SIMULATION-BASED COMPARISON OF ELECTRIC AND DIESEL MEDIUM-DUTY TRUCKS USING REAL-WORLD DRIVE CYCLES

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1. Introduction

The freight transport (logistics) sector accounts for about 5% of India's gross domestic product (GDP) and employs above 2 crore people [1] [2]. Further, more than 70% of the country's freight is transported via road through more than 50 lakh medium- and heavy-duty trucks (MHDTs, gross vehicle weight [GVW] > 3.5 t;) [3]. These MHDTs, which account for a mere 2% of the on-road vehicle fleet, are predominately diesel-run and disproportionately contribute to 45% of sectoral emissions [1]. For India to reach its climate targets as per the Paris Agreement, electrification of its carbon-intensive road freight transport sector is crucial.

Electric three-wheeler freight vehicles—offered by Mahindra and Piaggio original equipment manufacturers (OEMs) and primarily used for urban deliveries—have been on Indian roads for some time now and are gaining interest from city logistics operators [4] [5]. Tata ACE EV and Switch IeV are other electric freight vehicles in the sub 3.5 t category available in the Indian market [6] [7]. Barring a 55-t model by IPL Tech Electric Pvt Ltd, a 14 t by Ashok Leyland, and two models (7 t and 9 t) by Tata Motors, electric MHDTs (e-MHDTs) are yet to be commercially available. Therefore, to support adoption of e-MHDTs and attract attention from stakeholders, they have been included in the PM E-DRIVE scheme with an outlay of INR 500 crore.

Given the early stages of domestic e-MHDT adoption, it is vital to examine their performance, particularly in Indian conditions. Hence, we evaluated, through simulation, the fuel efficiency and emissions of a 12 t battery electric truck and compared with that of its diesel counterparts for the same driving cycle.

2. Simulation: Approach, Assumptions, and Inputs

2.1 Approach

We collected second-by-second speed data from a 12-t diesel truck by plugging in an on-board diagnostics (OBD) device during its normal operations on inter-city routes in Karnataka, Maharashtra, and Gujarat. About 2 lakh data points corresponding to 2 months of travel, covering more than 30,000 km distance on Indian highways and traffic

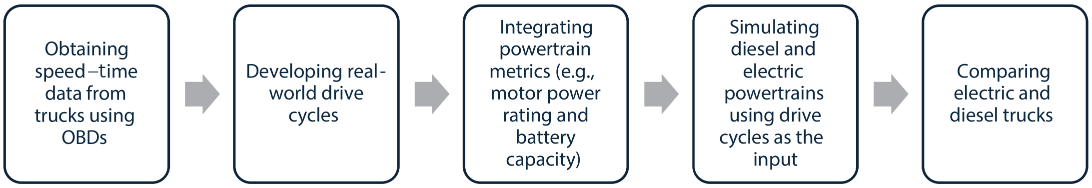


Figure 1: Simulation approach

conditions, were used to develop real-world drive cycles for the truck [8]. These drive cycles were used as common inputs for the simulation of both electric and diesel powertrains (Figure 1).

We used ADVISOR, a simulation platform to evaluate the performance and fuel economy of various powertrains, including conventional (gasoline and diesel), hybrid-electric, full-electric, and fuel cell systems [9].

Inputs required by ADVISOR define the vehicle's characteristics, including that of critical components such as the drivetrain, fuel converter, transmission, wheels, and battery. Once the vehicle is configured, the software integrates a variety of road and test conditions, including drive cycles, acceleration, payload, and rolling resistance, to run the simulation.

2.2 Assumptions and inputs

Parameters that impact fuel consumption of trucks the most are key inputs to powertrain simulation. Open-access data and common engineering knowledge were used to define the truck and its parameters. In instances where data on parameters were unavailable, default parameter values in ADVISOR were considered.

Input parameters were calibrated to match the energy consumption results from the simulation with that of the real world for a diesel powertrain. The input parameters

considered for calibrating the simulation are tabulated in Table 1. Real-world energy consumption records were gathered from company claims, media reports, and user reviews [10] [11] [12].

Table 1: Input parameters

Parameter	Diesel	Electric
GVW (in kg)	11,990	
Number of gears	5	NA
Engine power (kW)	92	NA
Motor power (kW)	NA	92
Frontal area (m^2)	5.25–5.5	5.25–5.5
Drag coefficient (C_d)	0.6–0.7	0.6–0.7
Coefficient of rolling resistance	0.006–0.0088	0.006–0.0088
Wheel radius (m)	0.4–0.5	0.4–0.5
Cell weight (kg)	NA	0.188
Battery size (in kWh)	NA	250
Cell energy (in kWh)	NA	0.0209

Limitations: Due to the unavailability of laboratory test data on parameters such as fuel maps of modern diesel engines, we relied on default engine data available in ADVISOR. A similar approach was adopted for other vehicle parameters not available in the OEM brochure or not open to public.

