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Case Study

Grassroots Energy Transitions: Economic, Safety and Climate Dimensions of LPG Adoption Among Small Businesses in Karu LGA

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A B S T R A C T

This study investigates the grassroots transition from petrol to Liquefied Petroleum Gas (LPG)-powered generators among small businesses in Karu Local Government Area (LGA), Nigeria. Driven by rising petrol costs, frequent power outages and increasing environmental awareness, this localized shift represents a tangible contribution toward Nigeria's 2030 climate goals. Using a mixed-methods approach combining surveys and interviews, the study examines the drivers, opportunities, challenges and broader implications of LPG adoption. Findings reveal that while substantial economic benefits, including significant reductions in daily fuel expenditure and improved operational sustainability, motivate the transition, critical barriers remain. Chief among these are the high initial conversion costs and pervasive safety concerns related to potential gas leakage and explosions. The transition also follows a scale-adaptive pattern, with small businesses retrofitting generators, medium-sized enterprises adopting purpose-built LPG generators and larger industries shifting towards compressed natural gas (CNG) systems. The study highlights the need for targeted financial incentives, safety assurance programs and capacity-building initiatives to overcome these barriers. Supporting and scaling these grassroots efforts can foster a more inclusive, resilient and low-carbon energy transition, positioning small businesses as key contributors to Nigeria's Nationally Determined Contributions (NDCs) and broader climate strategy.

Keywords: Climate Goals, Energy Transition, LPG Transition, Nigeria & Small Businesses

Introduction

Climate change remains one of the most significant global challenges of the 21st century, with wide-ranging impacts on ecosystems, economies and human well-being. Rising global temperatures, erratic weather patterns, sea-level rise and increasing frequency of extreme weather events have underscored the urgent need for a global transition towards low-carbon and climate-resilient development pathways[1]. Central to this transition is the shift from fossil fuel-based energy systems to cleaner, more sustainable energy sources capable of mitigating greenhouse gas (GHG) emissions.

In response to the global climate crisis, international

frameworks such as the Paris Agreement have emphasized the importance of limiting global warming to below 2°C, preferably to 1.5°C, compared to pre-industrial levels[2]. Nations worldwide have committed to submitting and implementing Nationally Determined Contributions (NDCs), detailing their efforts to reduce emissions and build resilience against climate impacts[3].

Nigeria, as Africa's largest economy and a significant oil producer, faces a dual challenge: balancing economic development with climate responsibility. Recognizing its vulnerability to climate change and the necessity for sustainable growth, Nigeria submitted an updated NDC in 2021, pledging to reduce GHG emissions by 20% unconditionally and up to 47% with international support by the year 2030[4]. Complementing this commitment, Nigeria enacted the Climate Change Act in 2021, institutionalizing climate action at all levels of governance and setting a target for achieving net-zero emissions between 2050 and 2070. These frameworks create a robust national commitment to energy transition, low-carbon development and climate resilience.

While much attention has focused on large-scale energy infrastructure and national-level interventions, small and medium-sized enterprises (SMEs) represent a critical, often overlooked, segment in achieving these climate targets. In Nigeria, SMEs account for approximately 96% of all businesses and contribute about 48% to the national Gross Domestic Product (GDP), providing employment to more than 84% of the working population[5]. Given their sheer number and economic footprint, SMEs are significant consumers of energy and their collective emissions are non-negligible. Consequently, interventions targeting this sector can have profound implications for national emission profiles and the realization of climate goals.

An emerging trend within SMEs in Karu Local Government Area (LGA) of Nasarawa State, Nigeria, illustrates a promising grassroots solution. In the face of rising petrol prices, frequent power outages and heightened environmental awareness, many small businesses in Karu are modifying their petroleum-powered generators to run on Liquefied Petroleum Gas (LPG), popularly known as cooking gas. This conversion typically involves changing the carburetor system to one compatible with LPG, offering a relatively affordable and accessible pathway for small businesses to transition to cleaner energy sources without overhauling their existing power infrastructure.

The shift from petroleum to LPG-powered generators among small businesses brings multiple advantages. Economically, LPG is more affordable than petrol on a per-kilowatt-hour basis, allowing businesses to cut operational costs significantly. Environmentally, LPG burns cleaner, emitting fewer greenhouse gases and air pollutants such as carbon monoxide, particulate matter and volatile organic compounds. Socially, LPG generators produce less noise, creating quieter and more pleasant working environments that are especially beneficial in densely populated urban areas like Karu. Furthermore, the adoption of LPG technologies supports broader societal goals such as energy security, job creation in the LPG supply chain and increased resilience of local economies to energy price shocks.

