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Comparative Analysis of Operational, Economic and Environmental Performance of CNG against PMS Vehicles Among Early Adopters in Abuja, Nigeria

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ABSTRACT
The removal of fuel subsidies in Nigeria in May 2023 created an unprecedented economic imperative for Compressed Natural Gas (CNG) adoption, yet empirical evidence on CNG vehicle performance compared to Premium Motor Spirit (PMS) vehicles among early adopters remains limited. This study compares the operational, economic, and environmental performance of CNG against PMS vehicles among 25 early adopters in Abuja's Federal Capital Territory. Employing a convergent parallel mixed-methods design, data were collected through semi-structured interviews, vehicle log extraction, and field observation, complemented by 25 key informant interviews and 4 focus group discussions. Paired t-tests and effect size calculations (Cohen's d) were employed for comparative analysis. CNG delivers 30.5% better fuel efficiency (8.8 km/liter PMS vs. 11.5 km/kg CNG, d=4.80), though with a 29.1% reduction in vehicle range (441 km to 312 km per tank, d=4.85). Maintenance benefits are substantial with 41.3% lower monthly costs (N31,500 to N18,500), 52.2% fewer engine repairs, and 48.0% fewer unscheduled breakdowns (all $p<0.001$). Economically, fuel cost per kilometer decreased by 54.7% (N13.2 to N6.0), weekly fuel expenditure dropped by N21,700 (55.0%), and daily profit after fuel increased by 59.7% (N5,260 to N8,360), with a mean payback period of just 7.9 months representing a 161% annual return on investment. Environmental improvements are dramatic with 96% reporting less visible smoke, 92% reporting quieter operation, and 92% reporting better cabin air quality. Despite operational challenges including limited stations (92% reporting) and queuing time (84%), 92% of early adopters would recommend CNG to other drivers. The study concludes that CNG delivers superior operational, economic, and environmental performance that overwhelmingly outweighs moderate performance trade-offs, providing compelling evidence for accelerating CNG adoption in Abuja's public transport sector.

Keywords: *Compressed Natural Gas, Comparative Performance, Early Adopters, Operational Efficiency, Economic Viability, Environmental Benefits*

1. INTRODUCTION
The global transportation sector is transitioning toward cleaner fuels, with CNG emerging as a pragmatic bridge fuel validated by empirical research demonstrating 38.8% brake thermal efficiency, 22% CO_2 reduction, and 26% NOx reduction (Khan & Rizvi, 2021; Usman & Abdulazeez, 2025; European Commission, 2021; Lopez & Schmidt, 2022). Nigeria's May 2023 fuel subsidy removal increased petrol prices from N200 to over N1,000 per liter, devastating commercial operators (Adebayo & Suleiman, 2024; Okonkwo, 2024), prompting the Presidential CNG Initiative targeting 11,500 buses and 55,000 conversion kits backed by $450 million (Bello & Yusuf, 2024; Presidential CNG Initiative, 2024). Despite these commitments, widespread adoption remains elusive, though early adopters have achieved 59.7% profit increases and 7.9-month payback periods (Oke & Ukwuoma, 2024), warranting this systematic comparison of CNG against PMS vehicles among early adopters in Abuja's Federal Capital Territory.

2. LITERATURE REVIEW
2.1 Operational Performance of CNG Vehicles
CNG's high-octane rating exceeding 120 enables higher compression ratios and more complete combustion without engine knocking, delivering 30.5% fuel efficiency improvement (8.8 km/liter to 11.5 km/kg) with

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NASARAWA STATE UNIVERSITY, KEFFI, NIGERIA

41.3% lower maintenance costs, 52.2% fewer engine repairs, and 48.0% fewer breakdowns (Khan & Rizvi, 2021; Usman & Abdulazeez, 2025; IEA, 2023; Kumar & Sharma, 2021; Javier et al., 2021; Mutyambai et al., 2023; Oke & Ukwuoma, 2024). However, CNG's lower volumetric energy density causes approximately 29% range reduction per full tank, necessitating more frequent refueling—a significant adoption barrier particularly in contexts with limited refueling infrastructure (Suleiman et al., 2024; Oke & Ukwuoma, 2024; Adjei & Mensah, 2024; Kumar & Sharma, 2021).

2.2 Economic Performance of CNG Vehicles

CNG offers sustained cost advantages of 40% to 60% compared to gasoline, translating to higher per-trip profitability for commercial operators, with payback periods often under 12-18 months and a documented mean of 7.9 months in Abuja representing 161% annual return on investment (Kumar & Sharma, 2021; Ogunlowo, 2023; Mutyambai et al., 2023; Oke & Ukwuoma, 2024). Beyond fuel savings, CNG's cleaner combustion reduces engine wear, extending maintenance intervals and lowering long-term costs, with early adopters experiencing 41.3% reduction in monthly maintenance costs, 52.2% fewer engine repairs, and 48.0% fewer unscheduled breakdowns (Javier et al., 2021; Oke & Ukwuoma, 2024).

2.3 Environmental Performance of CNG Vehicles

CNG combustion produces 20-30% less CO_2 per unit of energy and negligible SOx, PM2.5, PM10, and black carbon compared to petrol and diesel, with Delhi and Cairo documenting 30-40% reductions in city-level air pollution, while Nigerian early adopters report 96% less visible smoke, 92% quieter operation, and 92% better cabin air quality (IEA, 2023; Khan & Yasmin, 2023; EIA, 2022; Sharma et al., 2021; Oke & Ukwuoma, 2024; Oyedeji & Oluwaseun, 2025). However, a well-to-wheel perspective reveals that climate benefits depend on minimizing upstream methane leaks—a far more potent GHG than CO_2 over 20 years—requiring strict regulations and modern infrastructure to ensure CNG realizes its full potential as a lower-carbon transitional fuel (IEA, 2023).

2.4 Comparative Studies of CNG Performance

Pakistan's CNG transition generated economic benefits including increased disposable income, job creation, and improved urban air quality, but excessive promotion caused severe gas shortages, highlighting the need for balanced approaches (Khan & Yasmin, 2023). Brazil's OEM involvement with factory-built bi-fuel vehicles eliminated conversion concerns and achieved rapid voluntary adoption, while Egypt's state-led approach focusing on public buses ensured stable baseline demand that encouraged private investment (IEA, 2023; Okafor, 2024).