3. Comparison: Diesel vs Electric 12 t Truck

Simulation results for both diesel and electric powertrains, corresponding to input parameters in Table 1, are compared in Table 2. The results correspond to trucks running on a level road with maximum payload i.e., fully loaded (GVW: 12 t), tracing the real-world drive cycle. Although driving behaviour might vary based on the vehicle's powertrain, we used the same drive cycle for both trucks to ensure a fair comparative analysis.

Table 2: Simulation results for diesel vs electric truck

Powertrain metrics	Diesel	Electric
Fuel efficiency (claimed) [17]	7 to 8 kmpl	0.66 to 1.33 km/kWh
Fuel efficiency (user) [11][12]	4.5 to 7 kmpl	1.2 to 1.4 km/kWh
Fuel efficiency (ADVISOR)	4.2 to 4.9 kmpl	0.68 to 0.7 km/kWh
Energy consumed per km (ADVISOR)	7.75 to 9.04 MJ/km	5.14 to 5.29 MJ/km

Note: The electric truck efficiencies are observations from early electric truck trials in India

Table 3: Efficiency improvement comparison between electric and diesel trucks

Electric truck efficiency (km/kWh)	% efficiency improvement of electric truck over diesel				
1.4	72%	67%	63%	59%	53%
1.2	67%	61%	57%	53%	45%
1	60%	54%	48%	43%	34%
0.8	50%	42%	35%	29%	17%
0.7	43%	34%	26%	19%	5%
Diesel truck efficiency in km/l	4.2	4.9	5.5	6	7

ADVISOR simulation results revealed that the fuel efficiency of the diesel truck varies between 4.2 and 4.9 km/l and of the electric truck is between 0.6 and 0.7 km/kWh. The electric truck's fuel efficiency observed in this simulation might vary from that in real scenarios due to different driver behaviour, load, traffic, and road conditions. Authors' observations from recent electric truck trials in India suggest real-world fuel efficiencies of 1.2–1.4 km/kWh. Electric trucks' energy efficiency can be improved through behavioural changes or technological improvement. With 1.4 km/kWh electric trucks would be about 50% more efficient than diesel versions (Figure 2).

To get a common metric for comparison, fuel consumed in litres for the diesel truck and in kWh for the electric truck was converted to MJ. The energy consumed by the electric truck to cover a unit distance was **33%–42% lower** than that consumed by its diesel counterpart, indicating the running-cost advantage of the electric powertrain.

The emissions from each type of vehicle drive train were compared as well. Diesel as a fuel has an emission factor of 3.35 kg CO_{2e} per litre [13], whereas Indian grid-based electricity has an emission factor of 0.716 kg CO_{2e} per kWh [14]. Using these emission factors for the respective fuels, the emissions per kilometre of the 12-t diesel truck and electric truck were estimated as 0.68–0.79 kg CO_{2e} and 1.01–1.04 kg CO_{2e}, respectively.

3.1 Effect of payload

We examined, through simulations, variations in fuel efficiency for various loading conditions of the truck. Both electric and diesel trucks' fuel efficiency decreased linearly with an increase in the payload (Figure 2). In the case of a fully loaded (12 t) diesel truck, the fuel efficiency fell by 18% compared with a partially loaded (9 t) diesel truck. For similar payload, the efficiency of the electric truck dropped by 23%, indicating higher sensitivity of electric trucks to payload. Improving the battery energy density of electric trucks with

