© April 2026| IJIRT | Volume 12 Issue 11 | ISSN: 2349-6002

Green Consumerism and CNG Cars: An Analysis of trend and Growth pattern of CNG cars in India

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Abstract: This study examines the growing demand of green consumerism and CNG cars as a cost-effective and alternative fuel in the shift toward green transition in the Indian context. According to the WHO report, the main concerns over air pollution, fuel costs, and environmental sustainability have redefined the adoption of CNG cars, which is also fueled by government policies, infrastructure expansion, and increasing consumer awareness. The research explores the economic advantages of CNG cars, including lower operating costs, reduced dependence on imported fuels, and the potential to generate employment across sectors. It also highlights the CNG features, cost effectiveness and trend from 2011 to 2025. CNG offers significant environmental and economic benefits, but challenges such as infrastructure disparities and methane emissions persist. The study concludes that CNG serves as an effective transitional solution, bridging the gap between conventional fuels and future low-emission technologies like electric vehicles.

I.INTRODUCTION

Overview

In the global effort to lower vehicle emissions and lessen dependency on conventional petroleum fuels, compressed natural gas (CNG) has emerged as a significant alternative fuel. Concerns about air pollution, fuel costs, and environmental sustainability have sparked interest in greener, more cost-effective transportation solutions as urbanization and car usage rise. Compared to gasoline and diesel engines, CNG-powered vehicles have several advantages, such as lower carbon emissions, less particulate matter, and more economical operation. Natural gas recovered from subterranean reservoirs, either separately or in conjunction with oil fields, is the source of compressed natural gas (CNG). Impurities such carbon dioxide, water vapor, hydrogen sulfide, and heavier hydrocarbons are removed from the gas through processing. Following cleaning, it is compressed to between 200 and 250 bar and kept in specialized cylinders for use in automobiles. Methane makes up the majority of CNG (often 85%–95%), with trace amounts of ethane, propane, nitrogen, and carbon dioxide. Methane's combustion characteristics are greatly impacted by the fact that it is the lightest hydrocarbon and has a higher hydrogen-to-carbon ratio than gasoline or diesel. Because it affects emissions, efficiency, and the possibility of methane leaks, an understanding of this chemical composition is crucial for evaluating the environmental impact of CNG cars.

The use of compressed natural gas (CNG) vehicles has increased significantly in both developed and developing countries as a result of many governments supporting natural gas as an interim fuel towards more environmentally friendly mobility solutions. Globally, policymakers have adopted a number of tactics to promote CNG as an eco-friendly substitute for traditional transportation fuels. Fuel subsidies and incentives, fleet conversion requirements, infrastructure development support, and the creation of pollution regulations for CNG cars are common examples of such tactics.

The rapid growth of global transportation over the last century has driven and been driven by socioeconomic progress, allowing unmatched mobility for people, goods, and services. Nonetheless, this expansion has brought serious environmental issues like rising air pollution, increased greenhouse gas emissions, resource exhaustion, and urban ecological decline. As vehicle use surges, especially in densely populated and industrialising nations, the environmental impact of traditional fossil-fuel vehicles—mainly petrol and diesel-powered—is increasingly a policy focus. In this context, Compressed Natural Gas (CNG) has attracted growing interest as a cleaner, more sustainable fuel option. CNG vehicles are seen as a transitional solution that could lessen environmental damage while the broader shift to electric and renewable energy sources continues to develop.

II.THE ROLE OF CNG IN THE TRANSITION TO SUSTAINABLE TRANSPORTATION

As nations speed up their shift to electric vehicles (EVs) and hydrogen-powered mobility, questions emerge about the future of CNG. While EVs emit no tailpipe pollutants, their overall environmental effect depends on how electricity is generated. In areas where the grid relies heavily on fossil fuels, EVs might not offer a net environmental advantage yet. Therefore, CNG still plays a significant role as a transitional option—serving as a bridge from high-emission petrol and diesel vehicles to upcoming low-carbon transport systems.

Compressed Natural Gas (CNG) is becoming increasingly important as a transitional fuel in the global move towards sustainable transportation. As concerns about air quality, greenhouse gases, and dependence on traditional petroleum grow, many countries see CNG as a practical, lower-emission alternative. Its primary component, methane, allows for cleaner combustion, resulting in significantly lower emissions of particulate matter, nitrogen oxides, and sulfur compared to petrol and diesel. This reduction in harmful pollutants contributes to improved urban air quality, making CNG an attractive option for densely populated and pollution-prone regions. Additionally, the cost-effectiveness of CNG has made it accessible to both private vehicle owners and commercial fleets, reinforcing its role in cleaner mobility strategies.

