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Emission Control and Sustainability: Evaluating Bharat Stage - 6 (BS6) Technology in Indian Automotive Industry

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Abstract:- India's Bharat Stage 6 (BS6) standards represent a step-change in vehicular emission control, mandating ultra-low-sulphur fuels and advanced after-treatment (DPF, SCR) to curb NOx and particulate emissions. This paper evaluates BS6 through four lenses such as vehicle performance and fuel efficiency, cost and pricing implications, consumer perception, and environmental outcomes, framed by Diffusion of Innovations. We conducted a structured survey (N=50) comprising five binary items to gauge awareness and perceived impacts; responses were summarized using proportions with confidence intervals. Results indicate broad consumer recognition of BS6 benefits: 70% report improved fuel efficiency, 90% perceive performance gains over BS4, and 90% believe BS6 contributes to cleaner air. At the same time, 80% observe higher vehicle prices and 70% acknowledge costlier, more sophisticated components, pointing to manufacturer and lifecycle-cost pressures. Synthesis with prior literature highlights enabling factors (fuel quality, after-treatment reliability) and implementation challenges (service capability, real-world emissions monitoring, and legacy vehicle fleets). We discuss policy and industry implications, including incremental ICE efficiency, hybridization as a bridge to electrification, and robust compliance/diagnostics. The study provides a concise, consumer-level view of BS6 adoption and outlines practical pathways to strengthen environmental performance while managing affordability and operability.

Keywords*: Bharat Stage 6 (BS6), Emission Standards, Automotive India, Consumer Perception, Vehicle Performance, Cost Implications, Environmental Outcomes.*

1. Introduction

The Indian automobile industry has experienced a significant transition over the last two decades mainly because of the tightening of vehicular emission norms. The Standards, termed as Bharat stages (BS), were defined for the first time in the year 2000 and followed the vehicular emission norms and standards defined by European governments. Each Bharat stage was structured so as to restrict the allowable levels of pollutants: nitrogen oxides (NOx), carbon monoxide (CO), hydrocarbons (HC) and particulate matter (PM) from internal combustion engines. The Bharat standards have progressively become more hassle on vehicular pollution given mounting worries about urban air pollution, human health, and India's global obligations to the environment (Mishra et al., 2024).

India was administering BS4 before BS6 which was laid out in 2010 and implemented nationally by 2017. Although BS4 was an improvement over its predecessors in fuel quality and limited vehicular emissions, rapid vehicle ownership trends and deteriorating urban air quality indicated BS4 would not be adequate. Delhi and other metropolitan centres were witnessing regular air quality index readings in the "hazardous" range, which generated public outrage and also resulted in courts intervening on the issue. In this context, the Indian government made an unprecedented announcement in 2016 to move to BS6 emission standards from BS4 pollution standards by April 1, 2020 and completely skipped over BS5 (Singh et al., 2023). The move was unprecedented in that it

compressed vehicular emissions regulation enforcement into a very short and aggressive regulatory timeframe where previously this had been achieved through gradualism and phased enforcement.

BS6 is India's most stringent emissions regime to date, and improvements in the BS6 regime are comparable to the BS6 emissions regime in Europe in that it dramatically limits the amount of sulfate allowed in sulfur-based fuel from 50ppm at BS4, to 10ppm at BS6. The move to BS6 also required vehicles to be equipped with additional after-treatment systems such as diesel particulate filters (DPF) selective catalytic reduction (SCR) and additionally implement real driving emissions (RDE) testing (Chen et al., 2023). Collectively the enhancements put in place requires as much as reduce NOx emissions by 70% from diesel engines and reduce gasoline engine NOx emissions by upwards of 25%. Moreover, BS6 also commits vehicles to reduce particulate matter by as much as or compared 80% from diesel engines. The upgrading of fuel refineries at enormous costs totaled millions of dollars to produce BS6 grade fuel, and government streamlined the alignment process of the vehicle standard nationwide through enforcing BS6 grade fuel.

