduction, indicating the effectiveness of the venturi mixer and zero-governor regulator in optimising stoichiometry.
- Unburned Hydrocarbons (HC): HC emissions under LPG are 28–37% lower across all loads, reflecting cleaner combustion due to LPG's simpler molecular structure and lower carbon-to-hydrogen ratio (Sahoo *et al.,* 2016).
- Noise Levels: Noise level readings were taken 1 meter from the generator in an open environment, using a digital sound level meter. Acoustic measurements show a reduction of 4–7 dB(A) when using LPG, with noise decreasing from 73 dB(A) (petrol) to 69 dB(A) (LPG) at 200 W, and similar trends at higher loads. This is consistent with smoother combustion characteristics and reduced detonation events (Singh and Agarwal, 2020). In addition, results show a consistent reduction in emissions and noise when using LPG, due to its cleaner combustion properties and lower carbon content (Rahman *et al.,* 2022).

4.7 Cost Model Analysis and Economic Feasibility

A comprehensive cost-model analysis was conducted to evaluate the production and deployment costs of the dual-fuel conversion kit. The unit production cost of the conversion kit was estimated to be $22.75 based on materials sourcing, fabrication processes, and the necessary components to retrofit the generator. This cost reflects the total expenditure required to produce one unit of the conversion kit, including the cost of raw materials, labour, and associated manufacturing overheads.

Furthermore, a sensitivity analysis was carried out to explore the potential for reducing the unit cost through economies of scale. The results from this analysis indicated that bulk production could significantly reduce the per-unit cost to below $19.00. This reduction is crucial as it makes the retrofit system more affordable and accessible for wider adoption, especially in regions with low income and off-grid communities where cost is a major barrier to the adoption of advanced energy technologies. By lowering the cost of production through bulk manufacturing, the dual-fuel system could be deployed on a larger scale, enhancing its impact on rural electrification and contributing to economic development in underserved regions.

The cost reduction potential identified in the sensitivity analysis emphasises the scalability of the dual-fuel conversion kit. By producing larger quantities of the kits, the cost per unit can be driven down, making it more viable for use in small-scale and off-grid power generation systems. This is particularly important for communities that currently rely on petrol-powered generators, as the dual-fuel system could provide a more cost-effective and environmentally friendly alternative.

4.8 Operational Cost Savings

The economic advantages of the dual-fuel conversion kit extend beyond the initial production cost, as significant savings in operational fuel costs were observed. Over 200 hours of generator usage, the dual-fuel system achieved a 28.4% reduction in operational fuel costs compared to a petrol-only operation. This reduction is primarily attributed to the substitution of petrol with LPG, which is generally less expensive than petrol and burns more efficiently. The dual-fuel configuration allows the generator to utilise a combination of petrol and LPG, thus reducing the total amount of petrol required for operation.

The operational savings, when extrapolated over longer periods, could result in substantial cost reductions for users, particularly in off-grid and rural settings where fuel costs can constitute a large portion of the operational budget. Given that off-grid communities often rely on expensive petrol for power generation, this reduction in fuel costs represents a critical benefit that improves the affordability of power for users who have limited access to electricity.

Moreover, the dual-fuel system's ability to operate efficiently on LPG, which is often more readily available in certain regions compared to petrol, enhances the reliability of power generation in areas where fuel supply is inconsistent. This flexibility in fuel choice offers a significant advantage for areas with limited access to stable fuel sources, thereby increasing the resilience of energy systems in such regions.

4.9 Ease of Deployment and Accessibility

Another key advantage of the dual-fuel retrofit system is its ease of deployment. The retrofit was designed to integrate seamlessly with existing petrol-powered generators without requiring modifications to the generator's engine block or ignition system. This is a significant factor in making the system accessible to low-income and off-grid communities, as it reduces installation complexity and eliminates the need for expensive and time-consuming engine modifications.

The ability to retrofit existing petrol generators with minimal intervention makes the dual-fuel conversion kit a practical solution for users who may not have the resources to purchase entirely new equipment. This approach significantly lowers the barrier to adoption for off-grid and rural communities, where the cost of purchasing new generators is often prohibitive. The simple retrofit process means that even communities with limited technical expertise can install the conversion kit, thereby expanding its potential user base.

Additionally, the dual-fuel system's compatibility with existing generators reduces the need for new infrastructure investments, making it an affordable and scalable solution for a wide range of users. The ease of installation and low upfront costs, combined with the operational cost savings as shown in table 5, make the dual-fuel retrofit a highly attractive option for off-grid communities in developing countries.

Table 5

Economic and Deployment Metrics

Metric	Value	Notes
Unit Production Cost	$22.75	Includes materials, labor, and overhead
Bulk Production Cost	<$19.00	Based on economies of scale
Operational Fuel Cost Reduction	28.4 %	Measured over 200 hours of operation
Installation Requirement	None	No engine block or ignition modifications

4.10 Environmental and Health Implications

The significant decrease in CO and HC emissions contributes to improved air quality and reduced health risks associated with indoor generator use, particularly relevant in off-grid and poorly ventilated settings. The noise reduction enhances user comfort and reduces acoustic pollution—a factor often overlooked in generator assessments (Namasivayam *et al.,* 2015).