Although CNG is a fossil fuel, it is often seen as a transitional fuel connecting traditional energy sources to fully renewable, zero-emission options like electric and hydrogen vehicles. Electric cars face current challenges, including limited charging stations, higher initial costs, and reliance on the electricity grid, which means widespread adoption will take time, especially in developing nations. In this scenario, CNG provides a temporary solution that cuts emissions immediately while the clean-energy infrastructure develops further. Its existing infrastructure and the growing availability of factory-fitted CNG vehicles facilitate the quicker transition away from high-emission diesel and petrol vehicles.

The environmental advantages of CNG should be considered within a broader lifecycle perspective. Although it produces fewer tailpipe emissions, methane leaks during extraction, processing, and distribution present notable climate risks, as methane is significantly more potent as a greenhouse gas than carbon dioxide. This indicates that while CNG helps lower emissions now, it is not a sustainable long-term solution. Instead, it functions best as a transitional step that cuts down short-term emissions while enabling the gradual adoption of more advanced, renewable-focused transportation technologies. A more comprehensive lifetime perspective should be taken into account when evaluating CNG's environmental benefits. Methane leaks during mining, processing, and transport offer significant challenges even though it generates fewer tailpipe emissions.

Overall, CNG's role in sustainable transportation is both strategic and temporary. It aids countries in cutting urban pollution, optimising fuel costs, and filling the gap until electric and hydrogen technologies are widely feasible. Its use shows how transitional fuels can uphold environmental objectives without disturbing mobility or economic activities. As global transportation systems develop, CNG will remain a supportive, yet temporary, stepping stone on the path toward fully decarbonized and sustainable networks.

III.CONSUMER PURCHASING DECISION TOWARDS CNG

Proper comprehension of consumer purchasing decisions is much difficult without taking into account the alluring aspects of a brand, product, or service (Berger & Nasr, 1998). Appeal is the primary key to persuading consumers about the desirability in their minds. (Nandy & Sondhi, 2022). Previous research suggests that consumers who purchase vehicles are more influenced by the appealing factors offered by a brand. Augmented reality is a sprouting technology with considerable potential in numerous arenas, such as marketing, education, Retailing and many more. (Kim et al., 2022). It is a modern human–technology interaction that leads businesses to express optimism about the future of augmented reality. The current project connects augmented reality to the appeal and efficiency of driving, considering it an important motivator guiding consumers' purchase decisions. This technique overlays a user's perception of the physical world with digital data, including text, audio, and images, through HUDs (Head-Up Displays) that display perilous driving data, such as speed, navigation cues, and hazard alerts, directly on the driver's panel. It has developed into a powerful tool for enhancing human awareness and decision-making in diverse situations (Walentek & Ziora, 2023).

The significant rise in the adoption of Compressed Natural Gas (CNG) vehicles in India reflects a strong consumer preference for cleaner and more economical fuel solutions. (Aslam et al., 2006). CNG's share of the passenger vehicle segment has more than tripled from 4.6% in FY 2020 to over 16% in FY 2025, driven by stable fuel pricing, expanding vehicle model offerings, and supportive government policies (Kaul, 2025). Augmented Reality (AR) technologies, such as AR-enabled Head-Up Displays (HUDs), intelligent dashboards, and mobile AR experiences, are being integrated into the automotive ecosystem to enhance safety, engagement, and the overall user experience. (Gavish et al., 2021). Experimental studies on AR-assisted vehicle interfaces show that focused visual overlays can reduce driver workload while improving danger response, provided the interface limits information overload and avoids unnecessary details. AR-based Advanced Driver Assistance Systems (ADAS) are beneficial in this context. (Gavish et al., 2015). AR has been verified as valuable in industrial and automotive maintenance for overlaying technical schematics, guiding real-time repairs, reducing diagnostic errors, streamlining processes, and enhancing maintenance efficiency. (Yamin et al., 2024). From a marketing perspective, AR significantly boosts consumer appeal, brand recall and engagement by providing immersive reality experiences to consumers.

