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Authors

Bae, Youngeun, PhD
Ritchie, Stephen G., PhD
Rindt, Craig Ross, PhD

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Youngeun Bae, Ph.D., Corresponding Author Assistant Project Scientist
Stephen G. Ritchie, Ph.D., Professor, Civil and Environmental Engineering Director
Craig Ross Rindt, Ph.D., Project Scientist

UC Institute of Transportation Studies, Irvine

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Youngeun Bae, Ph.D., Corresponding Author
Assistant Project Scientist
Institute of Transportation Studies
4000 AIRB
University of California, Irvine
Irvine, CA 92697-3600
youngeub@uci.edu
ORCiD: 0000-0003-0798-6418

Stephen G. Ritchie, Ph.D.
Professor, Civil and Environmental Engineering
Director, Institute of Transportation Studies
4000 AIRB
University of California, Irvine
Irvine, CA 92697-3600
sritchie@uci.edu
ORCiD: 0000-0001-7881-0415

Craig Ross Rindt, Ph.D.
Project Scientist
Institute of Transportation Studies
4000 AIRB
University of California, Irvine
Irvine, CA 92697-3600
crindt@uci.edu
ORCiD: 0000-0002-3278-6488

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ABSTRACT

Given that small fleets (defined as those with 20 or fewer vehicles) represent a considerable portion of the heavy-duty vehicle (HDV) sector, understanding their perspectives, along with those of large fleets, on zero-emission vehicles (ZEVs) and related policies is crucial for achieving the U.S. HDV sector's ZEV transition goals. However, research focusing on small fleets or comparing both segments has been limited. Focusing on California's drayage sector with stringent ZEV transition targets, this study investigates the awareness and perceptions of small and large fleet operators on ZEV technologies and policies established to promote ZEV adoption. Using a fleet survey, we obtained 71 responses from both small and large fleets. We employed a comprehensive exploratory approach, utilizing descriptive analysis, hypothesis testing, and thematic analysis. Findings reveal that both segments generally rated their ZEV knowledge as close to neutral, with about a third reporting limited awareness of the ZEV policy. Both segments highlighted various adoption barriers, including challenges with infrastructure, costs, and operational compatibility. Business strategies under the ZEV policy differed significantly: small fleets planned to delay or avoid ZEV procurement, with some considering relocation, while large fleets were more proactive, with many already having procured or preparing to procure ZEVs. Both segments voiced concerns about the disproportionate impact on small fleets. The findings enhance our understanding of equity issues in ZEV adoption across fleet segments and offer valuable insights for policymakers committed to a more equitable distribution of the impacts.

Keywords: heavy-duty vehicle, zero-emission truck, ZEV policy, fleet survey, small fleet, equity in innovation adoption.

BACKGROUND

Approximately 90% of medium and heavy-duty vehicles (referred to as 'HDVs,' with a gross vehicle weight rating (GVWR) exceeding 10,000 lbs according to the U.S. FHWA, or over 8,500 lbs according to the U.S. EPA) are used as fleet vehicles for business purposes rather than personal transportation (*1*). These HDVs account for approximately 23% of greenhouse gas emissions in the U.S. transportation sector (*2*). The criteria air pollutants emitted from diesel HDVs also have harmful effects on public health. To address these issues, many U.S. states are supporting a full transition of the HDV sector to zero-emission vehicles (ZEVs), such as battery electric or hydrogen fuel cell electric vehicles (*3*). Among these states, California is leading these efforts under Executive Order N-79-20 (*4*), aiming for a 100% transition to ZEVs by 2045, wherever feasible, and an even more accelerated timeline for drayage trucks, targeting a full transition by 2035. To achieve these ambitious targets, California has established the Advanced Clean Trucks regulation (*5*) to increase ZEV sales, and the Advanced Clean Fleets (ACF) regulation (*6*) to promote ZEV adoption among HDV fleets, complemented by various incentive programs. However, the current penetration rate of ZEVs remains very low, with only 0.2% of HDVs in California being ZEVs (*7*). To develop effective demand-side strategies, it is essential to understand HDV fleet operator perspectives on ZEV technologies and related policies.

Fleet size, defined as the number of HDVs an organization owns or operates, is known to influence fleet operator perceptions and decisions regarding alternative fuel vehicles (AFVs), including ZEVs and other gaseous fuel technologies (*8*). It is therefore critical to include a range of fleet sizes in research on fleet operator perspectives. In this study, small fleets are defined as those with 20 or fewer vehicles (*9*) and large fleets as those with over 20 vehicles. Small fleets constitute a considerable portion of the fleet population, comprising approximately 70% of the California drayage industry (*10*), for example. However, previous research on ZEV or AFV adoption, often based on interview or survey methods, has tended to focus on large fleets, likely due to their higher response rates to recruitment efforts. Understanding and comparing the perspectives of small and large fleets is crucial to obtain comprehensive insights and identify any equity issues between these segments. Consequently, this study aimed to investigate and compare the viewpoints of small and large fleet operators on ZEV technologies and related policies.

Relatively few recent studies have examined ZEV or AFV adoption among HDV fleets, while studies on light-duty vehicle (LDV) fleets have been more prevalent (*9*). Some of these studies utilized fleet surveys, but did not compare different fleet sizes in their analyses (e.g., *11*), or provided limited insights (e.g., *12–14*) beyond general findings that large fleets are more inclined to adopt clean fuel technologies due to greater environmental awareness and more economic resources. Other studies employed qualitative interviews, yielding detailed insights (e.g., *15–17*), but small sample sizes (e.g., 20 organizations with 10% being small fleets (*15*)) restricted in-depth comparative discussions. In contrast, a study by Golob et al. (*18*), focusing on LDV fleets, detailed the relationship between fleet size and AFV adoption, benefiting from a large sample of 2,023 fleets, half of which were small fleets. Nonetheless, the data, collected three decades ago and focusing on LDV fleets (*18*), may not reflect current fleet operator perspectives on the latest ZEV technologies and recently established ZEV policies affecting the HDV sector.

According to Litman (*19*), 'equity' is defined as the fair and appropriate distribution of impacts, including benefits and costs, among individuals and groups. Also, Rogers (*20*) discussed that the diffusion of innovations ("an idea, practice, or object that is perceived as new by a unit of adoption" (*20*, p.11), such as ZEVs) can widen the socioeconomic gap between higher and lower status segments of a system. Rogers also pointed out that researchers have not paid much attention to the inequity consequences of innovation, attributing this to the 'pro-innovation bias', overemphasizing the positive outcomes of innovation, and methodological difficulties in such assessments. A recent study by Guo et al. (*21*) reviewed 61 papers to evaluate the state-of-the-art of examining equity performance in transportation systems and developed a framework for equity analysis. The authors also noted that current studies on the equity performance of emerging transportation technologies are still in their infancy, with limited research primarily focusing on shared mobility (*21*). These insights from the literature underscore the need for our research to shed light on equity issues between small and large fleets in heavy-duty ZEV adoption.

Aiming to investigate and compare fleet operator perspectives on ZEV technologies and related policies, we conducted a case study focusing on drayage fleets in California. Drayage trucks, as defined by the U.S. EPA, are heavy-duty Class 8 trucks with a GVWR exceeding 33,000 lbs that transport containers and bulk freight between ports and near-port facilities (*22*). These trucks face stringent targets under the ACF regulation, requiring all vehicles newly registered in the Truck Regulation Upload, Compliance, and Reporting System to be ZEVs starting January 2024, and all drayage trucks entering seaports and intermodal railyards to be zero-emission by 2035 (*6*).

In this context, our research addresses the following research questions:

1) How do small and large fleets perceive their levels of awareness of ZEV technologies and the ACF policy?
2) What perceptions do small and large fleets hold regarding ZEV technologies? Are their perceptions similar or different, across battery electric trucks (BETs) and hydrogen fuel cell electric trucks (HFCETs)?
3) How do small and large fleets respond to the ACF regulation in terms of business plans, and what are their perceptions of the policy?

