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Evaluating the Impact of Electric Vehicle (EV) Transition on Bus Drivers in India

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Executive Summary

This study examines the shift from diesel (dBus) to electric buses (eBus) focusing on driver experiences, perceptions, attitudes and awareness related to technology, policy, well-being, operations performance. A total of 615 drivers were surveyed —150 eBus and 150 dBus drivers each, plying for Bengaluru and Delhi's public transport agencies. Results indicate consistently higher satisfaction and strengthening consensus among Delhi's eBus drivers regarding EV's air quality, level-of-service and efficiency benefits. A composite score of twelve EV technology features revealed significant perception gaps between eBus and dBus drivers and across Delhi and Bengaluru. Using Latent Class Analysis, eight EV driving motivational archetypes were identified, four each for dBus and eBus drivers. eBus drivers are drawn by environmental, experiential, social recognition and technological benefits backed by strong institutional and policy support, while dBus drivers prioritize job security, stability, salaries and benefits, and community anchored upskilling and training.

1 Background

In the context of mobility, the prioritization of livelihood, inclusivity, and accessibility in India starkly contrasts from individual choice, asset ownership, freedom, and personal mobility, often emphasized in the advanced economies. This manifests in the particular vehicular segments leading the EV transition in the respective countries. India's EV transition is led by buses and two and three-wheelers (2/3W), unlike advanced economies like the Nordic countries, the U.K., France, Germany, and the U.S., where passenger cars play a significant role. Launched in April 2019, the Faster Adoption and Manufacturing of (Hybrid and) EVs (FAME—I and II) scheme is the cornerstone of India's efforts to promote e-mobility. The substantial subsidies provided under FAME have made EVs more affordable for many users, particularly in the electric two/three-wheeler (e2/3W) segment, which is crucial for last-mile connectivity and livelihood generation. Of the cumulatively registered 4.6 million EVs on the road, e2/3Ws account for nearly 91%—2.3 million e2W and 1.9 million e3W [1-3]. As of August 2022, the number of buses (public sector) operated by the sixty-two city/state road transport undertakings (C/STUs) stood at ~156,000 which dropped by 5% to ~148,000 as of June 2024. This accounts for a paltry ~10% of the 1.8 million cumulatively registered buses till date [4]. The decline in the number of C/STU (public) operated buses since 2022 points to the aging, fossil-fueled and shrinking fleet is in need of major operational and infrastructural overhaul. This presents a timely opportunity for fleet electrification to simultaneously improve the level and quality of service as well as improve the air quality [5]. Initiatives like the PM eBus Sewa and National eBus Program (NEBP) are designed to accelerate the adoption of ebuses, making them a priority for policy interventions and public investment [6]. Through the FAME policy, till date about ~5000–6000 ebuses are plying, which is expected to nearly double by 2025. The PM e-Bus Sewa also seeks to ensure that the benefits of electrification reach a broader population, addressing the rural-urban disparity in public transport services by prioritizing medium and small-sized cities. The PM–eBus Sewa is a flagship initiative announced in 2023, which builds on the foundation laid by FAME, targeting to deploy 10,000 eBuses by 2030 with an outlay of US$ 2.4 billion across 169 eligible cities[7].

1.1 India's eBus procurement and major C/STU's plying eBuses

India's eBus adoption relies on Gross Cost Contract (GCC) basis–a type of public-private partnership (PPP) wherein the ownership, operations, maintenance, staffing, charging and depot infrastructure rests with private operator or a special purpose vehicle (SPV) and the public C/STU's retain control over route planning, fare collection and scheduling [8]. The private operator or SPV gets in return a fixed per-kilometer fee. Tenders for procurement, usually concentrated for aggregating demand, is floated by Convergence Energy Services Limited (CESL), a subsidiary of Energy Efficiency Service Limited (EESL) [9]. To ensure interoperability, scalability and performance, financial as well as operational benchmarking, Request-for-proposal (RfP) for procurement standardizes eBus specifications–bus length, passenger capacity, low-floor, universal accessibility, AC, CCTV, on-board telematics amongst others [10]. Delhi Transport Corporation (DTC–~1600 eBuses) and Bengaluru Metropolitan Transport Corporation (BMTC–1350 eBuses) are among the top-three operators accounting for nearly ~50% of ~6000 eBuses operated by C/STU's [11, 12]. Additionally, DTC and BMTC operate two of the largest bus fleet by numbers (all fuel types) [4].

1.2 Research inquiries

The body of literature on the technical advantages, environmental benefits and economic value proposition of EVs over conventional Internal Combustion Engine (ICE) variants in the Indian context is reasonably documented [13-17]. In contrast, limited attention has been given to the experiences from driver perspective. Diesel exhaust exposure, in-cabin air pollution, noise levels, and poor ergonomics are all factors that contribute to the negative health impacts experienced by drivers [18, 19]. Long-term exposure to diesel exhaust has been linked to cardiometabolic risks, including heart disease and diabetes, as well as an increased risk of respiratory illnesses and cancer [20, 21]. Furthermore, poor noise insulation and inadequate climate control within diesel-powered vehicles contribute to driver fatigue and stress, which are associated with increased accident risks and deterioration in quality of work-life [22, 23]. Paucity of studies and inferences on EV transition from a driver centric perspective, especially in the Indian context is a critical gap in the literature, which this study seeks to address.