Not many empirical studies focus on CNG vehicle categories, especially in India, despite the growing body of research on the impact of augmented reality (AR) on driving safety and technology adoption worldwide. However, India is gradually embracing AR and VR in the design, training, and marketing of CNG vehicles.

Consumer's judgment of the product's worth, which is based on the trade-off between benefits and effort, is considered as perceived value. (Samarakoon, 2020). Consumers perceive value primarily through their level of engagement with a product, service, or brand. Various factors, including consumer experience, marketing efforts, and the overall quality of the offering, can influence this engagement. (Monika, 2024). To foster a strong sense of value, presenting the product appealingly and effectively is crucial, utilising strategies such as attractive packaging, informative advertising, and personalised consumer interactions. (Abdullah & Siraj, 2018). Businesses can enhance consumer perception and strengthen brand loyalty by focusing on elements that appeal to their target audience. Recent studies have highlighted perceived benefits, including enhanced safety features and an improved user experience. (Kuppelwieser et al., 2021), along with perceived risks, such as concerns about data privacy and technology reliability, are fundamental factors in shaping positive attitudes and intentions toward adopting vehicles equipped with augmented reality (AR) technologies. By understanding these perceptions, manufacturers and marketers can better address potential consumers' concerns and promote the advantages of AR-enhanced vehicles, ultimately encouraging wider acceptance and integration of this innovative technology in the automotive industry. (Mendoza-Ramírez et al., 2023).

IV.CNG VEHICLE FEATURES

Many modern cars feature Heads-Up Displays (HUDs) that project information such as speed, local speed limits, and navigation instructions, effectively working as an extension of the driver's eyes. Similarly, commercial airliners and military aircraft use HUDs to provide pilots with critical data directly in their line of sight, including altitude and airspeed. (Park et al., 2013).

The driver's understanding of navigation, orientation, route planning, and cost and risk estimation can be supported by displays. During short drives, the information features may be simple, accessible, and provided according to the driver's comprehension, but they may also seem attractive and flattering. (Bauerfeind et al., 2021). Information in augmented reality (AR) is accurately superimposed on relevant objects, making them appear closer. (Choi et al., 2013). Consequently, the driver no longer has to alternate between the real rush-hour traffic situation and virtual information. By projecting visuals onto a transparent surface, typically a screen or visor, an augmented reality (AR) display enables users to simultaneously observe pertinent data or images while maintaining their focus on their physical surroundings. (Zhao et al., 2023). HUD provides data that strongly mirrors real-world conditions, ensuring its relevance and accuracy.. (Wu et al., 2024).

India's energy sector is at the nexus of an ambitious economic transformation, and Compressed Natural Gas (CNG) has emerged as a critical vector in this transition, bridging the imperatives of sustainable development, cost efficiency, employment generation, and energy security. As the world's third-largest energy consumer, India faces the dual challenge of meeting rapidly growing energy demands while minimizing environmental degradation and reducing economic vulnerabilities associated with fossil fuel imports. Within this context, CNG, a cleaner and relatively cheaper alternative to conventional petroleum fuels, offers an analytically robust entry point to understand how targeted energy transitions can yield multifaceted economic dividends. The economic rationale for promoting CNG rests on three interlinked pillars: cost-effectiveness, employment potential, and the strategic imperative of reducing import dependency. From a cost standpoint, CNG has consistently demonstrated lower operational expenses in transportation and industrial applications compared to petrol and diesel, offering both microeconomic benefits to individual consumers and macroeconomic advantages in terms of subsidy reduction and fiscal savings. Empirical data suggests that CNG prices per kilometer are substantially lower, especially in densely populated urban centers, incentivizing adoption among both private vehicle owners and commercial fleet operators. These cost advantages have cascading effects across logistics, urban mobility, and freight management sectors, reducing input costs for businesses and improving overall productivity. Moreover, the infrastructural development of CNG networks — involving pipelines, refueling stations, and vehicle retrofitting facilities — has catalyzed localized employment generation across skilled, semi-skilled, and unskilled labor segments.

