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Towards Sustainable Transportation: Drivers of Compressed Natural Gas Adoption in Dar es Salaam City, Tanzania

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ABSTRACT

The adoption of compressed natural gas (CNG) vehicles has increased over the last decade, even in developing countries, in the pursuit of sustainable cities. This study examined the technological and environmental factors influencing CNG adoption as a vehicle fuel in Dar es Salaam, using a cross-sectional approach. It integrates quantitative survey data from vehicle owners with qualitative insights from interviews with natural gas sector stakeholders, transport operators, and policymakers. The analysis employs inferential statistics, including multiple response analysis, linear regression, and thematic analysis. Findings show a strong awareness of CNG's environmental benefits, including a 73% reduction in greenhouse gas (GHG) emissions and a 67% decrease in pollution. However, concerns about the availability of CNG refueling stations (73%), compatibility with vehicles (67%), and maintenance services (58%) hinder adoption. Government policies play a crucial role in promoting CNG adoption, with subsidies and stricter emissions regulations serving as key motivators. However, public awareness campaigns are limited in effectiveness, revealing an insufficient understanding of CNG's benefits. Overall, this study emphasizes the need for collaboration between government and private sector stakeholders to enhance CNG adoption in Dar es Salaam and advance toward a sustainable transportation system that improves air quality and reduces greenhouse gas emissions.

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1.0 Introduction

Urbanization, population growth, and industrialization have significantly increased transportation demand worldwide, particularly in metropolitan cities in developing countries (Dyr *et al.*, 2019; Krause *et al.*, 2024). The transportation sector still relies heavily on fossil fuels, which makes it one of the biggest energy users and a major source of pollution around the world, especially in developing countries (Krause *et al.,* 2024; Alonso-Villar *et al.*, 2022). The sector is one of the major consumers of global oil (40%) (Krause *et al.*, 2024; Yoro & Daramola, 2020) and the second largest emitter (10–25%) of CO_2 after electricity and heat generation (IPCC, 2022). Road transport is the largest contributor to global CO_2 emissions, accounting for 75% of these emissions, and is projected to remain the largest contributor by 2050 (Pieriegud & Zawieska, 2017; Krelling and Badami, 2019; Zhao *et al.,* 2023; Gabriel et al., 2021). However, concerns about environmental degradation, climate change, and global warming have prompted a shift towards clean energy and sustainable cities, which embrace renewable energy (Aderibigbe & Gumbo, 2024; Li *et al.,* 2022; Oswald, 2021; Du *et al.,* 2017).

Clean energy plays a vital role in sustainable development, and natural gas is increasingly considered a viable alternative fuel for public transportation. It improves air quality in cities and costs less to buy and maintain than diesel buses (Dyr *et al.,* 2019; Savage *et al.,* 2024; Vicente-Serrano *et al.,* 2019). The adoption of alternative fuels for transport, such as compressed natural gas (CNG), liquefied petroleum gas (LPG), and electricity, is increasing in many cities across both developed and developing countries (Vicente-Serrano *et al.,* 2019; Wang *et al.,* 2022). Natural gas (NG) is gaining interest as a transportation fuel due to stringent emission legislation. Over 23 million natural gas vehicles are operating globally (Krause *et al.,* 2024; Khan *et al.*, 2015; Wang *et al.,* 2022), with many located in Asia, Europe, and America, while few are found in Africa. The market for NG vehicles around the world is growing (Gabriel *et al.,* 2021; Spherical Insights, 2024).

The transportation sector remains heavily reliant on fossil fuels, making it a significant energy consumer and a major contributor to global pollution. The demand for natural gas as a primary energy source has surged over the past decade, reaching 23% (Alonso-Villar et al., 2022; Gabriel et al., 2021; Haider *et al.,* 2025; IEA, 2024). Numerous alternative fuel vehicle (AFV) technologies are available for road freight transport, including biodiesel, CNG, liquid natural gas (LNG), and hydrogen fuel cell vehicles (FCEV) (Krause *et al.,* 2024; Savage *et al.,* 2024; Liu *et al.,* 2025).

Recent advancements in technology and new natural gas reserves have positioned it as the leading resource for transitioning to lower carbon energy mixes worldwide, especially in addressing the intermittency of renewables (Mohareb & Kennedy, 2014).

Transport is often a significant contributor to atmospheric carbon emissions, which are gases produced by motor vehicles and factories (Wang *et al.,* 2022; Jiang *et al.,* 2020). Globally, CO_2 emissions from the transport sector have grown the fastest in recent decades and are expected to increase by 41% by 2030 (Jiang *et al.,* 2020; Prati & Costagliola, 2022). In developing countries, this situation largely arises from the use of second-hand products, such as used cars from developed countries. When these cars are imported for use, they often come with wear and tear (Aderibigbe & Gumbo, 2024).

Sustainable transport has become an important part of the world's efforts to protect the environment, keep the economy stable, and promote social justice (Bozzetto, 2022; Mohammed *et al.,* 2020; Abdin, 2024). It encompasses a broad spectrum of transportation modes and technologies designed to minimize negative externalities while enhancing accessibility and efficiency (Aderibigbe & Gumbo, 2024; Oswald, 2021). The goal of sustainable transport is to ensure that transportation operates effectively without harming the environment (Savage *et al.,* 2024; Hidayatno *et al.,* 2020). Addressing economic, social, and policy factors alongside environmental issues creates a comprehensive framework that promotes the sustainability of future transportation systems. Diversifying and optimizing the transportation fuel portfolio will result in more sustainable transport. Such an outcome means that low carbon emissions are important factors in

sustainable transportation (Krause *et al.,* 2024; Du *et al.,* 2017).

Additionally, reducing traffic in cities by cutting down on personal motor vehicles, promoting walking, and encouraging the use of public transportation can benefit both mobility and the environment (Haider *et al.,* 2025; Li *et al.,* 2022; Mohareb & Kennedy, 2014).

The availability of alternative fuels for use in transportation highlights the critical role of renewable energy in promoting sustainable development (Savage *et al.,* 2024; Haider *et al.,* 2025; Oswald, 2021). The use of natural gas is on the rise, making it one of the most widely used alternative fuels for public transportation, which contributes to better air quality in urban settings and supports cleaner production in the transport sector. However, the investment and maintenance expenses associated with buses powered by compressed natural gas (CNG) are higher than those of diesel buses (Dyr *et al.,* 2019; Haider *et al.,* 2025).

NG is recognized for its low carbon content, clean-burning characteristics, safety, environmental friendliness, and affordability (Savage *et al.,* 2024; Haider *et al.,* 2025; Dyr *et al.,* 2019; Mohareb & Kennedy, 2014). The Paris Agreement emphasizes the need for countries to adopt clean energy to reduce greenhouse gas (GHG) emissions and transition to sustainable energy systems, making CNG a viable alternative fuel (Wang *et al.,* 2022; Li *et al.,* 2022; Greyson *et al.,* 2021) in achieving this goal. Alternative fuel vehicles (AFVs) are increasingly acknowledged as essential strategies to address energy dependence, improve air quality, and combat climate change (Savage *et al.,* 2024; Haider *et al.,* 2025; Dyr *et al.,* 2019; Mohareb & Kennedy, 2014). Consequently, natural gas vehicles (NGVs) have gained popularity in both developed and developing countries as cleaner substitutes for petrol and diesel since the energy crisis of the 1970s (Krause *et al.,* 2024; Wang *et al.,* 2016; Savage *et al.,* 2024; Haider *et al.,* 2025).