This paper investigates the possible benefits that bus drivers in India could gain by transitioning from traditional diesel-powered (dBus) to EVs (eBus). Study first investigates benefits, barriers and attitude towards EVs as well as their overall implications on C/STU performance metrics, both reported and perceived by eBus and dBus drivers respectively. Second, the impact of social, occupational, employment and technological factors pertaining to EV adoption, adaption and driving are systematically examined. Lastly, eight distinct archetypes of EV driving motivation were identified among Delhi and Bengaluru eBus and dBus drivers using latent class analysis. These objectives were accomplished by surveying 615 drivers—both diesel (309) and electric (306) plying for C/STUs in Bengaluru (BEN/BMTC) and Delhi (DEL/DTC). To the best of the authors' knowledge and abilities, this is the first study to comparatively assess through a dual-lens framework anchored fromdrivers perspective: inter–and or intra–city/technology—BEN, DEL/dBus, eBus, within the larger canvas of public transit (bus) electrification studies in India or for that matter anywhere else.

Figure 1: Overview of key survey thematic constructs. *Note: LoS-level of service, AQ- air quality, OBD-On-board diagnostic; For EV drivers, responses are construed as their stated responses whereas for ICE drivers, the phrasing is intended to capture their perception or perceived benefit/barriers*

2 Data and methods

2.1 Survey design, sampling and statistical validity

Study employs a quantitative survey administered Computer Aided Personal Interview (CAPI) style to capture a comprehensive range of insights from dBus and eBus drivers (Figure 1). Questionnaire captures almost dozen themes: demographics, socio-economics, work/driving and rest/dwelling patterns, employment (permanent, long-term or short-term contract) details, eBus experiences compared to dBus as well as satisfaction with respect to technology and overall job. Survey instrument collected drivers' information diet, opinion influencers (peers, dealers, friends and families, depot manager or any other authority figure for example) as well as key motivators and barriers to EV transition. A distinct set of questions probe notions around pride and status gain from EV driving. The instrument also recorded responses from an ecosystem level – such as EV transition adoption barriers to disaggregated individual disposition on motivating factors to switch to eBus driving and whether or not drivers would recommend driving (bus driving in general and a separate question specifically on eBus driving). Survey also included a subset of questions carefully administered only to either eBus or dBus drivers and such instances are highlighted in the **Results** section. For current eBus drivers, questions and responses reflect their actual experiences whereas for dBus drivers, it is framed to elicit their expectations, beliefs or perceptions about EVs. This contextual (re)framing ensures the consistency of the thematic intent of the questions despite differing experiential basis.

Due to the absence of sampling frame of bus drivers in general and considering that due to the GCC model which decouples procurement and staffing from day-to-day planning, eBus drivers are employed by 3rd party staffing agencies rather than directly by the C/STUs (which is typically the case with dBus drivers), probabilistic or random sampling was infeasible. A hybrid combination of purposive and convenience sampling was adopted instead. At the expense of limited generalizability, targeting a cross-section of current drivers most pertinent to study objectives and scope of research inquires across both cities was instead prioritized. This sampling strategy was necessitated—justifiably so—given the absence of publicly available driver database, restrictions on accessing such information if at all available, practical on-ground realities, resource requirements, narrow driver availability windows during breaks and shift changes as well as the logistical constraints of administering the survey during regular hours within depot premises.

A total of 615 samples were collected during July to October 2024— 309 BEN/BMTC (155 dBus and 154 eBus); and 306 DEL/DTC (154 dBus and 152 eBus drivers). *Post-hoc* (*compute power given α=0.05, sample size and large effect size Cohen's d=0.8*) and *Compromise* (*compute implied α and power, given β/α ratio, sample size and large effect size Cohen's d=0.8*) analyses conducted using G*Power [24], confirmed that the statistical power (1-β) exceeded 0.98 and Type I error (α) was well below 0.05. Sample size was therefore deemed statistically valid and more than sufficient to detect large effects with high degree of confidence.

2.2 Analytical techniques

All constructs are measured using the most appropriate response formats (5-point Likert–satisfaction/improvement/change, sliding scales–rating from 1-10, numeric entries–distances, trips for example, select one or more from choice set provided and open-ended unstructured text for any feedback post survey completion). Wherever applicable and relevant, Likert responses were recoded into numeric levels from 1 to 5 with higher values denoting more favorability towards eBus compared to dBus, which were then aggregated into a composite score. Internal consistency of such multi-item constructs was first computed using Cronbach's alpha (α) and constructs with $\alpha \geq 0.7$ were retained due to acceptable reliability. Unless otherwise explicitly mentioned, tests for statistical significance were conducted at 95% confidence intervals. Inferential, hypothesis and group means comparison tests were chosen depending on the nature of the variable. To overcome sparsity in the case of Likert-scale responses, categories were collapsed/consolidated into a fewer number of levels wherever deemed necessary to avoid losing their interpretive relevance and meet test assumptions. In order to derive meaningful insights from the collected data, a suite of exploratory and inferential statistical methods listed below:

- Descriptive and distributional central tendency and dispersion measures wherever applicable
- ANOVA, post-hoc non-parametric Wilcoxon/Kruskal-Wallis group means comparison for continuous variables
- Frequency distributions, cross tabs (contingency tables) to capture within and between-groups associations subsequent application of ChiSq (χ^2), Fishers exact, Likelihood Ratio (LR), Pearsons and Cochran-Armitage
- Latent class clustering within and between groups (city–Bengaluru and Delhi, segment–eBus and dBus) for deducing eight EV driving motivational archetypes—four each for dBus and eBus, respectively.