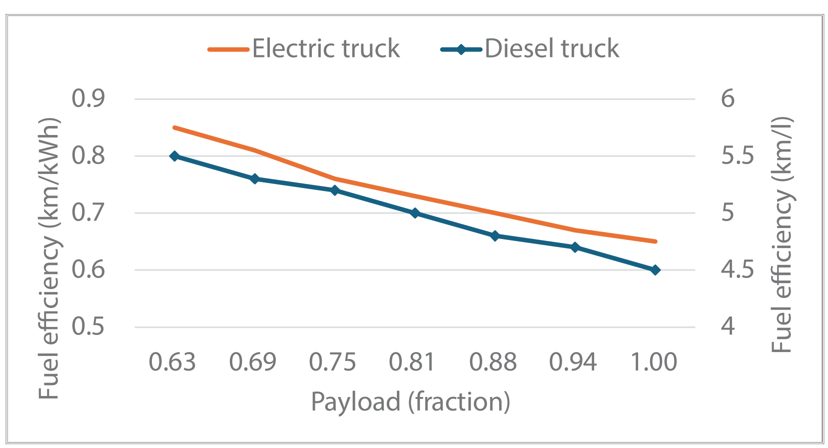


Figure 2: Variation in fuel efficiency with payload

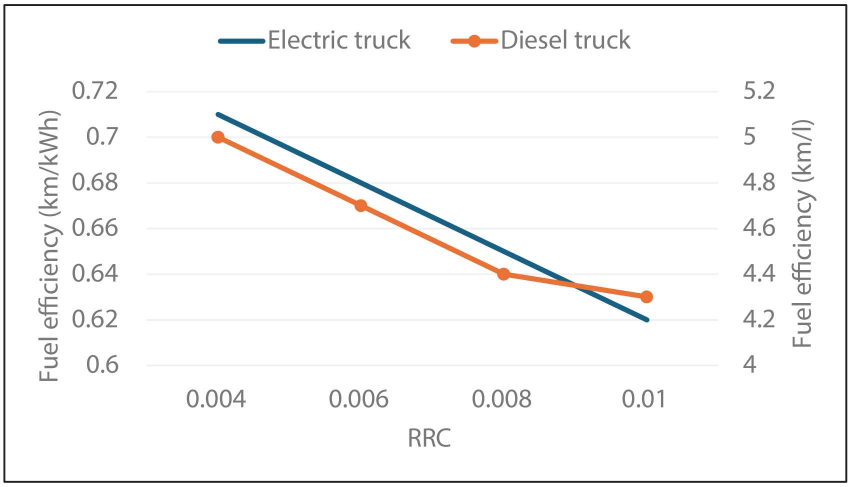


Figure 3: Variation in fuel efficiency with rolling resistance

solid-state technology could reduce the impact of payload on fuel efficiency.

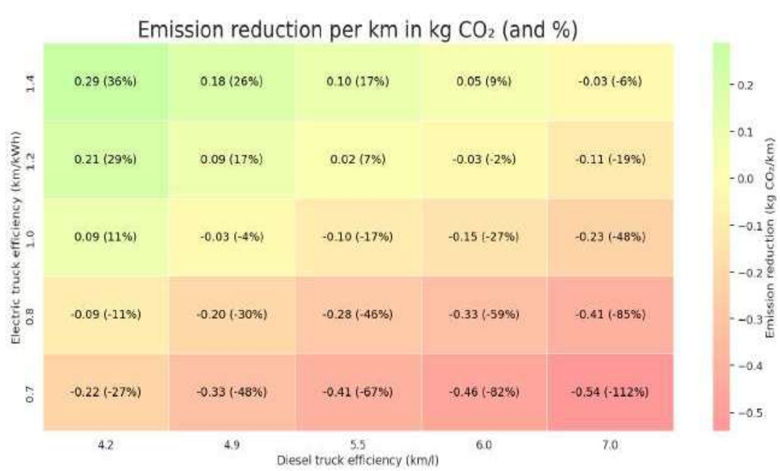
3.2 Effect of rolling resistance

Rolling resistance depends on the wheel type and road surface. The rolling resistance coefficient (RRC) of a tyre depends on its construction, material, and air pressure, among other factors. During simulations, in addition to the payload, the effect of rolling resistance on fuel efficiency was examined as well. We assumed pneumatic truck tyres on asphalt pavement and varied RRC from 0.004 to 0.01 during simulations [15] [16]. A linear drop in fuel efficiency was observed for electric (13%) and diesel (14%) trucks with increase in RRC (Figure 3). Thus, 14% increase in fuel consumption makes a compelling case for the authorities to ensure high road qualities to reduce fuel consumption and emissions, regardless of fuel type.

3.3 Emission reduction potential

Based on the efficiencies obtained for both diesel and electric trucks, a comparison of emissions (kg CO_{2e}) per km was performed and a heat map was generated. Table 4 illustrates and quantifies the emissions avoided per km by the electric truck in comparison with a diesel truck at different diesel and electric efficiencies.

Table 4: Emission reduction (kg CO2e) by electric truck per km at different diesel and electric efficiencies



4. Conclusions

The simulation analysis performed helped to quantify the differences between performance of a 12-t diesel and electric truck under Indian driving conditions. Electric trucks consume 33% to 42% less energy than their diesel counterparts while carrying the same payload at similar speeds, offering significant fuel efficiency gains. However, with India's coal-heavy grid, their CO_2 emissions can sometimes exceed diesel's, as shown in Table 4. These findings show that electric trucks can outperform diesel in many cases, but maximizing their climate benefits requires parallel progress in grid decarbonization. Freight electrification and cleaner electricity must advance together to deliver the strongest environmental impact.

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