We conducted a fleet survey, with the questionnaire developed based on comprehensive insights from our previous qualitative research (*15*–*17*). The questionnaire included various items such as single/multiple-option questions, Likert scales, and open-ended questions. We recruited drayage truck fleet operators using the Drayage Truck Registry for the Ports of Los Angeles and Long Beach in California. By April 2024, a total of 71 responses were obtained, encompassing both small and large fleets. The data were analyzed using a comprehensive exploratory approach, including descriptive analysis, statistical hypothesis testing, and thematic analysis.

The research findings serve as an initial step toward enhancing our understanding of equity issues in ZEV adoption among different fleet segments, contributing to the body of knowledge in this field. Furthermore, by offering comprehensive quantitative and qualitative insights into ZEV policies and technologies, this study provides valuable information for policymakers, encouraging them to consider equity issues and how to more equitably distribute the impacts of ZEV policies and technologies.

This paper is structured as follows. The next section outlines the methodology used in this study. Following that, the results of the study are discussed. We then present a summary of the conclusions and propose recommendations for future research.

METHODOLOGY

Survey Questionnaire Design

We developed a comprehensive survey questionnaire organized into the following main sections: 1) Basic Fleet Information, 2) Truck Choices, 3) Fleet Management Practices and Strategies, 4) Potential Charging Behavior, and 5) Perceptions. The initial draft questionnaire was formulated based upon prior qualitative research findings from HDV fleet interviews (*8*, *15*–*17*, *23*). We adopted a multi-phase approach for survey implementation, comprising pretesting, a pilot survey, and a main survey. The questionnaire was uploaded to the online platform, SurveyEngine (*24*), and underwent internal pretesting. A pilot survey was conducted with a small group of fleet operators to test the questionnaire. Based on the feedback, the main survey questionnaire was refined and improved. We prepared both English and Spanish versions of the questionnaire to accommodate comprehensive respondents.

For this study, we selected survey items from the Basic Fleet Information, Fleet Management Practices and Strategies, and Perceptions sections to address the research questions. In the Perceptions sections, a set of Likert scale (*25*) statements was provided with various categories of technology characteristics, such as monetary costs, environmental benefits, operational compatibility, charging/refueling accessibility, and operational reliability for trucks and fuels. These categories were selected based on our previous research (*15*), which developed a framework for alternative fuel adoption decisions in heavy-duty vehicle fleets using existing literature and theories (*20*), and qualitative analyses of fleet interviews. For each category, three statements were typically included, and respondents were asked to provide ratings for BET (or electricity as a fuel) and HFCET (or hydrogen) separately on a 7-point scale: 1 (completely disagree), 2 (disagree), 3 (somewhat disagree), 4 (neutral), 5 (somewhat agree), 6 (agree), and 7 (completely agree). In addition to these, the selected items included basic fleet details, such as fleet size, annual revenue, and fuel types, self-assessed knowledge level on ZEVs, awareness of the ACF policy, and business strategies in response to the policy. The survey items were structured in single/multiple-option, rating scale, and open-ended formats. Table 1 outlines the selected survey items, their answer options, scale statements, and types.

TABLE 1. List of Selected Survey Items and Response Options

Category	**Item**	**Answer options / Statement for scale items**	**Type** (a)
Basic fleet information	Fleet size (trucks)	1; 2-5; 6-10; 11-20; 21-49; 50-99; 100+	S
	Approximate annual revenue	Less than \$10M; Between \$10M and \$15M; Between \$15M and \$30M; More than \$30M; Decline to state	S
	Fuel types	Diesel; Biodiesel; Renewable diesel; Gasoline; Compressed natural gas; Liquefied natural gas; Propane; Electricity (battery electric truck); Hydrogen (fuel cell electric truck); Ethanol; Others (Please specify)	M
Awareness of ZEV technology and policy	Self-assessed knowledge level on ZEVs (BET and HFCET, separately)	I, or key decision-makers in our organization, have sufficient knowledge regarding zero-emission trucks and fuels.	Rating scale item (b)
	Awareness of the ACF policy	Yes, I am fully aware of this policy; I have heard about this policy, but have limited knowledge; No, I am completely unaware of this policy.	S
Perceptions on ZEVs (BET and HFCET, separately)	Acceptable monetary costs	• The total cost of ownership of ZE trucks is acceptable today, considering both procurement and operational costs. • The procurement costs of ZE trucks are higher than traditional diesel trucks. (reversed) • Using a zero-emission fuel could potentially result in cost savings in our organization.	Likert scale (b)
	Environmental benefits	• The use of ZE fuels is important for protecting the climate. • The use of ZE fuels is important for helping to reduce local air pollution. • Replacing diesel trucks with ZE trucks would be beneficial to our environment in the long term.	Likert scale

Category	**Item**	**Answer options / Statement for scale items**	**Type** (a)
	Operational compatibility	• A ZE truck can satisfy my organization's operational requirements. • A ZE truck can be sufficient for our operations, for example, in terms of driving range, top speed, power, payload, and duty cycle. • We believe that ZE trucks can serve our operational needs at least as well as diesel trucks.	Likert scale
	Charging / refueling accessibility	• Our organization has sufficient accessibility to charging/refueling facilities for ZE truck operation. • Charging/refueling ZE trucks presents logistical challenges, such as difficulties with fleet scheduling. (reversed) • We think the construction of charging/refueling infrastructure for ZE trucks as a straightforward process.	Likert scale
	Truck reliability	• A ZE truck has an acceptable level of safety and reliability. • A ZE truck is generally more reliable than a diesel truck, with fewer occurrences of component malfunctions or other reliability issues. • A ZE truck drivetrain is at least as reliable as conventional diesel.	Likert scale
	Stable supply of fuel	• The supply of ZE fuel is expected to be stable. • We are concerned about disruptions to fuel security caused by natural disasters or geopolitical events. (reversed)	Likert scale
Business plans in response to ZEV Regulations	Overall business plans in response to ACF	We will continue our drayage business in California; We will move to another state to continue our drayage business without being subject to the mandate; We will discontinue our drayage business.	S
	Specific business strategies under ACF (c)	We are making preparations in procuring ZEVs to be compliant with the ZEV mandate; We will delay the procurement of ZEVs as long as possible; We do NOT intend to procure ZEVs and will stay in the business as long as possible with only non-ZEV trucks; Others (Please specify)	S
	Specific fleet management strategies under ACF	*A text box provided for free answer*	(O)
Free comments	Any final comments regarding the topics covered in this survey	*A text box provided for free answer*	(O)

Note: (a) S = single-option selection question. M = multiple-option selection question. O = open-ended question. ( ) = optional question. (b) For Likert scales and single scale items, a 7-point scale was provided, ranging from 1 (completely disagree) to 7 (completely agree). (c) This question was asked only to respondents who indicated they planned to continue their business in California.

Sampling and Recruitment

The target population for our study comprised drayage fleet operators at the Port of Los Angeles (POLA) and Port of Long Beach (POLB) in California. In 2019, approximately 22,500 drayage trucks were operating in California (*26*), with about 75% at POLA and POLB and the remaining 25% at other ports (*26*). Although full registration data were inaccessible, according to POLA's June 2023 analysis (*10*), 72.5% (810 out of 1,117) of drayage companies accessing the port were small fleets with 20 or fewer trucks, and 27.5% (307) were large fleets with more than 20 trucks. Most of the drayage trucks at POLA (94.3%) operated on diesel, while 5.2% used natural gas and 0.5% used electricity.

We aimed to collect 60 to 100 valid responses, based on previous studies (*11*, *27*), with about 10% of this sample targeted for the pilot survey. Stratified random sampling was used for the pilot survey to ensure a balance between subpopulations across fleet size and alternative fuel adoption status. For the main survey, the census method was employed, which involves contacting all potential participants within the target population, to ensure an adequate sample size. Invitations were sent via email using the POLA/POLB drayage truck registries, which contain about 3,200 fleet operator contacts (*28, 29*). A $100 Amazon eGift card was offered to valid respondents, unless declined. All study materials and survey protocols were processed by the Institutional Review Board of the University of California, Irvine.