2.3 Sample descriptives

Table 1 presents basic information across select strata of the 615 bus drivers across DEL and BEN, with a roughly even split city-wise as well between eBus and dBus drivers. Drivers with high-school and secondary education levels constituted the largest share in BEN (dBus, eBus and overall) and DEL (dBus, eBus and overall), respectively. eBus drivers on average are slightly younger compared to dBus drivers and thereby possess less CDL and bus driving experience. Household size varied notably by city and fuel type. eBus drivers in BEN largely came from smaller households of ≤ 3 members, whereas nearly two-thirds DEL drivers hail from households ≥ 5 members. Approximately a quarter of respondents reported having an immediate family member who is a truck (165 out of 615) or bus driver (153 out of 615). It is worth highlighting in BEN, almost all dBus drivers permanently employed with the C/STU (BMTC) and roughly 75% of eBus drivers have long-term employment contract (> 1 year). Nearly half of DEL dBus and eBus drivers are either employed on short-term (< 1 year) or long-term contract basis. eBus drivers with permanent contract across both cities accounted for only about 5% (~15 in both DEL and BEN). Almost all BEN dBus drivers make 25000 INR (~ $300) or more per month. Overwhelming share of DEL eBus drivers fall in the 20000-25000 INR bracket (85%, 129/152). DEL dBus drivers exhibit a more even income distribution in the highest (25000 INR or more) and the 10000-15000 INR bracket. The range limitations and charging requirements of eBus manifests in the higher share of eBus drivers in both cities plying fixed or predictable routes. Across all sub-groups, union membership remains low with a higher share not interested in joining a worker's union, followed by those who desire but unable to. About one-third of drivers receive no bonus (performance, punctuality, overnight or additional shifts, festival, annual increments are a few examples) on top of salaries and wages. In both cities, eBus and dBus drivers receive at least one type of bonus. A sizeable share of DEL dBus drivers (101/152, 66%) reported availing multiple bonus benefits. In contrast, BEN eBus drivers represent the largest sub-group that did not avail or had access to any bonus.

Table 1 summarizes the key structural, administrative and operational between eBus and dBus drivers in DEL and BEN. When considered together with the statistical validity and explanatory power of the sample size, these stylized differences offer a city-specific and technology-sensitive contextual baseline for further analyses. Findings are elaborated in the next section.

Table 1: Bengaluru and Delhi eBus and dBus drivers sample descriptions

	Bengaluru (BEN), N=309		**Delhi (DEL), N=306**	
	dBus (155)	eBus (154)	dBus (154)	eBus (152)
	educ_level			
Primary, middle school or lower	2	35	4	1
Secondary	58	11	57	79
High school	85	92	53	49
Degree, diploma or more	10	16	40	23
	**fam_truck_drv*			
No	109	121	113	107
Yes	46	33	41	45
	**fam_bus_drv*			
No	119	122	116	105
Yes	36	32	38	47
	Household (HH)_size			
1 to 3	41	113	11	12
4	79	37	42	34
5+	35	4	101	106
	Monthly income, Indian Rupees (INR)			
10000-15000 INR	0	14	2	0
15000-20000 INR	3	95	41	3
20000-25000 INR	8	41	69	129
> 25000 INR	144	4	42	20
	Daily driving route			
Fixed	46	113	35	74
Predictable	73	27	58	44
Variable	36	14	61	34
	Employment type			
Flex_On-demand/ad-hoc	3	3	0	10
Perm	144	15	35	14
Long-term contract > 1 year	5	110	37	80
Short-term contract < 1 year	3	25	82	48
	Workers or labor union membership			
No, and don't want to	72	77	96	84
No, but want to	57	55	42	42
Yes	26	22	16	26
	Additional bonus components beyond base salary			
0-No bonus	78	53	37	41
1	71	72	97	101
2+	6	29	20	10
	Mean (μ) ± Standard Deviation (σ)			
Age	39.6 ± 3.8	35.8 ± 5.8	41.6 ± 7.5	39.5 ± 8.4
&CDL_exp	16.3 ± 4.4	5.5 ± 3.1	16.4 ± 7.	15.5 ± 8.40
$tot_bus_driv_exp	13.1 ± 4.4	3.8 ± 3.0	12.9 ± 6.6	13.5 ± 8.4

3 Results

The results section first compares using aggregate and distributional summaries of key performance indicators and EV technology feature scores. A suite of tests (by city and or vehicle type) evaluates whether the differences in dBus drivers' satisfaction with his current dBus as well as EV technology and policy awareness are statistically significant. Reported and perceived pride and status associated with eBus driving is then evaluated using contingency tables. Lastly, EV driving motivational archetype profiles of Delhi and Bengaluru eBus and dBus drivers deduced using latent class word cloud clustering are presented.

3.1 Aggregate and distributional summaries

3.1.1 Operational and performative metrics

Table 2 presents the mean and standard deviation of responses on a sliding scale from 1 to 10 (higher the better) alongside daily driving and dwelling patterns (trips, distances, breaks per day and break duration) of eBus and dBus drivers in both cities. BEN dBus drivers' average daily driving distance exceeds that of their DEL counterparts due to more trips and longer trip distances. Conversely, BEN eBus drivers log more trips and total distance daily, but their individual trips are shorter than those of DEL eBus drivers. Although each of the four subgroups averaged two daily breaks, DEL drivers (eBus and dBus) took breaks half as long as BEN drivers (eBus and dBus).

Table 2: Bengaluru and Delhi eBus and dBus drivers' comparison of key performance indicators