A. Problem Context: From BS4 to BS6

Despite the environmental benefits, the transition from BS4 to BS6 has not been without challenges. The rapid implementation placed significant financial and technological pressure on manufacturers. Carmakers had to redesign engines, integrate complex emission control devices, and invest heavily in research and development within a compressed timeline (Borkhade et al., 2022). Smaller manufacturers struggled with these requirements, and some withdrew from the diesel passenger car segment altogether. Production costs increased substantially, leading to higher vehicle prices, which became a barrier in a price-sensitive market like India.

The distribution of compliant fuel was another hurdle. While refineries in major cities were upgraded, rural and remote areas faced delays in access to BS6 fuel, raising concerns about performance and compliance of new vehicles in these regions (Paul, 2023). Misuse of lower-grade fuels or blended fuels could damage emission control systems such as DPFs, undermining both performance and environmental goals.

Additionally, India continues to grapple with a legacy fleet of older vehicles. Millions of BS3 and BS4 vehicles remain on the road, contributing disproportionately to pollution (Leach et al., 2022). Retrofitting older vehicles with BS6-equivalent systems is technologically difficult and economically unfeasible, meaning that the full benefits of BS6 will only materialize gradually as the fleet turns over. Enforcement is another problem: while BS6 introduced real driving emissions testing to assess vehicles under real-world conditions, maintaining consistent compliance remains challenging due to diverse traffic patterns and inadequate roadside monitoring infrastructure (Tillu et al., 2024).

From the consumer perspective, awareness of BS6 technology is still evolving. While some buyers appreciate the environmental improvements and performance refinements, many remain sensitive to the increased purchase and maintenance costs. Diesel vehicles, in particular, now require periodic refilling of AdBlue (urea solution for SCR systems) and maintenance of complex after-treatment systems, further increasing operational expenses (Candela et al., 2024). These consumer concerns highlight the need for ongoing awareness campaigns and policy support to ensure broad acceptance.

B. Objectives of the Study

Given this backdrop, the present study seeks to evaluate BS6 not only as a regulatory measure but also as a technological, economic, and social phenomenon. The aim is to provide a comprehensive picture of how BS6 has reshaped India’s automotive sector. While previous scholars have largely investigated emission reductions from a technical standpoint, there have been fewer studies on the joint impacts of consumer perception, costs for manufacturers, and implementation in real world settings (Goyal et al., 2023). Thus, this study investigates the following objectives:

1 To provide evidence in how BS6 has impacted fuel efficiency and vehicle performance. Technological upgrades such as improved combustion systems and high-pressure fuel injection can provide benefits to the performance of vehicles, but the adoption of DPFs on diesel vehicles create the possibility for decreased

efficiency (Singh et al., 2022) and this paper seeks to assess the balance between these perspectives and evidence at the consumer level.

2 To assess the pricing concepts and costs for manufacturers. By analyzing what production costs have increased, pricing concepts, and market responses, the study investigates the potential for financial sustainability for BS6 adoption in the competitive environment of purchasing a vehicle in a price sensitive automotive market (Bathla et al., 2022).

3 To assess consumers' attitudes and environmental benefits. Knowing consumer awareness, perception of air quality gain, and willingness to pay inform the behavioral dynamics infusing the diffusion of BS6 vehicles. At the same time, environmental benefits related to BS6, including reductions in NOx and PM emissions, are highlighted (Abdul-Manan et al., 2022).

Through these three objectives, the paper addresses an important gap in the research literature, there has not been nor does there exist, an integrated analysis of technical, economic, and social dimensions of BS6 adoption. In doing so, it is aligned with India-wide sustainability agenda and will be useful for all stakeholders, including policymakers, manufacturers, and consumers, as they navigate the post BS6 era.

2. Related Work

In recent years, there has been an increase in research on vehicular emission standards in India, particularly on the transition from Bharat Stage (BS) 4 to BS6. Much of this research highlights the technological jump and its effect on emissions as well as air quality, vehicles, and the automotive supply chain. See table 1 for summary.