Participants completed the pilot survey in July 2023 and the main survey from December 2023 to April 2024. A total of 108 companies responded positively to the initial invitations (3.4%) and 71 completed the survey with valid responses (2.2%). The survey completion allowed for single or multiple sittings to accommodate flexibility. The average completion time was 41 minutes for one sitting (59 respondents) or 4.4 days for multiple sittings (12 respondents). After excluding a partial response from the subset of the survey data related to this work, 70 completed responses were used for analysis. The characteristics of the participating fleets are summarized in Table 2.

Data Analysis Methods

To address the research questions, we employed a comprehensive exploratory analysis using various approaches. For the survey items with single/multiple-choice questions and Likert scales, we first performed a descriptive analysis to understand an overview of the responses and observe any patterns or trends. Basic summary statistics were generated, accompanied by various charts and graphs. For the analysis of Likert scale data, we followed the guidance provided by Harpe (*25*), including treating aggregated rating scales as continuous data. Subsequently, we further examined the data to identify potential differences between small and large fleets. To examine these differences statistically, we conducted hypothesis tests, including *t*-test, Mann-Whitney U test, Levene's test, Chi-Square test, and Fisher's exact test (*30*).

For the analysis of text responses in open-ended questions, we employed thematic analysis (*31*) as a qualitative research approach, following Braun and Clarke (*32*)'s six-phase approach: familiarizing with the data, generating initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the report. Through this process, we coded the qualitative data, extracted patterns, and identified themes to address the research questions.

TABLE 2. Basic Characteristics of Participating Fleets

Category	Number of fleets	%	Category	Number of fleets	%
Fleet size (a)			**Fuel adoption status** (b, c)		
Small fleet (≤20 trucks)	**49**	**70.0%**	Non-NGV-ZEV fleets	**51**	**72.9%**
1	2	2.9%	Diesel trucks only	42	60.0%
2 - 5	18	25.7%	Biodiesel adopters	8	11.4%
6 - 10	18	25.7%	Renewable diesel adopters	7	10.0%
11 - 20	11	15.7%	NGV adopters	**14**	**20.0%**
Large fleet (> 20 trucks)	**21**	**30.0%**	CNG adopters	11	15.7%
21 - 49	11	15.7%	LNG adopters	4	5.7%
50 - 99	4	5.7%	ZEV adopters	**11**	**15.7%**
≥ 100	6	8.6%	BET adopters	11	15.7%
Approximate annual revenue			HFCET adopters	4	5.7%
< $10M	39	55.7%			
$10M - $15M	8	11.4%			
$15M - $30M	5	7.1%			
> $30M	7	10.0%			
Decline to state	11	15.7%	**Total**	**70**	**100.0%**

Note: (a) The criterion defining a small vs large fleet was informed by CARB's Innovative Small E-Fleet program. (*9*). (b) ZEV = zero-emission vehicle, BET = battery electric truck, HFCET = hydrogen fuel cell electric truck, NGV = natural gas vehicle, CNG = compressed natural gas, LNG = liquefied natural gas. (c) The sum of each adopter category may exceed 100% as some fleets adopted multiple fuel types.

RESULTS AND DISCUSSION

Characteristics of Participating Fleets

To characterize the participating drayage fleets, we analyzed survey responses from the Basic Fleet Information section, including fleet size, annual revenue, and fuel technologies used (see Table 2). Fleet sizes ranged from 1 truck to over 100 trucks. To facilitate subsequent analyses, we categorized these diverse fleet sizes into two groups, following the definitions used in (*9*): small fleets with 20 trucks or fewer, comprising 70% of survey participants, and large fleets with over 20 trucks, representing 30%. In terms of annual revenue, slightly more than half the companies (56%) reported revenue below $10 million, and 11% reported revenue between $10 and $15 million. Companies with annual revenue above $15 million accounted for 17%, and 16% did not disclose their revenue.

We define "adopters" as companies that have adopted at least one truck using an alternative fuel in their fleets. Among the 70 participating fleets, 40% were adopters of alternative fuel trucks (including gaseous and/or zero-emission fuels), while 60% operated solely with diesel trucks. Specifically, 20% operated natural gas trucks, 16% operated BETs, 6% operated HFCETs, 11% utilized biodiesel, and 10% utilized renewable diesel.

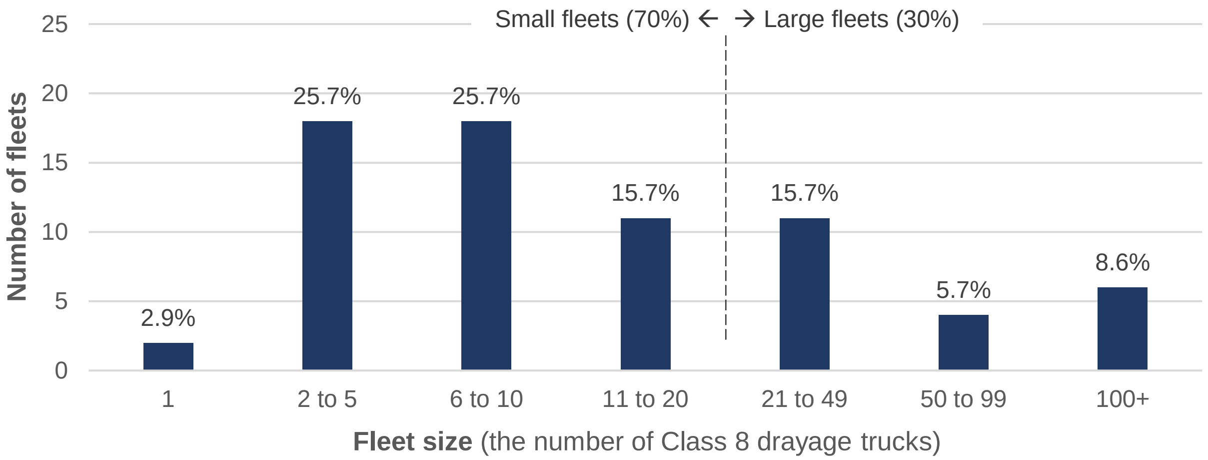
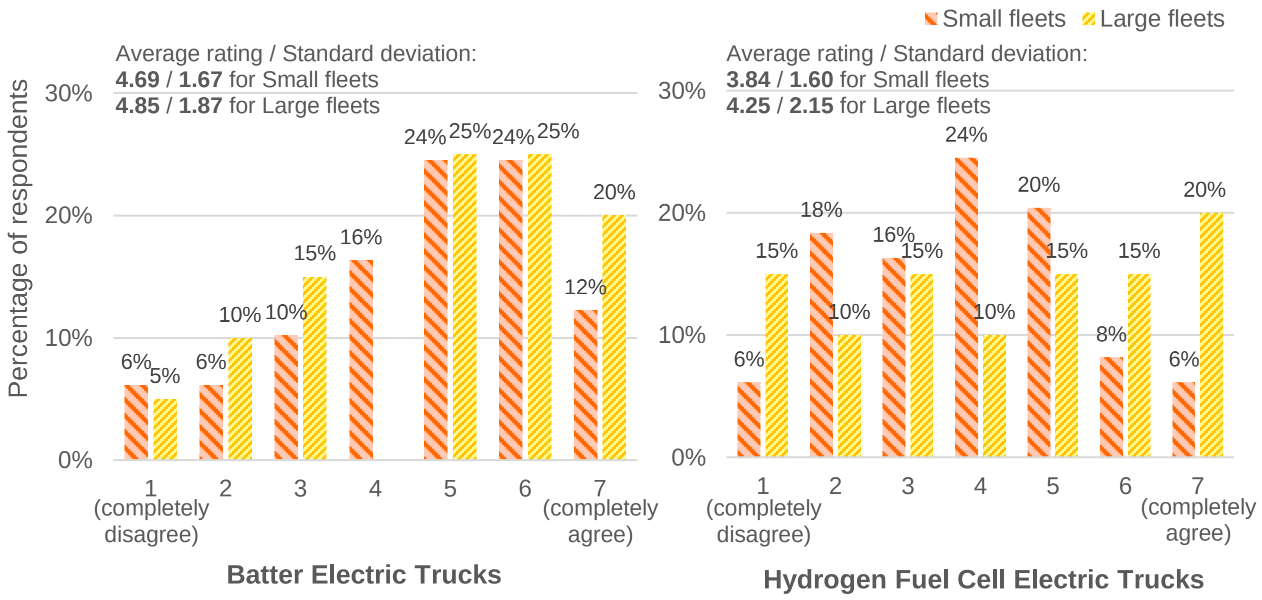