	Bengaluru		**Delhi**	
	eBus	**dBus**	**eBus**	**dBus**
	Mean (μ) ± Standard Deviation (σ)			
Daily trips	5.5 ± 1.7	6.6 ± 1.8	4.4 ± 1.05	4.7 ± 1.1
Trip Distance, km	21.6 ± 11.8	29.2 ± 12.6	28.1 ± 8.3	24.6 ± 7.0
Daily Distance, km	137 ± 30.5	178.3 ± 50.7	112.6 ± 13.8	110.3 ± 17
Bus satisfaction	7.9 ± 0.96	8.3 ± 1.4	9.2 ± 1.5	8.1 ± 2.1
Job Satisfaction	7.8 ± 1.2	9.2 ± 1.3	8.4 ± 2.3	7.5 ± 2.7
Job security	7.6 ± 0.9	8.2 ± 1.1	7.8 ± 2.77	7.1 ± 2.8
Income satisfaction	7.5 ± 1.1	8.1 ± 1.0	7.2 ± 2.63	6.7 ± 2.9
Rest breaks	1.9 ± 0.3	2.0 ± 0.1	2.2 ± 1.42	2.1 ± 0.71
Average break duration, minutes	32.7 ± 8.8	24.9 ± 4.5	15.5 ± 10.3	13.7 ± 8.3
$Very dissatisfied to very satisfied				
Pollution exposure		5.4 ± 0.9		6.2 ± 2.8
Driving comfort		7.2 ± 1.1		7.4 ± 2.4
Infrastructure facilities		7.2 ± 1.1		8.5 ± 1.9
$Strongly disagree to strongly agree		*Perceived*		*Perceived*
Improves accessibility	7.4 ± 0.9	5.6 ± 0.9	8.8 ± 1.7	7.8 ± 2.1
Maintenance & downtime reduction	7.4 ± 1.1	5.7 ± 1.1	8.7 ± 1.8	7.9 ± 1.9
Ridership increase	7.8 ± 0.9	5.5 ± 1.1	8.7 ± 1.8	8.6 ± 1.9
Clean air, better air quality	7.9 ± 1.0	6.8 ± 1.2	9.6 ± 0.99	8.9 ± 1.8
Increased passenger satisfaction	7.7 ± 1.0	6.1 ± 1.2	9.3 ± 1.49	8.3 ± 2.2
Maintain schedule adherence	7.8 ± 1.0	6.3 ± 1.4	8.7 ± 1.81	8.2 ± 2.0
$ sliding scale from 1 to 10				

Referring to Table 2, within BEN, dBus drivers reported higher satisfaction with their bus, job, employment security and income than eBus drivers. Across cities, BEN dBus drivers outscored DEL dBus and DEL eBus drivers on these metrics. Conversely, DEL eBus drivers rated higher on the same set of variables in comparison to DEL dBus as well as BEN eBus drivers. A subset of questions posed only to dBus drivers (pollution exposure, driving comfort and infrastructure facilities) asking them to rate their satisfaction based on actual experience. DEL once again out-performs BEN dBus drivers. It is pertinent to note that the higher rating of driving comfort and infrastructural facilities (depot) by DEL dBus drivers, in both relative (to BEN dBus) and absolute terms may stem from the Delhi government's aggressive measures to curb air pollution by phasing out more than 10-year old diesel vehicles in 2015, which coincided with launch of the FAME-I policy. From a cabin comfort, ergonomics, telematics and technology upgrades, not much distinguishes a diesel/CNG from an eBus of comparable age and specifications.

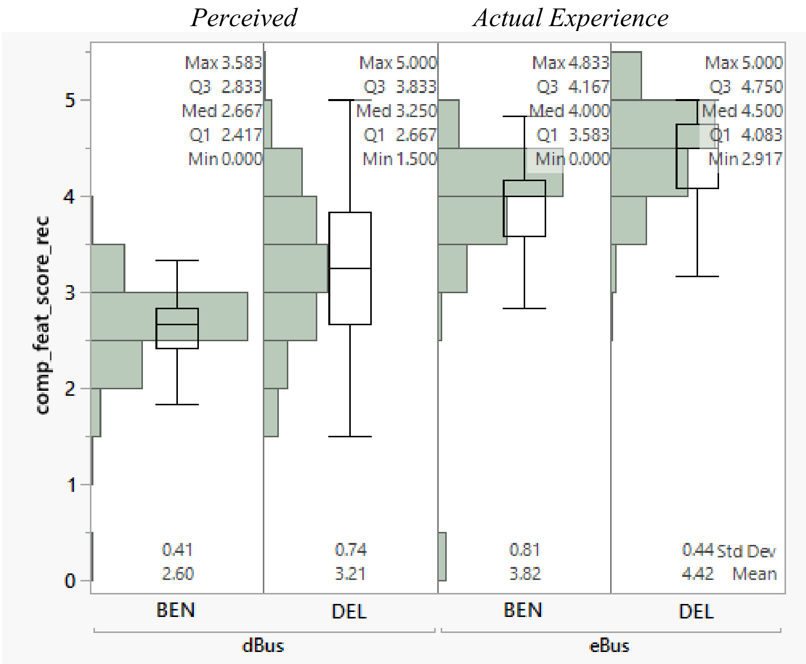
3.2 Within, between and cross-group comparisons

3.2.1 Operational efficiency and service enhancement

In both cities, eBus drivers reported higher levels (compared to dBus drivers' perceptions) of agreement, favorable disposition towards the positive impact of EVs on: operational efficiency– *maintain schedule adherence and maintenance & downtime reduction*; service enhancement – *improves accessibility, increased ridership and passenger satisfaction levels*; and environmental outcomes – *Clean air, better air quality*. DEL eBus drivers on average rated 9 out 10 across these six aspects indicative of a broader consensus on the tangible benefits of eBus deployment. It is worth highlighting that that strongest (highest score) agreement was on air quality aspects–exhaust as well as in-cabin exposure, followed by passenger satisfaction. Together these high ratings point to the direct, visible and experiential benefits for the passenger and the driver, as well as the environment. dBus drivers on the other hand exhibit a more tempered response driven by scepticism, uncertainty and internalized beliefs on legacy or status quo systems. The perception gap is more prominent among BEN dBus drivers whereas even the dBus drivers in DEL indicate moderately favorable perceptions. Unfamiliarity, distance from first-hand experience, toned-down public discussion and deliberation on air quality aspects in BEN compared to DEL, status-quo already operationally efficient offering high service quality and reliability and information asymmetry leading to undervaluing marginal benefits of EVs could be one of the many plausible reasons attributable to the perception gap.

