WHITE PAPER

JUNE 2023

HEAVY-DUTY TRUCKS IN INDIA: TECHNOLOGY POTENTIAL AND COST-EFFECTIVENESS OF FUEL-EFFICIENCY TECHNOLOGIES IN THE 2025–2030 TIME FRAME

Aviral Yadav, Anirudh Narla, and Oscar Delgado

www.theicct.org

communications@theicct.org

twitter @theicct

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

BEIJING | BERLIN | SAN FRANCISCO | SÃO PAULO | WASHINGTON

ACKNOWLEDGMENTS

The authors are grateful to S S Jadhav, M/s Aayush Enterprises, Talegaon Dabhade, Pune, Maharashtra, India for giving ICCT access to the truck models for our data collection. Thanks also to Ben Sharpe, Claire Buysse, and Harsimran Kaur of ICCT and Sharif Qamar of The Energy and Resources Institute for their critical reviews and helpful comments, and to ICCT colleagues Lingzhi Jin and Claire Buysse for providing inputs on the duty cycle and hybrid model development, respectively. Special thanks to Jennifer Callahan for her assistance in editing this work.

International Council on Clean Transportation
1500 K Street NW, Suite 650
Washington, DC 20005

communications@theicct.org | www.theicct.org | @TheICCT

EXECUTIVE SUMMARY

Heavy-duty trucks (HDTs) are 2% of the on-road vehicle stock in India but comprise more than 40% of on-road vehicle fuel consumption and carbon dioxide (CO_2) emissions. Accordingly, reducing HDT fuel consumption is critical for many of India's goals, including reducing its dependence on imported oil. In 2017, the Government of India passed a regulation defining the first-ever fuel consumption standards for heavy-duty vehicles (HDVs), which include HDT's and buses; it took effect on April 1, 2023. While an important first step, vehicle technology has evolved since 2017, and it may be possible to significantly reduce fuel consumption beyond the regulation's ambition.

This paper makes policymakers and others aware of the potential benefits and costs of fuel consumption reduction technologies and provides evidence of technical and economic feasibility to support a future, more stringent fuel consumption standard for HDVs in India. (Although this analysis focuses on HDTs, results are applicable to buses, also, because they have the same power train.) We examined the potential for fuel consumption reduction technology in HDTs between 2022 and 2030, with the baselines estimated from real-world data. We analyzed incremental improvements in conventional internal combustion engine (ICE) technology and alternative power trains in the form of both hybrid and battery-electric trucks. We focus on five HDT segments that cover a range of axle configurations and gross vehicle weights, and we evaluated the cost and benefits of various fuel consumption reduction technologies after grouping them into different technology packages (TPs). We evaluated TPs in terms of costs and benefits, payback periods, and lifetime savings in both 2025 and 2030. Further, we performed a sensitivity analysis to understand the impact of key parameters and assumptions on the findings.

Figures ES1 and ES2 summarize the potential of technology to reduce fuel consumption and the associated payback periods for four rigid trucks and one tractor-trailer, respectively. These results suggest that India can significantly reduce fuel consumption in HDTs. Improvements in ICE technology result in fuel consumption reductions of up to 43% for rigid trucks and 49% for tractor-trailers over model year (MY) 2022 vehicles. Hybrid technology reduced fuel consumption by 4% for the rigid trucks and 2% for the tractor-trailer, largely because they mostly operated on highways and not in stop-and-go traffic. In terms of energy consumption, electrification provided a 77% reduction for both rigid trucks and tractor-trailers.

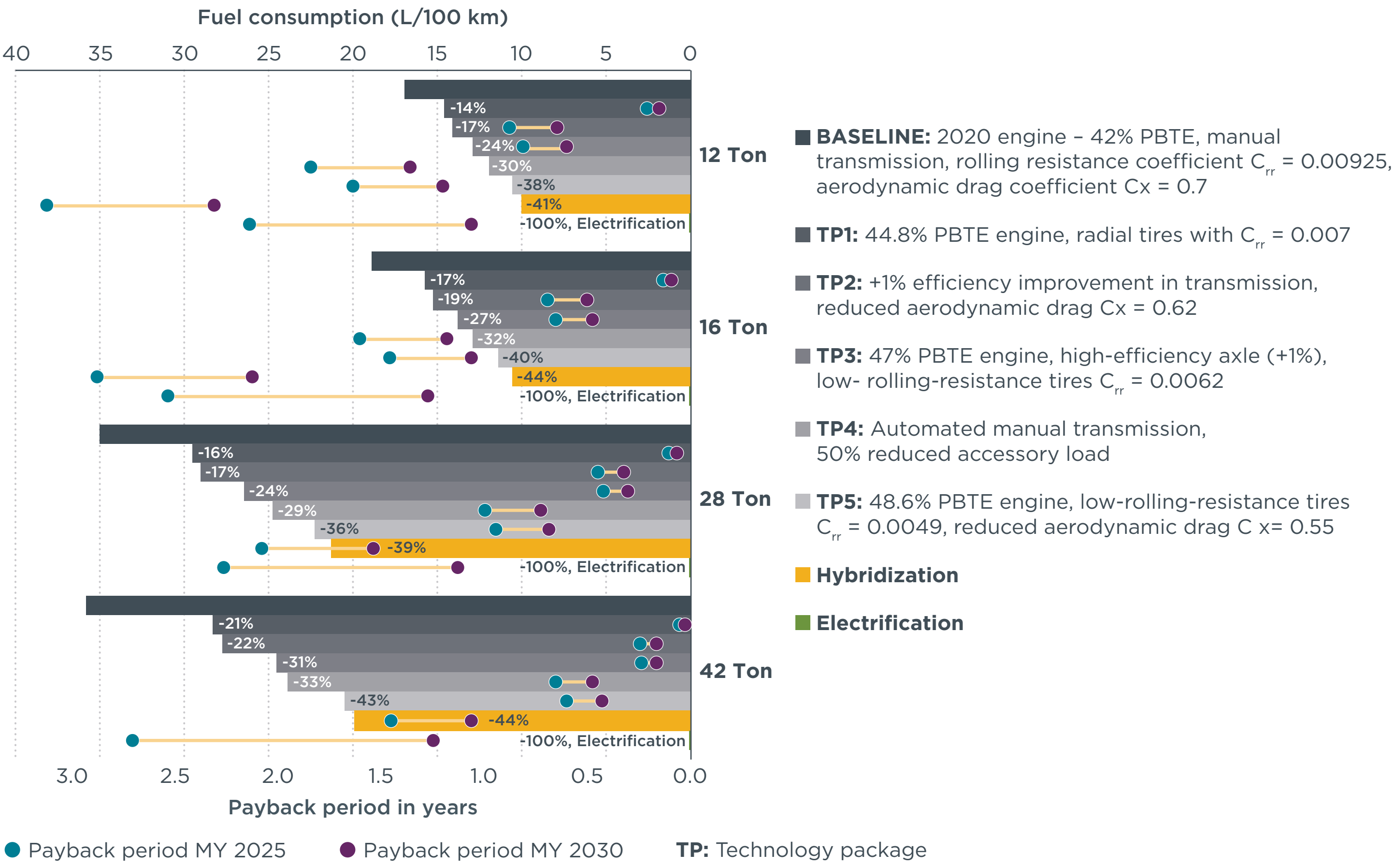


Figure ES1. Fuel consumption reduction potential and payback periods for the rigid truck technology packages.