FIGURE 1. Distribution of Fleet Sizes among Participating Fleets

Awareness of ZEV Technologies and ACF Policy

To address the first research question ("How do small and large fleets perceive their levels of awareness of ZEV technologies and the ACF policy?"), we analyzed relevant survey data by comparing the responses between small and large fleets. Figure 2 presents the distribution of responses to the 7-point rating scale item on the statement, "I, or key decision-makers in our organization, have sufficient knowledge regarding zero-emission trucks and fuels." On average, both segments rated their BET knowledge levels close to 5 points (between neutral and somewhat agree) and their knowledge of HFCETs around 4 points (neutral). Small fleets tended to report lower self-assessed knowledge levels compared to large fleets, both for BETs (4.69 vs. 4.85) and HFCETs (3.84 vs. 4.25). However, the Mann-Whitney U test results showed no significant differences between the two groups (p-values > 0.05). Table 3 summarizes all hypothesis test results for this study, including this comparison.

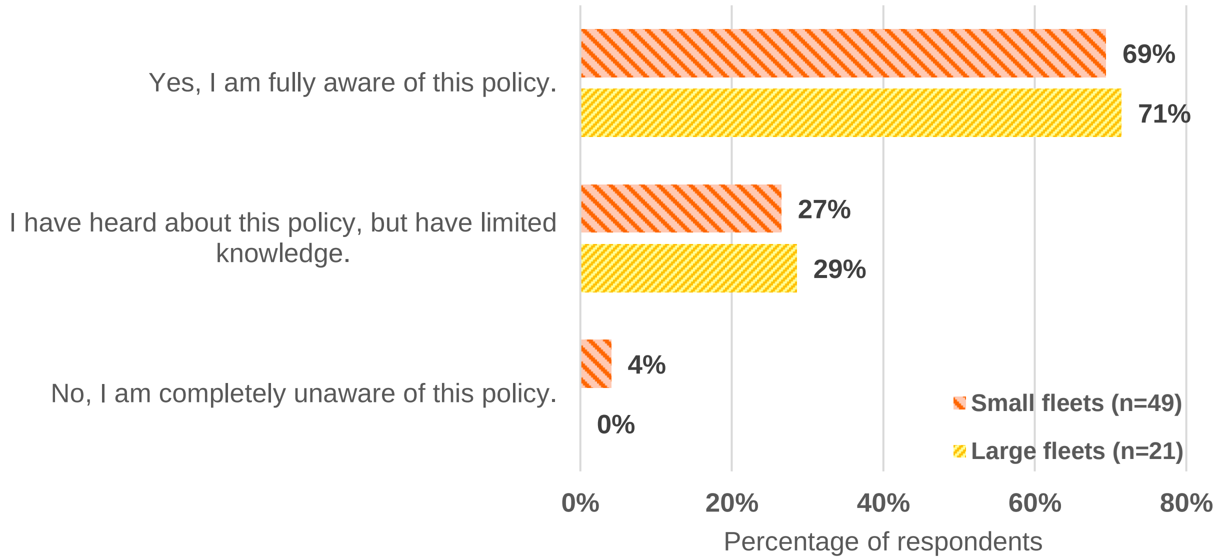


Note: The ratings indicate the level of agreement on a scale from 1 (completely disagree) to 7 (completely agree) with the statement: "I, or key decision-makers in our organization, have sufficient knowledge regarding zero-emission trucks and fuels."

FIGURE 2. Distribution of Self-assessment of Knowledge on ZEVs between Small and Large Fleets

Self-assessed knowledge levels varied widely for both BETs and HFCETs, ranging from 1.0 (completely disagree) to 7.0 (completely agree), across both fleet sizes. The standard deviations of these ratings were similar for BETs between small fleets (1.67) and large fleets (1.87). In contrast, for HFCETs, the standard deviation was higher for large fleets (2.15) compared to small fleets (1.60). Levene's test for homogeneity of variance revealed a significant difference in the variance of knowledge levels for HFCETs between small and large fleets (p-value < 0.05) (see Table 3). Overall, these findings suggest the importance of outreach efforts for both small and large fleets to increase their knowledge on ZEVs, with particularly tailored efforts for small fleets regarding HFCETs.

Figure 3 illustrates the frequency distributions of responses to the survey item on awareness of the ACF policy. Approximately 70% of both small and large fleets reported being fully aware, while about 30% indicated having heard of the policy but possessing limited knowledge. Notably, 4% of small fleets reported complete unawareness of the policy. Meanwhile, Fisher's exact test indicated no statistically significant differences between small and large fleets (Table 3). It is important to note that the survey participants, by their willingness to engage in this study, were likely to have a higher interest in ZEV policies, which could have potentially underestimated the population proportion with limited knowledge or complete unawareness of the policy. The results imply the need for more proactive outreach and educational efforts to enhance ZEV policy awareness among fleets.



Note: The survey question reads as follows: 'The California Air Resources Board has approved the implementation of the ZEV mandate in the drayage sector under the Advanced Clean Fleets regulation, starting in January 2024. Are you aware of this policy?'

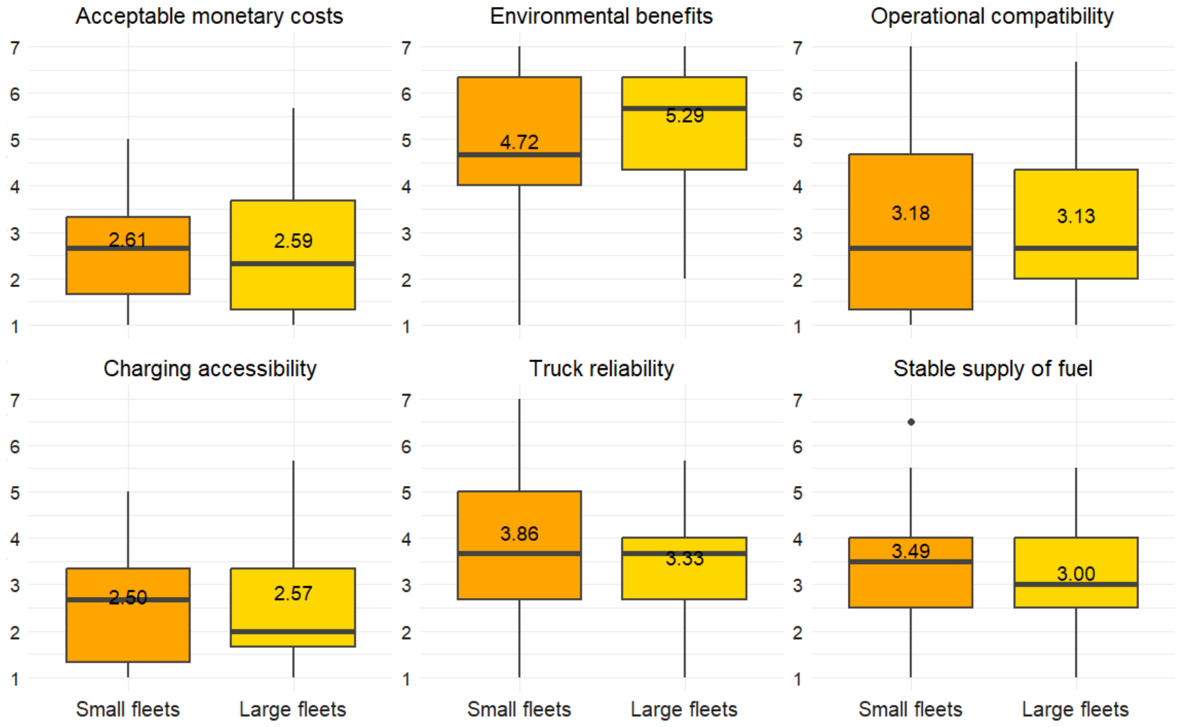
FIGURE 3. Awareness of the Advanced Clean Fleet Policy between Small and Large Fleets