The Spherical Insights 2024 and the Business Research Company 2025 reports reveal that the global CNG and LPG vehicle market size will increase from USD 5.40 billion in 2023 to USD 8.44 billion by 2033, reflecting a compound annual growth rate (CAGR) of 4.57% during this period. Currently, natural gas is priced 40–50% lower than equivalent volumes of petrol, making CNG vehicles a source of significant fuel savings. Amid rising petrol and diesel prices due to fluctuating crude oil costs, consumers are increasingly attracted to CNG as a reliable and economical fuel option. Additionally, CNG's eco-friendliness is crucial, as it produces 25–30% fewer greenhouse gases compared to diesel or petrol (SLOCAT, 2021; Spherical Insight, 2024).

The Asia-Pacific and Europe regions are expected to dominate the global CNG and LPG vehicle market due to the increasing presence of CNG/LPG-powered vehicles on major ASEAN metropolitan roads. Europe is expected to be the fastest-growing region in the forecast period. This growth is attributed to stricter emission regulations, renewable energy integration, urbanization challenges, sustainable mobility shifts, and market expansion strategies (United Nations, Economic and Social Commission for Asia and the Pacific [UNESCAP], 2024). Some of the most important trends are the use of biogas and bio-LPG, the integration of advanced vehicle technologies, the growth of mobility-as-a-service solutions, the rise of next-generation infrastructure, and a move towards circular economy models. The market report covers regions such as Asia–Pacific, Western Europe, Eastern Europe, North America, South America, the Middle East, and Africa (Ghadikolaei *et al.,* 2021; Spherical Insight, 2024).

Today, many countries across the globe are adopting NGV technology for environmental and socioeconomic reasons. Latin American nations, particularly Brazil, Argentina, and Mexico, have prioritized the implementation of NGVs due to increasing urban populations and concerns regarding energy security and pollution (Santos & Silva, 2018). This emphasis has led to the establishment of numerous natural gas vehicle (NGV) filling stations and the development of advanced vehicle technologies (Machado *et al.,* 2021; Bozzetto, 2022; Teoh & Khoo, 2020; Vahl & Filho, 2014).

In Asia, major economies such as China and India have promoted NGVs to tackle air pollution, energy security, and the environmental impacts of traditional fossil fuels. The Chinese government has implemented incentives, including subsidies for NGV purchases and investments in refueling infrastructure, to

mitigate urban air pollution (Oswald, 2021; Khan, 2017). India has introduced initiatives such as the National Gas Mobility Program, aimed at expanding the network of compressed natural gas stations and encouraging NGV use among transport operators (IGU & UNECE, 2012; Spherical Insights, 2024; Government of India, 2023). As of 2023, India had 3.5 million vehicles operating on compressed natural gas (Government of India, 2023; IGU & UNECE, 2012). Iran leads the world with 4.07 million NGVs and a significant government programme supporting development in this sector (Government of India, 2023; Spherical Insights, 2024).

Concurrently, the Asia–Pacific region is undergoing rapid industrialization and urbanization, resulting in dramatic shifts in transportation demands over the past few decades (UNESCAP, 2024). Transport-induced emissions, including GHGs that contribute to climate change, most notably CO_2, along with air pollutants such as nitrogen oxides, have become significant concerns (Zhao *et al.*, 2023; Abdullah & Anwar, 2021). Several travel demand management and mobility policies have been implemented to encourage road users to adopt low-carbon transport modes, but their effectiveness in terms of mode changes or aggregate travel volume implications has been modest (Savage *et al.,* 2024; Hasan & Mohammad, 2019; Dyr *et al.,* 2019). Over the past twenty years, city management has been a major obstacle to sustainable development. Many cities and societies strive to protect natural capital and achieve a social–economic–environmental balance (UN, 2021; Bouzguenda *et al.,* 2019). These environmental, economic, and social issues have prompted professional and academic circles to explore and implement sustainable urban development solutions.

The African continent is also awakening to alternative fuel, although it still heavily relies on fossil fuels. Recently, countries like Mozambique and Tanzania have identified significant recoverable natural gas resources, with large reserves being exploited in Nigeria, Algeria, Libya, and Egypt. Mozambique's production is primarily onshore in the Pande and Temane regions, with 135 Bcf produced in 2011 and with 117 Bcf exported to South Africa via an 860 km pipeline (Olanrewaju, 2024; The Business Research Company, 2025). Tanzania produces natural gas in Songo Songo Island and Mnazi Bay, with Songo Songo delivering gas to Dar es Salaam via a 250 km pipeline and Mnazi Bay supplying the Mtwara Power Plant via a 27 km pipeline. A pipeline was constructed to facilitate gas deliveries from Mnazi Bay to Dar es Salaam, with an expected completion date of 2014. The production at Mnazi Bay is expected to increase to around 30 Bcf/year (Nuhu *et al.,* 2020).

Sub-Saharan African countries, including Tanzania, are urbanizing quickly, presenting significant opportunities for investing in NGV use due to their growing urban populations and rising transportation needs (Nuhu *et al.,* 2020; IEA, 2024). Therefore, decarbonizing transportation is crucial for both national and international climate policy. It accounts for one-quarter of global GHG emissions and lags behind other sectors. With global policymakers aiming for climate neutrality by mid-century (SLOCAT, 2021; Iradukunda, 2024), the transport sector must significantly decarbonize by 2050. Vehicles are the largest contributors to GHG emissions (Abdullah & Anwar, 2021; SLOCAT, 2021).

Studies (Shah *et al.,* 2021; Gerutu *et al.,* 2023; Kusakana *et al.,* 2020; Hidayatno *et al.,* 2020) indicate that significant barriers exist in achieving widespread public acceptance of alternative fuel vehicles (AFVs). For example, in China, government rules have made it much easier for people to use CNG buses and taxis, which has led to big drops in emissions and better air quality (Li *et al.,* 2022). Studies have examined factors influencing the adoption of CNG vehicles. Similarly, a study in Mexico City revealed that lower operational expenses and reduced emissions compared to conventional fuels positively influenced the inclination toward CNG (Martinez-Hernandez *et al.,* 2020). Additionally, car owners are more likely to absorb conversion costs and seek loans if their vehicles are in good condition, newer models, or equipped with more cylinders (Ishengoma & Gabriel, 2021). In Tanzania, transport is an important sector that contributes to the development of other sectors, as it serves as a link in transporting goods and people from one place to another (Nuhu *et al.,* 2020; Greyson *et al.,* 2021).