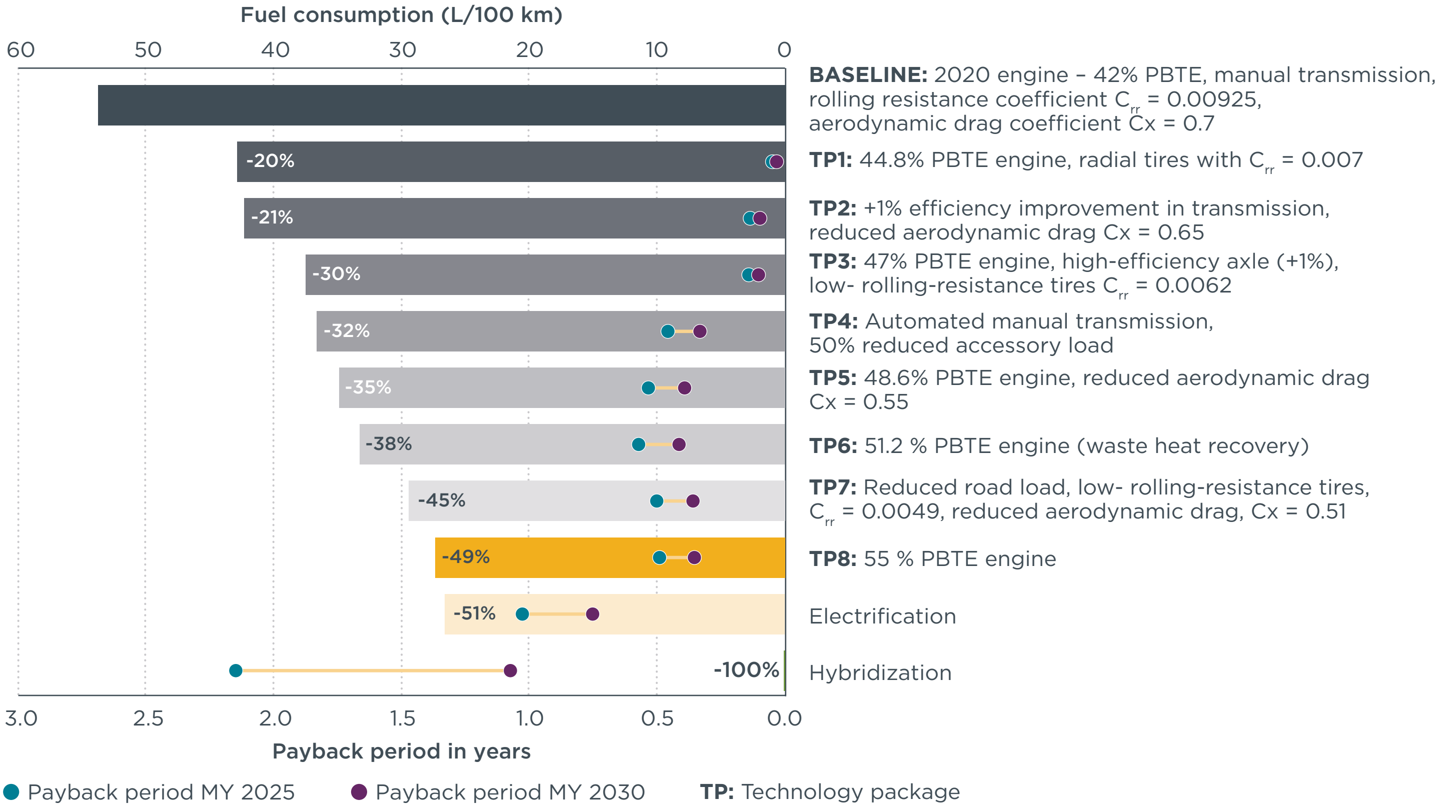


Figure ES2. Fuel consumption reduction potential and payback periods for tractor-trailer technology packages.

Results suggest near-, mid-, and long-term approaches to reduce fuel consumption in India:

Near-term, readily deployable : With TP1, 14%–21% fuel consumption reduction for rigid trucks and 20% for tractor-trailers can be achieved by deploying best-in-class engines and tires already on the market.

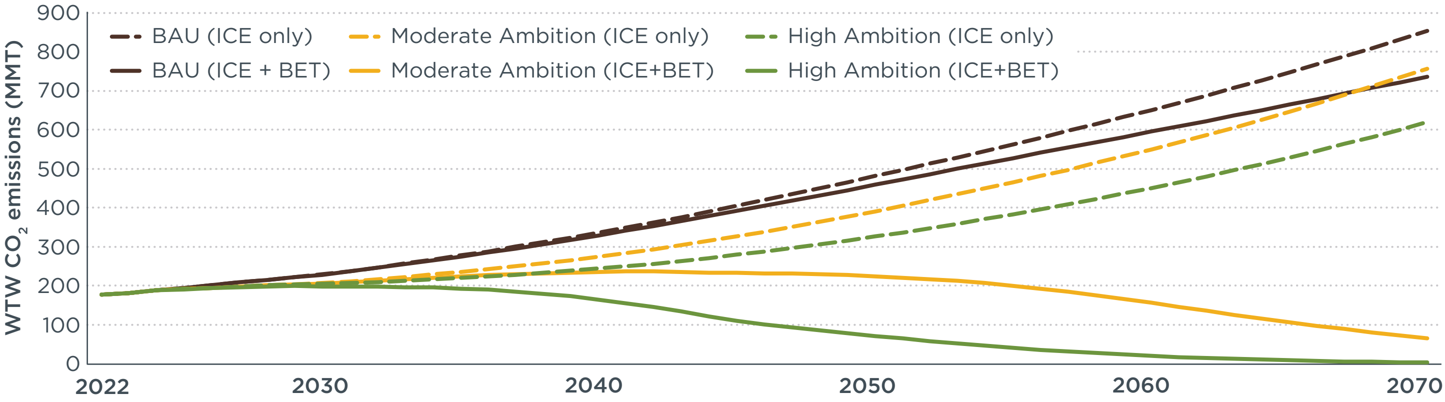
Mid-term, deployable by 2025: Fuel consumption benefits of 24%–31% for rigid trucks and up to 30% for tractor-trailers are possible with TP3. These technologies are commercialized and ready for deployment.

Long-term, deployable by 2030 or later: The best-case fuel consumption reduction from pure ICE improvement for rigid trucks peaks at 43% with TP5. Tractor-trailers can further improve with waste heat recovery technology to reduce fuel consumption by as much as 49% with TP8. These technologies are not currently commercialized but could be deployed later.

Although battery-electric trucks (BETs) have high upfront costs, they bring significant fuel savings. As there are no BET models currently for sale in India, we developed an electrification package that converts ICE trucks into BETs by replacing the engine and power train without changing the vehicle glider. The electrification package has a payback period of about 2.5 years if deployed in 2025 and less than 1.5 years if deployed in 2030, the latter due to reduced component costs and expected rising fuel prices. The shorter payback period is due to inefficient ICE trucks and the shorter range assumed for our modeled BETs (about half the range of those in developed countries due to cost sensitivity among consumers). Less range leads to smaller batteries and thus lower cost, which contributes to the shorter payback period. Still, higher range models are expected as technology develops. Meanwhile, smaller gross vehicle weight trucks show promising returns on electrification even in 2025; for heavier trucks, the upfront cost is high due to larger power trains and range.

In terms of technology, tires and engine improvements provide the most benefits in terms of fuel consumption, 15%–23% and 12%–24%, respectively. They are followed by driveline, about 7%, and auxiliary improvements, approximately 1%. This suggests an immediate need to shift to low-rolling-resistance radial tires for all HDTs in India.

Based on the technology potential, we modeled CO_2 emissions and oil demand under three policy scenarios: Business-as-Usual (BAU), Moderate Ambition, and High Ambition. Each of the scenarios combines two regulations—stringent fuel consumption standards and a BET sales mandate. Figure ES3 illustrates the results. Without further policy intervention, India is projected to more than quadruple its HDT emissions by 2070. **However, with the combined benefits of technology packages and BET penetration, India can avoid up to 85% of annual CO_2 emissions and 22% of overall oil demand in 2050**. **Up to 75% of cumulative emissions between 2022 and 2070 can also be avoided under the High Ambition scenario**. Importantly, this shows that India has the potential to use cost-effective technology to reverse the emissions trend of HDTs as early as 2032.



ES3. Annual CO_2 emissions from HDTs in various scenarios

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

India is the sixth largest commercial vehicle market. It is also the sixth largest economy and is projected to grow rapidly to become the third largest economy by 2030 (Centre for Economics and Business Research, 2021). Freight transport will play a significant role in this economic expansion; road transport was 71% of total freight transportation in India in 2020 (NITI Aayog et al., 2021). With an improving highway system, the demand for road freight transport and, therefore, HDTs is expected to increase. India's 2.8 million HDTs are 2% of the country's on-road vehicle stock but contribute more than 40% of on-road CO_2 emissions, according to estimates from ICCT's India Emissions Model.