Perspectives on ZEVs between Small and Large Fleets

To explore the second research question ("What perceptions do small and large fleets hold regarding ZEV technologies? Are their perceptions similar or different across BETs and HFCETs?"), we analyzed survey data related to ZEV perceptions. Using the Likert scale data, we derived aggregated mean ratings for six categories of technology characteristics: *Acceptable monetary costs*, *Environmental benefits*, *Operational compatibility*, *Charging/refueling accessibility*, *Truck reliability*, and S*table fuel supply*. Figures 4 and 5 present box plots comparing these mean ratings between small and large fleets. Furthermore, thematic analysis of text responses to open-ended questions revealed themes related to ZEV perceptions, which are summarized in Figure 6.

As shown in Figure 4, both small and large fleets, on average, rated *Environmental benefits* of BETs positively (above 4 points, neutral), with averages of 4.72 for small fleets and 5.29 for large fleets. However, all other technology categories received negative ratings (below 4 points). Small fleets rated *Truck reliability* closest to neutral (3.86), followed by *Stable supply of fuel* (3.49) and *Operational compatibility* (3.18), indicating scores between neutral and somewhat disagree. More negative ratings were for *Acceptable monetary costs* (2.61) and *Charging accessibility* (2.50), between somewhat disagree and disagree. Large fleets exhibited a similar hierarchy of mean ratings. The least negative rating was for *Truck reliability* (3.33), followed by *Operational compatibility* (3.13) and *Stable supply of fuel* (3.00). More negative ratings were given for *Acceptable monetary costs* (2.59) and *Charging accessibility* (2.57), similar to small fleets. These mean ratings indicate considerable concerns across various technological aspects held by both small and large fleets regarding BETs.

When comparing the two groups, slight differences in mean ratings were observed, with differences up to 0.56 points. For instance, large fleets perceived *Environmental benefits* more positively than small fleets, while small fleets were slightly less concerned about *Truck reliability*. However, the Mann-Whitney U test and *t*-test indicated no statistically significant differences between small and large fleets (Table 3).



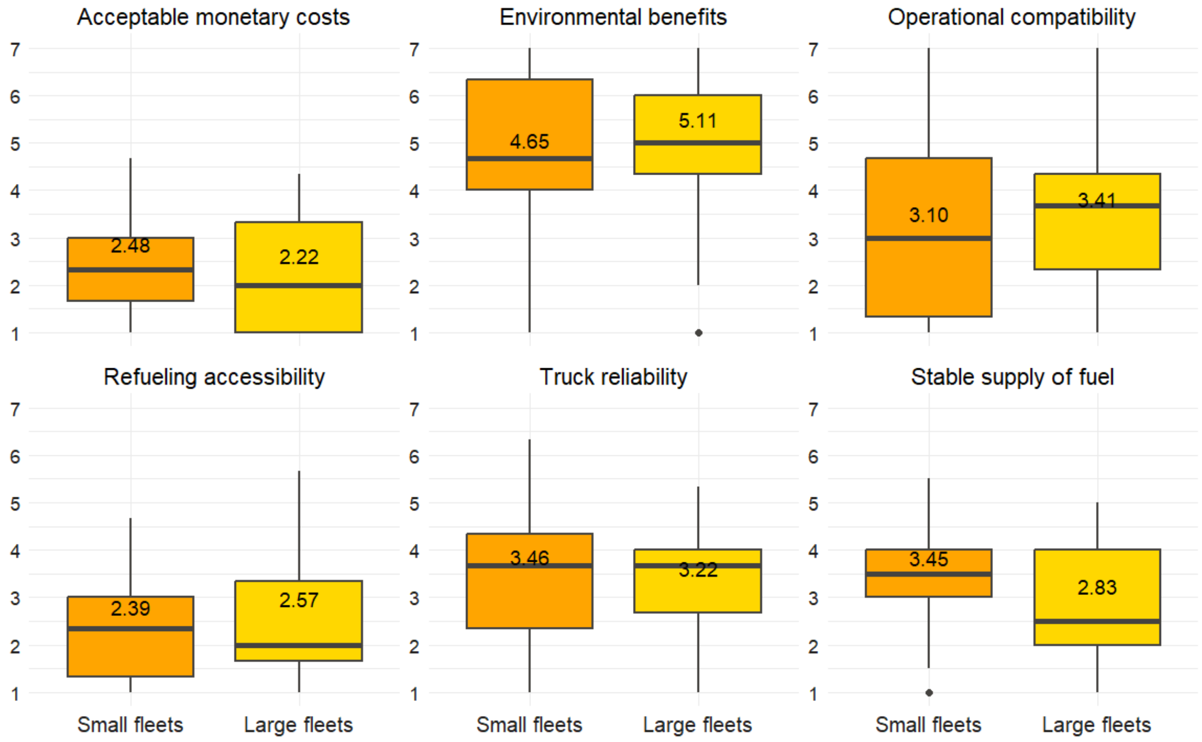
Note: The numbers within the boxes indicate average ratings.

FIGURE 4. Comparison of BET Perceptions between Small and Large Fleets

Meanwhile, the box plots provided insights into the distribution of ratings. For small fleets, *Operational compatibility* exhibited the widest interquartile range (IQR = 3.33), indicating a broader dispersion in ratings. Conversely, *Stable fuel supply* had the narrowest IQR (1.50), indicating more concentrated ratings. For large fleets, the longest IQRs were found in *Operational compatibility* and *Acceptable monetary costs* (2.33 each), while *Truck reliability* had the shortest (1.33). In addition, the upper whiskers for *Operational compatibility* were the longest in both groups, suggesting that the upper 25% of ratings were more varied (from slightly above neutral to completely agree). This variation could indicate distinct operational characteristics across fleets, leading to varied BET compatibility ratings.

Environmental benefits showed the longest lower whiskers in both segments, indicating the lower 25% of ratings were more dispersed (from slightly above neutral to completely disagree). This could reflect different levels of skepticism about environmental benefits among fleet operators. Overall, similarities were often observed in the BET perception distribution between small and large fleets. Levene's test results confirmed no significant differences in variances between the two groups.

Figure 5 presents box plots illustrating small and large fleet perceptions on the technology categories for HFCETs. Similar to their perceptions of BETs, both segments rated *Environmental benefits* of HFCETs positively on average, while rating other technology aspects negatively. Small fleets' mean ratings across categories for HFCETs mirrored the patterns for BETs, though slightly lower. Large fleets exhibited slightly different patterns for HFCETs compared to BETs. For instance, *Operational compatibility* had the least negative mean rating, while *Acceptable monetary costs* received the most negative rating. Differences in mean ratings between these segments were up to 0.62 points, but Mann-Whitney U test and *t*-test indicated no significant differences (Table 3). For rating distributions, larger IQR differences were observed between small and large fleets for HFCETs compared to BETs. For instance, *Operational compatibility* had an IQR difference of 1.33 for HFCETs (versus 1.00 for BETs), and *Stable fuel supply* had an IQR difference of 1.00 for HFCETs (versus 0.00 for BETs). Levene's test indicated significant variance differences for *Operational compatibility* (p-value < 0.1) and *Stable supply of fuel* (p-value < 0.01) between the two groups (Table 3).