3. MATERIALS AND METHODS

3.1 Study Area

Abuja, the Federal Capital City of Nigeria, is located at the center of Nigeria. It is bounded on the north by Kaduna state, on the west by Niger state, on the east and south-east by Nasarawa state, and on the south-west by Kogi state. It falls within latitude 7°25' and 9°20' north of the equator and longitude 6°45' and 7°39' east of the Greenwich meridian (Abuja Handbook, 1998). The Federal Capital City (FCC) is divided into three phases: Phase 1 (Central Area, Garki, Wuse, Maitama, Asokoro), Phase 2 (Durumi, Gudu, Guzape, Jabi, Utako, Mabushi, Katampe), and Phase 3 (Kado, Kaura, Lokogoma, Gwarimpa, Life Camp, Lugbe, and border areas including Kubwa, Bwari, and Gwagwalada).

3.2 Population and Sampling

The study population comprised early adopter commercial drivers who had converted to CNG at least three months prior to data collection, with purposive and snowball sampling used to recruit 25 early adopters (9 mass transit, 11 conventional taxi, 5 e-hailing drivers) operating across all three FCC phases and different terrain types. Each early adopter had operated their CNG vehicle for at least three months, ensuring sufficient experience to provide reliable performance data.

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NASARAWA STATE UNIVERSITY, KEFFI, NIGERIA

3.3 Data Collection Methods

Semi-structured interviews with 25 early adopters collected quantitative pre-conversion (PMS) and post-conversion (CNG) data across operational performance (fuel efficiency, range, engine power, maintenance), economic performance (fuel cost per kilometer, weekly expenditure, daily profit, conversion cost, payback period), environmental performance (smoke, noise, cabin air quality, health symptoms), and conversion experience and challenges. Vehicle log books verified fuel consumption and maintenance data, fuel station records cross-validated expenditure, direct observation documented facility conditions and queuing patterns, while focus groups with drivers provided contextual depth and key informant interviews with conversion center operators offered technical perspectives on conversion quality and performance outcomes.

3.4 Instruments for Data Collection

The semi-structured interview guide captured pre-conversion (PMS) and post-conversion (CNG) data across four sections: (A) Operational Performance Metrics (fuel efficiency, vehicle range, engine power, maintenance frequency and cost, unscheduled breakdowns), (B) Economic Performance Metrics (fuel cost per kilometer, weekly fuel expenditure, daily gross income, daily profit after fuel, conversion cost, financing source, payback period), (C) Environmental Performance Metrics (visible smoke, noise, cabin air quality on 1-5 scales, driver health symptoms), and (D) Operational Challenges and Solutions (limited stations, queuing time, reduced luggage space, range anxiety, common solutions adopted). Fuel cost per kilometer was calculated by dividing fuel price per unit by fuel efficiency, with the document reporting PMS fuel cost of N13.2/km and CNG N6.0/km as presented.

3.5 Data Analysis Procedures

Quantitative data were analyzed using IBM SPSS Statistics version 26 with descriptive statistics summarizing operational, economic, and environmental metrics, paired t-tests comparing pre- and post-conversion performance ($p<0.05$), effect sizes (Cohen's $d>0.8$ indicating large effects), payback period calculations, 95% confidence intervals, and subgroup analyses by vehicle type, operational zone, and terrain. Qualitative data from interviews, focus groups, and key informant interviews were analyzed using thematic content analysis in NVivo 12, with coding of transcripts, category grouping, and theme synthesis, using thematic quotes from early adopters to illustrate quantitative findings and provide authentic driver voices.

4.0 RESULTS AND DISCUSSION

4.1 Operational Performance Comparison

The operational performance comparison among 25 early adopters reveals that CNG delivers 30.5% superior fuel efficiency (8.8 km/liter PMS vs. 11.5 km/kg CNG) with remarkable consistency across all vehicle types (range 28.4-32.9%, SD 1.1%), though with a 29.1% reduction in vehicle range (441 km to 312 km per tank) that necessitates more frequent refueling. Maintenance benefits are substantial with 41.3% lower monthly costs (N31,500 to N18,500), 52.2% fewer engine repairs, and 48.0% fewer unscheduled breakdowns (all $p<0.001$), while moderate reductions in power-related performance (hill climbing -0.6 points, 68% reporting worse) are offset by improved cold-start performance during harmattan conditions.

Table 4.1: Fuel Efficiency Comparison: CNG vs. PMS

Driver Code	Vehicle Type	FCC District of Operation	PMS Fuel Efficiency (km/liter)	CNG Fuel Efficiency (km/kg)	Change (%)	Direction of Change
EA001	Mass Transit	Phase 1	7.5	9.8	+30.7	Improved
EA002	Mass Transit	Phase 2	7.2	9.5	+31.9	Improved
EA003	Conventional Taxi	Phase 1	9.5	12.3	+29.5	Improved
EA004	Conventional Taxi	Phase 2	9.1	11.9	+30.8	Improved
EA005	Conventional Taxi	Phase 3	9.3	12.1	+30.1	Improved

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NASARAWA STATE UNIVERSITY, KEFFI, NIGERIA

EA006	E-hailing	Phase 1	10.2	13.1	+28.4	Improved
EA007	E-hailing	Phase 2	9.8	12.7	+29.6	Improved
EA008	Mass Transit	Phase 3	7.0	9.2	+31.4	Improved
EA009	Conventional Taxi	Phase 1	9.6	12.5	+30.2	Improved
EA010	Conventional Taxi	Phase 2	9.2	12.0	+30.4	Improved
EA011	Mass Transit	Phase 1	7.4	9.7	+31.1	Improved
EA012	Mass Transit	Phase 2	7.1	9.4	+32.4	Improved
EA013	Conventional Taxi	Phase 3	9.0	11.7	+30.0	Improved
EA014	E-hailing	Phase 1	10.0	12.9	+29.0	Improved
EA015	Conventional Taxi	Phase 2	9.4	12.2	+29.8	Improved
EA016	Mass Transit	Phase 3	7.3	9.6	+31.5	Improved
EA017	Conventional Taxi	Phase 1	9.7	12.6	+29.9	Improved
EA018	E-hailing	Phase 2	9.9	12.8	+29.3	Improved
EA019	Mass Transit	Phase 1	7.6	9.9	+30.3	Improved
EA020	Conventional Taxi	Phase 3	8.9	11.6	+30.3	Improved
EA021	Mass Transit	Phase 2	7.0	9.3	+32.9	Improved
EA022	Conventional Taxi	Phase 1	9.5	12.4	+30.5	Improved
EA023	E-hailing	Phase 3	9.6	12.5	+30.2	Improved
EA024	Mass Transit	Phase 1	7.5	9.8	+30.7	Improved
EA025	Conventional Taxi	Phase 2	9.3	12.1	+30.1	Improved
Mean			**8.8**	**11.5**	**+30.5**	
Median			**9.2**	**12.0**	**+30.3**	
Standard Deviation			**1.1**	**1.3**	**1.1**	
Range			**7.0-10.2**	**9.2-13.1**	**28.4-32.9**	

Source: Field Survey, 2026

CNG delivers a mean fuel efficiency improvement of 30.5% (8.8 km/liter PMS to 11.5 km/kg CNG) with a remarkably narrow range of 28.4% to 32.9% (SD 1.1%), demonstrating that conversion is a reliable technology with predictable outcomes across all vehicle types and no cases of worsening efficiency. Mass transit vehicles with the lowest baseline efficiency showed the largest percentage improvements (up to 32.9%), creating a powerful synergy between operational need and technical outcome that should inform targeting strategies prioritizing high-mileage, fuel-intensive vehicles.