V.GOVERNMENT INITIATIVES

The expansion of city gas distribution (CGD) networks under government policies such as the 'Sustainable Alternative Towards Affordable Transportation' (SATAT) initiative not only boosts job creation but also fosters regional development, especially in Tier-2 and Tier-3 cities where infrastructure gaps are more pronounced. This employment impact is not merely quantitative but qualitative, as the sector demands specialized training in areas like CNG handling, safety protocols, mechanical maintenance, and digital monitoring systems, thereby contributing to upskilling and human capital enhancement. In parallel, CNG's domestic sourcing potential aligns with India's strategic objective to curb its dependency on imported crude oil, which currently accounts for over 85% of the country's petroleum requirements and poses significant risks to macroeconomic stability due to fluctuating global oil prices and geopolitical uncertainties. With the government aiming to raise the share of natural gas in the energy mix from 6% to 15% by 2030, enhancing indigenous gas production and infrastructure investment becomes pivotal. By substituting a portion of liquid fuel consumption with domestically produced or regionally sourced natural gas, India can reduce its current account deficit, stabilize the rupee, and insulate its economy from external shocks. Furthermore, the environmental externalities of traditional fossil fuels — including air pollution, carbon emissions, and public health costs — are substantially mitigated through CNG usage, thereby indirectly contributing to economic resilience and sustainability. However, the transformative potential of CNG is not without constraints. Issues such as uneven geographic distribution of infrastructure, supply-demand imbalances, policy fragmentation between central and state governments, and initial capital costs of conversion continue to hinder widespread adoption. A nuanced analysis must therefore account for regional disparities, regulatory dynamics, and the interplay between public and private stakeholders in scaling the CNG ecosystem. Moreover, while CNG may serve as a transitional fuel in the medium term, its long-term economic relevance will depend on technological advancements, integration with renewable energy systems, and the evolution of global energy markets. Nevertheless, when evaluated through the composite lens of cost efficiency, employment generation, and strategic energy autonomy, CNG holds considerable promise in catalyzing India's economic transformation by aligning short-term gains with long-term structural shifts. As such, the exploration of CNG's role in India must go beyond technological feasibility or environmental benefits alone; it requires a rigorous, multidimensional economic analysis that situates the fuel within broader narratives of industrial modernization, inclusive development, and national energy sovereignty. This analytical inquiry, therefore, seeks to dissect the economic contours of CNG deployment in India by systematically evaluating its cost advantages, labor market implications, and capacity to reduce external energy dependencies, thereby offering a data-driven assessment of how a single fuel can influence multiple vectors of national progress.

VI.COST EFFECTIVENESS AND CNG

The cost effectiveness of Compressed Natural Gas (CNG) as an alternative fuel has attracted considerable scholarly attention in recent years, with studies focusing on operational savings, lifecycle economics, and comparative affordability against conventional fossil fuels. Scholars have evaluated CNG across transportation, industrial, and household sectors to assess its economic viability. According to Singh (2020), the operational cost of CNG vehicles is significantly lower than petrol and diesel, especially for high-mileage users such as public transport fleets and commercial vehicles, making it a viable cost-saving alternative. Mehta and Sharma (2021) underscore that despite higher initial investment costs in CNG-compatible vehicles or retrofitting kits, the long-term fuel cost savings make the payback period relatively short, often within 12–18 months depending on usage intensity. Their findings also highlight how price volatility in global crude markets adds to the attractiveness of CNG in countries like India where domestic or regionally sourced natural gas offers more stable pricing. Patel (2022) examines the role of government subsidies and pricing frameworks in enhancing the cost competitiveness of CNG, noting that regulated pricing, reduced taxes, and infrastructural support under initiatives such as the City Gas Distribution (CGD) expansion have helped lower end-user costs. Kumar and Desai (2023) provide a comparative lifecycle cost analysis of CNG versus diesel and petrol vehicles, demonstrating that over a 5-year horizon, CNG vehicles offer 20–30% lower total cost of ownership (TCO), with greater savings in high-utilization urban settings. Their model also factors in maintenance costs, where CNG vehicles, while requiring more frequent valve adjustments, benefit from lower engine wear due to cleaner combustion. In a more macroeconomic context, Reddy et al. (2021) analyze CNG's contribution to lowering the national fuel subsidy burden, suggesting that widespread CNG adoption could save the Indian government billions in petroleum subsidies annually. Another dimension explored by Iqbal and Verma (2023) is the regional disparity in CNG cost benefits, where metropolitan cities with robust distribution infrastructure see significantly greater consumer savings compared to Tier-2 and Tier-3 cities still lacking in CNG network penetration. Their research emphasizes the need for infrastructural parity to unlock nationwide economic gains. Bansal (2020) also finds that the elasticity of demand for CNG is relatively high in urban areas, indicating that consumers are responsive to price differences and are likely to switch to CNG when cost incentives are apparent. Recent technological developments in CNG engine design have also contributed to improved mileage and performance, as reported by Rao (2024), who suggests that such innovations further enhance cost competitiveness. Overall, the literature consolidates a consensus that CNG is not only cost-effective in specific user contexts but also supports broader economic stability through reduced fuel import bills and energy diversification. However, studies uniformly caution that the full economic potential of CNG can only be realized with coordinated policy support, investment in infrastructure, and pricing mechanisms that favor long-term affordability and accessibility.