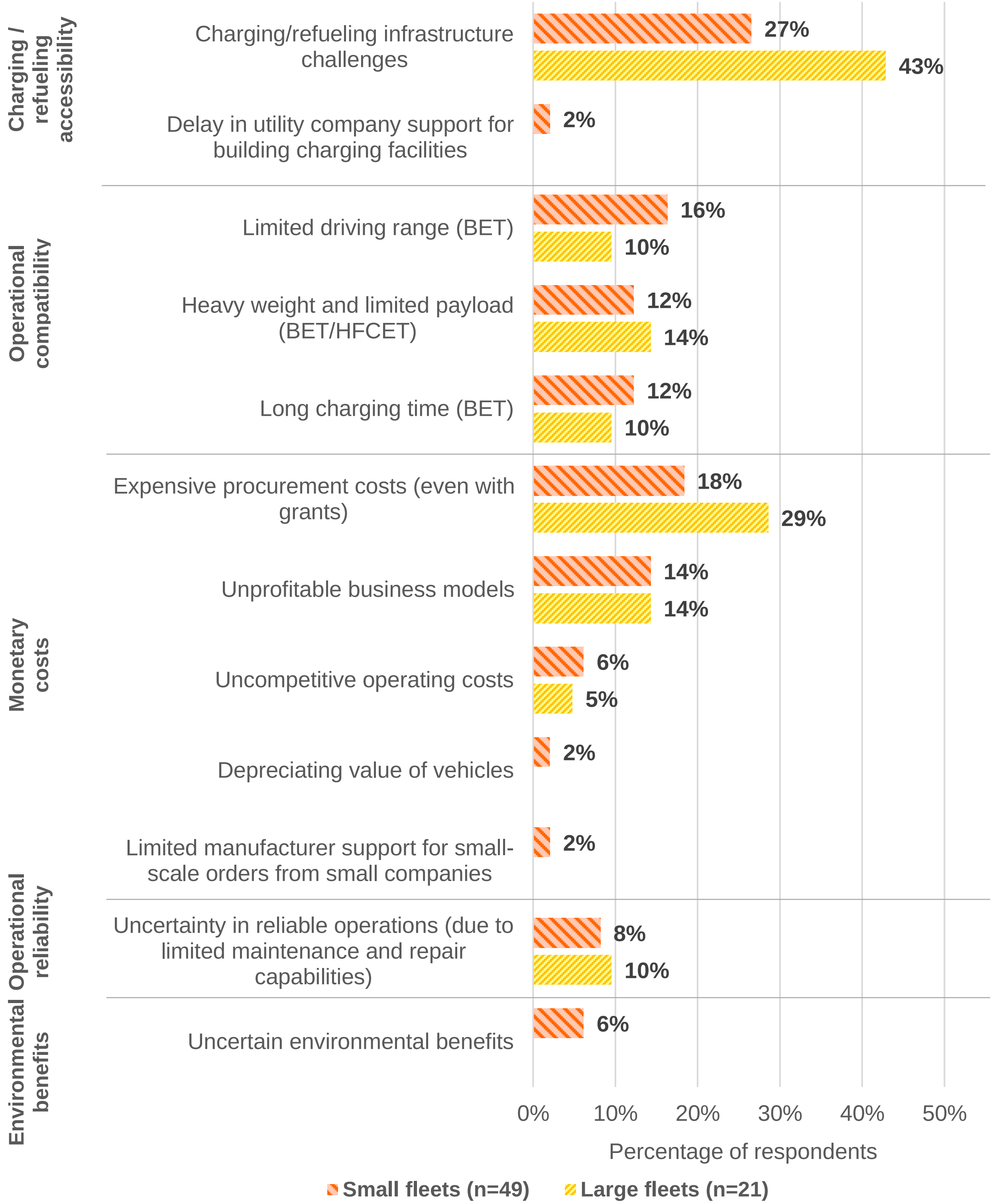


Note: The numbers within the boxes indicate average ratings.

FIGURE 5. Comparison of HFCET Perceptions between Small and Large Fleets

An in-depth exploration of fleet perceptions on ZEVs was conducted using thematic analysis based on text responses. Identified themes were categorized and compared between small and large fleets, as shown in Figure 6. These qualitative findings not only align with the Likert scale data analysis but also provide detailed evidence that reinforces the findings. Only the key points are discussed below.

- **Charging/refueling infrastructure** – The most prominent adoption barrier, reported by 27% of small fleets and 43% of large fleets, was challenges encountered with charging/refueling infrastructure. One small fleet operator emphasized the importance of infrastructure, stating, "*Operation costs nor price of the vehicle is not the criteria for us to choose which vehicle to purchase. Refueling accessibility is most important factor for our operation*." However, many fleets described facing "*too many bottlenecks*" in building the infrastructure, citing issues such as costs, processes, and utility company support: "*Even if we had fund, electric company can't install until they are ready*."
- **Operational compatibility** – Issues related to operational compatibility were highlighted by similar fractions of small and large fleets (10-16%). For BETs, limited driving range, heavy weight and limited payload, and long charging time were raised as "*huge problems*." One large fleet, who adopted BETs, remarked on an overstated range of BETs: "*I KNOW ppl are telling us these trucks are good for 300+ miles, but it's just not true. Today's electric truck range is determined by weight, hills, so on*." Other fleets mentioned that the limited range, limited payload, and long charging times required them to "*need two/three BETs to replace one diesel truck to match the diesel truck's output*." For HFCETs, the heavy weight was a concern, but range/fueling time issues were not reported.
- **Monetary costs** – Financial concerns were also frequently addressed, with up to 18% of small fleets and 29% of large fleets, highlighting issues such as high procurement costs and operating expenses. Many fleets also stated that the compatibility issues discussed earlier (e.g., needing 2-3 BETs to replace 1 diesel truck) would render their business unprofitable. One small fleet elaborated: "*We see our cost tripling […] acquisition costs are significantly above those for a comparable diesel truck [...] operational cost will be very high due to the learning curve to familiarize with the true capabilities of the truck [trucks would] get towed back to base facility significantly initially [...] the worst part is that we would need to purchase 2 electric trucks to produce the same output as one diesel truck (The true costs are: two registration fees, two insurance policies, two parking spots, […])*"
- **Operational reliability** – Concerns about reliable operations of ZEVs were expressed by 8-10% of small and large fleets. They especially noted situations requiring repairs and dealing with out-of-order vehicles, which could impact their business: "*How long does it take to repair an EV vs a diesel truck? And while it is out of service you still have to make payments that are very high.*"
- **Environmental benefits** – Furthermore, some small fleet operators were skeptical about the environmental benefits of ZEVs. Concerns included potential environmental hazards from battery disposal, and uncertain life cycle emissions: "*I am uncertain about the extent of pollution and emissions associated with generating electricity and hydrogen. When factoring in all emissions related to energy production, does ZEV still remain the best solution*?"