Sustainable cities implement strategies to address environmental pollution resulting from carbon emissions from factories and vehicles. Recognizing this, the governments of developed countries have created a favourable environment to tackle the challenge of carbon emissions. The government's strategies in response to this challenge include fostering an environment conducive to the use of non-motorized transport that is free from carbon emissions (Zhang *et al.,* 2020; Khan, 2017; Du *et al.,* 2017). Although global cities are increasingly adopting sustainable city initiatives, such as NGV adoption, most African cities have lagged in this regard, despite having abundant natural gas resources and experiencing rapid urbanization (Olanrewaju, 2024; IEA, 2024). Hence, this study examines the technological and environmental factors influencing the widespread adoption of CNG in Tanzanian cities, using Dar es Salaam as a case study to develop a more sustainable transportation system that improves air quality, reduces GHG emissions, enhances quality of life, and supports the realization of sustainable cities in Africa (Nuhu *et al.,* 2020).

Governments in African countries, such as Tanzania, Rwanda, and Kenya, have initiated measures to control carbon emissions. These initiatives include regulations on the importation of vehicles to prevent those older than 10 years from entering the country. Furthermore, various regulatory policies and mandates have been implemented to promote the adoption of CNG vehicles across different regions. Tanzania is endowed with abundant natural gas reserves, with recent discoveries suggesting potential resources exceeding 57 trillion cubic feet (Nuhu *et al.,* 2020). Nevertheless, the country's transportation sector remains heavily reliant on imported fossil fuels, with only a minimal number of vehicles converted to run on CNG, about 1500 conversions in 2022, representing just 0.08% of the total vehicle population out of more than 1.2 million registered vehicles in the country (Gerutu *et al.,* 2023). The need to transition to alternative transport fuels in developing nations like Tanzania is emphasized by increasing fuel costs, persistent petroleum scarcity, and excessive road emissions. Despite the recognized benefits of natural gas as an alternative fuel, the adoption of CNG remains low due to various obstacles.

Recent gas finds in Tanzania could greatly benefit the country and the East Africa region in general as a significant alternative fuel and clean energy source. However, despite the Tanzania National Natural Gas Policy recognizing CNG as an alternative fuel for automobiles, adaptation for vehicles is very minimal and presently only performed in Dar es Salaam city, where there is a network of pipes for CNG. NG has various applications, including cooking, power generation, transportation, and fertilizer production, but in Tanzania, it is mostly used for domestic energy (cooking) with little use in the transportation sector (Gerutu *et al.,* 2023). Therefore, this study wanted to examine the environmental and technological drivers of CNG adoption as an alternative vehicle fuel in Dar es Salaam city.

The diffusion of innovations theory (Lindstrom & Olsson, 2015) and the theory of planned behaviour (TPB) (Al-Suqri *et al.,* 1980) are two theoretical frameworks used to study the adoption of natural gas vehicles. The TPB, proposed by Ajzen and Fishbein in 1980 (Ajzen, 1996), has been utilized to develop a research framework to determine the influence of preferences and the intentions of respondents to switch from petrol to NGVs. The diffusion of innovations theory identifies five critical attributes that influence adoption: relative advantage, compatibility, complexity, trialability, and observability. It helps understand how environmental benefits and technological advancements can accelerate the adoption of natural gas as a vehicle fuel. By integrating the societal focus of the diffusion of innovations theory with the individual-level analysis of the TPB, this framework provides a comprehensive approach to studying the adoption of natural gas vehicles, addressing both macro- and micro-level determinants.

As a general rule, the stronger the intention to engage in a behaviour, the more likely its performance should be; however, a behavioural intention can be expressed in behaviour only if the behaviour in question is under volitional control (Lindstrom & Olsson, 2015). The Theory of Planned Behaviour assumes that individuals act rationally in accordance with their attitudes, subjective norms, and perceived behavioural control. These factors are not necessarily actively or consciously considered during the decision-

making process, but form the backdrop for it. In other words, people may not articulate a particular attitude, yet it may still influence their decision-making. Research in this area aims to uncover these hidden values and ideas that affect decision-making (Ajzen, 1991). There is some debate regarding the assumption of rationality, as humans sometimes act emotionally rather than rationally. Instead of saying that humans behave rationally, some researchers refer to this as "sense-making". However, the theory has some weaknesses, as it may not fully capture the complexity of human behaviour.

Additionally, the theory assumes that behaviour is determined by a person's attitudes, subjective norms, and perceived behavioural control. In reality, behaviour is influenced by various factors, including emotions, past experiences, and situational factors. Another limitation is that the TPB assumes that people can plan and control their behaviour, which may not always hold true (Lindstrom & Olsson, 2015; Ajzen, 2012).

2.0 Materials and Methods

2.1 Study Area

The City of Dar es Salaam is situated between latitudes 6.36° and 7.0° south of the Equator and longitudes 39.0° and 33.33° east of Greenwich. It is bordered by the Indian Ocean to the east and by the Coast Region on the other sides (Ishengoma & Gabiriel, 2021). The city experiences a modified equatorial climate, with an average temperature of 29°. The hottest season lasts from October to March, with temperatures reaching up to 35°C, while the coolest period extends from May to August, with temperatures dropping to 25°C. There are two main rainy seasons, with an average rainfall of 1000 mm (Smith, 2012). Tanzania's largest city, Dar es Salaam, serves as the country's economic centre, featuring a diverse array of socio-economic activities and growth. The city is divided into three ecological zones, characterised by coastal shrubs, Miombo woodlands, coastal swamps, and mangroves. It hosts various sectors, including transportation, fishing, trading, education, health services, tourism, and infrastructure projects. The city consists of five districts: Kinondoni, Ilala, Temeke, Kigamboni, and Ubungo, covering an area of 1493 km² (Burton, 2019). According to the 2022 country population and housing census, the city's population is (NBS, 2023).

This city was chosen as a case due to its size, population size, and commercial activities. Dar es Salaam is the main economic engine of Tanzania, providing industrial, transport, and educational services, fishing, infrastructure projects, and serving as a trade and commercial hub (Burton, 2019); hence, sustainable transport is crucial for a metropolis like it.

2.2 Research Design and Sample

This study employed a cross-sectional design, integrating quantitative data from surveys conducted with vehicle owners and qualitative insights obtained through interviews (Creswell, 2014). The study included respondents who were vehicle owners in the city, regardless of whether they were petrol users, NGV users, or both. It also included stakeholders in the natural gas industry, transport company operators, and policymakers. Respondents were invited to share their opinions on different modes of transport based on their experiences; however, limited resources such as time, money, and the willingness of people to participate restricted the sample size.

The present study includes respondents who are vehicle owners, transport company operators, policymakers, experts, and stakeholders in the natural gas sector in Tanzania, regardless of whether they are petrol users, NGV users, or both. Simple random sampling, convenience sampling, and purposive sampling designs were employed to ensure that key members with knowledge about vehicles or fuelling systems were selected for participation in the study. This diverse group provided firsthand information about the challenges associated with adopting CNG as a fuel alternative (Mugenda & Mugenda, 2008). Due to the lack of precise published data regarding car owners in Dar es Salaam, an estimated population of 385 individuals was posited for this study based on its status as Tanzania's largest city. The Cochran formula was used to calculate an appropriate sample size that is both manageable and representative. Sekaran & Bougie (2010) suggested that a sample size larger than 30 and less than 500 would be

appropriate for survey and experimental research design.