VII.EMPLOYMENT GENERATION AND CNG

The intersection of Compressed Natural Gas (CNG) adoption and employment generation has become an important area of inquiry in recent years, as governments seek to align energy transitions with inclusive economic development. Numerous studies have assessed how the expansion of CNG infrastructure, distribution networks, and vehicle adaptation contributes to both direct and indirect job creation across various sectors. According to Sharma and Tiwari (2020), the development of City Gas Distribution (CGD) projects has emerged as a major source of employment in urban and semi-urban regions, creating jobs in construction, pipeline installation, equipment maintenance, and station operations. They found that for every ₹100 crore invested in CGD infrastructure, approximately 400–600 direct and indirect jobs are created. Verma and Singh (2021) further support this by highlighting how ancillary industries, including manufacturing of CNG cylinders, conversion kits, and compressors, have expanded due to increasing demand, thereby generating significant employment opportunities in the industrial manufacturing ecosystem. A study by Rao et al. (2022) analyzed employment trends in the CNG sector over a five-year period and observed a 35% increase in skilled and semi-skilled jobs linked to CNG expansion, particularly in metropolitan clusters such as Delhi NCR, Mumbai, and Ahmedabad. These jobs include roles in station management, vehicle retrofitting, safety auditing, and logistics, reflecting a growing need for technical expertise and vocational training. Mishra and Patel (2023) focused on the employment potential in the vehicle conversion industry, noting that the retrofitting sector alone employs tens of thousands across the country and presents a scalable opportunity with policy support and financial incentives. Their study also emphasized the gender dimension of employment, finding that an increasing number of women are entering administrative and technical roles within the CGD and service provider companies, particularly in urban areas. Bhatia (2021) examined government-led initiatives such as SATAT (Sustainable Alternative Towards Affordable Transportation), which promotes the use of bio-CNG, concluding that decentralized CNG production from agricultural waste not only generates rural employment but also strengthens rural economies through waste-to-energy models. He found that each bio-CNG plant can generate 50–100 direct jobs and numerous indirect opportunities in feedstock collection and transportation. Joshi and Nair (2022) raised concerns about regional disparities in job creation, stating that while high-density regions benefit substantially from CNG-based employment, many backward areas lag due to insufficient infrastructure and investment. They call for targeted regional planning and skills development to balance these gaps. Technological advancement also plays a role, with Deshmukh (2024) highlighting how digitalization in station monitoring and fleet management has created demand for IT-skilled workers in the energy-tech domain. Overall, recent literature confirms that CNG expansion serves as a robust employment generator, particularly in infrastructure, transportation, manufacturing, and clean energy sectors. However, consistent findings across studies underscore the importance of complementary policies in skill development, infrastructure deployment, and financial incentives to unlock the full employment potential of the CNG ecosystem, thereby making it a significant contributor to India’s green economic transition.

VIII.TREND AND GROWTH PATTERN OF CNG CARS IN THE INDIAN MARKET SINCE 2011

This study examines the evolution of CNG (Compressed Natural Gas) passenger-vehicle adoption in India from 2011 to the present (data available through 2024–2025). It focuses on year-on-year registration and sales trends, the role of original equipment manufacturers (OEMs), infrastructure expansion (CNG refuelling stations), policy interventions, regional patterns, and the principal economic and environmental drivers that influenced consumer choices. The analysis draws on government registration datasets, industry reports, and contemporary media and policy announcements to present an evidence-based picture of growth patterns and turning points. From 2011 to the mid-2010s, CNG vehicle registrations in India grew steadily but moderately, mainly driven by targeted city fleet conversions, taxi/autonomous fleet conversions, and localised subsidy/policy pushes. The period from 2015 to 2020 saw broader OEM engagement — factory-fitted CNG variants increased, making CNG a mainstream option for private car buyers. Since roughly 2021–2022, the market entered a stronger growth phase: greater penetration of factory-fitted CNG variants (led by Maruti Suzuki), improved refuelling networks, and rising petrol/diesel prices led to a surge in consumer preference for CNG in several states, culminating in record shares of CNG variants among some OEM sales in FY24–FY25. Overall market reports and PNGRB/registration datasets show sustained expansion in both the number of CNG vehicles and stations through 2024.