ANOVA (by city and by vehicle type) was performed to determine if there are any statistically significant differences in the group means of twelve of the fifteen variables/responses listed in Table 2 (3 questions posed only to dBus drivers omitted). If ANOVA test yielded *Prob > F < .0001*, post-hoc non-parametric Wilcoxon/Kruskal-Wallis test was conducted to validate the results. Bus satisfaction and Job Satisfaction differences—across cities (eBus DEL vs. eBus BEN) and between vehicle types (eBus DEL vs. dBus DEL), were statistically significant (Prob > |Z| and Prob > χ^2 < *0.0001)*. DEL eBus drivers consistently rated higher agreement scores than BEN eBus as well as DEL dBus perceptions across the six items capturing operational efficiency and service enhancement. Similar trends were observed when comparing DEL eBus and DEL dBus along the same dimensions. In both instances, post-hoc Wilcoxon and Kruskal-Wallis tests confirmed that these differences were statistically significant (*p-val < 0.0001*). These insights perhaps reflect the stronger/higher positive perception of DEL eBus than both DEL dBus and BEN eBus by bus driving community.

Figure 2: Histogram and boxplot distribution of composite EV feature score ratings. *ANOVA and non-parametric group means comparison test statistic annotated inline*



Item reliability score (Cronbach's α) was separately calculated overall for 615 samples; by city; by segment/vehicle type; and by city–vehicle type sub-groups; α ≥ 0.8 in cases

ANOVA Prob > F < 0.0001	*ANOVA Prob > F < 0.0001*
Kruskal-Wallis Prob > χ^2 *< .0001*	*Kruskal-Wallis Prob >* χ^2 *< .0001*
Wilcoxon Prob > Z & Prob |Z| < .0001	*Wilcoxon Prob > Z & Prob |Z| < .0001*

3.2.2 Composite EV technology feature scoring construct

The perception gap briefly explained touched upon operational and level-of-service aspects. This is further examined strictly from a technological standpoint that is more proximal and immediate to the driver's day-to-day habits, preferences, routine and patterns. This is achieved by creating a composite feature score, a multi-item construct derived from twelve EV technology attributes. These twelve attributes are: steering, in-cabin features, noise, vibration, reliability, maintenance and repair, refueling/recharging speed and time, refueling/recharging availability/accessibility, operational expenses (OPEX), navigating traffic, ease of driving and range. This is evaluated based on the respondents (perceived) relative disadvantage/advantage of operating an eBus over dBus recorded in the form of a 5-point Likert scale from 1-*Much Better (ICE)* to 5-*Much Better (EV)* with ICE and EV same as the neutral midpoint. Composite feature score (*comp_feat_score_rec*) is the average across the dozen attributes. Figure 2 depicts the boxplot distribution and histogram of the composite feature score among eBus and dBus drivers in DEL and BEN.

The distribution and histogram of the composite feature score accentuate the perception gap. As previously mentioned, DEL eBus drivers consistently rate high with the highest composite score of 4.4

followed by BEN eBus drivers (3.82). In stark contrast, both DEL and BEN dBus drivers assigned markedly lower scores—3.2 and 2.6, respectively. Higher median and the tighter clustering of eBus scores, especially in DEL, indicates a stronger and more positive valuation of EV technology features and emerging consensus among eBus drivers. Wider variation, especially among DEL dBus drivers, and lower median scores perhaps point to a mix of skepticism, uncertainty and unfamiliarity. The differences were found to be statistically significant (both ANOVA and post-hoc non-parametric tests (Kruskal-Wallis χ^2 and Wilcoxon Z), with all *p-val* < *0.0001*) across city as well as segment/vehicle type.

The operational efficiency and service enhancement construct captures route, societal and system outcomes that effectuate cumulatively over a period of time. The composite feature score concentrates on core technological dimensions which are real-time, situational, potentially transient and dynamic as well as more personalized. Though the mechanics are distinct, one could posit a meaningful association between these two constructs, essentially bridging the experiential familiarity disaggregated at the individual/driver level with the meso–to macro–scale perceptions of EV's operational value.

3.2.3 dBus driver reported satisfaction levels

Table 3: Comparison of select vehicle and support infrastructure attributes

Attribute	**BEN**	**DEL**	**Prob>F**	**Prob > Z**	**Prob> $\lvert Z \rvert$**	**Prob> χ^2**
	(μ) ± (σ)		*ANOVA*	*Wilcoxon*		*Kruskal -Wallis*
Depot & allied facilities	7.2 ± 1.1	8.5 ± 1.9	0.002	*<.0001*	*<.0001*	*<.0001*
Driving comfort	7.2 ± 1.1	7.4 ± 2.4	0.32	0.05	0.10	0.10
In-cabin pollution exposure	5.4 ± 0.9	6.2 ± 2.8	*<.0001*	*<.0001*	*<.0001*	*<.0001*

Table 3 summarizes dBus driver reported satisfaction levels with current dBus depot facilities, dBus driving comfort and in-cabin air pollution exposure. Across all these three infrastructure and in-vehicle driving and exposure aspects, DEL dBus drivers reported higher average satisfaction levels than BEN dBus drivers. DEL dBus drivers experience a better supporting infrastructure, possibly due to investments in depot upgrades, comfort and convenience services provision necessitated by the fleet transition from diesel to CNG and subsequently to eBus. dBus drivers' rating of driving comfort seems fairly unform in DEL and BEN. Co-location and or proximal siting of eBus and dBus infrastructure for resource sharing, asset utilization (land, civil and electrical works, maintenance and repair, refueling/recharging) and passenger convenience (lighting, annunciator systems, restrooms etc.). Likewise, Del dBus drivers' higher satisfaction with in-cabin pollution exposure likely stems from newer buses following the fleet transition to CNG and eBus. In BEN, at least 85% of BMTC's fleet is still diesel, while the proportion is slightly less (~70%) in DTC [4]. Differences in dBus drivers reported satisfaction levels of depot and allied facilities and in-cabin pollution exposure were found to be statistically significant according to ANOVA and post-hoc non-parametric group means comparison tests (Table 3). Despite different daily driving requirements and trip metrics (Table 2), urban form, infrastructure readiness and exposure, dBus drivers in BEN and DEL rate their driving comfort similarly.