2.3 Data Collection and Analysis

By administering structured surveys, the research gathered quantitative data that offers numerical comparisons to the current state of CNG adoption. Concurrently, interviews with key informants yielded qualitative data that offered detailed insights into various factors affecting CNG adoption. This comprehensive approach enables a robust analysis of the research problem by capturing a complete snapshot of current attitudes, behaviours, and conditions related to CNG adoption in Tanzania (Creswell, 2014).

The study utilised both primary and secondary data. A questionnaire survey was conducted to collect quantitative data from vehicle owners and drivers in Dar es Salaam city. In-depth qualitative insights were obtained through interviews with stakeholders in the natural gas sector, drivers, and government officials. Also, a direct observation was conducted to assess the current state of CNG infrastructures, installed vehicles, and gas filling. Qualitative data analysis involved thematic analysis to identify recurring themes related to CNG adoption factors. Quantitative data analysis utilised inferential statistics to examine survey responses regarding perceptions of CNG (Creswell, 2014; Mugenda & Mugenda, 2008).

3.0 Results and Discussion

3.1. Technological and Environmental Benefits of Adopting CNG in Vehicles

3.1.1. Technological Drivers of CNG Adoption in the City

3.1.1.1 Type of Vehicles and Fuel Used

Regarding vehicle ownership, a significant majority of people (82.7%) own cars, indicating that initiatives to promote CNG should mainly target this group of vehicle owners who might gain from alternative fuel options. Moreover, an examination of fuel preferences reveals that petrol is the most widely used among respondents, at 56.2%, followed by diesel at 17.3% and hybrid vehicles; nevertheless, only 8.8% currently utilize CNG, underscoring both the challenges and opportunities for enhancing CNG adoption in Dar es Salaam (Table 1). This finding aligns with Nuhu *et al.* (2020), who assert that vehicles account for approximately 40% of global petroleum consumption. Additionally, Abdin (2024) and Imam (2024) note that respondents perceive traditional fuels as a significant barrier to CNG adoption, highlighting potential market resistance. Moreover, they believe that more substantial government intervention is necessary to overcome the dominance of petrol and diesel, highlighting the need for more proactive policies.

Table 1
Vehicle Types and Fuel Types

Characteristics	Category	Frequency (%)
Vehicle type	Auto rickshaw (Bajaji)	43 (17.3%)
	Automobile (Car)	206 (82.7%)
Vehicles fuel type	Compressed Natural Gas (CNG)	22 (8.8%)
	Diesel	43 (17.3%)
	Hybrid	44 (17.7%)
	Petrol	140 (56.2%)

The analysis addressing the study's objectives yielded valuable insights through multiple response analyses. This method provided a thorough examination of respondents' perceptions regarding critical technological factors related to CNG. The analysis focused on the study's objectives and presented insights via multiple response analyses. This method looked closely at how respondents feel about important technological factors related to CNG. These factors included the availability of CNG refuelling stations, vehicle compatibility with CNG, access to maintenance and repair services, CNG's performance and efficiency, and the safety features associated with its use. The findings indicated differing levels of concern and support for these factors among respondents, summarised in Table 2, which presents the outcomes of the multiple response analysis on the technological factors affecting the adoption of CNG as a vehicle fuel in Dar es Salaam city. Vehicle compatibility with CNG closely followed, receiving 25.6% of total responses and a frequency of 67%, underscoring its significance in promoting adoption. Furthermore, the availability of maintenance and repair services for CNG vehicles received 22.2% of total responses and a frequency of 58%, suggesting that it is necessary to address this issue for broader adoption. In contrast, safety features related to CNG use

garnered only 11.9% of total responses and a frequency of 31%, suggesting that safety concerns could impede acceptance. Lastly, performance and efficiency compared to other fuels accounted for 12.5% of the responses, with a 33% frequency, indicating that while performance is recognized, it may not be as vital as infrastructure availability. These factors included the availability of CNG refueling stations and vehicle compatibility with CNG.

Table 2
Technological Factors

Technological factors		Frequencies and Percentage		
		Responses		Percent of cases
		N	Percent	
Technological factors	Availability of CNG refueling stations	181	27.9%	73%
	Compatibility of my vehicle with CNG	166	25.6%	67%
	Availability of maintenance and repair services for CNG vehicles	144	22.2%	58%
	Safety features of using CNG	77	11.9%	31%
	Performance and efficiency of CNG compared to other fuels	81	12.5%	33%
Total		649	100.0%	260.6%

Dichotomy group tabulated at value 1.

3.1.1.2 Availability of CNG Refueling Stations

The availability of CNG refueling stations was identified as the most vital factor (27.9% of total), with a 73% frequency, indicating strong support among respondents for this aspect as essential for CNG adoption (Table 2). This highlights its importance in their decision-making process. The limited number of operational refueling stations, only three currently, poses a substantial barrier to potential adopters, making the transition to CNG inconvenient. Transport company operators echoed these concerns, noting that the scarcity of refueling infrastructure negatively impacts their operational efficiency, leading to longer wait times and reduced profitability, especially when one station is closed. Policymakers have acknowledged this issue and are actively working to expand the network to meet the growing demand for CNG. For instance, from 30 September to 10 October 2024, one of the three available stations in the city was closed due to technical issues, which led to a long queue of vehicles waiting to be refueled at the Ubungo station. An interview with some of the tricycle or rickshaw (Bajaji) drivers on 1 October 2024 revealed their concerns: *"There are only three stations in the city, and one is closed; that's why we are here queuing for refueling at Ubungo station. It's chaotic, a waste of time, and a loss"* (Figure 1).

One operator stated, "*The few existing stations create long wait times for our drivers, which ultimately affects our service delivery and profitability*."

Additionally, policymakers acknowledged this issue, noting that "*The government is aware of the challenges posed by the limited number of refuelling stations and is actively working to expand the network to meet the growing demand*."

These findings are supported by those of Al-Mansour & Al-Jawahri (2021), who identified the lack of widespread CNG refueling stations as a barrier to adoption in Saudi Arabia, leading to apprehensions among vehicle owners regarding fuel availability and convenience. Imam (2024) and Olanrewaju (2024) found that the scarcity of CNG refueling stations posed a major challenge, particularly in regions outside major cities in Nigeria. This finding somewhat contradicts Krishnaswamy *et al.*'s (2015) and Teoh & Khoo's (2020) findings in Malaysia, who found that despite having a high number of CNG refueling stations, the use of CNG in vehicles was low. This implies that having CNG-supporting infrastructure does not guarantee the use of CNG in vehicles. This calls for policies and regulations that will encourage or mandate vehicle owners to adopt CNG to reduce GHG emissions from the sector. Also, countries like India have more than 6800 refueling stations and plan to increase them to promote adoption (India Petrol and Natural Gas Regulatory Board, 2024), thereby influencing adoption. High refueling infrastructure costs hinder CNG adoption but can be mitigated with demand, incentives, and rising oil prices. Over time, increasing oil prices will further encourage this shift in fuel (Haider *et al.,* 2025).