At COP26, India pledged to achieve net-zero emissions by 2070 (PIB, 2022). To achieve this target, India's crude oil consumption should peak by 2050 (Chaturvedi & Malyan, 2021). Additionally, as part of India's nationally determined contribution (NDC) under the Paris Climate Agreement, the country aims to reduce its carbon emissions intensity by 33–35% between 2005 and 2030 (PIB Delhi, 2022). India's dependence on oil imports is also high, at about 85% of total crude oil consumption in 2020 (Ministry of Petroleum and Natural Gas, 2021); the national government seeks to reduce this dependence.

In 2017, the Government of India developed a regulation to define fuel consumption standards for HDVs (Garg & Sharpe, 2017). The regulation was the result of a combined effort by the Ministry of Road Transport and Highways (MoRTH), the Petroleum Conservation and Research Association (part of the Ministry of Petroleum and Natural Gas), the Ministry of Power (MoP), the Bureau of Energy Efficiency (BEE), and other stakeholders; its purpose was to reduce fuel consumption and greenhouse gas (GHG) emissions from diesel-powered trucks and buses with a gross vehicle weight (GVW) of 12 tonnes or more, which in India are classified as heavy-duty. After multiple delays and revisions, Phase 1 of the standards was implemented on April 1, 2023 (MoRTH, 2022). These standards are a minimum performance requirement the same as the Bharat Stage (BS) VI emission norms (Dallmann & Bandivadekar, 2016). To demonstrate compliance, each vehicle model and configuration must meet the fuel consumption target according to the defining equations while operating at a constant speed. Though an important first step, these standards do not exploit the full potential of existing technology to reduce HDT fuel consumption. Accordingly, and since vehicle technologies are expected to continue to advance, there is an opportunity to steer the Indian HDT market toward more fuel-efficient trucks through additional phases of more stringent fuel consumption standards.

The opportunity for improvement is significant because India's HDV fuel consumption standards are currently not as stringent as they are for similar vehicles in regions like the United States, China, and Europe (Xie & Rodríguez, 2021). Still, the fuel-saving potential of ICE trucks needs to be evaluated in the Indian context to determine the appropriate scope and stringency for future standards. To meet its net-zero emissions goal, India must deploy zero-emission trucks. But as fleet turnover for HDTs is slower than for other vehicle segments, it is critical to also improve the performance of conventional ICE trucks in the near and medium term. This study evaluates the cost and fuel-saving potential of HDV technologies to inform future HDV fuel consumption standards in India.

ICCT has published several studies that utilize vehicle simulation modeling to evaluate the fuel consumption reduction achievable in the 2020–2030 time frame and the associated cost-effectiveness of these technologies. These studies focused on trucks in the European Union (Delgado et al., 2017; Meszler et al., 2021), the United States (Buysse et al., 2021; Delgado & Lutsey, 2015), and China (Meszler, 2019; Delgado & Li, 2017). Following a similar approach, this study's primary objective is to estimate the costs and the benefits, based on potential fuel savings, of adding efficiency technologies to trucks in India. The methodology is comprised of two parts:

TECHNOLOGY POTENTIAL

To understand the baseline of trucks currently in the market, we examined fiscal year (FY) 2020–21 sales data and chose the five best-selling vehicles across the various GVW segments. The top-selling models were four rigid trucks and one tractor-trailer; all our analysis was done on these five vehicles by developing virtual truck models using manufacture specifications in vehicle simulation software. Real-world data on fuel consumption was used to calibrate and validate the models. We collected global positioning system (GPS) data from the five representative vehicles and developed individual drive cycles to standardize performance. After that, we simulated the virtual models on these drive cycles to derive baseline fuel consumption for each. In addition to incremental improvement in conventional ICE technologies, we also considered alternative power trains, both hybrid and battery-electric trucks.

We grouped the various efficiency technologies we considered into TPs that cover the engine, driveline, transmission, tires, aerodynamics, and accessories. These TPs progress from readily available, best-in-class near-term technology (deployment ready immediately), to technology expected to be available in the mid-term (deployment ready by 2025), and long-term (potentially deployable in 2030 or later). We developed seven TPs for rigid trucks and 10 for tractor-trailers; hybridization and electrification were the last two in each category.

COST-EFFECTIVENESS

The costs of fuel consumption reduction technologies assessed in this study are not readily available in the Indian market. Therefore, we used a conservative cost-scaling approach that sourced direct manufacturing costs and indirect costs from the U.S. Environmental Protection Agency (EPA)'s Phase 1 and Phase 2 Regulatory Impact Assessments and previous ICCT studies. Higher cost estimates from prior studies were scaled down to arrive at conservative cost-effectiveness estimates. While cost estimates will continue to be refined as technologies evolve and become mainstream, and reliable domestic costs for the Indian market might later become available, this study presents current best-estimate costs as refined mainly from costs in the Chinese market, based on its similarities with India. The evaluated cost of each individual piece of technology was combined with the others in each package to arrive at the final cost of each TP.

After completing this cost assessment, we estimated the costs and benefits for individual truck models and then estimated CO_2 emissions and oil consumption reduction potentials of scenarios of policies for HDTs with various degrees of stringency of standards. The overall methodology is summarized in Figure 1.

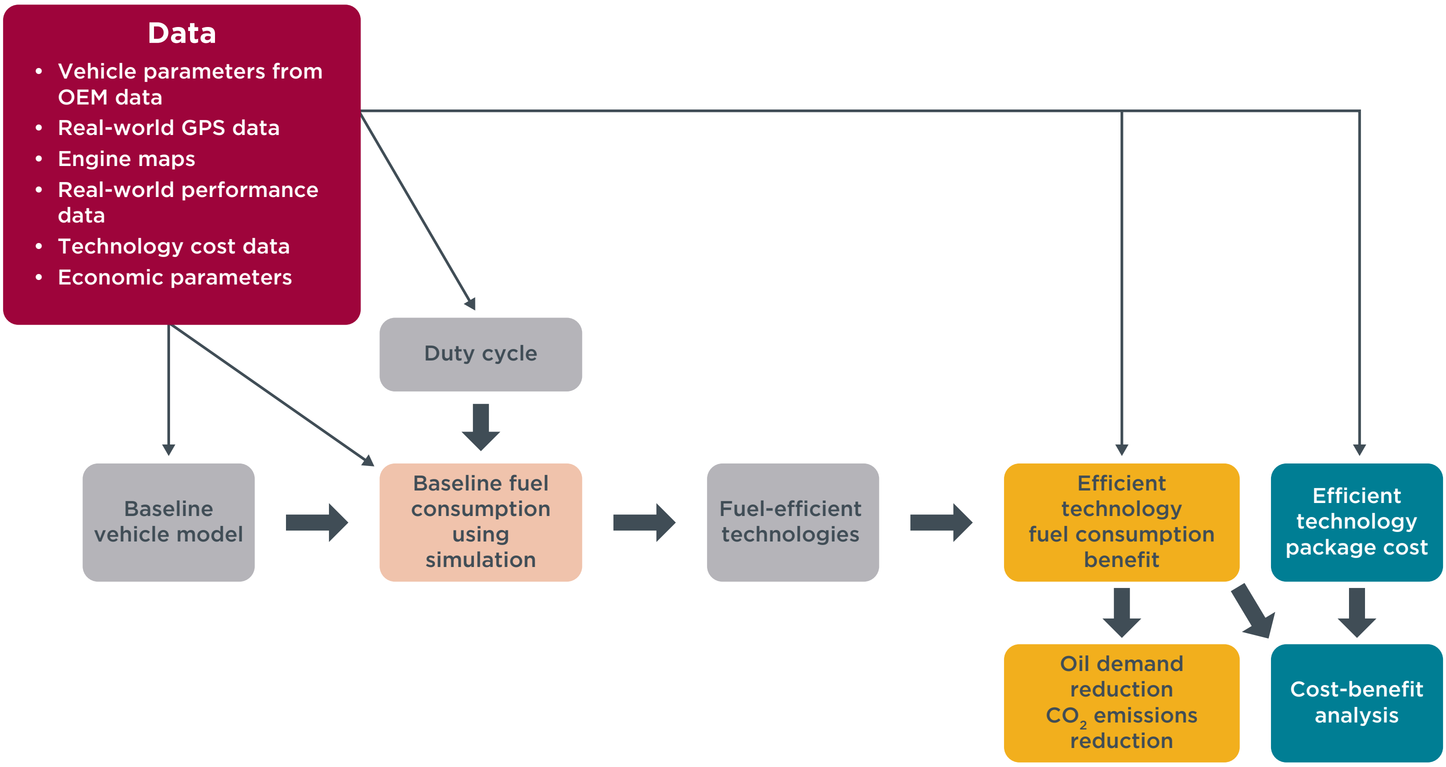


Figure 1. Overall methodology of the study.