This localized innovation signifies a tangible step toward achieving Nigeria's NDC commitments and broader climate aspirations outlined in the Climate Change Act. It demonstrates that the pathway to a low-carbon future is not solely dependent on top-down governmental interventions or multinational corporate actions but also on bottom-up, community-driven initiatives. The small business-led LPG transition in Karu LGA highlights the potential for scaling grassroots energy solutions across Nigeria and provides a compelling case for integrating SMEs into national climate strategies and support mechanisms.

Thus, this study aims to investigate the drivers, opportunities, challenges and broader implications of the small business-led transition to LPG in Karu LGA, assessing its role as a meaningful contribution to Nigeria's 2030 climate goals and offering insights for policy formulation, climate action programming and sustainable local development.

Statement of the Research Problem

Nigeria's transition toward a low-carbon economy faces significant structural, financial and institutional challenges[6]. Despite the country's commitment under the Paris Agreement and the enactment of the Climate Change Act to achieve net-zero emissions by 2060[4], practical efforts at decentralizing and democratizing climate action, particularly among small businesses, remain limited and underexplored. Much of the national focus has centered on large-scale renewable energy projects and industrial decarbonization[7], while the potential role of small and medium-sized enterprises (SMEs) which constitute about 96% of Nigerian businesses[8] has been relatively overlooked in climate planning and policy implementation.

Meanwhile, small businesses across the country, driven by economic necessity and persistent energy insecurity, are organically innovating alternative energy solutions[9]. In Karu LGA of Nasarawa State, a notable trend has emerged: the modification of petrol-powered generators to use Liquefied Petroleum Gas (LPG) for power generation. This localized energy transition offers promising economic, environmental and social benefits, including lower operating costs, reduced greenhouse gas emissions, quieter operations and improved indoor and outdoor air quality[10,11]. Yet, despite its potential significance, there is a noticeable gap in academic research, policy attention and programmatic support directed towards understanding and scaling up this grassroots innovation.

Current literature and policy discourse often fail to recognize the agency of small businesses in contributing to national climate objectives[12]. Consequently, there is limited empirical evidence on the motivations, barriers, benefits and broader sustainability implications of the small business-led LPG transition in Nigeria. Without a systematic understanding of this phenomenon, opportunities to align grassroots energy transitions with national and global climate targets risk being missed.

Moreover, the absence of targeted interventions to support and incentivize such grassroots transitions could slow down their spread, limit their impact and perpetuate inequalities in access to cleaner energy solutions[6,9]. This situation raises critical questions:

- What drives small businesses to adopt LPG technology for power generation?
- What economic, social and environmental impacts are associated with this transition?
- What barriers hinder wider adoption and what enabling mechanisms could promote scaling?

- How can these local efforts be better integrated into Nigeria's broader climate action strategies?

Addressing these questions is critical for advancing a more inclusive, just and effective energy transition in Nigeria. Therefore, this study seeks to investigate the small business-led LPG transition in Karu LGA as a tangible, bottom-up contribution to Nigeria's 2030 climate goals. The research aims to fill the knowledge gap by systematically analyzing the drivers, challenges, impacts and potential policy linkages of this emerging trend, providing evidence that can inform more decentralized and people-centered climate action pathways.

Description of Study Area

The study will be conducted in Karu Local Government Area (LGA), located in Nasarawa State, Nigeria. Karu LGA is part of the rapidly urbanizing corridor adjoining the Federal Capital Territory, Abuja. It has an area of 2640 km[13]. It hosts a population of approximately 205,477 residents, according to the 2006 national census, with a projected significant increase in subsequent years due to migration and urban sprawl. The economy is characterized by a large concentration of small and medium-sized enterprises (SMEs), including retail, services, hospitality and light manufacturing sectors. Karu LGA is strategically selected for this study because of its growing economic activities, frequent energy supply challenges and the observed trend of SMEs adopting alternative energy sources like LPG-powered generators. The urban-rural blend and the diversity of businesses make it a relevant setting for studying LPG adoption and its associated benefits and challenges **(Figure 1)**.