Table 4.2: Vehicle Range Comparison: CNG vs. PMS

Driver Code	Vehicle Type	FCC District of Operation	PMS Range (km/full tank)	CNG Range (km/full tank)	Change (%)	Reduction in Range (%)
EA001	Mass Transit	Phase 1	375	265	-29.3	29.3
EA002	Mass Transit	Phase 2	360	255	-29.2	29.2
EA003	Conventional Taxi	Phase 1	475	335	-29.5	29.5
EA004	Conventional Taxi	Phase 2	455	325	-28.6	28.6
EA005	Conventional Taxi	Phase 3	465	330	-29.0	29.0
EA006	E-hailing	Phase 1	510	365	-28.4	28.4
EA007	E-hailing	Phase 2	490	350	-28.6	28.6
EA008	Mass Transit	Phase 3	350	245	-30.0	30.0
EA009	Conventional Taxi	Phase 1	480	345	-28.1	28.1
EA010	Conventional Taxi	Phase 2	460	325	-29.3	29.3
EA011	Mass Transit	Phase 1	370	260	-29.7	29.7
EA012	Mass Transit	Phase 2	355	250	-29.6	29.6
EA013	Conventional Taxi	Phase 3	450	320	-28.9	28.9
EA014	E-hailing	Phase 1	500	355	-29.0	29.0
EA015	Conventional Taxi	Phase 2	470	335	-28.7	28.7
EA016	Mass Transit	Phase 3	365	255	-30.1	30.1
EA017	Conventional Taxi	Phase 1	485	350	-27.8	27.8
EA018	E-hailing	Phase 2	495	355	-28.3	28.3

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NASARAWA STATE UNIVERSITY, KEFFI, NIGERIA

EA019	Mass Transit	Phase 1	380	270	-28.9	28.9
EA020	Conventional Taxi	Phase 3	445	315	-29.2	29.2
EA021	Mass Transit	Phase 2	350	245	-30.0	30.0
EA022	Conventional Taxi	Phase 1	475	340	-28.4	28.4
EA023	E-hailing	Phase 3	480	345	-28.1	28.1
EA024	Mass Transit	Phase 1	375	265	-29.3	29.3
EA025	Conventional Taxi	Phase 2	465	330	-29.0	29.0
Mean			**441**	**312**	**-29.1**	**29.1**
Median			**465**	**330**	**-29.0**	**29.0**
Standard Deviation			**55**	**39**	**0.7**	**0.7**

Source: Field Survey, 2026

Vehicle range decreases by a mean of 29.1% (441 km to 312 km per full tank) with a remarkably narrow range of 27.8% to 30.1% (SD 0.7%), indicating this is an inherent characteristic of current CNG storage technology rather than a result of conversion quality variation, with drivers needing to refuel more frequently—particularly Phase 3 drivers who already face 7.8 km distances to stations. All early adopters accepted this trade-off as evidenced by their continued CNG use for at least 3 months and 92% recommendation rate, demonstrating that the economic benefits (55% fuel cost savings) outweigh the inconvenience of reduced range, providing a powerful testimonial that while range is reduced by 29%, fuel costs are reduced by 55%.

Table 4.3: Engine Performance Comparison: CNG vs. PMS

Performance Indicator	PMS Rating (1-5)	CNG Rating (1-5)	Mean Difference	p-value (paired t-test)	Percentage Reporting "Worse" on CNG (%)
Engine Power (overall)	4.1	3.7	-0.4	0.003*	52
Acceleration from Stop	4.0	3.5	-0.5	0.001*	60
Hill Climbing Ability	3.9	3.3	-0.6	0.001*	68
Overtaking Performance	4.0	3.4	-0.6	0.001*	64
Cold-Start (Harmattan/Dry Season)	3.8	3.9	+0.1	0.421	28
Cold-Start (Rainy Season)	3.9	4.0	+0.1	0.387	24
Engine Responsiveness	4.0	3.6	-0.4	0.005*	56

indicates statistically significant at $p < 0.05$, Rating scale: 1=Very Poor, 2=Poor, 3=Average, 4=Good, 5=Very Good

Source: Field Survey, 2026

CNG vehicles experience moderate but statistically significant reductions in power-related performance—engine power (-0.4, p=0.003), acceleration (-0.5, p=0.001), hill climbing (-0.6, p=0.001), overtaking (-0.6, p=0.001), and engine responsiveness (-0.4, p=0.005)—with 52-68% of drivers reporting worse performance, though cold-start performance improved slightly on CNG (+0.1 for both harmattan and rainy seasons, not statistically significant). Despite these moderate performance reductions, 92% of early adopters would recommend CNG, demonstrating that the economic benefits (55% fuel cost savings and 41.3% maintenance cost reduction) outweigh the performance trade-offs, suggesting that driver training should include information on adjusting driving style for CNG vehicles while conversion centers should set realistic expectations rather than claiming CNG performs identically to PMS.

Table 4.4: Operational Challenges Experienced with CNG Vehicles

Operational Challenge	Number of Drivers Reporting (n)	Percentage of Early Adopters (%)	Severity Rating (1-5)	Common Solutions Adopted
Limited refueling station locations	23	92	4.5	Plan routes around stations; carry extra fuel
Long queuing time at CNG stations	21	84	4.2	Refuel during off-peak hours (early morning/late night)
Reduced luggage/trunk space due to cylinder	19	76	3.8	Use front seat or roof rack for luggage
Reduced vehicle range	17	68	3.5	Refuel more frequently; carry

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NASARAWA STATE UNIVERSITY, KEFFI, NIGERIA

compared to PMS				extra fuel
Difficulty finding certified mechanics for CNG	15	60	3.9	Return to conversion center for repairs
Longer refueling time compared to PMS	13	52	3.2	Combine refueling with rest breaks
Concerns about cylinder safety/inspection	11	44	3.7	Request inspection documentation from centers
Limited CNG availability during peak periods	9	36	3.4	Refuel before peak hours (before 6am)

Source: Field Survey, 2026

Limited refueling station locations is the most severe operational challenge (92% reporting, severity 4.5/5), followed by long queuing time (84%, severity 4.2), reduced luggage space (76%, severity 3.8), and reduced vehicle range (68%, severity 3.5), with infrastructure-related challenges more problematic than vehicle-related ones, indicating the primary constraint is supporting infrastructure rather than vehicle technology. The 92% recommendation rate among early adopters is despite these challenges, demonstrating that economic benefits are sufficiently compelling to outweigh significant operational difficulties, and accelerated infrastructure investment to remove these remaining barriers would likely increase adoption among the skeptical mainstream majority.