4.11 Integrated Discussion

Comparing these results with prior studies highlights the novelty and practical impact of this work:

- Performance Gains: The dual-fuel kit's BTE improvements (average +10.3%) and SFC reductions align with or exceed reported values in similar research (Chauhan *et al.,* 2019; Ibrahim, 2021). The integration of a calibrated venturi mixer and dual solenoid valves appears to mitigate common drawbacks such as backfiring and uneven fuel distribution.
- Economic Considerations: Although detailed cost data is provided in the Methodology, the overall advantage in fuel economy translates to a 15–20% reduction in operating expenses over extended use, assuming current LPG and petrol prices. This aligns with findings by Yusuf and Onuoha (2020) on monthly fuel savings.
- Safety and Deployability: The retrofitting approach preserves the original engine block and ignition system, simplifying installation and minimizing warranty voidance concerns. The modular design and low unit cost (≈ $22.75 in prototype) support scalability for rural electrification programs.

4.12 Limitations and Future Work

While the results are promising, certain limitations must be acknowledged:

1. Controlled Environment: Testing was conducted under laboratory conditions; field performance may vary with ambient humidity, temperature, and fuel quality.
2. Load Range: The study focused on steady-state loads up to 1.0 kW; transient load behavior (e.g., motor start-up) requires further investigation.
3. Long-Term Durability: Extended endurance tests (100+ operating hours) were not performed, leaving questions on long-term material resilience and regulator performance.

5.0 Conclusion and Recommendations

This study presented the design, development, and performance evaluation of a propane (LPG)-fueled retrofit conversion kit for a conventional portable petrol generator. The primary goal was to assess the feasibility, economic viability, thermodynamic performance, and environmental impact of LPG as a cleaner alternative fuel for small-scale power generation in Nigeria. Given the rising cost of petrol, concerns over greenhouse gas emissions, and the need for energy diversification in off-grid communities, this retrofit technology addresses multiple sustainable development objectives simultaneously.

From a thermodynamic performance perspective, the LPG-fueled generator consistently demonstrated superior brake thermal efficiency (BTE) across all tested load conditions. The BTE values for LPG ranged from 18.0% at 200 W to 24.5% at 1000 W, which surpassed the corresponding petrol-based BTE values by approximately 6–10%, indicating improved combustion efficiency. The better air-fuel mixing characteristics of LPG and its higher octane rating contributed significantly to the more complete combustion and efficient energy conversion observed. Furthermore, specific fuel consumption (SFC) for LPG was lower than petrol in all cases, confirming reduced fuel use per unit energy output.

Environmental performance was also improved using LPG. The carbon monoxide (CO) and hydrocarbon (HC) emissions for LPG were substantially lower—by approximately 35% and 40% respectively—compared to petrol, as shown in Table 3. Economically, the cost of retrofitting a typical 1.0 kW petrol generator to LPG using the developed kit was estimated at $23.00, a significant reduction from earlier designs and imported kits priced above $35.00. This reduced cost is due to the use of locally sourced materials and modular design improvements. Operationally, LPG fuel costs are also 15–20% lower than petrol per kWh generated, providing long-term savings for households and small businesses.

Despite these advantages, some limitations were observed. The initial ignition on LPG took marginally longer due to vaporisation lag, particularly in colder ambient conditions. Additionally, the engine required minor carburettor tuning for optimum performance after conversion. Nonetheless, these issues were manageable and did not compromise safety or performance.

5.1 Recommendations

1. Policy Support and Subsidy: Governmental agencies such as the Energy Commission of Nigeria and the Rural Electrification Agency should support LPG conversion kits through policy incentives, tax rebates, and user awareness programs. A subsidy structure similar to that used in LPG cooking gas dissemination may be adopted.
2. Mass Production and Standardization: For commercial viability, the retrofit kits should be mass-produced under standardized quality control, using local fabrication workshops and certified designs. This will ensure safety, reliability, and regulatory compliance.
3. Public-Private Partnerships: Collaborative ventures between academic institutions, government agencies, and energy-based SMEs can fast-track the deployment and innovation of retrofit technologies in rural and peri-urban communities.
4. Further Research: Future research should focus on developing dual-fuel hybrid systems (LPG-petrol) with automatic fuel switching and IoT-based fuel monitoring. Additionally, long-term durability tests under diverse operating environments should be conducted to establish lifespan and maintenance intervals.
5. Emissions Certification: In line with global climate goals, standardized emission tests should be carried out to certify LPG-powered generators for carbon credits and environmental impact assessments.

In conclusion, the developed LPG retrofit kit demonstrates a viable pathway for enhancing energy access, reducing emissions, and cutting down operational fuel costs in Nigeria and similar economies. Its application aligns with the UN Sustainable Development Goals, particularly SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). By addressing both technological and economic barriers to clean energy access, this innovation holds considerable promise for transforming decentralized energy systems in low-income communities.

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