Table 4: Comparison of dBus driver's EV technology and policy awareness drivers using Likelihood Ratio (LR) and Pearson's Chi-square (χ^2) tests

Tests	d_btry_sys_rec	d_chg_mech_rec	d_poli_fame	d_init_pm_ebus
	Battery systems	*Charging*	*FAME*	*PM-eBus*
Likelihood Ratio	32.86	63.18	73.06	124.28
Prob > χ^2	*<.0001*	*<.0001*	*<.0001*	*<.0001*
Pearson	32.25	60.37	70.10	115.67
Prob > χ^2	*<.0001*	*<.0001*	*<.0001*	*<.0001*
Fisher's Exact	2-sided Prob ≤ P		2-tail and Right	
	<.0001	*<.0001*	*<.0001*	*<.0001*
	Cochran-Armitage, Asymptotic			
Z	-3.87	-5.45	-8.37	-10.75
Prob < Z	*<.0001*	*<.0001*	*<.0001*	*<.0001*
Prob > $\lvert Z \rvert$	*<.0001*	*<.0001*	*<.0001*	*<.0001*

Likert scale response to Awareness (Poor, Average, Good); Policy awareness Yes/No

3.2.4 dBus driver awareness and familiarity

dBus drivers in DEL and BEN were asked to rate their awareness of EV technology and key EV policies. Battery and charging mechanisms constituted EV technology awareness which was recorded on a 3-point Likert scale. Familiarity with EV policies, specifically FAME and PM eBus initiative was gathered using a binary choice Yes/No format. Nearly a half and nearly an identical proportion of DEL dBus drivers rated their awareness of both battery systems and charging mechanisms (~55%, 87/154) as *"good"*. Corresponding share of BEN dBus drivers who reported *"good"* awareness of battery systems and charging mechanisms stood at 27% (42/155) and 15% (24/155). This relative gap in technological awareness also reflected in sizeable share – 71% (111/155) and 82% (127/154) of BEN dBus drivers who were not familiar with FAME and PM eBus initiative respectively. The converse was observed among DEL dBus drivers with ~78% (120/154) aware of both FAME policy and PM eBus initiative. Using cross-tabulations (contingency tables), LR, Pearson and Fishers exact test revealed statistically significant differences in EV technology awareness and policy familiarity between DEL and BEN dBus drivers (Table 4). The Conchran-Armitage trend test results indicate statistically significant empirical evidence of ordinal trend among dBus drivers across both cities (Table 4). Z-scores of -3.87 and -5.45 with *p-val* < 0.00001 corresponding to battery systems and charging mechanisms points to monotonicity (increase or decrease) in awareness based on city grouping. This trend becomes even more pronounced when comparing the Z-scores of FAME (-8.37) and PM eBus initiative (-10.75) familiarity with *p-val* < 0.00001. The magnitude and direction of the Z-scores suggests a systematically graded higher exposure trajectory in DEL compared to BEN in the technological awareness and policy familiarity domains.

3.3 eBus motivating factors: Latent Class Word Cloud Analysis

The survey asked eBus and dBus drivers to identify up to three factors that would motivate them to transition to eBuses from the following options— *better driving experience, social status and image, environmental benefits, higher wages, job opportunity, experience new technology, more test driving opportunities, demand from passengers, stable employment contract, free upskilling and training classes/workshops, vehicle reliability, vehicle performance, government subsidies/incentives, more occupational benefits*. Latent Class Analysis (LCA) is applied to uncover underlying relationships expressed in the form of text, terms, words or phrases. Distinct word cloud clusters are identified using LCA based on the relative frequency of co-occurrence of words or alternatively *clustering of responses* that share common trait. Each respondent/driver is assigned a probability of belonging to one of the latent class clusters. The output of the LCA is the visual density of frequently mentioned word (word cloud), cluster mixture probabilities and top terms by cluster.

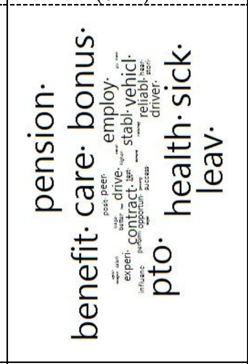
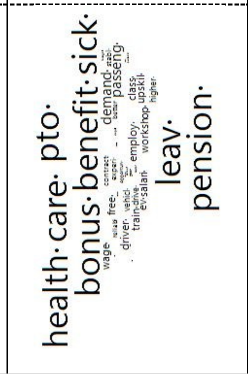
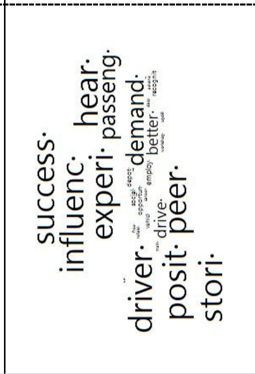
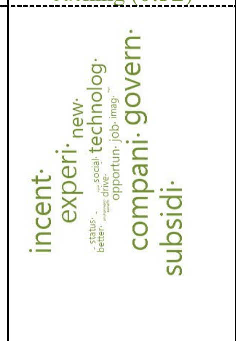
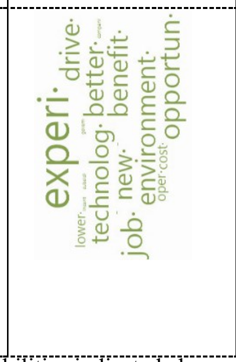
Minimum number of terms, term frequency, maximum/minimum characters per word, maximum words per phrase and maximum number of phrases were suitably adjusted. The number of clusters were varied from 3 to 6. Model selection was based on the Bayesian Information Criterion (BIC), lower being the better. Cluster grouping was checked for clear separation and visually validated using multi-dimensional scaling (MDS) plots. Cluster interpretability, distinctiveness, associativity and top terms per cluster were examined. Minimum cluster mixture probability was set at 0.1. The entire dataset of 615 samples is divided into four sub-groups–BEN dBus, DEL dBus, BEN eBus and DEL eBus and LCA was applied on individual sub-groups. Four latent cluster solution across all the four groups was eventually chosen. Apart from model selection criteria, cluster grouping, key terms, visual diagnostics, and cluster mixture probabilities, a few other practical aspects were considered. These include, analytically tractable, parsimonious, balancing statistical fit, conceptual clarity, thematic cohesion and explanatory power.