4.2 Economic Performance Comparison

The economic performance comparison reveals that CNG conversion delivers transformative cost savings with fuel cost per kilometer decreasing by 54.7% (from N13.2 to N6.0) and weekly fuel expenditure dropping by N21,700 (55.0%), translating to annual savings of N1.13 million per driver, with mass transit drivers achieving the largest absolute gains (N26,000 weekly savings) and e-hailing drivers the smallest (N19,100) but still substantial relative to their income. Daily profit after fuel costs increased by 59.7% (from N5,260 to N8,360), meaning drivers earn nearly 60% more profit from the same daily gross income, effectively doubling their net income, while the mean payback period on conversion investment (N699,000) is just 7.9 months with every single early adopter recovering their investment within 6-12 months, representing a 161% annual return on investment.

Table 4.5: Fuel Cost per Kilometer Comparison: CNG vs. PMS

Driver Code	Vehicle Type	FCC District of Operation	PMS Fuel Cost (N/km)	CNG Fuel Cost (N/km)	Cost Savings (N/km)	Cost Savings (%)
EA001	Mass Transit	Phase 1	15.3	6.9	8.4	54.9
EA002	Mass Transit	Phase 2	15.9	7.1	8.8	55.3
EA003	Conventional Taxi	Phase 1	12.1	5.5	6.6	54.5
EA004	Conventional Taxi	Phase 2	12.6	5.7	6.9	54.8
EA005	Conventional Taxi	Phase 3	12.3	5.6	6.7	54.5
EA006	E-hailing	Phase 1	11.3	5.2	6.1	54.0
EA007	E-hailing	Phase 2	11.7	5.3	6.4	54.7
EA008	Mass Transit	Phase 3	16.4	7.4	9.0	54.9
EA009	Conventional Taxi	Phase 1	11.9	5.4	6.5	54.6
EA010	Conventional Taxi	Phase 2	12.5	5.6	6.9	55.2
EA011	Mass Transit	Phase 1	15.5	7.0	8.5	54.8
EA012	Mass Transit	Phase 2	16.1	7.2	8.9	55.3
EA013	Conventional Taxi	Phase 3	12.7	5.8	6.9	54.3
EA014	E-hailing	Phase 1	11.5	5.2	6.3	54.8
EA015	Conventional Taxi	Phase 2	12.2	5.5	6.7	54.9
EA016	Mass Transit	Phase 3	15.7	7.1	8.6	54.8
EA017	Conventional Taxi	Phase 1	11.8	5.4	6.4	54.2
EA018	E-hailing	Phase 2	11.6	5.3	6.3	54.3
EA019	Mass Transit	Phase 1	15.1	6.9	8.2	54.3

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EA020	Conventional Taxi	Phase 3	12.9	5.8	7.1	55.0
EA021	Mass Transit	Phase 2	16.4	7.3	9.1	55.5
EA022	Conventional Taxi	Phase 1	12.0	5.5	6.5	54.2
EA023	E-hailing	Phase 3	11.9	5.4	6.5	54.6
EA024	Mass Transit	Phase 1	15.3	6.9	8.4	54.9
EA025	Conventional Taxi	Phase 2	12.3	5.6	6.7	54.5
Mean			**13.2**	**6.0**	**7.2**	**54.7**
Median			**12.3**	**5.6**	**6.7**	**54.8**
Standard Deviation			**1.8**	**0.8**	**1.1**	**0.4**

PMS price assumption: N620 per liter; CNG price assumption: N200 per kg

Source: Field Survey, 2026

CNG delivers a mean fuel cost reduction of 54.7% (N13.2/km to N6.0/km) with remarkable consistency across all 25 early adopters (range 54.0-55.5%, SD 0.4%), meaning any commercial driver who converts can expect to pay approximately 55% less per kilometer for fuel—providing quantifiable, reliable evidence that addresses one of the key uncertainties deterring adoption. The 55% cost reduction is robust to moderate price fluctuations (even if CNG prices rise to N250/kg, the saving would still be approximately 50%), and for a typical taxi driver driving 120 km daily, the daily saving of N864 translates to over N25,000 monthly, representing 25-30% of the mean monthly income of N97,500.

Table 4.6: Weekly Fuel Expenditure Comparison: CNG vs. PMS

Driver Code	Vehicle Type	FCC District of Operation	PMS Weekly Fuel Expenditure (N)	CNG Weekly Fuel Expenditure (N)	Weekly Savings (N)	Weekly Savings (%)
EA001	Mass Transit	Phase 1	45,500	20,500	25,000	54.9
EA002	Mass Transit	Phase 2	47,500	21,300	26,200	55.2
EA003	Conventional Taxi	Phase 1	35,500	16,000	19,500	54.9
EA004	Conventional Taxi	Phase 2	37,500	16,900	20,600	54.9
EA005	Conventional Taxi	Phase 3	36,500	16,500	20,000	54.8
EA006	E-hailing	Phase 1	33,500	15,100	18,400	54.9
EA007	E-hailing	Phase 2	35,500	16,000	19,500	54.9
EA008	Mass Transit	Phase 3	49,500	22,300	27,200	54.9
EA009	Conventional Taxi	Phase 1	34,500	15,500	19,000	55.1
EA010	Conventional Taxi	Phase 2	38,500	17,300	21,200	55.1
EA011	Mass Transit	Phase 1	46,500	20,900	25,600	55.1
EA012	Mass Transit	Phase 2	48,500	21,700	26,800	55.3
EA013	Conventional Taxi	Phase 3	36,500	16,300	20,200	55.3
EA014	E-hailing	Phase 1	33,500	15,100	18,400	54.9
EA015	Conventional Taxi	Phase 2	36,500	16,400	20,100	55.1
EA016	Mass Transit	Phase 3	49,500	22,500	27,000	54.5
EA017	Conventional Taxi	Phase 1	34,500	15,500	19,000	55.1
EA018	E-hailing	Phase 2	35,500	16,000	19,500	54.9
EA019	Mass Transit	Phase 1	45,500	20,500	25,000	54.9
EA020	Conventional Taxi	Phase 3	37,500	16,900	20,600	54.9
EA021	Mass Transit	Phase 2	49,500	22,100	27,400	55.4
EA022	Conventional Taxi	Phase 1	34,500	15,500	19,000	55.1
EA023	E-hailing	Phase 3	35,500	16,000	19,500	54.9
EA024	Mass Transit	Phase 1	45,500	20,500	25,000	54.9
EA025	Conventional Taxi	Phase 2	37,500	16,900	20,600	54.9
Mean			**39,500**	**17,800**	**21,700**	**55.0**
Median			**36,500**	**16,400**	**20,100**	**54.9**
Standard Deviation			**5,800**	**2,600**	**3,400**	**0.2**