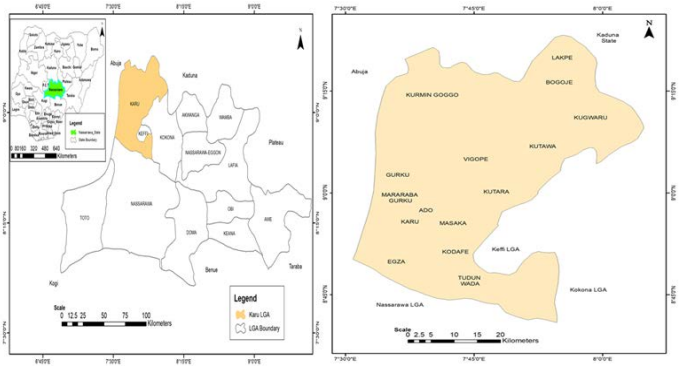

Figure 1: Map of the Study Area.

Methodology

This study adopted a pragmatist research philosophy to guide the investigation of the economic and environmental implications of liquefied petroleum gas (LPG)-powered generator adoption among small businesses in Karu Local Government Area (LGA), Nasarawa State, Nigeria. Pragmatism provided the flexibility to integrate both quantitative and qualitative methods in addressing the research problem, allowing for a richer understanding of the multifaceted drivers and outcomes associated with energy transitions in a developing urban context[14]. Karu LGA was purposively selected due to its rapid urbanization, proximity to the Federal Capital Territory, Abuja and the increasing prevalence of small and medium-sized enterprises (SMEs) facing chronic power supply issues and seeking alternative energy solutions. A mixed-methods design was employed. The qualitative component involved 10 semi-structured interviews with purposively and snowball-selected participants, including early adopters of LPG technology, energy suppliers and local stakeholders, to explore contextual insights and lived experiences. Ethical consideration involved obtaining informed consent of the respondents, ensuring anonymity, voluntary participation and data confidentiality. Data collection was conducted via direct field visits and scheduled interviews, with audio recordings and detailed field notes taken upon consent. Quantitative data were analyzed using descriptive statistics. Qualitative data were transcribed verbatim and analyzed thematically following Braun and Clarke's six-phase approach[15]. The integration of both data types during interpretation facilitated triangulation, enhancing the validity and depth of findings and offering comprehensive insights into the economic and environmental dynamics influencing LPG generator adoption among SMEs[16].

Result of the Findings

The findings of this study reveal crucial insights into the dynamics of the small business-led LPG transition in Karu LGA, highlighting both the economic benefits and the challenges associated with this shift.

Adoption of LPG-powered generators by small businesses

Findings from the field revealed a growing trend among small business operators in Karu LGA toward the adoption of Liquefied Petroleum Gas (LPG)-powered generators (**Figure 2-6**). The primary driver for this transition was the high operational cost associated with the use of petrol-powered generators. Small-scale businesses, particularly those engaged in phone and electronic device charging services, restaurant, patent medicine stores (chemist), photocopying business centre, BetNija business centres among others reported previously spending an average of ₦10,000 daily on petrol to sustain their daily operations for approximately 13 hours (8:00 am to 9:00 pm). By contrast, after converting to LPG-powered generators, the same businesses now purchase 10kg of LPG at ₦1,100 per kilogram, costing ₦11,000 for a quantity that lasts two full working days (about 26 operational hours). This shift resulted in significant operational savings, effectively halving their daily fuel expenditure and improving business sustainability.

Figures 2 and 3: Small Scale Business Generator with Converted Carburetor at Auta Balefi, Karu

Implications of Transitioning to LPG

Despite the economic advantages post-transition, the initial cost of conversion was identified as a major barrier. Converting a petrol-powered generator to LPG involved:

- Purchase of an LPG cylinder which varies depending on the size such as (10kg = ₦60,000, 5kg = ₦30,000 etc)

- Procurement of an LPG regulator and compatible carburetor (₦30,000). This also varies depending on the size of generator or single/double carburetor.
- Workmanship and miscellaneous expenses (this vary between ₦5,000 to ₦10,000)

Figures 4 and 5: Converted Generator Used in Patent Medicine store and BetNija Football shop at Masaka

Figures 6: Converted Generator Used in Restaurant at Masaka, Karu LGA

Altogether, the conversion cost summed up to approximately ₦100,000 per business aside the cost of purchasing the generator itself which also varies depending on the size and capacity from ₦80,000 to ₦200,000. For many small-scale operators in Karu LGA, this amount was perceived as prohibitively expensive without external financial support. Consequently, while the operational cost savings were clear, the affordability of conversion remained a critical challenge restricting wider adoption.