STUDY LIMITATIONS

We limited the scope to trucks with GVW of more than 7.5 tonnes. The technologies considered are limited to: ICE engine, transmission, and vehicle technology improvements; hybridization; and electrification. We excluded strategies that target driver behavior, operations, or logistics. Additionally, energy consumption values were collected from a limited number of representative trucks, but these do not capture the full spectrum of vehicle specifications and use cases of HDTs in India. For example, trucks used for data collection operated more on the highway than in urban traffic. Thus, the benefits of hybrid technologies are likely underestimated.

We also made assumptions regarding fuel maps and engine performance. We used a Euro VI engine map and scaled it to a Bharat Stage (BS) VI engine, because emission standards are similar. An analysis of the actual BS VI engine map might provide more accuracy. We did not include the cabin cooling load on the engine because most trucks in India lack air conditioning. For the cost-benefit analysis, while we considered upfront payment for simplicity, financing costs can also have some impact. Additionally, future electricity grid composition and carbon intensity will impact CO_2 emissions reduction benefits for hybrid and electric vehicles. Due to uncertainty surrounding long-term grid carbon intensity, we assumed continuous grid improvement based on a previous ICCT study (Sen et al., 2021).

2. BASELINE FUEL CONSUMPTION

REFERENCE VEHICLES

This analysis followed the GVW-based truck classification used under the Central Motor Vehicle Rules (CMVR Rules 1989); we focused on the N2 and N3 categories. While our primary focus is on HDTs (greater than 12 tonnes), we also added one medium-duty truck from the 7.5–12 tonnes segment. Sales data showed a high proportion of "edge case" 11.9 tonnes trucks in that segment. Based on sales data from Sathiamoorthy et al. (2021) and the truck categories with the most fuel consumption according to the Ministry of Power's latest HDV fuel consumption standards (Garg & Sharpe, 2017), we selected four categories of rigid trucks, 7.5–12 tonnes, 12–16.2 tonnes, 16.2–31 tonnes, and 31 tonnes, along with a fifth category of tractor-trailers above 40 tonnes. These five segments cover a broad range of the market in terms of axle configuration and GVW; they represent 64% of India's truck sales above 7.5 tonnes GVW in FY 2020–21.

We chose five reference models to analyze. If the top-selling model in a category was unavailable for testing, we chose the second-best-selling model. Additionally, because BS VI versions of two of these trucks were unavailable, we analyzed other available BS VI models with similar technical specifications. These models are hereafter referred to by their reference model (RM) numbers – RM1, RM2, RM3, RM4, and RM5. Table 1 summarizes their key parameters.

Table 1. Reference vehicle parameters

Reference model number	RM1	RM2	RM3	RM4	RM5
Body type	**Rigid truck**	**Rigid truck**	**Rigid truck**	**Rigid truck**	**Tractor-trailer**
Model name	**Tata 1212**	**Ashok Leyland 1615 HE**	**Tata 2818**	**Ashok Leyland 4220- 5.7TD HM 10x2**	**Ashok Leyland 5525**
Axle configuration	4 X 2	4 X 2	6 X 2	10 X 2	6 X 4
Number of tires	Steer: 2 Driver: 4	Steer: 2 Driver: 4	Steer: 2 Driver: 8	Steer: 4 Driver/Tag: 10	Steer: 2 Driver/Tag/ Trailer: 8
GVW (kg)	11,990	16,100	28,000	42,000	55,000
Payload (kg)	7,500	10,800	20,000	28,000	40,000
Engine displacement (cc)	3,300	3,839	5,600	5,660	5,300
Emission standard	BS VI				
Maximum engine power (kW)	125	111.8	140	149	186.4
Maximum engine torque	390 Nm@1000–2,200 rpm	450 Nm @ 1,250–2,000 rpm	850Nm@ 1,000–1,700 rpm	700Nm@ 1,200–2,000 rpm	900 Nm @ 1,200–1,900 rpm
Tire	8.25 R 20 -16 PR RIB	9.00 R20 16 PR	295/90R20 16 PR	295/90R20 16 PR	295/ 90R20 16 PR
Transmission type	Manual				
Number of gears	5F + 1R	6F + 1R	6F + 1R	8	9F + 1R
Rear axle ratio	5.285	6.833	6.14	5.63	6.17
Coefficient of aerodynamic drag (C_D)	0.7				
Coefficient of rolling resistance (C_{rr})	0.0095				

REAL-WORLD DRIVING AND FUEL CONSUMPTION DATA

We gathered information about real-world driving patterns and fuel consumption with the help of a freight service provider in India, Aayush Enterprises.[1] This data was collected from the BS VI versions of the five models using a GPS device and a data logger plugged into the onboard diagnostic port (OBD) of the trucks. The relevant parameters recorded include GPS coordinates, vehicle speed, direction, engine speed, and fuel consumption. For each of the reference trucks, data sets were developed over 2 months of operation and about 10,000 km of driving.

MODELING AND SIMULATION

Simulation models are widely used because they offer reliable estimates of HDV fuel efficiency. Modeling means avoiding the significant amounts of time and resources required for vehicle testing and expedites the analysis process for manufacturers and regulators. For this study, a multi-physics simulation software, Amesim (Siemens, 2020), was used to run the vehicle models on the developed drive cycles at full load to simulate the real-world operation and assess fuel consumption. Computer models were developed for the reference trucks selected; these models were then run on a reference duty cycle based on real-world GPS data.

Each vehicle was modeled using data on vehicle characteristics from the sales database and product details catalog from manufacturers. The engines, transmissions, and GVW characteristics were based on the specifications of vehicle models. The remaining parameters were based on data from comparable vehicles in other markets and the authors' best judgment.

Another crucial input required for our reference models is the fuel map—a dataset covering an engine's fueling rate across its entire operating range. The representative engine fuel maps used for our baseline analysis were the same as those used in Delgado et al. (2017) and came from a recognized engineering service provider, AVL. This representative engine map was scaled according to all models' engine size, torque curve, and efficiency improvement steps.

Drive cycle development

Drive cycles are needed to simulate real-world driving. They standardize the effect of external conditions on a vehicle so that relative changes in performance and fuel consumption can be studied. Previous studies in India used the World Harmonized Vehicle Cycle (WHVC)-India drive cycle, a modified version of the WHVC, which is used globally for vehicle testing (Gopal et al., 2017). The WHVC-India cycle was developed to account for driving conditions in India.

In the study, we developed novel drive cycles to represent the different driving profiles of the reference trucks and help ensure findings reflected real-world operations as much as possible. The methodology for developing these cycles is from Jin et al. (2020), which researched bus routes in India. One developed cycle is illustrated in Figure 2. The rest are presented in Appendix A.

---

[1] S S Jadhav, M/s Aayush Enterprises, Talegaon Dabhade, Pune, Maharashtra, India.