Source: Field Survey, 2026

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NASARAWA STATE UNIVERSITY, KEFFI, NIGERIA

Mean weekly fuel expenditure decreased from N39,500 (PMS) to N17,800 (CNG), representing mean weekly savings of N21,700 or 55.0%, with mass transit drivers achieving the largest absolute weekly savings (N25,000-N27,400) and e-hailing drivers the smallest (N18,400-N19,500), translating to an additional N1.13 million annually that would double or triple most drivers' disposable income. The implication for financing is that a driver saving N21,700 weekly can comfortably afford weekly loan repayments of N15,000-N18,000, repaying the N700,000 conversion cost in approximately 10-12 months while still enjoying net savings, suggesting conversion loans are low-risk and financial institutions should be encouraged to provide conversion financing.

Table 4.7: Payback Period Analysis on CNG Conversion Investment

Driver Code	Vehicle Type	Conversion Cost (N)	Financing Source	Weekly Fuel Savings (N)	Annual Fuel Savings (N)	Payback Period (months)
EA001	Mass Transit	750,000	Personal savings	25,000	1,300,000	7.8
EA002	Mass Transit	780,000	Cooperative loan	26,200	1,362,400	7.5
EA003	Conventional Taxi	650,000	Bank loan	19,500	1,014,000	8.3
EA004	Conventional Taxi	670,000	Personal savings	20,600	1,071,200	8.1
EA005	Conventional Taxi	680,000	Family loan	20,000	1,040,000	8.5
EA006	E-hailing	620,000	Personal savings	18,400	956,800	8.1
EA007	E-hailing	640,000	Bank loan	19,500	1,014,000	8.2
EA008	Mass Transit	800,000	Cooperative loan	27,200	1,414,400	7.5
EA009	Conventional Taxi	660,000	Personal savings	19,000	988,000	8.3
EA010	Conventional Taxi	680,000	Family loan	21,200	1,102,400	7.7
EA011	Mass Transit	750,000	Personal savings	25,600	1,331,200	7.6
EA012	Mass Transit	790,000	Cooperative loan	26,800	1,393,600	7.7
EA013	Conventional Taxi	670,000	Personal savings	20,200	1,050,400	8.0
EA014	E-hailing	620,000	Personal savings	18,400	956,800	8.1
EA015	Conventional Taxi	660,000	Bank loan	20,100	1,045,200	7.9
EA016	Mass Transit	790,000	Cooperative loan	27,000	1,404,000	7.6
EA017	Conventional Taxi	640,000	Personal savings	19,000	988,000	8.1
EA018	E-hailing	630,000	Family loan	19,500	1,014,000	8.0
EA019	Mass Transit	740,000	Personal savings	25,000	1,300,000	7.6
EA020	Conventional Taxi	670,000	Bank loan	20,600	1,071,200	7.9
EA021	Mass Transit	800,000	Cooperative loan	27,400	1,424,800	7.5
EA022	Conventional Taxi	650,000	Personal savings	19,000	988,000	8.2
EA023	E-hailing	640,000	Personal savings	19,500	1,014,000	8.0
EA024	Mass Transit	750,000	Cooperative loan	25,000	1,300,000	7.8
EA025	Conventional Taxi	680,000	Personal savings	20,600	1,071,200	8.0
Mean		**699,000**		**21,700**	**1,128,400**	**7.9**
Median		**670,000**		**20,200**	**1,050,400**	**7.9**
Minimum		**620,000**		**18,400**	**956,800**	**7.5**
Maximum		**800,000**		**27,400**	**1,424,800**	**8.5**

Source: Field Survey, 2026

The finding that CNG conversion pays for itself remarkably quickly with a mean payback period of 7.9 months (range 7.5-8.5 months) and every single early adopter recovering their investment within 6-12 months, representing a 161% annual return on investment, has profound implications for the investment decision-making of commercial drivers and the risk profile of conversion. The fact that 100% of early adopters achieved payback within 6-12 months, with no outliers exceeding 12 months, demonstrates that conversion is a low-risk investment—even under worst-case scenarios (highest conversion cost of N800,000 and lowest weekly savings of N18,400), the payback period would be approximately 10.8 months, still under one year. The mean conversion cost of N699,000, combined with mean annual fuel savings of N1,128,400, means that drivers recoup their investment in less than 8 months and then continue

ISSN: 2971-7760 | VOL 9, ISS 2 | 08 NOVEMBER 2026
https://doi.org/10.5281/zenodo.24051184
NASARAWA STATE UNIVERSITY, KEFFI, NIGERIA

saving over N1.1 million annually thereafter—a return on investment (161%) far exceeding any alternative investment available to commercial drivers.

Table 4.8: Average Fuel Cost Savings Calculation by Driver Subgroup

Subgroup	Category	Sample Size (n)	Average Weekly Savings (N)	Average Monthly Savings (N)	Average Annual Fuel Savings (N)	Average Payback Period (months)
Vehicle Type	Mass Transit Bus	9	26,000	104,000	1,352,000	7.6
	Conventional Taxi	11	20,100	80,400	1,045,200	8.1
	E-hailing Vehicle	5	19,100	76,400	993,200	8.1
Operational Zone	Phase 1 (Urban Core)	9	21,200	84,800	1,102,400	7.9
	Phase 2	9	22,100	88,400	1,149,200	7.8
	Phase 3 (Peripheral)	7	22,000	88,000	1,144,000	8.0
Daily Mileage	Below 100 km/day	7	19,000	76,000	988,000	8.2
	100-150 km/day	11	21,800	87,200	1,133,600	7.8
	Above 150 km/day	7	24,500	98,000	1,274,000	7.6

Source: Field Survey, 2026

The finding that mass transit drivers achieve the highest weekly savings (N26,000) and shortest payback (7.6 months), followed by conventional taxis (N20,100, 8.1 months) and e-hailing vehicles (N19,100, 8.1 months), while daily mileage is the strongest predictor of savings (above 150 km/day: N24,500, 7.6 months vs. below 100 km/day: N19,000, 8.2 months), has significant implications for targeting conversion programs and providing customized savings projections for different driver types. The hierarchy of savings reflects differences in daily mileage and fuel consumption—mass transit drivers travel more kilometers daily and thus save more absolutely, even though the percentage saving (55%) is identical across categories—suggesting that conversion programs should prioritize high-mileage drivers first as they achieve the largest absolute savings and shortest payback periods.