Comparative analysis of fuel costs: Petrol vs LPG

The transition from petrol-powered to LPG-powered generators among small-scale business operators in Karu LGA demonstrates significant economic advantages. Based on key informant interviews, operators running mobile charging businesses indicated that prior to transitioning to LPG, their daily expenditure on petrol was approximately ₦10,000 to operate their generators for about 13 hours (8:00 AM to 9:00 PM). However, after converting to LPG-powered generators, they reported purchasing 10kg of LPG at ₦1,100 per kg, amounting to ₦11,000, which lasted for two full working days (approximately 26 hours). Consequently, their daily fuel expenditure dropped to about ₦5,500, translating to a 45-50% reduction in operational energy costs. **(Figure 7)** presents a graphical comparison of the daily, weekly and monthly operational costs for petrol and LPG usage.

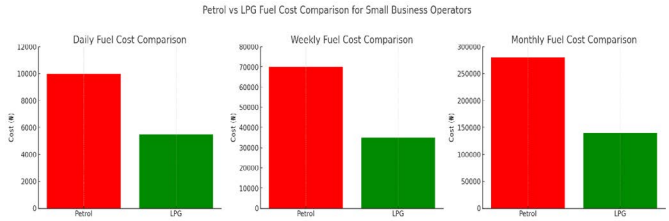

Figure 7: Comparative Fuel Costs (Petrol vs LPG) for Small Business Operators in Karu LGA

The comparative cost analysis presented in Figure 7 highlights the substantial economic benefits associated with the transition from petrol-powered to LPG-powered generators among small-scale business operators in Karu LGA. The data, disaggregated into daily, weekly and monthly operational costs, reveal a clear and consistent pattern: LPG utilization offers significant cost savings across all timeframes. Daily operational expenses average ₦10,000 for petrol users compared to ₦5,500 for LPG users depending on the type and size of the business. This trend persists at larger scales, with weekly costs totaling ₦70,000 for petrol and ₦35,000 for LPG and monthly expenditures reaching ₦280,000 for petrol and ₦140,000 for LPG which also varies according to the size of the business and LPG cylinder used. The findings indicate that LPG adoption reduces fuel costs by approximately 50%, thereby enhancing the financial viability and resilience of small enterprises.

A patent medicine shop owner, who transitioned from petrol to gas-powered generators, provided insights into the cost implications of the switch. The breakdown of the transition costs includes:

- Gas Carburetor: ₦12,000
- Gas Cylinder: ₦25,000 (cost dependent on the size of the cylinder)
- Gas Pipe: ₦2,000 for four yards, variable depending on the distance of placement
- Generator (Small Size): ₦70,000
- Workmanship: ₦5,000

The total upfront cost of transitioning to a gas-powered generator was ₦114,000. Prior to the transition, the owner spent ₦50,000 weekly on petrol for the generator. After the transition, weekly fuel costs were reduced to ₦30,000, resulting in a ₦20,000 weekly savings. This reduction in operational costs demonstrates that the initial investment in the gas system can be recovered in approximately six weeks or much less.

These findings highlight the economic advantages of transitioning from petrol to gas-powered generators, especially for small businesses facing fluctuating fuel costs and unreliable electricity. The significant savings in weekly fuel expenses contribute to a more sustainable and cost-efficient operation. Beyond economic considerations, the transition to LPG aligns with broader environmental and energy policy objectives, offering a pragmatic pathway toward achieving Nigeria's 2030 climate goals. The substantial operational savings and reduced carbon footprint position LPG as a strategic intermediate energy solution for decentralized, low-carbon development at the community level.

Economic and environmental benefits

The respondents noted several benefits beyond cost savings:

Reduced fuel consumption and expenses: The switch to LPG enabled substantial savings on fuel costs, freeing up resources for other aspects of business operations.

Cleaner combustion: LPG generators have lesser combustion which makes it produce fewer emissions compared to petrol generators, contributing to improved air quality in business premises and surrounding environments.