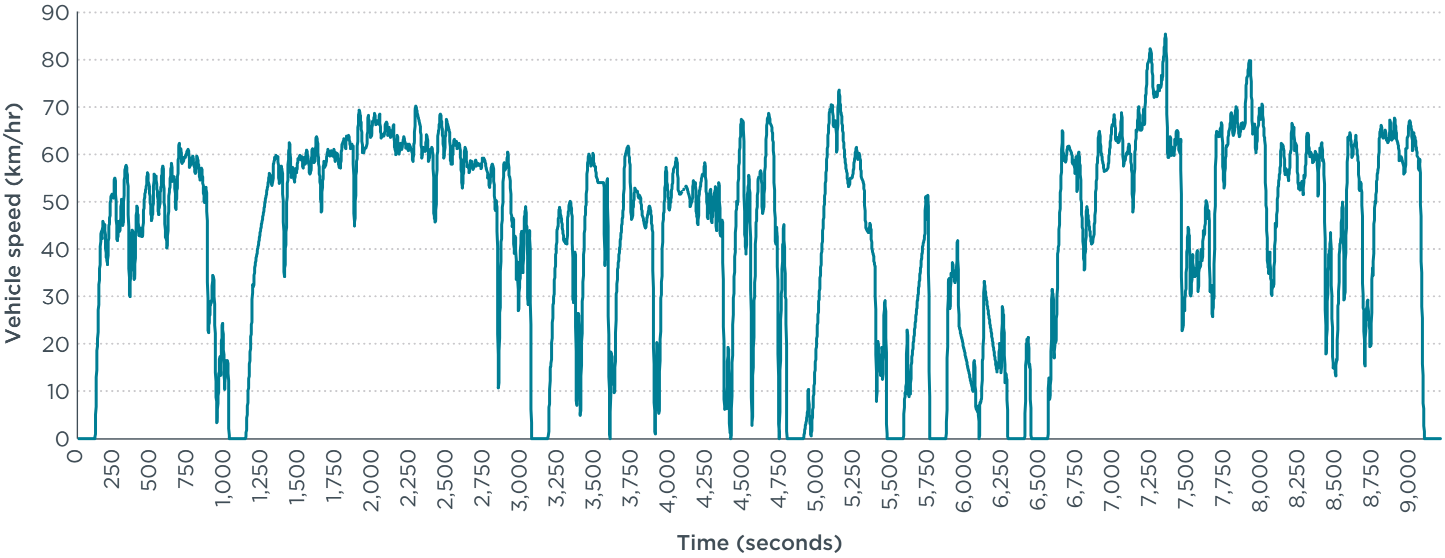


Figure 2. Drive cycle for the 12-tonne rigid truck, RM1.

Calibration and validation

We used real-world driving and fuel consumption data to validate the models. For each vehicle, we collected data for a few days of typical vehicle operation. In other words, the vehicle was run on its usual delivery route with its usual payload. This data was split into two subsets, one for calibration and the other for validation. We used the first subset to tune our model to reach the desired value of real-world fuel consumption and the second subset to validate the model and compare if simulation results for those days matched real-world fuel consumption. Simulation models were validated to within a difference of less than 5%.

Baseline fuel consumption values

Using the baseline vehicle parameters and duty cycle, the validated models gave the final values of fuel consumption in simulation. We measured all further improvement in fuel consumption against these baseline values.

Table 2. Baseline fuel consumption values over developed cycles

	RM1, Rigid truck	RM2, Rigid truck	RM3, Rigid truck	RM4, Rigid truck	RM5, Tractor-trailer
GVW	12 tonnes	16 tonnes	28 tonnes	42 tonnes	55 tonnes
Payload capacity used in simulation	100%				
Cycle used	Cycle-RM1	Cycle-RM2	Cycle-RM3	Cycle-RM4	Cycle-RM5
Simulated fuel consumption (L/100 km)	16.7	18.0	34.9	36.0	53.8

3. FUEL CONSUMPTION REDUCTION TECHNOLOGIES

The fuel consumption reduction technologies included in this study can be broadly put into two categories. One category is for those that increase the usable mechanical power delivered to the vehicles' wheels. These improvements in the ICE power train mean less fuel is required to produce the same amount of work needed for the vehicle. The second is for those that decrease external losses which occur when the vehicle is in motion so that less work is required to achieve the same utility (thus consuming less fuel). These are detailed below. We also included two alternate power train options, a hybrid and a battery electric truck.

POWER TRAIN IMPROVEMENT TECHNOLOGIES

Engine

The engine is the core of an ICE vehicle. It converts the chemical energy of fuel into mechanical energy. Even a small improvement in engine efficiency results in significant fuel savings over time. India presently has no efficiency criteria at the engine level.

Previous ICCT studies on China and Europe detailed available technologies for fuel consumption reduction between 2020 and 2030 (Delgado et al., 2017; Delgado & Li, 2017). Based on that work and in the Indian context, we considered these possible technologies:

- Friction reduction;
- On-demand accessories;
- Combustion system optimization;
- Advanced engine controls;
- Aftertreatment improvements;
- Turbocharger improvements; and
- Waste heat recovery (WHR) systems, including turbo compounding and Rankine bottoming cycles.

Utilizing these improvements incrementally, we defined five levels of engine efficiency that can be achieved and deployed in trucks in the 2022 to 2030 time frame.

Table 3. Engine efficiency improvements considered in this analysis

Engine technology level	Brake thermal Efficiency (BTE)
Baseline – 2020 engine	42%
Best in class engine – 2020 Level 1	44.8%
Engine Level 2	47%
Engine Level 3	48.6%
Engine Level 4 (WHR)*	51.2%
Engine Level 5 (SuperTruck target[a])*	55%

* Only applicable to tractor-trailers due to large engine.

[a] The U.S. Department of Energy SuperTruck program is a public-private partnership that promotes precompetitive research and development to improve the freight-hauling efficiency of heavy-duty Class 8 long-haul tractor-trailer trucks (Delgado & Lutsey, 2014).

Driveline

The driveline transmits power from the engine to the wheels. Internal friction in the transmission, driveline shaft, differentials, and axles can be incrementally reduced through in-gear efficiency, dry-sump lubrication, improved lubricants, and bearings. Smart lubrication systems reduce lubrication pump parasitic losses as part of dry sump systems. Based on similar improvements in the global market, we assumed transmission and axle efficiency will each improve by 1% in India (Delgado et al., 2017).

Automated manual transmission (AMT). AMT technology is essentially a standard manual transmission augmented with additional sensors and actuators that allow the transmission control module to undertake shifting activity the driver would otherwise perform. Fuel savings come from enabling engine down speeding, which reduces friction and pumping losses; shift strategy optimization, which keeps the engine operating at or near high-efficiency conditions; and a reduction in driver-to-driver shift variability. Although there are no AMT models presently available in India, given the benefits, we assumed that the industry might introduce AMT in trucks in India before 2025.

Table 4. Driveline efficiency improvements

Driveline technology level	Efficiency
Axle – Baseline	Different for all models
Axle – Improved	+ 1% improvement in axle efficiency
Transmission – Baseline	Varies based on truck model and gear ratio
Transmission – Improved	+1% improvement in transmission efficiency
Automated manual transmission	Gear efficiency remains the same but there is improvement due to better gear shift

VEHICLE TECHNOLOGIES

Other than increasing power delivery to the wheel, other technologies can reduce energy requirements when the vehicle moves. Power produced in the engine must overcome resistive forces due to tire deformation, headwind, inertia, and auxiliary systems. Possible improvements in these are examined in this section.

Tire rolling resistance

The coefficient of rolling resistance (C_{rr}) is a parameter that relates the force opposing the rotating motion of the tires to the normal force between the tire and the surface. It is a significant contributor to overall road load power requirements and fuel use. The dissipation of energy from the flexing of tire sidewalls and heat generation during tire revolution varies with tire design and is proportional to vehicle weight and speed. Tires with lower rolling resistance make trucks more fuel-efficient.

In 2022, India released a notification proposing new tire norms. These norms were incorporated based on Stage 2 of the Automotive Indian Standards (AIS) 142:2019 (ARAI, 2019). The standard specifies that new C3 class tires used for HDVs cannot exceed the rolling resistance value of 0.0095 for bias tires and 0.007 for radial tires. We learned through an interview with a local stakeholder that today's market is equally divided between bias and radial tires and thus assumed a baseline of 0.00925, which is the mean of the rolling resistance standard of the Stage 1 regulation for bias and radial tires.

A first step toward improvement is to phase out bias tires by making the more fuel-efficient radial tires mandatory. This can lead to significant fuel savings.