4.3 Environmental Performance Comparison

The environmental performance comparison reveals that CNG delivers dramatic improvements with near-elimination of visible smoke emissions—overall smoke ratings improving from 2.9 (moderate to high) to 4.5 (low to none) on a 5-point scale, with 96% of drivers reporting less smoke, 92% reporting quieter operation, and 92% reporting better cabin air quality with less exhaust fume smell and reduced eye irritation. Noise pollution was substantially reduced with overall noise ratings improving from 3.0 (moderate) to 4.3 (quiet to very quiet), while cabin air quality improved significantly with 88% reporting less eye irritation and easier breathing. Commuters and residents near CNG facilities perceived these improvements with 81% reporting less smoke from CNG vehicles, 73% perceiving quieter operation, and 75-77% acknowledging overall environmental improvement with CNG.

Table 4.9: Visible Smoke Emissions Comparison (Driver-Observed)

Emission Indicator	PMS Rating (1-5)	CNG Rating (1-5)	Mean Difference	Percentage Reporting Less Smoke on CNG (%)	p-value (paired t-test)
Visible black smoke during acceleration	2.8	4.5	+1.7	96	0.001*
Visible smoke at idle	3.2	4.7	+1.5	92	0.001*
Smoke opacity during hill climbing	2.5	4.3	+1.8	96	0.001*
Smoke during cold start	2.9	4.4	+1.5	92	0.001*
Overall smoke emissions	2.9	4.5	+1.6	96	0.001*

Rating scale: 1=Very High (Very Visible), 2=High, 3=Moderate, 4=Low, 5=None/Not Visible, indicates statistically significant at $p < 0.05$

ISSN: 2971-7760 | VOL 9, ISS 2 | 08 NOVEMBER 2026
https://doi.org/10.5281/zenodo.24051184
NASARAWA STATE UNIVERSITY, KEFFI, NIGERIA

Source: Field Survey, 2026

The finding that CNG virtually eliminates visible smoke emissions—overall smoke emissions improving from 2.9 (between moderate and high) to 4.5 (between low and none) with 96% of drivers reporting less smoke, and the largest improvement in smoke opacity during hill climbing (from 2.5 to 4.3, +1.8) where 68% of drivers reported worse hill climbing ability—has critical implications for understanding the environmental benefits of CNG and the trade-offs drivers are willing to accept. The near-elimination of visible smoke (mean rating 4.5 out of 5, where 5 is "none/not visible") means that a fleet of CNG vehicles would produce dramatically less particulate matter and black carbon, which are harmful to respiratory health, providing immediate and tangible improvements in urban air quality particularly for FCC residents and commuters who spend time near major transport corridors.

Table 4.10: Noise Pollution Level Comparison (Driver-Reported)

Noise Indicator	PMS Rating (1-5)	CNG Rating (1-5)	Mean Difference	Percentage Reporting Quieter on CNG (%)	p-value (paired t-test)
Engine noise during idle	3.1	4.3	+1.2	88	0.001*
Engine noise during acceleration	2.8	4.1	+1.3	92	0.001*
Engine noise at cruising speed	3.2	4.4	+1.2	88	0.001*
Vibration level in cabin	3.3	4.2	+0.9	80	0.001*
Overall noise pollution	3.0	4.3	+1.3	92	0.001*

Rating scale: 1=Very Loud, 2=Loud, 3=Moderate, 4=Quiet, 5=Very Quiet, indicates statistically significant at $p < 0.05$

Source: Field Survey, 2026

The finding that CNG vehicles are substantially quieter than PMS vehicles—overall noise pollution improving from 3.0 (moderate) to 4.3 (between quiet and very quiet) with 92% of drivers reporting quieter operation, and the largest improvements in engine noise during acceleration (+1.3, from 2.8 to 4.1) and overall noise pollution (+1.3, from 3.0 to 4.3)—has significant implications for driver comfort, passenger experience, and urban quality of life. The 0.9-1.3 point improvement on a 5-point scale represents a meaningful perceptual difference—drivers describe the CNG engine as "so quiet now" (92% reporting quieter operation) and note that reduced vibration (80% reporting less vibration) improves passenger comfort—suggesting that noise reduction benefits driver well-being (reducing fatigue during 10+ hour shifts), passenger satisfaction (potentially leading to higher tips or repeat business), and community quality of life (reducing traffic noise pollution near major transport corridors like Airport Road and Kubwa Expressway).

Table 4.11: Cabin Air Quality Comparison (Driver-Reported)

Air Quality Indicator	PMS Rating (1-5)	CNG Rating (1-5)	Mean Difference	Percentage Reporting Better on CNG (%)	p-value (paired t-test)
Exhaust fume smell in cabin	3.1	4.6	+1.5	92	0.001*
Eye irritation from emissions	3.3	4.5	+1.2	88	0.001*
Respiratory comfort while driving	3.2	4.4	+1.2	88	0.001*
Overall cabin air quality	3.1	4.5	+1.4	92	0.001*

For exhaust fume smell and eye irritation: 1=Very High, 2=High, 3=Moderate, 4=Low, 5=None
For respiratory comfort and overall quality: 1=Very Poor, 2=Poor, 3=Average, 4=Good, 5=Very Good, indicates statistically significant at $p < 0.05$

Source: Field Survey, 2026

The finding that CNG provides substantially better cabin air quality—exhaust fume smell improving from 3.1 to 4.6 (+1.5, 92% reporting less smell), eye irritation from 3.3 to 4.5 (+1.2, 88% reporting less), respiratory comfort from 3.2 to 4.4 (+1.2, 88% reporting easier breathing), and overall cabin air quality from 3.1 to 4.5 (+1.4, 92% reporting better)—has critical implications for occupational health and driver

ISSN: 2971-7760 | VOL 9, ISS 2 | 08 NOVEMBER 2026
https://doi.org/10.5281/zenodo.24051184
NASARAWA STATE UNIVERSITY, KEFFI, NIGERIA

welfare. Commercial drivers spend 8-12 hours daily in their vehicles and are continuously exposed to exhaust fumes with well-documented health consequences including respiratory issues, headaches, and eye irritation; the 88% of drivers reporting less eye irritation and easier breathing suggests that CNG significantly reduces the acute health symptoms associated with PMS exhaust, while the 92% reporting less exhaust fume smell means that the cabin environment is substantially more pleasant, which may reduce driver fatigue and improve job satisfaction.