Table 5 presents the unclustered and four latent class clusters word cloud as well as cluster mixture probabilities for the four sub-groups—BEN dBus, DEL dBus, BEN eBus and DEL eBus, respectively. Eight EV driving motivational archetypes were identified four-each for eBus and dBus drivers respectively. These archetype profiles are fixed across cities but vary by segment/vehicle type. This heuristic simplification was applied to maintain ease of interpretation and semantic cohesion whilst capturing intra-group heterogeneities. For both the eBus and ICE bus drivers, the clusters are well-separated, indicating that the motivations within each cluster are distinct. This clear separation suggests that each cluster represents a unique set of motivational factors affecting behavior and attitudes towards EV adoption. Upon further examining the cluster probabilities, MDS plots, top terms by cluster, term probabilities by cluster and cluster separation, supports this approach of maintaining the same set of archetypes by segment/vehicle type

3.3.1 dBus and eBus: unclustered EV driving motivational archetype

Security and employment stability are far more important to dBus drivers (particularly BEN), whereas eBus drivers are drawn to new opportunities, experience new technology, care more about pride, and rely on government incentives and subsidies. Passenger demand and level-of-service are other motivators for dBus drivers, especially in DEL. Both groups, value operational efficiency, with eBus drivers highlighting lower OPEX, whereas dBus drivers emphasize reliability and occupational benefits. eBus driver inferences largely hold true in BEN and DEL.

Table 5: EV driving motivational archetypes among Delhi and Bengaluru eBus and dBus drivers using latent class word cloud clustering

Unclustered	Cluster 1	Cluster 2	Cluster 3	Cluster 4
BEN dBus	Certainty & continuity (0.64)	Community support & visibility (0.12)	Non-salary benefits (0.12)	Peer influence & wage aspirations (0.11)
				
DEL dBus	(0.38)	(0.22)	(0.20)	(0.19)
				
BEN eBus	Institutional and policy backing (0.32)	Techno-environmental valuation (0.3)	Personal & social norms (0.2)	Career development (0.18)
				
DEL eBus	0.32	0.25	0.24	0.19
				

Cluster mixture probabilities indicated above each word cloud quantifies the proportion of respondents in the specific city–vehicle type group: BEN/DEL and dBus/eBus, respectively. Survey responses to the question on up to three factors that encouraging drivers to shift from ICE/CNG (dBus) to eBus

3.3.2 dBus drivers: Bengaluru and Delhi latent class EV motivational archetypes

Certainty and Continuity: Represents drivers who prioritize stability, security, permanent employment, and predictable work routines. High frequency lexical patterns include *contract*, *permanent*, *regular*, *safe*, *shift*, and *job security*. This archetype is dominant, particularly in Bengaluru, underscoring an often-overlooked fact that, for many drivers, switching to EV is structural and not technological. This subset of dBus drivers are risk-averse, often older, and consider switching if their current job benefits and pay are secure.

Community Support and Visibility: Drivers in this archetype take professional and occupation decisions through a social lens. This group is, strongly influenced by the views of peers. These drivers deeply care about the reputation of the job, social status, and public visibility. *Recognition, social, respect, recommend, peer, and union* are among the keywords in this profile. Endorsements from authority figures such as depot managers, or positive stories from passengers or peers who have switched plays a major role in shaping their motivation.

Non-Salary Benefits: This subset of dBus drivers value the broader and complete package inclusive of salary as well as benefits. Key terms like *health*, *leave*, *benefit*, *rest*, *medical*, and *pension* appear consistently. This cohort prioritizes healthcare, rest time, vacation and retirement benefits. They seek better working conditions, better social welfare safety net and institutional support.

Peer Influence and Wage Aspirations: This archetype of drivers possess a competitive, ambitious and aspirational mindset. Common keywords include *better*, *earning*, *salary*, *peer*, *income*, *high*, and *compare*. Their motivation is shaped by what others in the depot earn, perceived opportunity differentials, and stories of drivers moving "up" into better-paying, more responsibilities or higher-status roles.

3.3.3 eBus drivers: Bengaluru and Delhi latent class EV motivational archetypes

Institutional and Policy Backing: This cohort of eBus drivers have strong faith in government, institutions, systems and processes. Dominant terms include *government*, *FAME*, *secure*, *PM eBus*, *scheme*, and *approved*. These drivers trust that programs backed by the state offer more structured, rule-bound opportunities with better oversight and safeguards. They are more likely to view eBus adoption as a sub-component of broader energy transition

Techno-Environmental Valuation: Reflects drivers who have internalized the value of eBuses for their technological advantages and environmental benefits. Commonly occurring terms include *green*, *quiet*, *future*, *no pollution*, *tech*, and *smooth*. These drivers are motivated by the intrinsic features, specifications and capabilities of the eBus. They value quieter, cleaner, easier, futuristic and fatigue-free driving experience.