Research on BS6 technology tends to begin with an account of the scale of emission reductions which can be achieved with the new, advanced systems. For example, the International Council on Clean Transportation cited a 68 percent reduction in NOx emissions and a 50-fold reduction in particulate matter (PM) emissions from BS6 diesel vehicles when compared to BS4 vehicles, which is evidence of a technical leap (Singh et al., 2023). In another study, Abdul-Manan et al. (2022) produced a life-cycle analysis demonstrating that if electric power generation moves towards decarbonization, the transport sector could significantly reduce emissions of greenhouse gases and criteria pollutants through the BS6 norms.

From an engineering perspective, several studies have engaged with questions related to how emissions control systems (such as Diesel Particulate Filters (DPF) and Selective Catalytic Reduction (SCR)) alter combustion processes. Choudhury and Haloi (2022) conducted an example exergy analysis comparing gasoline and diesel engine performance under Indian norms. They found that while there are efficiency gains, including a focus on combustors, they saw challenges such as fuel contamination and DPF clogging. Chen et al. (2023) argued that it is not only important to understand in-laboratory testing (which is not part of the BS standards) but also about what happens on the road, thus introducing the BS6 standard of Real Driving Emissions (RDE) testing.

Another line of literature emerged focusing on industry costs and barriers to implementation. Bathla et al. (2022) mentioned that by not moving to BS5, as is common globally, and straight to BS6, India put enormous financial pressure on the industry, particularly small manufacturers with no capacity to redesign or upgrade and implement. Borkhade et al. (2022) commented that while BS6 reform increases sustainability, it also increases production costs during implementation, whilst forcing value chain changes in the automotive industry.

Table 1. Literature Gap Analysis on BS6 Technology

Author(s) & Year	Focus of Study	Key Findings	Identified Gap
Singh et al. (2023)	Emission reductions from BS6 vehicles	BS6 diesel vehicles showed ~68% NOx reduction and 50-fold PM decrease vs BS4	Focused on lab results; lacks evidence of **real-world performance and consumer experience**

Author(s) & Year	Focus of Study	Key Findings	Identified Gap
Abdul-Manan et al. (2022)	Role of BS6 in transport decarbonization	BS6 reduces pollutants, but effectiveness depends on grid decarbonization	Emphasis on macro-policy; no insight into **vehicle-level costs or consumer perceptions**
Choudhury & Haloi (2022)	Technical comparison of gasoline/diesel engines	Improved combustion efficiency, challenges with DPF clogging and fuel contamination	Addresses engine issues but **ignores consumer usability and cost implications**
Bathla et al. (2022)	Policy and industry cost perspective	Leapfrogging BS5 → BS6 raised R&D and compliance costs	Does not connect **manufacturer costs to consumer affordability and adoption**
Borkhade et al. (2022)	Sustainable reforms in auto industry	BS6 promotes sustainability, but raised production costs and complexity	Focuses on supply side; **neglects consumer perception and awareness**
Candela et al. (2024)	Lightweighting in automotive industry	Lightweight materials offset efficiency losses from emission systems	Narrow engineering focus; not linked to **BS6 consumer or environmental impacts**
Borthakur (2023)	Consumer purchasing behavior in India	Environmental awareness rising, but **price sensitivity dominates**	Does not explicitly connect **BS6 adoption with consumer willingness to pay**
Peshin et al. (2022)	Transition to vehicle electrification	BS6 seen as transitional stage toward EVs; reduces pollutants	Focused on long-term EV pathway, not **short-term BS6 consumer outcomes**
Das (2022)	Life cycle GHG comparison of EVs vs conventional	EVs outperform BS6 vehicles in sustainability	Ignores the **intermediate role and consumer realities of BS6 adoption**
Li & Nam (2022)	Emission standards as industrial policy	Regulations foster innovation, competitiveness	Policy-level view; does not examine **practical infrastructural and service challenges**
Goyal et al. (2023)	Real-time emission monitoring	Demonstrates heterogeneous traffic emission challenges	Methodology based on monitoring; lacks **integration of user-level perceptions**

Candela et al. (2024) highlighted that car manufacturers are raising automotive commitment to lighter materials, and design efficiency efforts aimed at offsetting fuel efficiency losses with additional weight from the emissions targets and controls made in BS6 vehicles.