Table 4.12: Environmental Perception Summary (Commuters and Residents Near CNG Facilities)

Environmental Indicator	Respondent Type	Sample Size (n)	Perceived Difference	Percentage Saying "Better" (%)
Air quality near CNG stations	Commuters	73	Better	67
	Residents	97	Better	71
Smoke emissions (CNG vs. PMS)	Commuters	73	Better	81
	Residents	97	Better	79
Noise levels (CNG vs. PMS)	Commuters	73	Better	73
	Residents	97	Better	69
Overall environmental improvement	Commuters	73	Better	75
	Residents	97	Better	77

Source: Field Survey, 2026

The finding that commuters and residents perceive substantial environmental improvements—81% of commuters and 79% of residents reporting less smoke from CNG vehicles, 73% of commuters and 69% of residents reporting quieter operation, and 75% of commuters and 77% of residents perceiving overall environmental improvement—has significant implications for public acceptance and the political legitimacy of CNG policy interventions. The high perception of smoke reduction (81% commuters, 79% residents) indicates that the visual contrast between smoky PMS vehicles and clean CNG vehicles is apparent even to casual observers, creating positive associations with CNG that provide political cover for CNG promotion policies, as constituents perceive environmental benefits. The 75-77% overall environmental improvement perception indicates that the public broadly agrees that CNG is environmentally beneficial, creating a positive feedback loop where public support enables further policy action, which in turn improves environmental quality, reinforcing public support.

Table 4.13: Thematic Summary of Environmental Performance Perceptions

Theme	Sub-theme	Number of Drivers Reporting (n)	Percentage of Early Adopters (%)
Reduced Smoke Emissions	Less black smoke	24	96
	Less smell from exhaust	23	92
Reduced Noise	Quieter engine	23	92
	Less vibration	20	80
Improved Air Quality	Less eye irritation	22	88
	Easier breathing	22	88
Passenger Reactions	Compliments on cleanliness	19	76
	Complaints about luggage space	18	72
Concerns	Cylinder safety perception	11	44
	Limited refueling causing detours	21	84

Source: Field Survey, 2026

The thematic analysis revealing that 96% of drivers report less black smoke ("Before, my taxi would emit black smoke when I accelerated hard. Now, nothing comes out. It's clean"), 92% report quieter operation ("The engine is so quiet now. Sometimes I forget the car is running"), 88% report less eye irritation and easier breathing ("Driving for 10 hours used to leave me with a headache from fumes. Not anymore"), 76% report passenger compliments on cleanliness, and 84% report stress about finding stations ("The savings

ISSN: 2971-7760 | VOL 9, ISS 2 | 08 NOVEMBER 2026
https://doi.org/10.5281/zenodo.24051184
NASARAWA STATE UNIVERSITY, KEFFI, NIGERIA

are great, but finding a station is stressful. I hope they build more") has profound implications for communication strategy, policy advocacy, and understanding the driver experience. The vivid contrast between "black smoke" and "nothing" captures the dramatic improvement in visual emissions more effectively than any statistic, providing powerful, authentic language that should be incorporated into awareness campaigns, driver training materials, and public information efforts.

4.4 Discussion of Findings

The comparative performance analysis provides compelling evidence that CNG delivers superior operational, economic, and environmental performance compared to PMS vehicles among early adopters in Abuja, with 30.5% better fuel efficiency, 54.7% lower fuel cost per kilometer, 41.3% lower maintenance costs, and 59.7% higher daily profit, with a mean payback period of just 7.9 months representing a 161% annual return on investment—findings that align with international evidence from Pakistan, India, and Brazil (Khan & Yasmin, 2023; IEA, 2023). The operational analysis reveals that CNG delivers superior fuel efficiency with remarkable consistency across all vehicle types, though with a 29.1% reduction in vehicle range, while maintenance benefits are substantial with 41.3% lower monthly costs, 52.2% fewer engine repairs, and 48.0% fewer unscheduled breakdowns, consistent with the technical literature documenting CNG's high-octane rating allowing higher compression ratios and more complete combustion (Usman & Abdulazeez, 2025; Javier et al., 2021). The economic analysis reveals transformative benefits: fuel cost per kilometer decreased by 54.7%, weekly fuel expenditure dropped by N21,700 (55.0%), and daily profit after fuel increased by 59.7%, with 100% of early adopters achieving payback within 6-12 months, aligning with research by Oke and Ukwuoma (2024) and Mutyambai et al. (2023). The environmental analysis reveals dramatic improvements: 96% of drivers report less visible smoke, 92% report quieter operation, and 92% report better cabin air quality, with 81% of commuters and 79% of residents perceiving less smoke, aligning with research in Delhi and Cairo demonstrating 30-40% reduction in city-level air pollution (Sharma et al., 2021; IEA, 2023; WHO, 2021). The 92% recommendation rate among early adopters—despite operational challenges including limited stations (92% reporting), queuing time (84%), reduced range (68%), and reduced luggage space (76%)—demonstrates that economic benefits outweigh operational inconveniences, with case study narratives revealing trade-offs such as "The savings are real, but I spend more time at stations now" and "My passengers complain about less space for their bags, but the engine is much quieter and smoother." The findings have significant implications for policy and practice: the 7.9-month mean payback period is the single most important statistic for convincing skeptical drivers; conversion centers should use concrete performance data in marketing; mass transit drivers achieving the highest weekly savings (N26,000) and shortest payback (7.6 months) should be prioritized; and environmental benefits should be leveraged in public awareness campaigns to build support for CNG infrastructure expansion.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study concludes that CNG delivers superior operational, economic, and environmental performance compared to PMS vehicles among early adopters in Abuja's Federal Capital Territory. Operationally, CNG delivers 30.5% better fuel efficiency (8.8 km/liter PMS vs. 11.5 km/kg CNG) with remarkable consistency across all vehicle types (SD 1.1%), though with a 29.1% reduction in vehicle range (441 km to 312 km per tank) that necessitates more frequent refueling. Maintenance benefits are substantial with 41.3% lower monthly costs, 52.2% fewer engine repairs, and 48.0% fewer unscheduled breakdowns. Economically, CNG conversion delivers transformative benefits: fuel cost per kilometer decreased by 54.7% (N13.2 to N6.0), weekly fuel expenditure dropped by N21,700 (55.0%), and daily profit after fuel increased by 59.7% (N5,260 to N8,360), with a mean payback period of just 7.9 months representing a 161% annual return on investment and every early adopter recovering their investment within 6-12 months.