Personal and Social Norms: This cluster of eBus drivers' motivations highly value pride, respect, self-image, public perception and recognition. Key terms include *pride*, *people*, *family*, *status*, *public*, and *image*. These drivers report that EV driving makes them feel more respected by passengers and viewed in respect by peers They are highly responsive to societal cues and narratives of symbolism, pride and prestige.

Career Development: This group represents aspirational orientation among drivers who see the EV shift as an opportunity for long-term growth, retraining and reskilling for a better future. Common terms include *training*, *license*, *promotion*, *skill*, *learn*, and *upgrade.* access to new certifications, pathways to supervisory roles, or entry into a higher-skilled labor market.

4 Conclusions

This ongoing study is part of a broader national effort to understand the human-centric perspective, beyond the well-established vehicle focused techno-economic and environmental case for EV transition. Bus driving community is the focal point of the first and second phase of this effort. This study offers one of the first empirical portraits of how public transit agency bus drivers perceive the shift from diesel to electric buses in two Indian megacities—Delhi and Bengaluru. Roughly equal number (~150) of drivers by segment/vehicle type and across the two cities were surveyed. By combining stratified descriptive comparisons, inferential tests, composite indices, and latent class clustering, the findings reveal a nuanced, multifaceted understanding of the transition. Results of this study reveal several distinct advantages in terms of operational performance, environmental benefits, and driver health outcomes. eBus drivers consistently report higher levels of satisfaction across multiple dimensions, from maintenance and downtime reduction to passenger comfort and air quality improvements. However, despite these clear advantages, some challenges remain. The lower income security and job satisfaction reported by eBus drivers reflect ongoing concerns related to the employment structures associated, which are often under concessionaire models rather than direct employment by C/STUs.

Aggregate, descriptive and distributional summaries showed meaningful and statistically significant differences along select performance, operational, satisfaction and technological dimensions, between segment/vehicle-type sub-groups and or across cities. Several practical insights emerged from the analysis, in terms of perceptual gaps and behavioral archetypes. First, a clear perception gap exists between eBus and dBus drivers. Across all the six indicators chosen to represent "*operational efficiency and service enhancement*" construct—*schedule adherence, downtime reduction, accessibility, ridership increase, passenger satisfaction, and air quality*—eBus drivers reported consistently higher agreement scores. This was especially pronounced among Delhi eBus drivers. The composite EV technology feature score further reinforced this gap. These two constructs taken together presents a compelling case for the positive association between system outcomes and individual substantiation. Lastly, latent class word cloud clustering offers a behavioral typology of eBus and dBus drivers. dBus archetypes were dominated by stability, social visibility, non-salary benefits, and peer-influenced wage aspirations. In contrast, eBus drivers were more likely to emphasize policy anchoring, institutional backing, technological features, social prestige, and future career prospects. These findings collectively highlight the complexity of fleet electrification in a deeply legacy rooted institution such as India's C/STU's. Oft-recurring themes such as job security, peer norms, and social as well as symbolic dimensions suggest the importance of aligning structural transformations with individual motivations

4.1 Recommendations

— <u>Guarantee employment security during transition</u>: SPVs, C/STUs, and service providers must formalize tripartite job transition frameworks that guarantee role continuity for existing drivers, offer bridging contracts during vehicle or depot electrification, and define upskilling mandates with no loss in pay or seniority.

— <u>Align financial incentives with upskilling and retention</u>: A clear pathway must be created where performance-linked bonuses, skill-based allowances, or retention-linked increments reward drivers transitioning to eBuses. , implementing a tiered salary structures for certified and experienced EV drivers could improve retention and attract fresh talent signaling that eBus driving is indeed a step-up and not a lateral move.

— <u>Mobilize peer influence through targeted "green ambassadors"</u>: The latent class analysis underscored how peer opinions and social respect heavily influence perceptions. Notably, eBus drivers felt more socially elevated—a sentiment not yet fully translated to dBus counterparts. This socially-contagious framing could do more than top-down messaging to normalize eBus driving as aspirational. Implementing peer ambassador programs where experienced eBus drivers' mentor dBus cohorts, incorporate driver testimonials in outreach videos, and recognition from family or passengers.

— <u>Tailor communication and training for diverse driver profiles</u>: Recognize the diversity of motivations within the driver community, region (geographies) and socio-cultural contexts and offer targeted communication and training programs. While some drivers may be incentivized by environmental or technical benefits, others will need more focus on economic and job security factors.

— <u>Enhance policy support for ebus drivers</u>: Continue offering and expanding government subsidies and incentives to attract and retain eBus drivers. As many eBus drivers see government policy as a motivator, maintaining robust policy backing will reinforce their commitment.

4.2 Study limitations and future work

While being comprehensive and methodical in assessing the various facets of technology transition—satisfaction, perception, awareness, motivating factors, relative performative advantage/disadvantage, operational etc., particularly in the context of India's ailing C/STUs, research design and sampling strategy has representativeness and generalizability limitations. The absence or access to reliable and current eBus/dBus driver database is perhaps the single biggest reason that ruled out any possibility of probabilistic or random sampling. Sample size, though statistically significant, may not capture the full range of benefits, motivations and perceptions across all geographic and socio-economic contexts. Additionally, the analysis relies on self-reported data, which can be subject to social desirability or recall biases. Moreover, the latent class analysis focuses on current perceptions and hypothetical motivations, particularly for ICE bus drivers who may have not yet experienced and/or familiarized with the full spectrum of EV's capabilities and features. Their responses may not yet fully constitute how they would react to an actual transition scenario. Future studies would benefit from longitudinal data tracking driver attitudes pre- and post-EV adoption, thereby enabling causal inference and a nuanced understanding of primary, secondary and tertiary layers of EV transition barriers, motivator and catalysts.

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