In many African countries, developing a sufficient and reliable infrastructure system for CNG will require time (Olanrewaju, 2024). However, it has been demonstrated that even with only 25%

adoption of gas as a primary energy source, it can be both affordable and significantly transformative for power generation, food supply, urban transportation, and cooking in cities (Demierre *et al.,* 2015). Many urban areas in the region are currently in a "chicken and egg" dilemma, similar to challenges faced by other cities in Asia. A comprehensive distribution pipeline and CNG stations cannot be established without a guaranteed supply at the city gate. Likewise, trunk networks leading to the city gate cannot be constructed without demand that can be monetized. This paper illustrates that this impasse can indeed be resolved. Insights from India's experiences with PNG and CNG programmes indicate that in-city distribution infrastructure must cater to both cooking and transportation needs while also promoting the broader use of gas in industry and energy production (Nandi *et al.,* 2022; Rajouriya & Taneja, 2023).

This challenge affects the adoption process since drivers often have to travel long distances to access CNG, reducing its economic attractiveness compared to conventional fuels. Fewer fuelling stations also affect emissions, as fewer vehicles will be converted to CNG systems due to long wait times for refueling, which will affect their role in decarbonization.

Figure 1

Vehicles in Long Queues

3.1.1.3. Limited Availability of Refueling Stations

The ANOVA results reveal that a lack of awareness and information significantly hinders CNG adoption in Dar es Salaam, with an F-value of 7.174 and a *p*-value of 0.008. Many vehicle owners do not fully understand the economic and environmental benefits of switching to CNG. Enhancing public awareness through educational campaigns could help shift perceptions and encourage adoption. Additionally, addressing the limited number of refueling stations is essential, as many potential adopters may not know where to access CNG. Bridging these informational gaps is crucial for increasing CNG adoption rates.

This finding highlights the importance of targeted communication strategies in promoting alternative fuel sources, such as CNG. The significant statistical results indicate that the current level of understanding among vehicle owners is inadequate. Efforts should be made not only to inform potential users about the benefits of CNG but also to create a supportive infrastructure that facilitates easy access to refueling locations. Without addressing these issues, the transition to CNG will remain slow, affecting broader environmental and economic goals in Dar es Salaam.

3.1.1.4 Compatibility of Vehicles with CNG

Compatibility with CNG is another important concern, as 67% of respondents indicate that it affects their decision to adopt this fuel. Many car owners are unsure whether their vehicles can be retrofitted for CNG use, and worries about the costs and technical challenges linked to retrofitting may impede adoption. Transport company operators also voiced concerns about the retrofitting process, highlighting compatibility issues as a major barrier. Stakeholders in the natural gas industry stressed the necessity for more vehicle models specifically designed for CNG to promote wider adoption (Table 2). Furthermore, feedback from transport company operators, who voiced concerns about the retrofitting process, reinforced the findings related to vehicle compatibility with CNG. They remarked, *"Many of our vehicles are incompatible with CNG systems, which complicates our transition to this fuel. The costs and technical*

challenges of retrofitting deter us from switching."

Additionally, stakeholders in the natural gas industry highlighted the necessity for more vehicle models specifically designed for CNG use, stating, *"The current market lacks sufficient options for vehicles that can easily be converted, limiting broader adoption"* (September 2024).

Oliveira *et al.* (2022) support this finding by emphasizing the role of technological advances in making CNG more attractive. Their research highlights innovations in CNG vehicle technology that enhance efficiency and reduce conversion costs. By investing in research and development, manufacturers are better positioned to leverage these advancements and can produce more efficient and affordable vehicles for consumers, which encourages adoption. They argue that these innovations are not merely incremental improvements; instead, they fundamentally reshape the landscape of automotive technology.

One of the foremost aspects of their research focuses on the enhancements in CNG vehicle technology. These improvements are pivotal, as they directly contribute to increased fuel efficiency. For instance, newer vehicle models integrated with state-of-the-art technology enable better fuel combustion and optimized engine performance. These kinds of improvements cut down on waste, which is good for the environment and saves consumers money. As the efficiency of CNG vehicles rises, so does the potential for wider adoption among various demographics, from individual consumers to commercial fleets (Alonso-Villar *et al.,* 2022; Liu *et al.,* 2025; Jiang *et al.,* 2020).

Moreover, Du *et al.* (2017) highlight the importance of reducing conversion costs associated with retrofitting vehicles to run on CNG. By streamlining production processes and employing novel materials or techniques, manufacturers can lower these costs significantly. This reduction makes it financially feasible for more vehicle owners to consider transitioning to CNG, particularly when they weigh long-term savings on fuel against initial conversion expenses. Their commitment to improving CNG vehicle performance facilitates the production of vehicles that are not only more efficient but also more affordable. Furthermore, Mohareb & Kennedy (2014) argue that this dynamic creates a positive feedback loop; as vehicles become more accessible, consumer interest grows, compelling manufacturers to innovate further to meet increasing demand.

Improvements in CNG technology and lower prices make CNG more appealing as a replacement for fossil fuels. This leads to widespread use and helps create a sustainable energy future. Increased CNG use is vital for reducing greenhouse gas (GHG) emissions in transportation, making it more environmentally friendly than conventional fuels. Thus, Al-Farook and Islam (2021) emphasize the importance of ongoing innovation in the automotive industry and broader environmental goals related to pollution reduction in Bangladesh.

3.1.1.5 Maintenance and Repair Services

The availability of maintenance and repair services for CNG vehicles is considered essential by 58% of respondents. Car owners have emphasized the need for reliable service options to address potential issues with CNG systems. Currently, only a limited number of facilities, like the Master Gas station in Pugu, are equipped to install and repair gas systems, which hinders adoption. Stakeholders in the natural gas industry observed a lack of diverse vehicle options designed for CNG use, further deterring potential adopters who find retrofitting existing vehicles both costly and complex. *"The market currently lacks a diverse range of vehicles designed for CNG use, discouraging potential adopters."*

Similarly, vehicle owners echoed these sentiments in their interviews, pointing out that retrofitting existing vehicles can be costly and technically challenging. One owner remarked, *"I would consider switching to CNG if I knew more vehicles were compatible; right now, it feels risky to invest in retrofitting."* (September 2024).

Typical modifications for NGVs involve upgrading exhaust valves and valve seats. However, these changes do not alter the engine's visual appearance or its maintenance and service needs. Modern vehicles feature advanced fuel systems that effectively store and deliver precise fuel quantities, optimizing performance while reducing harmful emissions. NGVs follow this trend, though their fuel storage and delivery

mechanisms may differ from those of traditionally fuelled vehicles. Maintenance for NGV systems is also unique. According to Li *et al.* (2022) and Mohareb and Kennedy (2014), NGV systems require unique maintenance. A critical addition to NGV maintenance is the regular inspection of fuel storage tanks, especially following accidents or suspected damage. It is also essential to be aware of the tank's end-of-life date to ensure safe decommissioning once it is no longer functional. Many vehicle owners are worrying about the availability and reliability of the maintenance service if their petrol vehicles are converted to CNG. If this issue is not addressed in many cities, including Dar es Salaam, it will affect the role of CNG in the cities' decarbonization, especially in African countries.