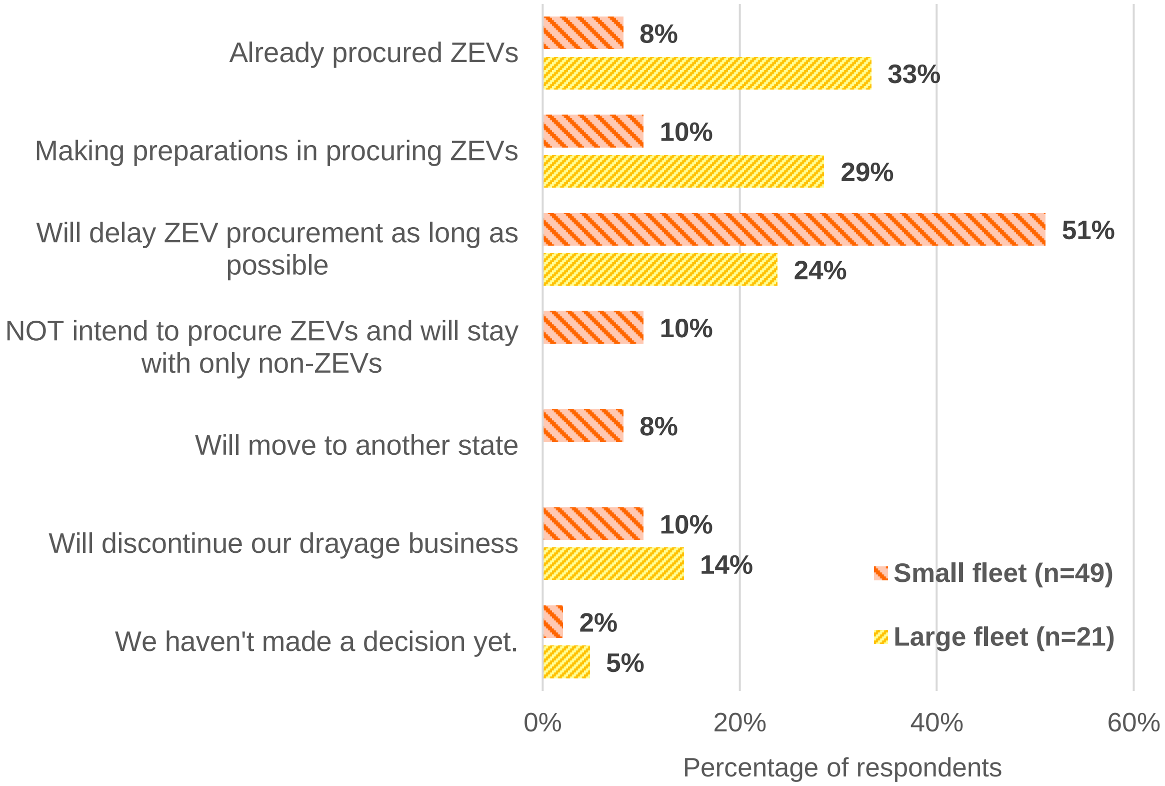
Note: The text responses were obtained from two open-ended questions: 1) ‘Considering the ZEV mandate beginning in January 2024, what strategies do you anticipate utilizing to manage your fleet in coming years?’ and 2) ‘This is the final question in this survey. Before concluding, is there anything you would like to share regarding the topics covered in this survey?’

FIGURE 6. Qualitative Remarks on Perspectives on ZEV technologies between Small and Large Fleets

Perspectives on ACF Policy between Small and Large Fleets

To investigate the third research question ("How do small and large fleets respond to the ACF regulation in terms of business plans, and what are their perceptions of the policy?"), we analyzed the related data, including items about business plans in response to the ACF regulation and text responses to the final survey comments. Figure 7 depicts the distribution of their business plans for responding to the policy, comparing small and large fleets. The figure shows distinct differences between these two segments. A third of large fleets reported that they have 'already procured ZEVs' (33%), whereas only 8% of small fleets had adopted ZEVs. In addition, those 'making preparations to procure ZEVs' were more prevalent among large fleets (29%) than small fleets (10%).

Negative responses were more frequently observed among small fleets. About half the participating small fleets (51%) indicated they would 'delay ZEV procurement as long as possible,' while about a quarter of large fleets (24%) reported this plan. Moreover, 10% of small fleets stated they were 'not intending to procure ZEVs and staying with only non-ZEV trucks,' a stance not seen among large fleets. Furthermore, some small fleets (8%) decided to 'move to another state to operate without being subject to the mandate,' whereas no large fleets chose this option. Meanwhile, some small (10%) and large fleets (14%) reported their plans to 'discontinue drayage business.' To statistically assess the relationship between fleet size and business plans under the ACF regulation, Fisher's exact test was performed. The results yielded a p-value of 0.0097, confirming significant differences between these two groups (see Table 3).

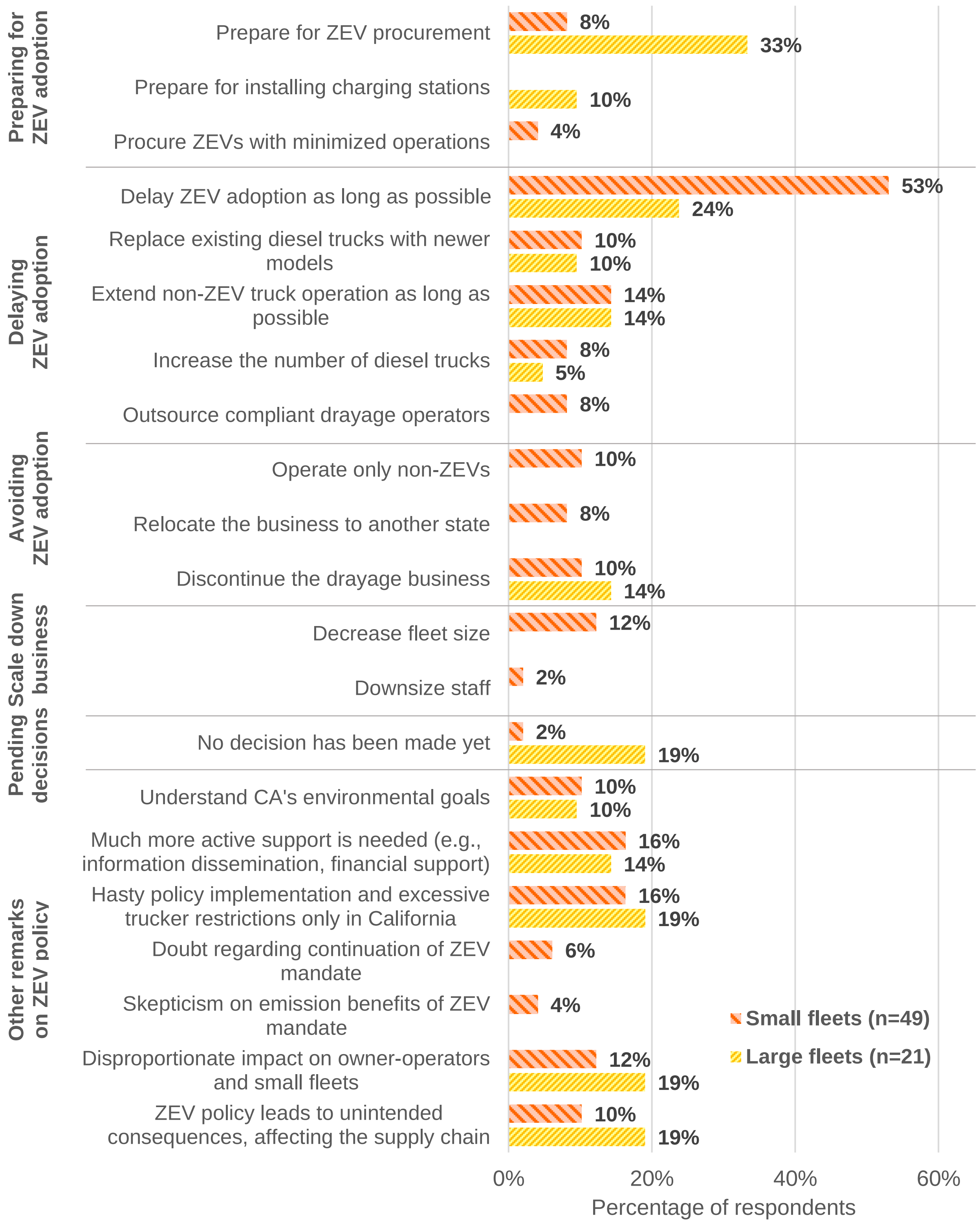


Note: The responses were obtained from one survey question about fuel technologies in use, and two questions regarding business plans in response to ZEV regulations. The latter questions asked: 1) 'How do you expect your business to respond to this ZEV mandate?' and 2) 'Which among the following would best describe your strategy regarding ZEV procurement?'

FIGURE 7. Business Plans in response to ACF Policy between Small and Large Fleets

The thematic analysis summarized in Figure 8 provides detailed insights into the specific fleet management strategies and broader opinions on the ZEV policy. Although numerous themes were identified, this discussion focuses on several key aspects below.