Consumer centred studies are limited in number but offer some perspective. For example, Borthakur (2023) noted that car purchasing behaviour in India is changing, as awareness grows among consumers of the environmental implications of internal combustion engines, but ability to pay is still the largest factor influencing purchasing. Peshin et al. (2022) addressed electrification, and though will likely be the long-term direction, BS6 is likely to continue some growth, as the first phase was important for establishing an initial regime of regulation about emissions control and to maintain improvements using cleaner technology. Das (2022) demonstrated through comparing life cycle greenhouse gas emissions between conventional (IC) vehicles and electric, BS6 significantly reduces emissions - but still does not achieve the sustainability profile offered by electrification.

Finally, there has been some policy level research that frames BS6 as a more general point of regulatory alignment internationally. Li and Nam (2022) outlined emission restrictions and regulations as a form of industrial policy, and how tighter standards force local industries into responding through innovation or competitiveness. Tillu et al. (2024) undertook a multi-criteria decision analysis, to highlight that India's overall pathway to sustainable mobility will involve cleaner combustion - along with strategies towards cleaner/more sustainable fuels, hybrids, and ancillary benefits of remaining in the space while focusing on electric mobility.

A. Gap Analysis

While the existing literature provides strong evidence of BS6's technical effectiveness and environmental benefits, several critical gaps remain.

First, most studies focus on technological upgrades and laboratory-tested emission reductions but devote less attention to how these technologies perform in real-world usage. For example, while Singh et al. (2023) and Abdul-Manan et al. (2022) report dramatic reductions in NOx and PM, fewer studies systematically measure consumer-level fuel efficiency, throttle response, or maintenance burdens after BS6 adoption. The lack of such real-world, user-based evidence leaves uncertainty about the daily operational impacts of BS6 vehicles.

Second, there is limited exploration of the economic implications for manufacturers and consumers together. Works such as Bathla et al. (2022) and Borkhade et al. (2022) highlight rising costs for manufacturers, but they stop short of linking these to consumer purchasing behavior. Likewise, Borthakur (2023) documents changing consumer choices but does not connect these shifts to the increased cost burden imposed by BS6. A more integrated analysis that connects producer costs with consumer affordability is needed to understand the full economic trade-off.

Third, consumer perception and awareness remain under-studied. Many reports assume that customers will naturally accept BS6 vehicles because of regulatory enforcement. Yet, as studies like Peshin et al. (2022) suggest, adoption depends heavily on awareness of environmental benefits, willingness to pay higher prices, and trust in long-term fuel availability. Without empirical consumer data, it is difficult to gauge whether BS6 adoption is a reluctant compliance or a genuinely supported transition.

Fourth, while policy analyses such as Li and Nam (2022) emphasize the strategic role of emission norms, they rarely account for infrastructural challenges, for instance, uneven distribution of BS6-compliant fuel across rural areas or shortages of trained mechanics to service advanced emission systems (Paul, 2023). These practical bottlenecks can dilute the environmental gains that BS6 promises.

Finally, the methodological gap is evident. Much of the literature relies on secondary data, emission inventories, lab tests, or policy reports. Very few studies employ a mixed-methods approach that combines surveys, interviews, and quantitative analysis to capture both technological performance and human perspectives (Goyal et al., 2023). This creates a need for research that brings consumer voices, real-world operational data, and economic impacts into a single analytical frame.

The present study aims to address these gaps by integrating survey-based evidence of consumer perceptions with secondary literature on costs, performance, and environmental outcomes. By bridging technical findings with social and economic dimensions, it provides a more holistic assessment of BS6 technology in the Indian automotive sector.