2011–2014: steady, policy-driven beginnings

Early growth was concentrated in cities with acute pollution concerns and with available gas infrastructure (e.g., Delhi). Public-sector interventions (fleet conversion programmes for buses, taxis, ambulances) and tax/price advantages for CNG kept growth steady but geographically concentrated. Precise city-level rollouts and conversions characterised this phase.

2015–2019: OEM entry and normalisation

Major manufacturers began offering factory-fitted CNG variants across multiple models. This lowered the quality/maintenance risk compared with aftermarket conversions and increased consumer acceptance. Infrastructure expansion continued, but growth remained uneven across states, depending on pipeline availability and state incentives.

2020–2022: consolidation amid changing fuel economics

The pandemic years temporarily depressed overall vehicle sales, but by 2021–2022, rising fuel prices and improved CNG availability renewed interest. Authorities and private players pushed to expand stations and gas distribution frameworks. Lifecycle cost calculations (fuel savings vs. upfront premium) favoured CNG in many buyer segments.

2023–2025: rapid growth and uneven regional acceleration

Recent years have seen a pronounced acceleration in CNG uptake in several states, with a record share of CNG variants in OEM portfolios. For instance, Maruti Suzuki reported that roughly one in three of its cars sold in FY24–25 were CNG variants, reflecting strong consumer migration toward CNG in price-sensitive segments. At the same time, pockets such as some coastal cities faced slower growth or retrenchment, where CNG price rises narrowed the cost advantage. Overall, national datasets show an expanding base of CNG registrations and planned infrastructure rollouts

IX.SIGNIFICANCE OF THE RESEARCH STUDY

Despite India's growing emphasis on clean and affordable energy alternatives, the full economic potential of Compressed Natural Gas (CNG) remains underutilised due to fragmented policy implementation, regional infrastructure disparities, and limited integration with broader employment and energy security goals. While CNG has proven cost-effective compared to conventional fuels and holds substantial promise for generating employment across the value chain—from infrastructure development to vehicle conversion and distribution services—the lack of uniform access, inconsistent regulatory frameworks, and insufficient investment in skill development hinder its scalability. Additionally, India’s persistent reliance on imported crude oil continues to pose macroeconomic vulnerabilities, undermining the strategic value of domestically sourced or regionally available CNG as a means to reduce import dependency. Furthermore, existing research on CNG’s economic impacts often addresses its components—cost savings, job creation, and energy substitution—in isolation rather than through an integrated lens. This fragmented understanding limits effective policy formulation and restricts stakeholders from leveraging CNG’s full potential as a driver of economic transformation. Therefore, a comprehensive analysis is necessary to evaluate how CNG can simultaneously reduce operational energy costs, stimulate employment, and enhance energy sovereignty in India, while identifying the structural and policy-level constraints that hinder its wider adoption and impact.

Previous studies have revealed that AR technologies are helpful for navigation, but they fail to define how they enhance driver efficiency and propensity to consume (Bauerfeind et al., 2021; Abulibdeh et al., 2024). Research shows drivers can easily understand Augmented Reality (AR) information. (Winkler & Soleimani, 2025). AR information is expected to be especially helpful for drivers when navigating in unclear environments. Creating high-quality augmented reality experiences prioritising authenticity, presence, and interactivity can effectively enhance perceived value. (Alimamy & Al-Imamy, 2022). By fostering positive user attitudes (Ahlawat et al., 2022), these encounters can foster a sense of psychological ownership, increasing engagement (Bijmolt et al., 2010). In automotive environments, augmented reality systems offer immersive visual enhancements that improve engagement and confidence in using technology. (Shi et al., 2025). (Wang et al., 2024) Demonstrate that both functional and emotional values associated with augmented reality (AR) experiences significantly influence psychological ownership and foster positive attitudes toward usage. Real-time eco-driving feedback and eco-routing systems hold considerable promise for enhancing fuel efficiency. (Aslam et al., 2006). Eco-route planning systems harness the power of real-time and historical traffic data, signal timing, road topology, and vehicle characteristics to deliver fuel-efficient routes that save money and contribute to a more sustainable environment. (Khan et al., 2015). These innovative systems not only instruct drivers on how to adopt smoother and more anticipatory driving habits but also identify and recommend routes that are less taxing on fuel consumption (Kakaee et al., 2014). These solutions can optimise overall vehicle performance when integrated with connected vehicle data and advanced predictive control technologies. (Aslam et al., 2006). Augmented Reality (AR) has evolved from a nascent technology to one approaching widespread adoption, characterised by significant technical maturity and a diverse range of applications. AR technologies boast impressive Technology Readiness Levels (TRLs) in diverse sectors, including retail, healthcare, education, and urban planning, showcasing their exciting potential for commercial and practical applications. (Goedertier et al., 2023).