Table 5. Tire efficiency improvements

Tire technology level	Rolling resistance coefficient
Baseline 2020	0.00925
Level 1 – Radial tires are mandatory	0.0070
Level 2 improvement	0.0062
Level 3 improvement	0.0049

Aerodynamic drag

Aerodynamic drag is particularly significant for long-haul HDV operation because of the large time spent at sustained highway speeds. Under continuous high-speed operation, aerodynamic drag power dissipation, which is proportional to the cube of speed, greatly exceeds that of other road load determinants.

In India, the average and maximum speeds of trucks today are relatively slow. This makes aerodynamic losses less significant than in some other regions. Nonetheless, as the time frame of this study is until 2030 and India's highway network is already being improved, the average speed of trucks and maximum permitted speed might increase and make aerodynamic improvement more significant.

There are several technologies available to reduce aerodynamic drag, including improved tractor design, integrated tractor and trailer design, gap reduction at the tractor/trailer interface, tractor and trailer side skirts, trailer rear-end aerodynamic devices such as boat-tails, and trailer underbody devices. The improvement steps in aerodynamic drag coefficient (Cd) are listed in Table 6. This drag coefficient is a dimensionless quantification of the resistance experienced by the vehicle from the air. There is one more step for the tractor-trailer, because we assumed more highway driving and higher speeds than for the trucks.

Table 6. Aerodynamic efficiency improvements

Aerodynamic technology level	Cd – Coefficient of aerodynamic drag
Rigid trucks	
Baseline – 2020	0.7
Level 1 improvement	0.62
Level 2 improvement	0.55
Tractor-trailer	
Baseline – 2020	0.7
Level 1 improvement	0.65
Level 2 improvement	0.55
Level 3 improvement	0.51

Weight reduction

Reducing vehicle weight results in lower power requirements and makes vehicles more fuel-efficient. Across all types of HDVs, manufacturers have commercialized and continue to develop products using alternative materials such as aluminum and composites that lower vehicle curb (empty) weight. In this study, we did not consider fuel consumption reduction due to weight reduction for two reasons. One, trucks in India already weigh less than those in other markets (Delgado et al., 2016). Additionally, as the market moves forward and manufacturers prioritize safety and comfort, additional components might be added that might increase weight; this could offset any fuel consumption reduction achieved from use of better materials.

Second, India has a highly competitive freight market. In some cases, the payload transported exceeds the load-carrying capacity of the vehicle. In such cases, any weight reduction in the vehicle could be offset by the increased payload and result in the same fuel efficiency in km/L. However, weight reduction does result in an increased freight efficiency (tonne-km/L).[2]

---

[2] Tonne in the freight efficiency metric corresponds to the weight of the payload transported, not the total weight of the truck.

Reduction in energy consumed by auxiliary components

Auxiliary accessories are vehicle systems whose functions are not related to propulsion, such as air conditioning or pressurized air systems. The power necessary to drive these accessories directly affects the fuel consumption performance. Decoupling accessories from the engine when accessory operation is not needed, operating them at optimal speeds, and harnessing vehicle inertia as a supplementary auxiliary energy source when excess inertial energy is available can all reduce loads and increase brake efficiency. Potential technologies to achieve this include clutches to engage and disengage the accessories, variable-speed electric motors, and variable-flow pumps.

The potential for fuel consumption reduction from improvements in the accessories depends on the duty cycle. This varies significantly across different model and variants. Based on a previous study of engine energy loss (Sharpe & Delgado, 2016), we assumed the auxiliary power consumption as 3.2% of the rated power. We also estimated that consumption from accessories can be reduced by 50% using the vehicle technologies assessed. Therefore, we have only a single step of improvement for auxiliary accessories.

HYBRIDIZATION

Hybrid technologies supplement engine power with electrical energy from batteries. Possible fuel efficiency technologies in hybrids include regenerative braking, stop-start and coasting (which shut off the engine when the vehicle is stopped and going downhill, respectively), and torque assist for propulsion. Braking energy losses can be recovered through an electric generator and returned to the vehicle as electricity that can power accessories or power torque assist using an electric motor.

There are no hybrid truck models on the market in India. Given this, the hybrid system in this study is assumed to have motor power that is one-third of ICE engine rated power (based on a survey of available hybrid truck models outside India). The battery size was kept relatively small because the state of charge varies little in the highway drive cycle driving of the trucks under study. When vocational trucks are driven in urban conditions, fuel-saving benefits from hybridization are up to 22% (Dahodwala et al., 2021). In this study, we used the results of simulations of conventional ICE trucks from Buysse et al. (2021) to evaluate braking and idling losses. A Python code was used to post-process results and estimate fuel savings from recovering braking losses and reducing idling losses using the electric motor and battery. The specifications of the electric motor and battery used in each of the reference models are in Table 7.

Table 7. Specifications of hybrid truck models

Reference model	RM1	RM2	RM3	RM4	RM5
Engine size in kW	92	111.8	148	149	186.425
Motor size in kW	30	40	50	50	60
Battery size in kWh	5	5	5	10	10

ELECTRIFICATION

Vehicle electrification involves completely changing the drivetrain to be powered only using electrical energy from the battery. While the potential for ICE technology improvement is limited by the laws of thermodynamics, electric motors are much more efficient than ICEs; to get better energy efficiency, manufacturers are shifting to battery electric trucks (BETs; Basma & Rodriguez, 2021; Mao & Rodríguez, 2021). Because these trucks run on electricity rather than diesel, they offer multiple advantages such as no harmful tailpipe emissions, less noise, and opportunities for energy regeneration.

The energy consumption of BETs is about 40% lower than ICEs, but the main drawback is the payload penalty due to the weight and volume of the electric battery. That payload penalty is expected to decline in coming years, though, as more energy-dense batteries are introduced.

Because there are not yet any BETs in India, we developed virtual models and replaced the ICE of the reference trucks with an electric motor and battery that could provide similar performance in terms of speed, power, and torque. The battery considered is a combination of lithium-iron-phosphate cells, one of the leading chemistries used in HDV electrification today (Mao et al., 2021). Based on the operational data collection exercise mentioned earlier, we designed the battery size to cover the average daily distance traveled by the trucks and tractor-trailers. The designed battery size and ranges are lower than those used in other studies of the other regions. This assumption is based on the sensitivity of Indian consumers to upfront truck cost and is supported by the ranges in announced future models and prototypes of BETs in the Indian market. Our data shows that truck buyers in India would like to spend less upfront and instead depend more on public charging infrastructure when the vehicle travels longer distances.

Table 8. Specifications of BET models

Reference model	RM1	RM2	RM3	RM4	RM5
GVW	11,990 kg	16,100 kg	28,000 kg	42,000 kg	55,000 kg
Motor size	90 kW	111 kW	150 kW	150 kW	186 kW
Motor efficiency	95%				
Battery size	92 kWh	120 kWh	255 kWh	418 kWh	471 kWh
Range	150 km	200 km	200 km	250 km	250 km
Energy consumption in kWh/km	0.39	0.43	0.8	1.07	1.22
Battery weight (included in GVW)	575 kg	756 kg	1,593 kg	2,612 kg	2,943kg
Battery weight proportion of GVW	4.8%	4.6%	5.6%	6.2%	5.3%
Battery DoD	70%				
Rolling resistance coefficient	0.0049				
Aerodynamic drag coefficient	0.55			0.51	

4. COST ASSESSMENT

DATA SOURCES AND APPROACH TO DATA PROCESSING

This section analyzes the marginal costs of technology improvements and focuses mainly on the technology areas detailed in Section 3. We used the data developed for assessing the cost-effectiveness of fuel-efficient technologies of long-haul tractor-trailers in Europe (Meszler et al., 2018), which was later updated for China (Meszler, 2019). The costs in the Europe study were sourced from the Regulatory Impact Analysis (RIA) of the U.S. Environmental Protection Agency's (EPA) Phase 1 (EPA & U.S. Department of Transportation, 2011) and Phase 2 (EPA & U.S. Department of Transportation, 2016) GHG emissions and fuel efficiency standards for medium- and heavy-duty vehicles. We did not adjust the costs from Meszler (2019), hereafter "the China study," because we assumed similar manufacturing market conditions for diesel-powered HDVs in India as in China. The only costs directly used for truck accessories were from the RIA of EPA's Phase 2 standards; those were not adjusted. The cost estimates from these studies were used without exception in this analysis to provide conservative cost-effectiveness estimates for India.