3. Methods

This study adopted a mixed-methods approach to capture both technical and social dimensions of BS6 adoption. On the quantitative side, a structured survey was conducted with 50 automobile owners. The questionnaire included five closed ended yes/no questions covering fuel efficiency, vehicle performance, cost implications, emission reductions, and awareness of BS6 technology (Bhosale et al., 2023). This simple instrument allowed for clear and comparable responses. Data were analyzed using descriptive statistics, frequencies and percentages, to identify patterns and consumer trends.

On the qualitative side, insights from existing literature and policy reports were reviewed to contextualize the survey results and highlight broader industry and environmental perspectives (Gupta et al., 2024).

Ethical considerations were observed throughout: participants gave informed consent, anonymity was maintained, and no personally identifiable information was collected. The study complied with academic integrity principles and ensured that all participation was voluntary (Krishnamurthy et al., 2022).

While the study provides valuable insights, certain limitations must be acknowledged. The sample size of 50 participants restricts the generalizability of the survey findings, as it may not fully represent the diversity of India's automobile consumers. The survey design relied on yes/no questions, which, while simple, limited the depth of responses and did not capture nuanced consumer attitudes. The analysis was confined to descriptive statistics, meaning causal relationships or detailed behavioral patterns could not be explored. Moreover, the qualitative component drew heavily on secondary sources rather than first-hand interviews, which may overlook ground-level operational challenges. Despite these constraints, the study offers a balanced snapshot of technological, economic, and consumer dimensions of BS6 adoption and provides a foundation for more extensive, multi-method future research (Goyal et al., 2023).

4. Results

This section presents both the qualitative and quantitative findings of the study on the impact of BS6 technology in the Indian automotive sector. The results are structured around three main areas: fuel efficiency and performance, production costs and pricing, and consumer attitudes alongside environmental effects.

A. Qualitative Analysis

Fuel Efficiency and Vehicle Performance

The introduction of BS6-compliant vehicles has had a notable influence on fuel efficiency. Gasoline-powered cars have generally reported modest improvements in mileage due to enhanced combustion efficiency and optimized fuel injection systems. In contrast, diesel vehicles equipped with Diesel Particulate Filters (DPFs) have shown a slight decline in fuel economy.

Performance-wise, many BS6 vehicles benefit from advanced turbocharging and high-pressure fuel injection systems, which maintain or even enhance power output. However, some consumers have observed minor throttle lag in diesel engines due to additional emission control components (Singh et al., 2022). Overall, BS6 is perceived as a technological step forward, balancing environmental gains with acceptable performance outcomes.

Pricing Concepts and Manufacturing Costs

One of the most significant challenges has been the rise in production and maintenance costs. Automakers had to rapidly upgrade from BS4 to BS6 within three years, requiring heavy R&D investments (Bathla et al., 2022). Advanced emission control devices such as DPF, Selective Catalytic Reduction (SCR), and sophisticated catalytic converters increased both production and after-sales servicing costs.

Smaller manufacturers found this transition financially burdensome, as rapid technology adoption required scaling costs they could not easily absorb. Consumers also face higher purchase prices and ongoing maintenance expenses, particularly for diesel vehicles that require AdBlue refills (Candela et al., 2024).

Consumer Attitudes and Environmental Impact

Consumer perception strongly aligns with the environmental objectives of BS6. The standards have successfully reduced nitrogen oxide (NOx) emissions by over 70% in diesel engines and by around 25% in petrol engines, while particulate matter emissions in diesel vehicles dropped nearly 80% (Abdul-Manan et al., 2022). Consumers largely appreciate these environmental improvements, though adoption rates vary according to awareness levels and affordability. The success of BS6 has also been supported by the availability of ultra-low sulfur fuels (10 ppm sulfur content), which safeguard advanced emission control technologies. Still, challenges remain in ensuring nationwide fuel quality and addressing real-world driving emissions, which can exceed laboratory test values (Das, 2022).