Reduced noise pollution: The quieter operation of LPG generators created more conducive work environments, particularly important in densely populated or residential areas.

Extended generator life span: Some informants reported lower maintenance costs and extended equipment life due to the cleaner combustion properties of LPG compared to petrol.

These benefits aligned with broader environmental and public health goals, demonstrating the potential for small businesses to actively contribute to local climate action.

Operational performance and reliability

Feedback from informants further indicates that LPG-powered generators offer comparable if not better operational reliability compared to petrol generators **(Table 1)**:

Table 1: Operational Performance and Reliability of Petrol and LPG Generators.

Performance Parameter	Petrol Generator	LPG Generator
Runtime Duration	13 hours per day	13 hours per day
Engine Wear & Tear	High (due to carbon build-up)	Lower (cleaner burning)
Maintenance Frequency	Frequent (every 1–2 months)	Reduced (every 3–4 months)
Emission Levels	High (visible smoke)	Lower (minimal visible emissions)

Table 1 reveals that LPG combustion reduces engine carbon deposits, leading to lower maintenance costs and longer engine life. The reduced smoke and exhaust fumes improve indoor and outdoor air quality around business premises.

Environmental and health Co-benefits

Though cost-saving was the main driver, the environmental impacts of LPG adoption are significant and align well with Nigeria's commitment under the Paris Agreement to reduce emissions. LPG burns more cleanly, producing less emission **(Table 2)**:

Table 2: Environmental and Health Co-Benefits,

Pollutant	Reduction with LPG Compared to Petrol
Carbon Monoxide (CO)	30–40% lower emissions
Hydrocarbons	40–50% lower emissions
Particulate Matter	70–90% lower emissions

Table 2 reveal that the cumulative adoption of LPG generators among small businesses could therefore contribute meaningfully to improved public health through reduced exposure to toxic fumes, reduction of greenhouse gases at a local scale and progress towards achieving Nigeria's target of cutting 20% of emissions unconditionally by 2030.

Challenges and barriers to transitioning to LPG

In addition to the high initial conversion costs, the study also identified other critical barriers to the widespread adoption of LPG-powered generators. A notable challenge is the prevalent emphasis on safety risks associated with LPG usage, particularly concerns about leakage and explosion. Although LPG-powered generators offer significant economic and environmental advantages, safety apprehensions remain a major deterrent for many small and medium-scale business owners.

Many participants reported that while they recognized the benefits of LPG such as lower fuel costs, reduced noise and lower emissions, they were equally influenced by perceived risks. Fear of potential gas leaks and explosions led to heightened caution or outright rejection of LPG technology by some businesses. This safety concern was often fueled by inadequate information, lack of standardized safety practices and occasional reports of accidents, even though actual incidents were relatively rare compared to perceptions.

Interestingly, the study also revealed that small businesses are adapting in diverse ways across scales. While smaller enterprises typically opt to convert petrol generators by changing the carburetor to an LPG-compatible system, medium-sized businesses increasingly prefer dedicated LPG generators, offering slightly better safety assurances. Larger industries are moving further by transitioning directly to compressed natural gas (CNG) systems, perceived to offer both efficiency and relatively higher safety standards at scale.

Thus, the transition to cleaner energy sources in Karu LGA follows a scale-based pattern:

- Small businesses → Retrofit existing petrol generators to LPG using modified carburetors
- Medium businesses → Invest in purpose-built LPG generators
- Large industries → Transition towards CNG systems for higher power demands

Addressing safety concerns through public education, technical certification for installers, safety standards enforcement and emergency response capacity building is essential to enable a just and confident transition across all business scales.

Drivers of LPG adoption

The main factors influencing the decision to adopt LPG technology were:

- **Escalating petrol costs:** Frequent hikes in petrol prices made alternatives economically attractive.
- **Frequent power outages:** Unreliable grid electricity made alternative, self-generated power a necessity for small businesses.
- **Awareness of LPG benefits:** Word-of-mouth information and observable savings among early adopters encouraged others to explore LPG conversion.
- **Government policy environment:** Although indirect, awareness of Nigeria's climate goals and energy policies positively influenced some business owners' decisions.