3.1.1.6 Performance and Efficiency of CNG

One quarter (33%) of participants expressed concerns about the performance and efficiency of CNG compared to traditional fuels. Car owners are particularly focused on whether CNG can deliver comparable performance and reliability. This apprehension may deter potential adopters who fear that switching to CNG could compromise their vehicle's power, especially during long trips. Transport company operators echoed these concerns, stating that CNG could adversely affect their business operations if it does not perform as well as diesel or petrol. *"I'm worried that switching to CNG might affect my vehicle's power and reliability, especially during long trips."*

Transport company operators also emphasized this issue in their interviews, stating that, *"If CNG doesn't perform well as diesel or petrol, it could hurt our business operations."* (September 2024). Aligned with this finding, Ishengoma and Gabriel (2021) report that maximum engine power produced when running on natural gas is 5–10% lower than that when running on gasoline. Khan *et al.* (2015) argue that the performance of a CNG-fuelled engine depends on its design and type, but the primary issue is brake power loss. Factors affecting engine power include low flame propagation speed, volumetric efficiency loss, and the absence of fuel evaporation, all of which impact the performance of CNG engines. Conventional CNG engines produce less brake power than gasoline due to flame speed and volumetric efficiency. Experimental studies indicate a 15–20% loss in total brake horsepower when running on natural gas. Studies have found that CNG generates 16% less brake power than gasoline (Darade & Dalu, 2013; Ebrahimi & Mercier, 2011; Evans & Blaszczyk, 1997). Rajouriya and Taneja (2023) and Gustafsson and Svensson (2020) highlighted the issue of vehicle engine compatibility with CNG systems in Asia. Their research revealed that retrofitting vehicle engines to accommodate CNG fuel poses a substantial challenge due to the high costs associated with conversion and the limited availability of skilled technicians. This barrier was noted by 65% of respondents, underscoring the necessity of investing in retrofitting technology and training programs to promote wider adoption. Similar challenges are anticipated in Dar es Salaam, where access to skilled personnel and affordable modification services could influence adoption rates. Furthermore, Darade and Dalu (2013) and Ebrahimi and Mercier (2011) compared the performance of CNG-powered vehicles with gasoline engines in Iran, finding slightly lower power output but significant environmental benefits, which were enhanced by technological advancements such as high-pressure fuel storage systems and optimised engine designs.

Jiang *et al.* (2020) reported that CNG vehicles generally exhibit good performance and fuel efficiency. CNG engines can have a higher brake thermal efficiency, averaging 1.1%-1.6% higher than gasoline engines. This improved efficiency, combined with advanced engine technologies, contributes to both performance and lower emissions compared to traditional fuels. The analysis of the experimental results showed a 19.25% and 10.86% reduction in brake power and a 15.96% and 14.68% reduction in brake-specific fuel consumption (BSFC) at 50% and 80% throttle positions, respectively, when the engine was fuelled with CNG compared to gasoline. However, the retrofitted engine produced 1.6% higher brake thermal efficiency and exhibited 24.21% higher exhaust gas temperature at 80% throttle, resulting in an average 40.84% higher NOx emissions over the 1500–5500 rpm range at 80% throttle. Other emission components

(unburnt HC, CO, O_2, and CO_2) were significantly lower than those of the gasoline emissions.

3.1.1.7 Technical Expertise for Maintenance

Inadequate technical expertise (F-value of 167.337), high conversion costs (F-value of 7.174), lack of awareness (F-value of 7.174), safety concerns (F-value of 12.043), limited refueling stations (F-value of 19.450), and limited vehicle options (F-value of 51.082) indicate significant socio-economic barriers to CNG adoption in the region. These findings suggest that there must be targeted interventions to address these challenges.

The ANOVA results indicate that a lack of technical expertise for maintenance significantly hinders CNG adoption in Dar es Salaam, with an F-value of 167.337 and a *p*-value of 0.000. Respondents perceive the absence of qualified technicians as a major barrier, causing vehicle owners to hesitate in converting to CNG due to concerns about maintenance and repairs. If owners are uncertain about finding skilled personnel, they may prefer conventional fuels, which they consider less risky. Addressing this gap in technical expertise is crucial to promoting CNG as a viable fuel alternative, as concerns about maintenance can deter potential adopters. Furthermore, ANOVA findings on inadequate technical expertise reveal an F-value of 167.337. At the same time, high conversion costs yield an F-value of 7.174, lack of awareness yields an F-value of 7.174, safety concerns yield an F-value of 12.043, limited refueling stations yield an F-value of 19.450, and limited vehicle options yield an F-value of 51.082. These findings confirm that socio-economic barriers hinder CNG adoption in the region, suggesting that there must be targeted interventions to address them.

CNG's physical properties offer safety benefits over diesel and gasoline. It has a narrow flammability range of 4.3% to 15.2% by volume in air, which prevents ignition even in the presence of a spark. Its high auto-ignition temperature and low density at atmospheric pressure reduce the chance of accidental ignition and combustion. Additionally, CNG cylinders are designed to resist high pressures, with a safety factor usually greater than two, making them safer than ordinary petrol tanks. Safety features associated with using CNG emerged as a key concern for 31% of respondents. Many drivers and vehicle owners are worried about the risks linked to compressed gas systems, which could deter them from considering CNG as a viable alternative fuel. Vehicle owners voiced significant safety concerns, fearing accidents related to CNG usage. Policymakers also recognized that ensuring safety in CNG installations is vital for building public trust and encouraging wider adoption among potential users.

Furthermore, the findings related to the safety features of using CNG were reinforced by insights from vehicle owners, who expressed considerable concerns about the perceived risks associated with CNG systems. One owner remarked, *"I worry about the safety of CNG; the idea of using compressed gas makes me nervous, especially since I've heard about accidents in other regions."*

Similarly, policymakers acknowledged these concerns during their interviews, emphasizing that; *"Ensuring the safety of CNG installations is crucial to building public trust and encouraging adoption."*(September 2024).

The results indicate that safety concerns significantly impede CNG adoption in Dar es Salaam, with an F-value of 12.043 and a *p*-value of 0.001. Respondents expressed fears regarding the risks associated with CNG storage and use, such as leaks or explosions. Addressing these safety concerns is essential for increasing acceptance of CNG as a viable fuel alternative. Effective communication about safety protocols at refueling stations and ensuring compliance with safety standards can help alleviate fears and build public trust in CNG infrastructure, ultimately promoting its adoption as a cleaner energy source.

Kim and Lee (2017) looked at how being aware of technology affects adoption rates in South Korea. They found that 78% of respondents lacked sufficient knowledge about the safety and efficiency of CNG systems. Concerns about safety and misunderstandings among the public make it even harder to adopt CNG. Martinez-Hernandez *et al.* (2020) revealed widespread apprehension about the safety of CNG systems in Mexico. Many participants expressed fears of gas leaks and explosions, despite evidence supporting

the safety of modern CNG technologies. This emphasizes that negative perceptions, fuelled by a lack of public education, created hesitancy among potential users. Public trust, therefore, emerged as an important factor influencing adoption rates. Public awareness campaigns significantly improved perceptions and adoption. Such evidence highlights the importance of educational and awareness initiatives to address gaps in understanding, which could be crucial for promoting CNG use in Dar es Salaam and other African cities.