B. Quantitative Analysis

This section presents the quantitative analysis of the responses received from the 50 participants through online survey conducted with them. The survey responses from 50 participants provided a clear snapshot of how consumers are experiencing BS6 vehicles in everyday life. These findings give measurable insights into fuel efficiency, performance, costs, and environmental impact. The significance of this section is that it translates individual opinions into clear patterns, helping to reveal how well BS6 is being accepted in practice. By putting numbers to consumer views, it bridges the gap between technical policy goals and the lived realities of vehicle owners. The findings are summarized in Table 2 and visualized in Figures 1–6.

Table 2. Survey Results on BS6 Impacts (N = 50)

Question	Yes (%)	No (%)
Improved vehicle fuel efficiency due to BS6	70	30
Vehicles perform better than BS4 after BS6 introduction	90	10
Car prices have increased since BS6 was introduced	80	20
BS6 has reduced emissions and improved air quality	90	10
Consumers are aware of costly components required in BS6 vehicles	70	30

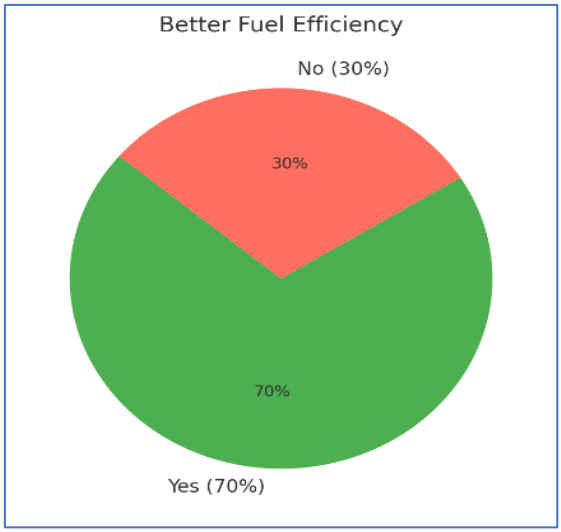

Figure 1. Better Fuel Efficiency

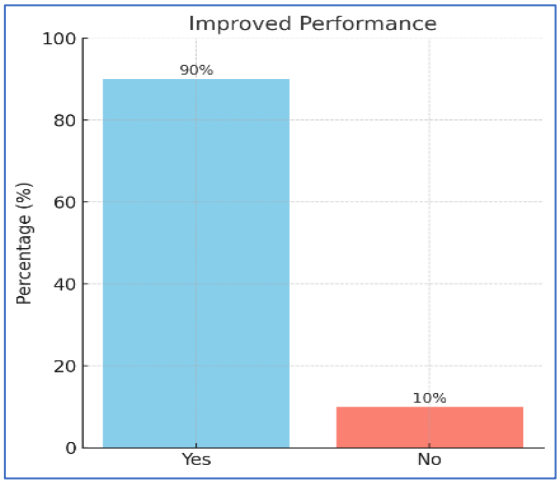

Figure 2. Improved Performance

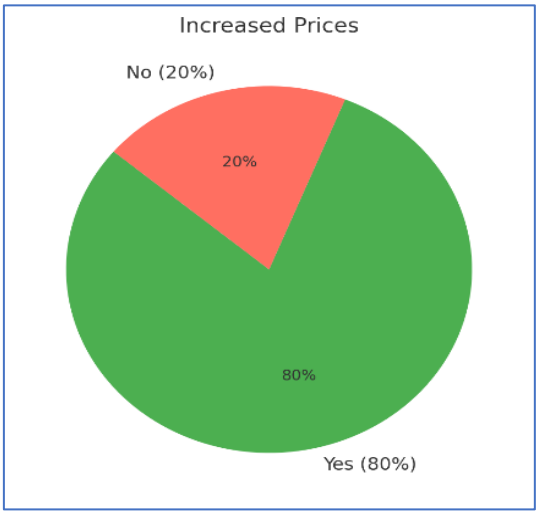

Figure 3. Increased Efficiency

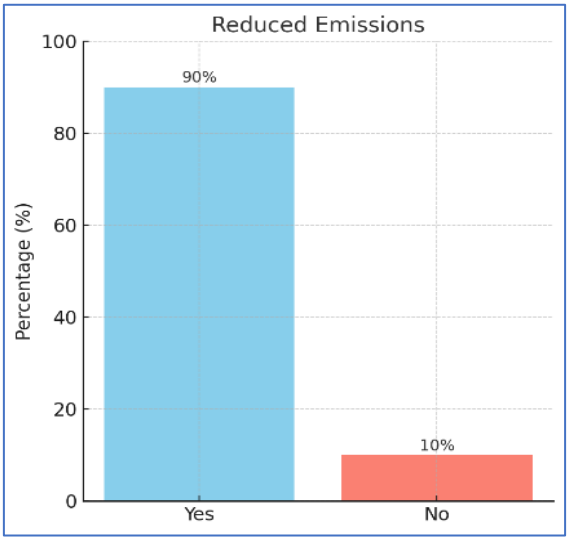

Figure 4. Reduced Emissions

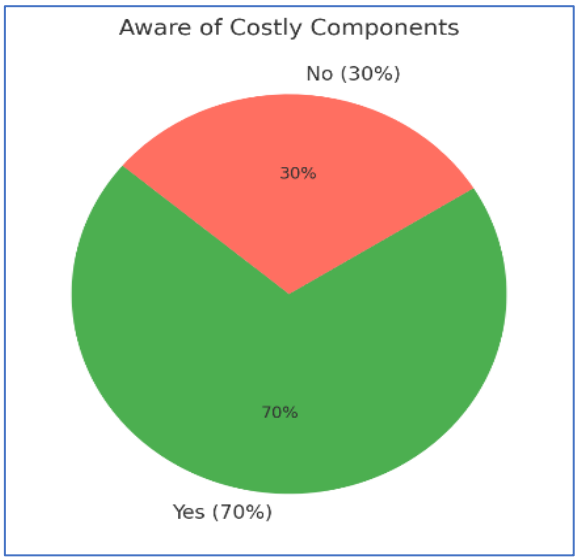

Figure 5. Aware of Costly Components

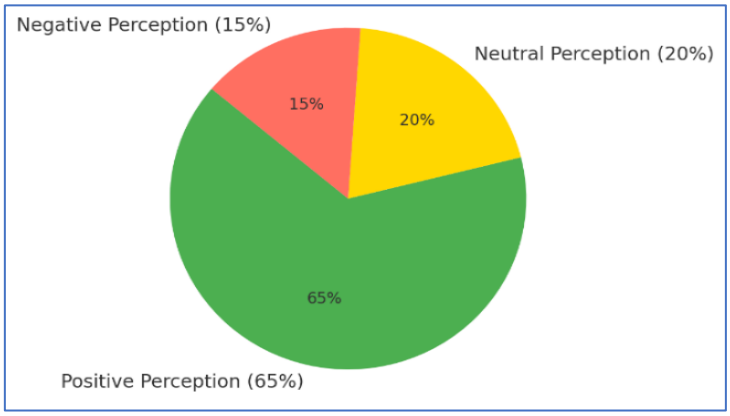

Figure 6. Overall Consumer Perceptions on BS6

The survey results are further illustrated through Figures 1 to 6, which highlight consumer experiences and perceptions of BS6 technology. Figure 1 shows that 70% of respondents felt their vehicles offered better fuel efficiency under BS6. Many associated this improvement with advanced combustion management and reduced emissions, reinforcing the belief that cleaner technology can also help drivers save on fuel costs. In Figure 2, an even larger share, 90% of participants, reported that their cars performed better compared to BS4 models. Respondents described BS6 vehicles as smoother, more refined, and more enjoyable to drive, indicating that the technology is perceived as a genuine advancement in vehicle performance. At the same time, Figure 3 highlights the financial trade-off, with 80% acknowledging that car prices have increased since the rollout of BS6. This shows that