A Sensitivity Analysis of Alternative Fuel Adoption in International Land Freight

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Abstract
The adoption of alternative fuels for hybrid heavy-duty trucks (HHDT) in international land freight along the Europe-Iran transit route is investigated in this paper. Six hundred-eighty-four international transport companies responded to a survey that revealed a Multinomial Logit (MNL) model examining economic, political, cognitive, environmental, and practical elements affecting alternative fuel adoption. According to marginal effect analysis, decisions are much influenced by alternative fuel pricing policies, infrastructure availability, cost savings, and safety enhancements. To improve the acceptance of sustainable fuels, the research underlines policy alignment between manufacturers and legislators (Burchart-Korol et al., 2020; Hovi et al., 2019).

Introduction
Land freight is expected to raise emissions by 2025 (Osieczko et al., 2021) and considerably adds to greenhouse gas (GHG) emissions. Proposed to lessen this impact are alternative fuels such Compressed Natural Gas (CNG), Liquefied Natural Gas (LNG), Electric Battery (BE), Hydrogen, and Biogas (Nguyen et al., 2021). Despite manufacturers' and governments' efforts, the alternative fuel truck (AFT) market share remains low (Anderhofstadt & Spinler, 2019, 2020).
With few studies examining international transit paths, existing research has mostly focused on urban freight (Sousa & Castañeda-Ayarza, 2022). Examining alternative fuel uptake in international land freight and investigating five types of influencing factors help this paper address this disparity (Giuliano et al., 2021; Müller, 2024).
The study aims to answer:

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- For HHDTs, what other fuel would transport firms like to use as an alternative?
- In what ways might cognitive, environmental, financial, policy, and pragmatic considerations affect alternative fuel choices?

The results offer ideas for overcoming adoption challenges, spotting incentives, and putting policies for AFT market growth into effect.

Methods

1. Survey and data gathering

Six thousand thirty-eight transportation firms spread over twenty countries—including Iran, Germany, France, and others—were surveyed. Using a five-point Likert scale, the questionnaire gauged firm background, fuel preference, and agreement with economic, environmental, and policy elements. The most often used fuel was diesel; CNG was the favored option (23% preferred BE, 14% Biogas, 5% LNG, 4% Hydrogen).

2- Multinomial Logit Model (MNL)

Discrete choice models and Multinomial Logit Model (MNL) is an appropriate mode choice modeling approach for categorical data. Each utility contains one dependent variable such as a specific mode choice, weighting parameters, and some independent variables (Greene & Hensher 2003). MNL model is also appropriate for choice behavior prediction (Jahaniaghdam et al., 2023). Effective factors on alternative fuel choice were analyzed using as MNL model with a 90% confidence interval. Companies' characteristics and likert scale variables were the independent variables. Following model generation, to answer the research questions, sensitivity analysis and elasticity was done. Elasticity consists of calculating changes in choice probability with every one percent change of each of the independent variables (Koppelman et al., 2006). In addition, the effect of 13 different scenarios on change share of alternative fuel choice were tested. In each meaningful scenario, a fixed value was considered for the independent variables to test the changes share of probabilities.

The MNL model approximated three different fuel group choice probabilities:

C1: CNG and LNG

C2: Electric Battery

C3: Hyrogen and biogas

Examined how independent variables affect decision probability using a marginal impact approach. Interaction effects were included into the second MNL model (Greene & Hensher 2003). Fuel price, refueling time, GHG emissions, hazardous cargo handling, and cost-effectiveness (Huin et al., 2021; Bae et al., 2022) were among the significant variables.

Results

1. MLN Model Results

The initial MNL model found important elements like driving range, gasoline cost, refuels time, and servicing cost. By including interaction terms, the second model enhanced explanatory ability. Important conclusions are:

- Shorter refueling durations and low GHG emissions from C1 (CNG & LNG) lessen acceptance. Important influences include economic ones like maintenance and servicing costs.

- Choice is influenced by perceived technical dependability, refueling safety, and service quality, or C2 (BE). Improved driving range and lower maintenance costs could boost acceptance (Konstantinou & Gkritza, 2023).
- C3 (Hydrogen & Biogas): Main issues include cost-effective pricing strategies and refueling safety.

2. Marginal Effect Study

Variable effectiveness was ranked by direct and cross-marginal impact analysis. Driving range, fuel pricing policies, and CO2 penalties particularly affected decision-making (Bridi et al., 2024). When choosing alternative fuels, companies give safety, operational efficiency, and economic viability first priority.

3. Scenario Analysis

Thirteen scenarios investigated how variations in perspective affected fuel choice.
Main conclusions:

- Shorter refueling times, less maintenance, and better performance all help BE adoption.
- Affordable pricing and safe refueling point to hydrogen and biogas.
- Service dependability and infrastructural availability (Zähringer et al., 2024) make CNG and LNG still preferable.

Examining Motivators and Obstacles for Adoption of Alternative Fuels: Results line up with earlier research stressing financial and pragmatic obstacles to acceptance of alternative fuels (Sugihara et al., 2024). Low maintenance costs, fuel availability, and technological dependability are what businesses value. Key motivators include infrastructure development, fuel pricing legislation, and tax incentives (Carboni et al., 2024).