X.CONCLUSION

The evolution of Compressed Natural Gas (CNG) as a transportation fuel in India and globally represents a compelling example of how transitional technologies can play a vital role in shaping sustainable mobility systems. As this study has shown, the rise of CNG vehicles is neither accidental nor purely market-driven; rather, it is the result of an interplay between environmental imperatives, economic considerations, policy frameworks, and infrastructural growth over more than a decade. From the early 2010s onward, India's transportation sector confronted rising urban pollution, increasing fuel prices, and the need for cleaner, more cost-effective alternatives to conventional petrol and diesel vehicles. Within this context, CNG emerged as a practical and scalable option, providing immediate emissions reductions and offering consumers and policymakers a viable bridge toward a more environmentally responsible mobility ecosystem. The overall trajectory of CNG adoption since 2011 has demonstrated consistent growth, punctuated by significant turning points—phases of accelerated expansion driven by policy interventions, OEM participation, infrastructure expansion, and shifting economic incentives.

One of the central insights of this research is that CNG's success stems from its dual ability to address environmental and economic priorities simultaneously. On the environmental front, CNG has delivered measurable reductions in key vehicular pollutants, including particulate matter (PM), nitrogen oxides (NO_x), carbon monoxide (CO), and sulfur oxides (SO_x), which are among the primary contributors to urban smog and respiratory illnesses. The cleaner combustion properties of methane, which forms the majority of CNG, have helped mitigate pollution in cities such as Delhi, Mumbai, Ahmedabad, and Pune—urban centres where vehicular emissions constitute a significant share of air-quality degradation. Meanwhile, on the economic front, CNG has offered Indian consumers a fuel option that consistently delivers a lower running cost per kilometre, particularly during periods of high petrol and diesel prices. Fleet operators, taxi services, and high-mileage private users have been particularly drawn to CNG due to its favourable cost dynamics, which enable significant long-term savings. This dual alignment of environmental benefit and economic practicality has been instrumental in accelerating CNG adoption across diverse user segments.

However, while CNG has brought tangible improvements to air quality and fuel economics, its trajectory also reflects the complexities of transitioning to a sustainable transport system in a developing economy. The Indian transportation sector faces a unique challenge: it must strike a balance between environmental responsibility and the mobility needs of a rapidly expanding population and a growing middle class. Electrification is widely acknowledged as the long-term pathway for sustainable mobility. However, EV adoption is constrained by the speed of charging infrastructure expansion, grid readiness, battery affordability, and consumer trust. In this transitional landscape, CNG has played a pivotal bridging role. It has provided a lower-emission alternative that can be deployed relatively quickly without the technological uncertainties and infrastructural bottlenecks associated with more advanced sustainable mobility options. Unlike EVs, which require fundamental changes in the energy ecosystem, CNG leverages existing natural gas infrastructure and benefits from lower incremental adoption costs. For many years and in many regions, it has represented the most realistic path toward reducing vehicular emissions while maintaining affordability and accessibility.

Methane leakage across the natural gas supply chain raises serious environmental concerns, despite tailpipe emissions from CNG vehicles being significantly cleaner than those from gasoline or diesel vehicles. Even tiny leakage rates from extraction sites, pipelines, compressors, and refuelling stations can undercut or even reverse the climatic benefits attributed to compressed natural gas (CNG). Methane is a potent greenhouse gas with a significantly more substantial short-term climate impact than carbon dioxide. This problem cannot be disregarded in a global setting where the need to mitigate climate change is growing. The long-term viability of CNG as a transitional fuel depends on the industry’s capacity to reduce methane emissions by enforcing stricter regulations, advancing detection technologies, and enhancing pipeline integrity management. Without these measures, CNG's role in decarbonization will be limited, and its overall environmental benefits could decrease over time.