Implications for nigeria's climate goals

The small business-led LPG transition in Karu LGA provides a concrete example of bottom-up contributions toward achieving Nigeria's 2030 climate goals. By reducing dependence on petrol generators, these businesses are:

- Lowering local GHG emissions
- Supporting decentralized clean energy transitions
- Contributing to broader societal benefits such as better public health (through reduced air pollution) and energy resilience

However, without targeted financial and policy support such as subsidies for conversion costs, technical training programs and public awareness campaigns the full potential of these grassroots initiatives may not be realized.

Implications for climate policy and energy transition

The findings from Karu LGA substantiate the argument that small business-led transitions to LPG can serve as a tangible step toward Nigeria's broader climate mitigation targets for 2030. Beyond the immediate economic savings, LPG combustion emits lower levels of carbon dioxide (CO_2), particulate matter and other pollutants compared to petrol, contributing to improved air quality and reduced greenhouse gas emissions at the community level.

Thus, promoting and subsidizing the transition to LPG for micro and small enterprises could yield dual benefits: improving the financial sustainability of local businesses and accelerating Nigeria's shift toward a lower-carbon energy system. Policy interventions such as microcredit schemes, targeted subsidies for LPG conversion kits and technical assistance programs could play a critical role in scaling up this transition across similar urban and peri-urban contexts.

While small businesses in Karu LGA demonstrate agency and innovation in transitioning to cleaner energy sources, the persistence of safety concerns particularly regarding LPG leakage and explosion risks highlights the need for a more integrated policy response. National climate and energy transition policies must go beyond promoting alternative fuels to explicitly address safety assurance as a fundamental component of a just transition. Incorporating mandatory safety standards for LPG conversion, technician certification schemes and public risk communication campaigns into Nigeria's energy transition strategy will build public trust, accelerate adoption rates and ensure that the benefits of low-carbon energy solutions are equitably and safely distributed across all business scales. By embedding safety frameworks within climate policies, Nigeria can strengthen the resilience, inclusivity and social acceptance of its transition toward a low-carbon economy.

Scaling transition: Support needs and policy recommendations

Despite the clear benefits, the transition faces significant barriers that could stall its momentum without external support. The key support needs identified include **(Table 3)**:

Without strategic interventions, LPG adoption risks becoming an elitist phenomenon, accessible only to a fraction of business operators. Unlocking broad-based adoption would not only improve local livelihoods but also contribute significantly towards Nigeria's national climate goals.

Table 3: Support Measure for Scaling Transition.

Support Measure	Details
Subsidized LPG Conversion Kits	Government or private sector subsidies to reduce upfront conversion costs for businesses.
Access to Low-Interest Energy Transition Loans	Small, flexible loans tailored to LPG transitions, repayable from fuel savings.
Public Awareness Campaigns	Programs to sensitize small businesses about long-term economic, health and environmental benefits of LPG.
Capacity Building for Technicians	Certification and training programs to ensure quality and safety of generator conversions.
Bulk Purchase and Cooperative Models	Organizing businesses into cooperatives for collective bargaining and lower LPG purchase and conversion costs.

Implications and the need for support

While the transition to LPG offers clear economic advantages for small-scale businesses in Karu LGA, the financial challenges associated with the initial investment cannot be overlooked. These findings underscore the necessity of providing support and incentives to facilitate wider adoption of LPG-powered generators. Addressing the affordability barrier is crucial for promoting the transition to cleaner energy alternatives and achieving Nigeria's climate goals.

Discussion

This study presents compelling evidence that small businesses in Karu LGA are increasingly adopting LPG-powered generators as a cost-saving and environmentally conscious alternative to petrol-based systems. The findings align with a growing body of literature emphasizing LPG's cleaner combustion profile and its suitability for decentralized, low-carbon energy transitions in developing contexts[10,11].

The observed economic benefits, particularly the reduction in fuel expenditure by nearly 50%, resonate strongly with earlier findings. For instance, Adaramola, highlighted that LPG, when used in small-scale energy applications[10], reduces running costs and improves business profitability. The transition by Karu SMEs demonstrates how affordability drives innovation at the grassroots, particularly under volatile fuel pricing conditions.

Environmental benefits reported in this study including reduced carbon monoxide, hydrocarbon and particulate matter emissions are consistent with empirical findings by Li, et al[17], who found that small LPG engines emitted significantly fewer pollutants than their petrol counterparts. The particulate emission reduction of up to 90% found in this study aligns with the broader literature on LPG's clean-burning characteristics[18].