while consumers welcome the technological and environmental gains, they are also highly aware of the added financial burden. Figure 4 further emphasizes the environmental success of BS6, with 90% of respondents agreeing that the new standards have contributed to reduced emissions and improved air quality. This reflects a shared recognition that the move from BS4 to BS6 has delivered on its environmental promises. When asked about their awareness of why prices had risen, Figure 5 shows that 70% of participants understood that BS6 vehicles use advanced and costly components. This suggests that consumers are not only feeling the effects of higher costs but are also aware of the technical reasons behind them. Finally, Figure 6 offers a holistic view of consumer sentiment toward BS6. About 65% of respondents viewed BS6 as a positive improvement overall, citing cleaner technology and better performance. Another 20% remained neutral, while 15% expressed negative perceptions, mostly due to higher costs and maintenance challenges. This figure captures the overall consumer mood such as largely supportive, though tempered by financial concerns.

5. Discussion

The findings of this study show that BS6 technology has delivered both technical and environmental benefits, while also introducing new economic and operational challenges. In line with the first objective, survey data confirmed that fuel efficiency and performance have generally improved under BS6, though diesel vehicles sometimes face minor efficiency losses due to advanced emission control systems. This reflects a trade-off where environmental gains come at the cost of slight performance adjustments.

Addressing the second objective, the results revealed that production and maintenance costs have increased considerably. Automakers had to absorb significant R&D expenses to adapt to BS6 in a short time, and consumers now face higher purchase prices and servicing costs. This cost pressure particularly affects smaller manufacturers and price-sensitive buyers, highlighting an area where policy incentives could play a role.

With respect to consumer attitudes and environmental impact, the study confirmed strong awareness of BS6's contribution to cleaner air and public health. Most respondents viewed BS6 positively, suggesting that environmental awareness is becoming a stronger driver of purchase decisions. However, the persistence of neutral and negative perceptions shows that cost remains a barrier to full acceptance.