Policy Implications

To promote adoption, governments might strengthen infrastructure and increase economic incentives—such as tax cuts and liability insurance discounts. Adoption of hydrogen and biogas could rise with safety rules and expanded refueling infrastructure (Bolz et al., 2024).

References:

Anderhofstadt, B., & Spinler, S. (2019). Factors affecting the purchasing decision and operation of alternative fuel-powered heavy-duty trucks in Germany – A Delphi study. Transportation Research Part D: Transport and Environment, 73, 87–107. https://doi.org/10.1016/j.trd.2019.06.003

Anderhofstadt, B., & Spinler, S. (2020). Preferences for autonomous and alternative fuel-powered heavy-duty trucks in Germany. Transportation Research Part D: Transport and Environment, 79, 102232. https://doi.org/10.1016/j.trd.2020.102232

Bae, Y., Mitra, S. K., Rindt, C. R., & Ritchie, S. G. (2022). Factors influencing alternative fuel adoption decisions in heavy-duty vehicle fleets. Transportation Research Part D: Transport and Environment, 102, 103150. https://doi.org/10.1016/j.trd.2021.103150

Bolz, S., Thiele, J., & Wendler, T. (2024). Regional capabilities and hydrogen adoption barriers. Energy Policy, 185, 113934. https://doi.org/10.1016/j.enpol.2023.113934

Bridi, R. M., Ben Jabra, M., Al Hosani, N., & Almurshidi, A. H. (2024). The propensity to adopt electric vehicles in the United Arab Emirates: An analysis of economic and geographic factors. Sustainability, 16(2), 770. https://doi.org/10.3390/su16020770

Burchart-Korol, D., Gazda-Grzywacz, M., & Zarębska, K. (2020). Research and prospects for the development of alternative fuels in the transport sector in Poland: A review. Energies, 13(11), 2988. https://doi.org/10.3390/en13112988

Carboni, M., Dall-Orsoletta, A., Hawkes, A., & Giarola, S. (2024). The future of road freight transport and alternative technologies: A case study for Italy. Energy Conversion and Management, 299, 117819. https://doi.org/10.1016/j.enconman.2023.117819

de Sousa, G. C., & Castañeda-Ayarza, J. A. (2022). PESTEL analysis and the macro-environmental factors that influence the development of the electric and hybrid vehicles industry in Brazil. Case Studies on Transport Policy, 10, 686–699. https://doi.org/10.1016/j.cstp.2022.01.030

Giuliano, G., Dessouky, M., Dexter, S., Fang, J., Hu, S., & Miller, M. (2021). Heavy-duty trucks: The challenge of getting to zero. Transportation Research Part D: Transport and Environment, 93, 102742. https://doi.org/10.1016/j.trd.2021.102742

Hovi, I. B., Pinchasik, D. R., Figenbaum, E., & Thorne, R. J. (2019). Experiences from battery-electric truck users in Norway. World Electric Vehicle Journal, 11(1), 5. https://doi.org/10.3390/wevj11010005

Huin, X., Loreto, M. D., Bideaux, E., & Benzaoui, H. (2021). Total cost of ownership optimization of a plug-in hybrid electric truck operating on a regional haul cycle. IFAC-PapersOnLine, 54, 284–289. https://doi.org/10.1016/j.ifacol.2021.10.177

Jahaniaghdam, T.; Mamdoohi, A.R.; Kheyrabadi, S.A.; Mehryar, M.; Ciari, F. Preferences for Alternative Fuel Trucks among International Transport Companies. *World* **2023**, *4*, 795–815, doi:10.3390/world4040050.

Koppelman, F.; Bhat, C.; AECOMConsult; University, N.; Administration, U.S.F.T. *A Self Instructing Course in Mode Choice Modeling: Multinomial and Nested Logit Models*; FTA, 2006.

Konstantinou, T., & Gkritza, K. (2023). Are we getting close to truck electrification? U.S. truck fleet managers' stated intentions to electrify their fleets. Transportation Research Part A: Policy and Practice, 173, 103697. https://doi.org/10.1016/j.tra.2023.103697

Müller, C. (2024). Transition to battery-electric and fuel cell heavy-duty trucks: A multi-level, multi-dimensional approach. Transportation Research Part D: Transport and Environment, 127, 104052. https://doi.org/10.1016/j.trd.2024.104052

Nguyen, D. K., Huynh, T. L. D., & Nasir, M. A. (2021). Carbon emissions determinants and forecasting: Evidence from G6 countries. Journal of Environmental Management, 285, 111988. https://doi.org/10.1016/j.jenvman.2021.111988

Osieczko, K., Zimon, D., Płaczek, E., & Prokopiuk, I. (2021). Factors that influence the expansion of electric delivery vehicles and trucks in EU countries. Journal of Environmental Management, 296, 113177. https://doi.org/10.1016/j.jenvman.2021.113177

Sugihara, C., Hardman, S., & Kurani, K. (2024). Who decides which trucks to buy? Implications for electrifying freight fleets. Transportation Research Part D: Transport and Environment, 126, 104015. https://doi.org/10.1016/j.trd.2023.104015

Zähringer, M., Teichert, O., Balke, G., Schneider, J., & Lienkamp, M. (2024). Optimizing the journey: Dynamic charging strategies for battery electric trucks in long-haul transport. Energies, 17(4), 973. https://doi.org/10.3390/en17040973