Similarly, the extended lifespan and reduced maintenance frequency of LPG generators corroborate mechanical studies such as those by Yusaf, et al[19], which reported cleaner combustion leading to lower engine wear and operational stability over time.

However, the findings of this study differ from existing literature in highlighting conversion costs and safety concerns as critical deterrents. While prior research often focuses on performance and emission benefits[20], this study foregrounds economic accessibility and perceived risk as major adoption barriers. This insight is particularly valuable for policy design, as it shows that environmental benefits alone may not incentivize adoption unless coupled with affordability and safety assurances.

Furthermore, while earlier studies on LPG adoption largely focused on household or vehicular use[21], this study's emphasis on commercial applications by SMEs in peri-urban Nigeria fills an important research gap. It showcases the role of informal innovation and peer learning in driving energy transitions outside institutional frameworks a factor underreported in broader literature.

The differences in findings regarding safety perceptions may be contextually driven. In low-income urban centers like Karu, the lack of regulatory oversight and public education campaigns amplifies fears about gas leaks and explosions. This contrasts with studies from regions with established LPG usage norms, where such concerns are mitigated by institutional regulation and public trust in gas infrastructure[17,19].

Additionally, while the economic benefits of LPG have been widely acknowledged, the cost of conversion kits, cylinders and installation which averaged ₦100,000 per small business in this study represents a significant barrier. This aligns with Nwokocha et al. (2022), who noted that without financial incentives, the transition to cleaner technologies remains inaccessible to many SMEs in Nigeria.

The study underscores the potential for bottom-up climate action, suggesting that small businesses, when supported appropriately, can play a vital role in meeting national climate targets. The grassroots LPG transition observed in Karu LGA exemplifies a scalable, people-centered approach to climate mitigation. Integrating such innovations into formal energy and climate policies could yield high-impact outcomes, especially when coupled with microfinance support, technician training and public awareness initiatives[5,9].

Conclusion

The small business-led transition to LPG in Karu LGA offers a compelling case for the integration of grassroots initiatives into Nigeria's climate strategy. This shift demonstrates significant economic advantages for small-scale businesses, primarily through substantial reductions in daily fuel expenditure. The environmental benefits, including cleaner combustion and reduced noise pollution, further align with Nigeria's broader climate goals. However, significant barriers persist: the high initial investment required for LPG conversion, coupled with pervasive safety concerns regarding gas leakage and explosion risks, inhibit wider adoption. Furthermore, the transition follows a scale-adaptive pattern where small businesses retrofit generators, medium businesses opt for dedicated LPG models and large industries transition to CNG systems. Addressing these challenges through targeted financial support, safety assurance programs, technical training, public awareness campaigns and tailored incentives across different business sizes is crucial for scaling up LPG adoption. By doing so, Nigeria can unlock the full potential of these grassroots efforts, fostering a more inclusive, just and sustainable energy transition that meaningfully contributes to achieving the country's Nationally Determined Contributions (NDCs) and building a resilient, low-carbon economy.

Recommendations

Based on the findings of the study, the following recommendations were made:

i. **Financial incentives and support mechanisms:** Introduce microcredit schemes and targeted subsidies to reduce the high upfront costs of LPG generator conversion, making cleaner energy alternatives accessible to more small-scale businesses.

ii. **Public awareness and safety education:** Launch public education programs emphasizing both the economic benefits and safe handling of LPG-powered generators. Clear communication strategies should correct misconceptions, manage risks and build confidence among potential adopters.

iii. **Technical certification and safety standards:** Establish technical training and certification programs for generator conversion technicians to ensure safe and standardized LPG installation practices. Implement quality control measures for conversion kits and LPG accessories.

iv. **Support for scale-appropriate transitions:** Develop policies that recognize the different needs of businesses by size:

v. Support small businesses with affordable retrofit options.

vi. Encourage medium businesses to adopt purpose-built LPG generators.

vii. Facilitate larger industries' transition to compressed natural gas (CNG) systems through concessional loans and regulatory support.

viii. **Strengthening LPG supply chain resilience:** Invest in expanding LPG storage, transportation and retail infrastructure to ensure reliable and stable supply, particularly during periods of high demand.

ix. **Integration into national climate strategies:** Formally recognize and integrate small and medium enterprise (SME) energy transitions into Nigeria's climate action plans, ensuring that bottom-up innovations contribute meaningfully to national emission reduction targets.

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