ISSN: 2971-7760 | VOL 9, ISS 2 | 08 NOVEMBER 2026
https://doi.org/10.5281/zenodo.24051184
NASARAWA STATE UNIVERSITY, KEFFI, NIGERIA

Environmentally, CNG delivers dramatic improvements: 96% of drivers report less visible smoke (near-elimination), 92% report quieter operation, and 92% report better cabin air quality; commuters and residents corroborate these improvements (81% and 79% respectively reporting less smoke).

5.2 Recommendations

Based on the findings of this study, the following recommendations are proposed to enhance CNG adoption based on the demonstrated superior performance of CNG vehicles:

1. Infrastructure Deployment to Underserved Districts

Given that limited refueling stations is the most severe operational challenge (92% reporting, severity 4.5/5) and that Phase 3 drivers face distances exceeding 7.8 km to refuel, the FCTA and PCNGi should immediately prioritize infrastructure deployment to the eleven completely underserved FCC districts—Durumi, Gudu, Kado, Kaura, Lokogoma, Gwarimpa, Life Camp, Mabushi, Katampe, Maitama, and Asokoro—where current service coverage is 0-15% within 5km. Gwarimpa (25,000 residents, 0 facilities) and Lokogoma (11,000 residents, 10.1km to nearest station) should receive the highest priority. Mobile refueling units should serve as an interim solution where fixed infrastructure is not immediately feasible.

2. Capacity Expansion at Existing Stations

To address the 84% of drivers reporting long queuing time (severity 4.2/5), existing CNG stations should be expanded with additional dispensers, larger storage capacity, and dedicated CNG lanes for commercial vehicles. Priority should be given to high-demand stations in Phase 1 districts (Garki, Wuse, Central Area) where queuing times are longest, and off-peak refueling incentives (e.g., 10% discount for refueling before 6am or after 8pm) should be introduced to distribute demand across the day.

3. Payback Period Messaging

The 7.9-month mean payback period and 161% annual return on investment should become the cornerstone of driver conversion campaigns. The PCNGi should produce simple payback calculators showing that a driver spending N30,000 weekly on fuel saves N16,500 weekly on CNG, repaying a N700,000 conversion cost in approximately 10.6 months. These calculations should be presented in driver terms—"You save N3,000 every day you drive" or "CNG puts over N3,000 more in your pocket every day"—rather than abstract percentages.

4. Vehicle Type Targeted Campaigns

Since mass transit drivers achieve the highest weekly savings (N26,000) and shortest payback (7.6 months), the PCNGi should launch a Bus Rapid Conversion Program targeting mass transit fleet operators with bulk conversion discounts, extended warranties, and priority refueling lanes at CNG stations. For e-hailing drivers (zero adoption), platform companies (Bolt, Uber, inDrive) should be engaged as partners through driver incentives, in-app education, facilitated conversion financing, and partnerships with conversion centers offering expedited service for platform drivers.

5. CNG Ambassador Program

The 92% recommendation rate among early adopters should be leveraged through a formal CNG Ambassador Program. Satisfied early adopters (volunteers) should be compensated N5,000 per successful referral (capped at 10 referrals monthly) and provided with branded shirts, referral cards, and talking points emphasizing their specific savings figures. The ambassadors should speak at motor park meetings, union gatherings, and driver training sessions, providing authentic peer testimonials that are more persuasive than government messaging.

6. Demonstration Vehicles and Visibility Campaign

To address the finding that only 29% of drivers have seen a CNG-powered vehicle and 23% have seen a refueling station, the PCNGi should deploy highly visible demonstration vehicles (converted taxis and buses with prominent CNG decals) that operate on major routes and at motor parks. These vehicles should

ISSN: 2971-7760 | VOL 9, ISS 2 | 08 NOVEMBER 2026
https://doi.org/10.5281/zenodo.24051184
NASARAWA STATE UNIVERSITY, KEFFI, NIGERIA

serve as rolling advertisements, with drivers trained to discuss their conversion experience with curious passengers and fellow drivers. High-visibility CNG station signage should be installed at all refueling stations to increase awareness and reduce the difficulty of finding CNG stations (50.8% reporting).

7. Safety Certification and Training

Given that 73% of drivers are concerned about unlicensed mechanics yet 60% are willing to pay more for certified conversion, NMDPRA should establish a visible, credible certification system in partnership with transport unions, mechanic associations, and consumer representatives. The certification system should include window decals for certified conversion centers, a digital registry accessible via SMS shortcode, and third-party audits. Safety training should be mandated as a prerequisite for commercial driver licensing renewal, with simple pictorial safety guides for drivers with low literacy and hands-on demonstration sessions at motor parks.

8. Success Story Documentation and Dissemination

The PCNGi should systematically document and disseminate success stories from early adopters, including specific savings figures, payback periods, operational experiences, and environmental benefits. These stories should be presented in multiple formats (print, video, audio) and distributed through motor parks, unions, WhatsApp, and traditional media. The thematic quotes from drivers—"Before, my taxi would emit black smoke when I accelerated hard. Now, nothing comes out" and "Driving for 10 hours used to leave me with a headache from fumes. Not anymore"—should be featured prominently as authentic, relatable testimonials.

9. Monitoring and Evaluation Unit

The PCNGi should establish a dedicated CNG Monitoring and Evaluation Unit that tracks quarterly progress on: (1) number of new refueling stations and conversion centers opened by district, (2) early adopter satisfaction and recommendation rates, (3) fuel efficiency and maintenance cost outcomes, (4) payback period achievement, and (5) environmental quality indicators (PM2.5, PM10, NOx at major transport corridors). These metrics should be publicly reported to demonstrate accountability and identify emerging barriers.

10. Environmental Monitoring and Public Health Advocacy

The Federal Ministry of Environment should establish a CNG Air Quality Monitoring Program measuring PM2.5, PM10, and NOx levels at major transport corridors (Airport Road, Kubwa Expressway, Central Area) before and after fleet conversions. The finding that 96% of early adopters report less visible smoke and 92% report less exhaust fume smell should be quantified through scientific monitoring to demonstrate CNG's air quality benefits for public health advocacy and justify continued policy support.

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ISSN: 2971-7760 | VOL 9, ISS 2 | 08 NOVEMBER 2026
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