From a market perspective, the growth pattern of CNG cars since 2011 has been influenced by a combination of supply-side and demand-side factors. On the supply side, vehicle manufacturers have played a crucial role by expanding their portfolios to include factory-fitted CNG variants. Initially limited to a few models, the availability of reliable, warranty-backed CNG options has increased significantly since the mid-2010s. Companies like Maruti Suzuki, Hyundai, and Tata Motors have recognised the shifting preferences of Indian consumers and responded by offering CNG versions of popular hatchbacks, sedans, and compact SUVs. This increased model diversity has boosted consumer confidence, making CNG a mainstream choice rather than a niche option. On the demand side, consumers have shown an increasing sensitivity to long-term operating costs, particularly in the context of rising living expenses and fluctuating fuel prices. The relative stability of CNG prices, compared to the volatility often associated with petrol and diesel, has reinforced consumer interest. These market dynamics underscore the fact that the success of CNG stems not merely from technological or environmental attributes but from its ability to align with the practical needs and preferences of vehicle buyers.

Infrastructure improvements have significantly facilitated the rise of the CNG market. Due to both government programs and private sector investment, the number of CNG filling stations in India has increased dramatically since 2011. The Petroleum and Natural Gas Regulatory Board's approval of new municipal gas distribution networks has significantly contributed to the expansion of CNG access beyond major urban areas into Tier 2 and Tier 3 cities. This regional growth has been essential in reducing range anxiety and increasing convenience for CNG consumers. States with well-established CGD networks, such as Gujarat, Maharashtra, Delhi-NCR, and Uttar Pradesh, have experienced significantly faster adoption rates compared to those with limited or no pipeline construction. This regional discrepancy highlights the importance of coordinated infrastructure rollout, investment planning, and policy continuity in promoting the success of alternative fuel adoption.

CNG will continue to play a significant yet transitory role in India's and the world's journey toward sustainable transportation, according to the research's subtle yet unambiguous findings. In an environment where EV adoption still faces obstacles, CNG remains a viable and efficient means of reducing urban air pollution, minimising operating costs, and providing an affordable alternative to fossil fuels in the short to medium term. It plays a vital role in the gradual decarbonization of the transportation industry, offering short-term advantages while long-term fixes are developed.

CNG, however, cannot be seen as an ultimate destination in the long run. Future mobility will eventually depend on zero-emission solutions, as evidenced by the global trend toward electrification, driven by technological innovation, declining battery costs, and supportive policy settings. Advanced hybrid systems, bio-CNG, synthetic methane, and hydrogen fuel cell technologies may also have complementary functions. Cleaner and genuinely renewable alternatives are anticipated to replace traditional fossil fuel-based CNG in this future environment.

This result has important ramifications, one of which is that CNG policy and market strategies need to be developed with a dual focus: maximising current benefits while planning for future transitions. When it is economically feasible, policymakers should keep building CNG infrastructure, but they should refrain from making excessive investments that can eventually result in stranded assets. Simultaneously, CNG's sustainability profile can be strengthened by enhancing its environmental performance through methane leak management and promoting the gradual integration of bio-CNG (renewable natural gas obtained from organic waste). It makes sense for automakers to continue offering CNG versions in high-demand markets, but long-term product planning needs to prioritise EVs and new green technologies.

In summary, understanding CNG's role in sustainable transportation involves viewing it as a transition—dynamic, strategic, and time-sensitive. Its value lies not in being an ultimate fix for vehicle emissions, but as a quick and scalable solution that bridges the gap between polluting fuels and future clean-energy systems. Since 2011, India’s experience has shown both the advantages and limitations of CNG: it improves air quality and affordability, yet remains dependent on infrastructure and policy support, with its own environmental limits. As India commits to deeper decarbonization and prepares for electric and hydrogen transport, CNG remains a valuable, temporary asset—best utilised responsibly today while planning for a greener future. Its journey reminds us that sustainability is a series of interconnected decisions, not a single technological breakthrough, each one advancing toward cleaner, healthier, and more resilient transportation.

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