- **Preparing for ZEV adoption** – The approaches to preparing for ZEV adoption differed between small and large fleets. Large fleets were preparing to install charging facilities, aiming to be "*one of the first with an extensive charging infrastructure*." In contrast, small fleets reported their plans to limit operations of BETs, after acquisition, due to concerns about the restricted range.
- **Delaying ZEV adoption** – Various strategies for delaying ZEV adoption were reported by both small and large fleets. These included replacing existing diesel trucks with newer models, extending the operation of non-ZEV trucks, increasing the diesel truck fleet, and outsourcing to compliant operators. One fleet operator explained, "*We have replaced a few trucks with newer model units with lower mileage so they can [be] operated for a long period of time and remaining compliant per the ZEV mandate*."
- **Avoiding ZEV adoption** – Small fleets, especially, detailed their strategies to avoid adopting ZEVs. For example, one operator stated, "*We will run diesel as long as we are able. Once we have exhausted the diesel option we will either leave the trucking business or decrease our fleet, depending on the trucking climate at that time*."
- **Disproportionate impact on owner-operators and small fleets** – Approximately a third of the participating fleets, with both small and large fleets, expressed concerns that the ZEV regulation would disproportionately affect smaller fleets. One remarked, "*It is very hard for small fleet to afford the huge costs transferring to zero emissions. Eventually, the very small fleet will be gone and the drayage market will be shared by the big companies which has the capital and land to adopt the new policies.*" Another pointed out equity issues among fleets, explaining, "*[...] Its apparent that equity and equality are less important than climate policy. The only 'success' stories everyone keeps throwing out there are large trucking companies or [those who] were very lucky and got carried across the finish line by a TAAS [Truck-as-a-Service] company. There is no legitimate path for the less fortunate*."
- **ZEV policy leads unintended consequences, affecting supply chain** – Given that small fleets represent a substantial portion of California's drayage trucking sector, the participating fleets voiced concern about the policy's potential impact on these businesses and the broader supply chain: "*We believe that these regulations will shrink California's capability to move containers for the largest ports in the world [...]*"
- **Much more active support is needed** – Consequently, fleet operators were calling for more substantial support. One large fleet remarked, "*We should be gradually changing as charging stations and truck prices become more accessible for the majority of small trucking companies*." In addition, small fleets expressed a need for enhanced support, both in terms of financial aid (e.g., existing fees and charge exceptions) and improved communication: "*We are not informed properly. I would need to be informed better and make a decision according to the new regulations*."



Note: The text responses were obtained from two open-ended questions: 1) 'Considering the ZEV mandate beginning in January 2024, what strategies do you anticipate utilizing to manage your fleet in coming years?' and 2) 'This is the final question in this survey. Before concluding, is there anything you would like to share regarding the topics covered in this survey?'

FIGURE 8. Qualitative Remarks on Perspectives on ZEV Policy between Small and Large Fleets

TABLE 3. Summary of Hypothesis Test Results for Differences between Small and Large Fleets

Null hypothesis (H_0)	**BET / HFCET**	**Type of test (a)**	**p-value**	**Rejection of H_0 (b)**
Self-assessed knowledge levels on ZEVs				
H_0: There is no difference in the distributions of self-assessed knowledge levels between small and large fleets.	BET	Mann-Whitney U test	0.595	Not rejected
	HFCET	Mann-Whitney U test	0.406	Not rejected
H_0: There is no difference in the variances of self-assessed knowledge levels between small and large fleets.	BET	Levene's test	0.580	Not rejected
	HFCET	Levene's test	0.030	*Rejected***
Awareness of ACF policy				
H_0: There is no difference in the level of awareness of the ACF policy between small and large fleets.	n/a	Fisher's exact test	1.000	Not rejected
Perceptions on ZEVs				
H_0: There is no difference in the distribution of perceptions regarding *Acceptable monetary costs* between small and large fleets.	BET	Mann-Whitney U test	0.728	Not rejected
	HFCET	Mann-Whitney U test	0.287	Not rejected
H_0: There is no difference in the distribution of perceptions regarding *Environmental benefits* between small and large fleets.	BET	Mann-Whitney U test	0.284	Not rejected
	HFCET	Mann-Whitney U test	0.406	Not rejected
H_0: There is no difference in the distribution of perceptions regarding *Operational compatibility* between small and large fleets.	BET	Mann-Whitney U test	0.949	Not rejected
	HFCET	Mann-Whitney U test	0.503	Not rejected
H_0: There is no difference in the distribution of perceptions regarding *Charging/refueling accessibility* between small and large fleets.	BET	Mann-Whitney U test	0.995	Not rejected
	HFCET	Mann-Whitney U test	0.727	Not rejected
H_0: There is no difference in the mean ratings of perceptions regarding *Truck reliability* between small and large fleets.	BET	*t*-test	0.186	Not rejected
	HFCET	*t*-test	0.491	Not rejected
H_0: There is no difference in the distribution of perceptions regarding *Stable supply of fuel* between small and large fleets.	BET	Mann-Whitney U test	0.122	Not rejected
	HFCET	Mann-Whitney U test	0.078	*Rejected**
H_0: There is no difference in the variances of perceptions on *Operational compatibility* between small and large fleets.	HFCET	Levene's test (c)	0.089	*Rejected**
H_0: There is no difference in the variances of perceptions on *Stable supply of fuel* between small and large fleets.	HFCET	Levene's test	0.006	*Rejected****
Business plans in response to ACF policy				
H_0: There is no difference in the distribution of business plans in response to the ACF policy between small and large fleets	n/a	Fisher's exact test	0.0097	*Rejected****

Note: (a) Various statistical tests were performed to compare small and large fleets, based on the nature of the data and the fulfillment of specific assumptions. For continuous data that was assumed to follow a normal distribution (verified by the Shapiro-Wilk normality test) and showed homogeneity of variances (checked by Levene's test), the *t*-test was used. If the data was ordinal or did not meet the *t*-test assumptions, the Mann-Whitney U test was applied. For categorical data, both the Chi-squared test and Fisher's exact test were performed. This table reports only the results of Fisher’s exact test, as some contingency table cells had expected values of 5 or fewer, which could lead to inaccuracies in the Chi-squared approximation. (b) Rejection of the null hypothesis at the 1%, 5%, and 10% significance levels is indicated by ***, **, and *, respectively. (c) For the other categories of technology characteristics, with Levene’s test results not listed in this table, the tests yielded p-values above 0.1, suggesting that the null hypotheses were not rejected.

CONCLUDING COMMENTS

Understanding the perspectives of both small and large fleets on ZEV technologies and policy is crucial for obtaining a thorough understanding and recognizing equity issues in ZEV adoption. This study focused on California’s drayage sector, yielding numerous findings and policy implications. Both segments, on average, rated their ZEV knowledge as close-to-neutral, with about a third indicating limited awareness of the ACF policy. Both cited adoption barriers, particularly highlighting challenges with charging/refueling infrastructure, high costs, and operational incompatibility. Some small fleets also doubted environmental benefits. Business strategies under the ACF policy differed significantly: small fleets planned to delay or avoid ZEV procurement, with some considering relocation, while large fleets were more proactive, with many already having procured or preparing to procure ZEVs. Both segments voiced concerns about the disproportionate impact on small fleets.

Policy measures to address these issues may include reducing procurement costs, improving infrastructure access, providing financial aid, tailored outreach, and proactive communication. Our findings represent an initial step toward understanding equity issues in ZEV adoption across fleet segments and offer valuable insights for policymakers to facilitate a more equitable distribution of the impacts. This study has several limitations. First, it used self-reported awareness levels. More objective measures of knowledge and targeted evaluations of specific gaps could offer practical guidance. Second, the influence of ZEV perceptions on business strategies or adoption decisions was not explored. Integrating factor analysis of Likert scale data into such models could provide additional insights. Lastly, the scope was limited to California’s drayage sector. Exploring other HDV sectors could broaden our understanding of equity issues in ZEV adoption.

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AUTHOR CONTRIBUTION STATEMENT

The authors confirm contribution to the paper as follows: study conception and design: YB, SGR, and CRR; data collection: YB; analysis and interpretation of results: YB; draft manuscript preparation: YB. All authors reviewed the results and approved the final version of the manuscript.

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