Sgaramella *et al.* (2024) propose that environmental protection and economic growth can be achieved simultaneously through technological innovation, institutional reforms, and shifts in production and consumption patterns. It emphasizes the role of technological advancements, regulatory frameworks, and market mechanisms in addressing environmental issues while fostering sustainable development. TAM proposes that users' behavioural intentions toward technology adoption hinge primarily on perceived usefulness and ease of use (Al-Suqri *et al.,* 1980; Lindstrom & Olsson, 2015). 'Perceived usefulness' refers to the degree to which individuals believe that a particular technology will enhance their performance or productivity, while 'perceived ease of use' relates to the extent to which users perceive a technology as effortless and user-friendly.

3.1.1.8 Vehicle Options

The ANOVA results reveal that limited vehicle options significantly hinder CNG adoption in Dar es Salaam, with an F-value of 51.082 and a *p*-value of 0.000 (see Supplementary materials). Respondents view the lack of compatible vehicle models as a critical barrier, causing many to hesitate to convert to CNG due to worries about performance and resale value. The narrow selection of vehicles specifically designed for CNG may discourage potential adopters from switching. The strong F-value highlights the necessity for a wider range of vehicles available for CNG use to boost adoption rates. With the number of vehicles transitioning to CNG increasing from 1139 in 2020/2021 to about 3000 in 2022/2023, demand for more diverse options is evident. Expanding vehicle availability could enhance consumer confidence and encourage more vehicle owners to consider converting to CNG, contributing to a more sustainable transportation landscape in the region.

3.1.2 Environmental Factors

NG is gaining interest as a transportation fuel due to its potential environmental benefits, including reduced air emissions and noise pollution. It is one of the cleanest-burning alternative vehicular fuels available today. A 1992 AGA survey found that NGVs had 34% lower injury rates per vehicle mile travelled than gasoline vehicles, with no fatalities reported. Environmental factors influencing the adoption of CNG as a vehicle fuel in Dar es Salaam were examined through multiple-response analysis, which revealed respondents' perceptions of key benefits, including reduced greenhouse gas emissions, lower air and noise pollution, and conservation of natural resources. Table 3 summarizes the results of the multiple-response analysis of environmental factors influencing the adoption of CNG as a vehicle fuel in Dar es Salaam. Overall, these results emphasize that promoting CNG's environmental benefits, particularly its effect on GHG emissions and air quality, could enhance its appeal to potential users in Dar es Salaam city.

Table 3
Environmental Factors

Environmental factors		Frequencies and Percent		
		Responses		Percent of cases
		N	Percent	
Environmental factors	Reduction in greenhouse gas emissions	181	31.9%	73%
	Reduction in air pollution	166	29.2%	67%
	Reduction in noise pollution	144	25.4%	58%
	Conservation of natural resources	77	13.6%	31%
Total		568	100.0%	238.7%

Dichotomy group tabulated at value 1.

3.1.2.1. Greenhouse Gas Emissions

Reduced greenhouse gas emissions are a crucial environmental factor influencing CNG adoption in Dar es Salaam, with 73% of respondents recognizing their importance. Many drivers are motivated by CNG's ability to lower emissions compared to traditional fuels like petrol and diesel. This concern for environmental impact indicates that promoting CNG's emission reduction benefits could effectively encourage adoption. Transport company operators also highlighted the environmental advantages, noting that switching to CNG reduces costs and enhances corporate responsibility by lowering carbon footprints. This is supported by findings from an interview conducted with transport stakeholders in September 2024, who argued that, *"CNG has the potential to drastically improve air quality in urban areas like Dar es Salaam, where pollution is a major health concern."*

Vehicle owners also addressed this issue during their interviews, with one stating: *"I'm motivated to consider CNG because it can help reduce harmful emissions that affect our health and environment."*

"Using CNG not only helps us save on fuel costs but also significantly reduces our carbon footprint, which is important for our corporate responsibility."

"The lower emissions from CNG compared to petrol and diesel are a major selling point for us when engaging potential customers."

These perspectives align with the study's findings, reinforcing the idea that CNG's potential to mitigate air pollution is a crucial motivator for its adoption among users in Dar es Salaam.

Studies also show that some car owners were more inclined to bear the costs of converting to NGVs and utilizing commercial loans if their vehicles are in better condition in terms of mileage, are newer or nearly new, and are equipped with a higher number of car cylinders (Quddus *et al.*, 2020; Ishengoma and Gabriel, 2021). Efficiency, environmental concerns, financial gains, and strategic advantages are the primary forces behind businesses' adoption of AFVs (Hidayatno *et al.,* 2020; Dyr *et al.,* 2019; Quddus *et al.,* 2020) in Asian countries like Pakistan and India. Environmental factors play a crucial role in adopting CNG as vehicle fuel. Similarly, the European Union (EU) has set a GHG emissions reduction target of at least 55% by 2030 (Ortega *et al.,* 2021). In the United States, vehicles running on CNG emit 20–25% less CO_2 and negligible amounts of sulfur dioxide (SO_2) (Spherical Insights, 2023; SLOCAT, 2021). CNG is also said to produce less greenhouse gases compared to conventional vehicles (Khan, 2017). Using CNG as a vehicle fuel instead of conventional fuels like petrol and diesel would result in a reduction of 19-22% in carbon dioxide emissions and particulate emissions in Poland (Kryzia & Pepłowska, 2023) and more than 90% by each vehicle. Delhi, the world's second-densest city, switched its public road transport to CNG-fueled vehicles in 2002, resulting in substantial reductions in CO, TSP, NOx, and SO_2 (Narla *et al.,* 2024). This highlights the importance of sustainable transportation in supporting societal mobility needs while minimizing environmental harm. Additionally, vehicle owners in Mexico City favoured CNG for its lower costs and reduced emissions (Martinez-Hernandez *et al.,* 2020), aligning with findings in Dar es Salaam, where the availability of CNG refueling stations was highlighted as a critical technological enabler for its adoption, with 73% of respondents considering it a key factor (Iradukunda, 2024). Among the key challenges in developing CNG are the limited space in vehicles, resulting from its lower energy density compared to gasoline and diesel, the time required to refuel, and the absence of infrastructure in certain areas.

3.1.2.2. Air Pollution

Reducing air pollution is another key factor recognized by 67% of participants as important for adopting CNG. In Dar es Salaam, where air quality is a pressing issue, this benefit resonates strongly with car owners who are aware of the health risks associated with pollution. The findings indicate that CNG's potential to improve air quality significantly motivates those seeking cleaner fuel alternatives. Stakeholders in the natural gas industry echoed this view, highlighting that CNG could greatly enhance urban air quality. At the same time, vehicle owners expressed motivation to consider CNG due to its ability to reduce harmful emissions.