The technology costs sourced from the RIAs done by the U.S. EPA were available in 2013 U.S. dollars and were converted to 2013 Indian rupees using the average exchange rate for that year; the cumulative inflation in India from 2013 to 2022 was used to get costs in 2022 Indian rupees.[3] Unless otherwise specified, all cost data that follows is expressed in 2022 Indian rupees.

The cost for each efficiency step includes direct manufacturing costs (DMCs) and indirect costs (ICs) used for calculating total costs (TCs). This DMC/IC/TC methodology is structurally identical to the method used by the EPA to support its Phase 1 and Phase 2 HDV GHG emissions and fuel efficiency standards and it has been subjected to rigorous development and review. The ICCT used it to support previous vehicle analyses, including the Europe and China tractor-trailer studies from which this study sourced costs. The DMCs are the costs to the vehicle or engine manufacturer of the materials and labor required to produce and assemble technology components. ICs cover research and development, overhead, marketing and distribution, and profit markups. Given the conservative nature of using U.S. data directly, indirect cost multipliers and the technology-specific learning curves developed in support of the U.S. Phase 2 rulemaking, which were used in ICCT's Europe and China tractor-trailer studies, apply to this study also. As with any study that evaluates future conditions, there is some uncertainty associated with our estimates. Future refinement of these cost estimates will continue as technologies evolve and become mainstream, and as reliable domestic costs for the Indian market become available.

IMPROVED ENGINE EFFICIENCY COSTS

The tractor-trailer assessed in the China study comes with a 10-liter engine, whereas the engines of five reference models in this study range from 3.3–5.7 liters (as mentioned in Table 1). Technology costs available for different efficiency steps (Table 3) of the 10-liter engine were linearly scaled down to the engine sizes of the reference models. Figure 3 represents the engine technology costs employed for RM1 (rigid truck) and RM5 (tractor-trailer), both derived from the China study. The costs for the remaining reference models are presented in Appendix B. The dotted lines in the figure represent the efficiency improvement steps mentioned in Table 3.

---

[3] Average exchange rate in 2013, $1 = ₹58.5501 (U.S. dollars to Indian rupees, 2022). Cumulative inflation of India from 2013 to 2022 was 55.20% (India Inflation Calculator, n.d.).

Figure 3. Engine efficiency improvement costs for RM1 and RM5.

IMPROVED DRIVELINE EFFICIENCY COSTS

Driveline improvement costs are assumed to be the same across all five models. Improvements are considered in the transmission and axle components, as described in Table 4 and represented by the dotted lines in Figure 4; the driveline improvement costs are relatively low compared with engine improvements across all reference models, as shown in Figure 4.

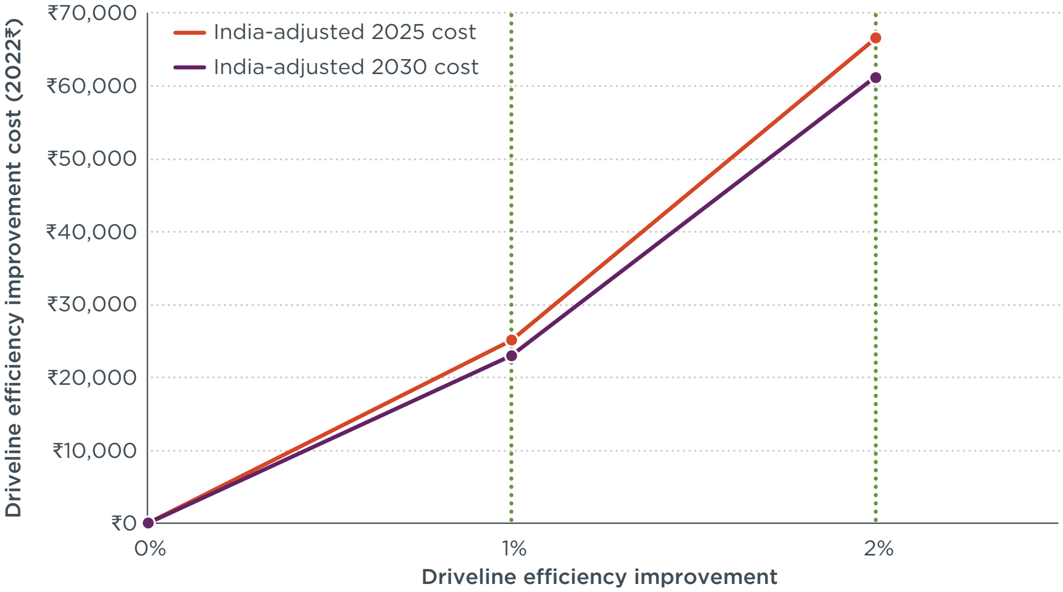


Figure 4. Driveline efficiency improvement costs.

The transmission is further improved with a shift from manual transmission to AMT. The cost incurred for this shift is assumed to be the same across all five models, around ₹360,000 in 2025 and about ₹340,000 in 2030. For the rigid truck models, this is the highest cost and for the tractor-trailer model, it is the second highest behind best-case engine improvement costs.

ROLLING-RESISTANCE REDUCTION COSTS

Costs of three levels of rolling-resistance reduction technology were estimated for the five reference models. Figure 5 shows the costs for RM1 and RM2 (see Appendix B for costs for the remaining reference models) and the dotted lines represent the efficiency improvement steps mentioned in Table 5. We derived the costs for the improvement steps using the best-fitting curve equations for the data from the China study. Costs heavily depend on the axle configuration that determines the number of steer, drive, and tag/trailer tires, as mentioned in Table 1. While RM1 and RM2 have the same axle configuration, RM3 and RM5 have similar costs because they have the same number of drive and tag/trailer tires.

Figure 5. Rolling-resistance improvement cost curves for RM1 and RM2.

AERODYNAMIC DRAG REDUCTION COSTS

When assessing aerodynamic improvement costs, the combined tractor and trailer costs for aerodynamic drag coefficient (Cd) improvement from the China study were used; they were extrapolated linearly to derive the costs for Cd improvement (Table 6) for RM5, the tractor-trailer, from the curve equations. Because Cd improvement costs were not available for rigid trucks, we used the Cd improvement costs of only tractors, which were linearly extrapolated according to the improvement steps in Table 6 for the four rigid truck reference models. Figure 6 illustrates the improvement in Cd and associated costs and the dotted lines represent the efficiency improvement steps mentioned in Table 6.

Figure 6. Aerodynamic drag coefficient cost curves for the five reference models.

AUXILIARY POWER CONSUMPTION REDUCTION COSTS

Auxiliary power consumption reduction costs include the costs of upgrading to a 42-volt electrical system and electric power steering, as considered by the EPA for the Phase 2 standards. The cost of a 50% improvement in accessories' power consumption, as detailed in Section 3.2, was assessed for all five reference models and is shown in Figure 7.