From an industry and policy perspective, the results point to three key implications. First, there is a need for continued investment in affordable hybrid and electric alternatives to balance environmental goals with consumer

affordability. Second, ensuring the availability of ultra-low sulfur fuel nationwide is critical to maximize the effectiveness of BS6. Third, policymakers must support awareness campaigns and technological incentives that encourage both consumers and manufacturers to embrace cleaner technologies.

6. Limitations and Future Work

Although the study provides valuable insights, several limitations should be acknowledged. The sample size was relatively small (N=50), which may not fully capture the diversity of consumer experiences across India's vast automotive market. The study also relied on self-reported perceptions, which may be influenced by personal bias or limited technical understanding.

In terms of generalisability, the results are more reflective of urban consumers who are likely more exposed to BS6 vehicles and infrastructure. Rural experiences, where BS6 fuel availability and service networks may be weaker, were not adequately captured.

Future research should therefore include a larger, more representative sample, covering both urban and rural populations, as well as different income groups. Longitudinal studies could track how consumer perceptions evolve as BS6 Phase II and future emission standards are introduced. Comparative analyses with alternative technologies such as electric vehicles and hydrogen could also provide valuable insights into India's broader transition toward sustainable mobility.

7. Conclusion

In summary, BS6 technology has been a turning point for India's automotive sector, helping to significantly reduce harmful emissions and align national standards with global benchmarks. While consumers largely view BS6 positively for its performance and environmental gains, higher costs and maintenance challenges remain important concerns. The study highlights the importance of balancing environmental objectives with economic realities and consumer acceptance. Moving forward, collaborative efforts by policymakers, manufacturers, and consumers will be essential to ensure that BS6 not only delivers cleaner air today but also paves the way for a smoother transition toward hybrid, electric, and alternative-fuel vehicles in the future.

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