Furthermore, the findings regarding the reduction in noise pollution as a benefit of adopting CNG were supported by vehicle owners, who appreciated the quieter operation of CNG vehicles. One owner remarked that: *"Driving a CNG vehicle is much quieter than my old diesel car, which makes for a more pleasant experience, especially in heavy traffic"* (September 2024).

Additionally, transport company operators emphasized that quieter vehicles could improve the working environment for both drivers and passengers. One operator stated that: *"Reducing noise pollution is a bonus; it not only enhances comfort but also contributes to a better urban atmosphere"* (September 2024).

These insights align with the findings of the study, reinforcing the notion that while noise reduction may not be the primary motivator for all users, it still plays a significant role in shaping attitudes toward the adoption of CNG in many developing cities. Wang *et al.* (2016) conducted a study in China, examining the link between CNG adoption and improvements in air quality. Their findings indicated that replacing gasoline and diesel vehicles with CNG-powered alternatives reduced particulate matter (PM2.5) levels by 18%. This improvement in urban air quality spurred public pressure and incentivized government support for CNG adoption, demonstrating the direct link between environmental benefits and fuel adoption. The use of CNG in public transportation can enhance urban air quality, mitigate health risks, and alleviate social pollution costs in Rwanda (Iradukunda, 2024). Du *et al.* (2017) and Wang *et al.* (2022) explored how policies targeting urban pollution control in Shanghai, China, contributed to a 15% reduction in urban smog through mandated CNG use in public transportation. The study emphasized that environmental regulations could drive large-scale adoption of CNG as a cleaner alternative.

3.1.2.3. Noise Pollution

Reduction in noise pollution is considered an important environmental benefit by 58% of respondents. Although it is not as prominent as other factors, some drivers appreciate the quieter operation of CNG vehicles. The results show that noise reduction may not be the main benefit, but it is appealing to people who are sensitive to noise pollution. Vehicle owners noted that driving CNG vehicles offers a quieter experience than diesel cars, enhancing comfort, especially in traffic. Transport company operators also highlighted that quieter vehicles positively affect the working environment. Results from interviews also reveal similar findings: *"CNG is a local resource that helps us conserve our non-renewable energy sources, which is vital for our energy security".*

Additionally, vehicle owners demonstrated a growing awareness of the need for sustainable fuel options, with one owner stating that: *"Using CNG not only benefits my wallet but also helps protect our natural resources for future generations"* (September 2024).

In line with these findings, Wang *et al.* (2022) emphasized the importance of perceived cost savings and environmental benefits in driving the acceptance of CNG vehicles in their study of taxi drivers in China. Similarly, Zhang *et al.* (2020) explored the relationship between natural resource availability and the adoption of alternative fuels in Tanzania, noting that CNG adoption is largely influenced by the country's natural gas reserves and the government's promotion of cleaner energy sources. These findings suggest that economic and environmental considerations are pivotal in encouraging the shift towards CNG, aligning with the results of this study in Dar es Salaam and other African cities. Furthermore, the findings regarding the conservation of natural resources as a key factor influencing the adoption of CNG were echoed by stakeholders in the natural gas industry, who highlighted the importance of reducing reliance on imported fossil fuels.

3.1.2.4. Conservation of Natural Resources

A total of 31% of respondents view the conservation of natural resources as an important factor. In Dar es Salaam, the belief that CNG contributes to the conservation of non-renewable resources, such as petroleum, increases interest in adopting this fuel. The findings indicate that drivers are increasingly seeking sustainable fuel options to lessen their dependence on imported fossil fuels. Industry stakeholders reinforced this perspective, stating that CNG is a local resource vital to energy

security. Vehicle owners demonstrated awareness of the necessity for sustainable fuels, suggesting that CNG is beneficial for their finances and future resource management availability.

4.0 Conclusion and Recommendations

Clean energy is vital for sustainable development, with natural gas becoming a popular alternative for public transportation. It enhances air quality in cities and lowers investment and maintenance costs compared to diesel buses. CNG buses cut fuel costs and decrease environmental impact. Switching from diesel to CNG buses reduces toxic substances and greenhouse gas emissions, improving economic effectiveness in the transport sector. This study on the factors affecting the adoption of CNG in vehicles in Dar es Salaam, Tanzania, is one of the few studies from the East African region and Tanzania, since the use of CNG as a transportation and energy source is very low (18%), as more than 80% of Tanzanian CNG is used in power generation, and reveals important insights into the importance of this insight and the complexities of this transition towards clean energy. The study highlights both the benefits and significant obstacles involved. The findings indicate increasing awareness of CNG's environmental benefits, including reduced greenhouse gas emissions and improved air quality. However, several barriers hinder its widespread use. These barriers include technological issues related to (i) inadequate refueling stations (73%), (ii) vehicle compatibility with CNG systems (67%), and (iii) a shortage of trained maintenance technicians (58%). Socio-economic factors were not included in the study, which calls for further studies on their contribution towards adoption. The research highlights the crucial role of government policies and regulations in promoting CNG adoption, emphasizing that supportive measures, such as subsidies and incentives, are vital in overcoming financial barriers. This study emphasizes the need for a comprehensive strategy to promote CNG adoption in Dar es Salaam city and throughout the country, aiming to reduce transport-related emissions by addressing both infrastructural and educational gaps, thereby encouraging a shift toward cleaner energy sources.

Adopting CNG offers mature technology and environmental benefits like energy efficiency and renewability. The authors suggest infrastructure deployment outside cities and tax cuts. High refueling costs hinder adoption, but they can be overcome through demand and incentives. Rising oil prices may also encourage a shift. Supporting sustainable development, including the broader adoption of alternative fuels, particularly renewables, in urban transportation, is vital. While compressed and liquefied natural gas (methane) are considered alternative fuels due to their cleaner burning properties, they are still technically classified as fossil fuels. Limited refueling infrastructure hinders progress; most existing stations were designed for large fleet operators, like city bus companies and long-distance transport, to ensure profitability. The use of non-motorized transport to address the challenges posed by carbon emissions in the environment is recommended, especially for short routes, to promote sustainability.

This study suggests that the government should focus on establishing additional CNG refueling stations in Dar es Salaam, collaborating with private investors to address logistical challenges and enhance the sustainability of infrastructure development. A vocational course should be implemented at institutions such as DIT, NIT, and Arusha Technical College to equip mechanics and technicians with essential skills for CNG maintenance. Certification programmes will help validate technicians' competencies and boost confidence in CNG maintenance services. Public awareness campaigns should be initiated to educate vehicle owners about the environmental and cost advantages of CNG. Partnering with automotive manufacturers in Japan and Europe can facilitate the adoption process. Enforcing stringent safety regulations for CNG systems is crucial for ensuring user safety and building consumer trust in CNG technology. Implementing strict safety regulations for CNG systems, raising awareness through campaigns, and creating certification processes for service centres can enhance consumer trust in CNG technology, thereby achieving UNSDG goals 11 and 13.

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7.0 Declaration of Conflicting Interests

The authors declare no conflict of interest.

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