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Decarbonizing German Heavy-Duty Transport: A Scenario-Based Study of Hydrogen Truck Fleet Evolution

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Decarbonizing heavy-duty transport is essential for European climate neutrality by 2050, yet the transition pathway for hydrogen-powered trucks in Germany remains uncertain due to nonlinear feedbacks among policy, infrastructure, and total cost of ownership. This study quantified how these interdependencies shape the German heavy-duty vehicle fleet from 2020 to 2050 and identified key levers for hydrogen diffusion. A System Dynamics simulation in Stella Architect integrated a Bass diffusion formulation distinguishing innovation and imitation-driven adoption. The model represented competition among fossil-fuel trucks, battery-electric vehicles (BEVs), and hydrogen fuel cell electric vehicles (FCEVs) through attractiveness-based adoption, hydrogen refueling station (HRS) expansion with delays and minimum threshold, and dynamic CAPEX learning and hydrogen price decay. The model was verified through multiple tests and calibrated to German data (2020-2025), showing 535,000 diesel trucks, 10,597 BEVs (Q3 2025) and 188 FCEVs, using p=0.0083 and q=0.5 for hydrogen. Baseline projections showed fossil-fuel decline, BEVs emerging as

Abbreviations: BEV, battery-electric vehicles; FCEV, fuel cell electric vehicle; HRS, hydrogen refueling stations.

primary successor by 2049, and hydrogen remaining niche without external acceleration. Scenario analysis showed increasing policy-driven innovation disproportionately accelerates early uptake, but long-term diffusion depends most on hydrogen fuel costs: with initial 11 EUR/kg and decay d=0.03 toward 5 EUR/kg by 2050, baseline yields 10,000 hydrogen trucks, while doubling price reduction produces >25,000. Infrastructure streamlining (reduced bureaucracy and construction time) moderately increases the 2050 hydrogen fleet (9,000 to 12,000). Meeting targets requires shifting from upfront subsidies to operational-cost reductions while maintaining adequate HRS coverage for self-reinforcing diffusion.

KEYWORDS
green hydrogen, trucking sector, heavy-duty transport, hydrogen truck