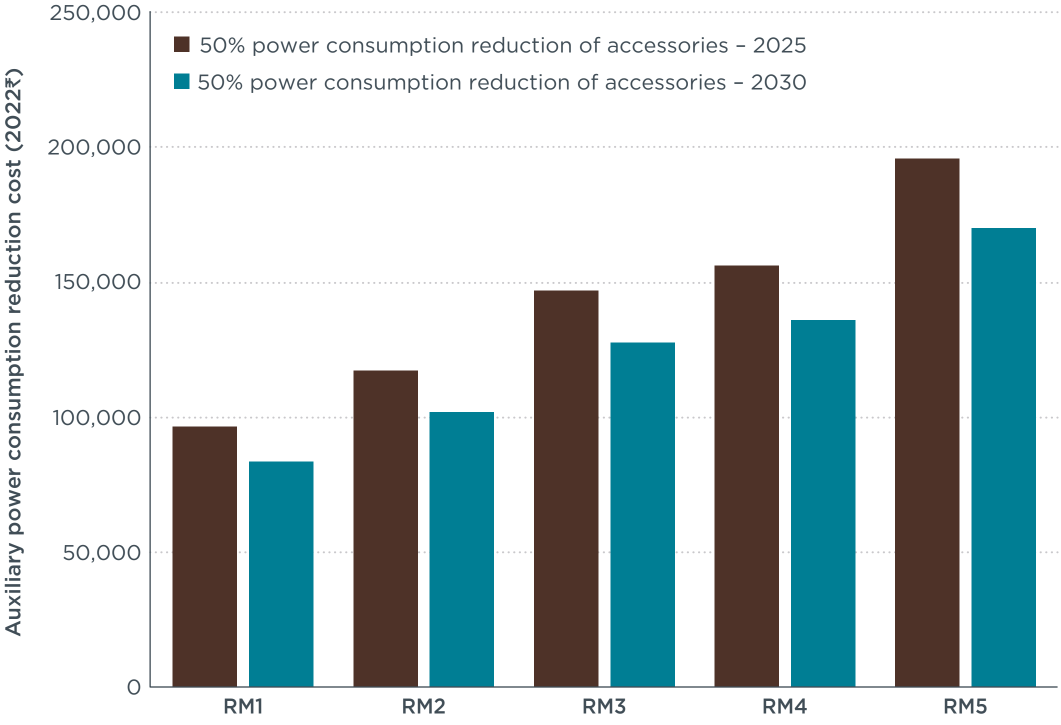


Figure 7. Auxiliary consumption reduction costs for the five reference models.

HYBRIDIZATION AND ELECTRIFICATION COSTS

While the best-case technology improvements apply to the hybrid reference models (as shown in Table 10 and Table 11), there are additional costs for batteries, electric drive, and auxiliaries, each based on their capacities, as mentioned in Table 7. For electrification, the conventional ICE vehicle's diesel engine and power train are replaced by an electric motor, battery, and, electrical system while keeping the vehicle glider the same. According to Ricardo Strategic Consulting (2021), the power train, including engine, engine accessories, aftertreatment, fuel tank, DEF tank, and transmission, is 43% of a truck's baseline cost (Table 12); this is excluded in the electrification step. Based on their capacities, as listed in Table 8, the additional costs of batteries, electric drive, and auxiliaries for BETs were estimated. In the case of electrification, the best-case improvements apply only to rolling resistance, aerodynamic drag, and accessories.

DMCs for the hybrid and electric reference models were taken from a recent ICCT meta-study on purchase costs for zero-emission trucks (Sharpe & Basma, 2022); these costs were in terms of U.S. dollars per kW for the electric drive (the electric motor, inverter, and transmission system) and the auxiliary components (only those not covered earlier in this section) and in terms of U.S. dollars per kWh for batteries, and were converted to 2022 Indian rupees.[4] While the meta-study does not cover hybrids, few auxiliaries were considered in our cost assessment of hybrids, as shown in Table 9.

---

[4] Average exchange rate in 2022, $1 = ₹75.3663 (U.S. dollars to Indian rupees, 2022).

The total hybridization and electrification costs are detailed further in the technology packages in Section 5.

Table 9. Electric drive, battery, and auxiliary components DMCs for battery electric and hybrid trucks

		2025	2030	Used in electric truck	Used in hybrid truck
Battery	US$/kWh	150	100	Yes	Yes
Electric drive	US$/kW	35	25	Yes	Yes
High voltage distribution system		27	27	Yes	Yes
Thermal management		21	21	Yes	Yes
Onboard charger		58	52	Yes	No
Electric air brake compressor system*		1,500	1,500	Yes	No
High voltage DC-DC converter*		72	67.5	Yes	No

* The kW sizing of these components was determined through the ratio of the component's kW rating to motor kW rating used in an ICCT commissioned study, Ricardo Strategic Consulting (2021). Final DMCs were derived based on this ratio percentage: 1.7% for electric air brake compressor, 1.7% for high voltage DC-DC converter, and 12.5% for the onboard charger.

5. TECHNOLOGY PACKAGES

The technology steps discussed in Section 3 were combined into seven TPs for the rigid trucks and 10 TPs for the tractor-trailer. The details of the packages are in Tables 10 and 11. Each successive package includes a more advanced level of technology, and hence there is progressively less fuel consumption and technology improvement costs increase.

Table 10. Technology packages for the rigid trucks

	Baseline	TP1	TP2	TP3	TP4	TP5	TP6-Hybrid	TP7-Electric
Engine								
2020 engine (42% Peak BTE) – Baseline	●							
2020 44.8% PBTE engine Level 1		●	●					
47% PBTE Level 2				●	●			
48.6% PBTE Level 3						●	●	
Transmission								
Manual	●	●	●	●				
AMT					●	●	●	
Driveline								
Baseline	●	●						
High-efficiency transmission (+1%)			●	●	●	●	●	
High-efficiency axle (+1%)				●	●	●	●	●
Hybridization							●	
Electrification								●
Tire rolling resistance								
Baseline 9.25 kg/tonne	●							
Level 1 tire (RR of 7 kg/tonne is mandatory for new radial tires)		●	●					
Level 2 tire 6.2 kg/tonne				●	●			
Level 3 tire 4.9 Kg/tonne						●	●	●
Aerodynamics								
Baseline (0.7 Cd)	●	●						
Level 1 aero – (0.62 Cd)			●	●	●			
Level 2 aero – (0.55 Cd)						●	●	●
Accessories								
Baseline consumption – 3.2% of engine power	●	●	●	●				
Improved accessories- 1.6% of engine power					●	●	●	●

Table 11. Technology packages for the tractor-trailer

	Baseline	TP1	TP2	TP3	TP4	TP5	TP6	TP7	TP8	TP-9 Hybrid	TP10-Electric
Engine											
2020 engine (42% PBTE) – Baseline	●										
2020 44.8% PBTE engine (BIC) L1		●	●								
47% PBTE L2				●	●						
48.6% PBTE L3						●					
51.2 % PBTE engine (waste heat recovery) L4							●	●			
55% PBTE engine L5									●	●	
Transmission											
Manual	●	●	●	●							
AMT					●	●	●	●	●	●	
Driveline											
Baseline	●	●									
High-efficiency transmission (+1%)			●	●	●	●	●	●	●	●	
High-efficiency axle (+1%) +2% driveline efficiency				●	●	●	●	●	●	●	●
Hybridization (% regeneration efficiency)										●	
Electrification											●
Tire rolling resistance											
Baseline 9.25 Kg/tonne	●										
Level 1 tire (RR of 7 kg/tonne is mandatory for new radial tires		●	●								
Level 2 tire 6.2 kg/tonne				●	●	●	●				
Level 3 tire 4.9 kg/tonne								●	●	●	●
Aerodynamics											
Baseline (0.7 Cd)	●	●									
Level 1 Aero – (0.65 Cd)			●	●	●						
Level 2 Aero – (0.55 Cd)						●	●				
Level 2 Aero – (0.51 Cd)								●	●	●	●
Accessories											
Baseline consumption – 3.2%	●	●	●	●							
Improved accessories – 1.6%					●	●	●	●	●	●	●

TP costs are over and above the 2022 market prices of the reference models (Table 12), which are the baseline costs. These 2022 baseline prices were assumed to remain the same in 2025 and 2030.

Table 12. 2022 market prices of the five reference models

Reference model	RM1	RM2	RM3	RM4	RM5
2022 market price (₹ lakhs)	21.71	24.78	31.02	38.67	39.14

Source: trucks.cardekho.com, accessed in February 2022

Electrification package cost: The electrification TP for all five reference models includes the best-case driveline, tire rolling resistance, aerodynamics, and accessories improvements plus the components listed in Table 9. The ICE power train cost is excluded from the truck's baseline cost.

Cost curves: Figures 8 and 9 show the cost curves for the reference models. These showcase TP costs and the benefits they provide. In all cases for rigid trucks, the slope of the ICE TPs increases rapidly after TP3; this is due to the high cost and low marginal benefit of ICE improvement. The cost curve for electrification from TP3 shows that the cost increase compared to the benefits is less when moving toward BETs. However, for tractor-trailers, the electrification cost curve is steep relative to ICE packages until TP7. This is due to the high cost of a tractor-trailer's larger power train; these vehicles need a longer electric range and for that, a larger battery.

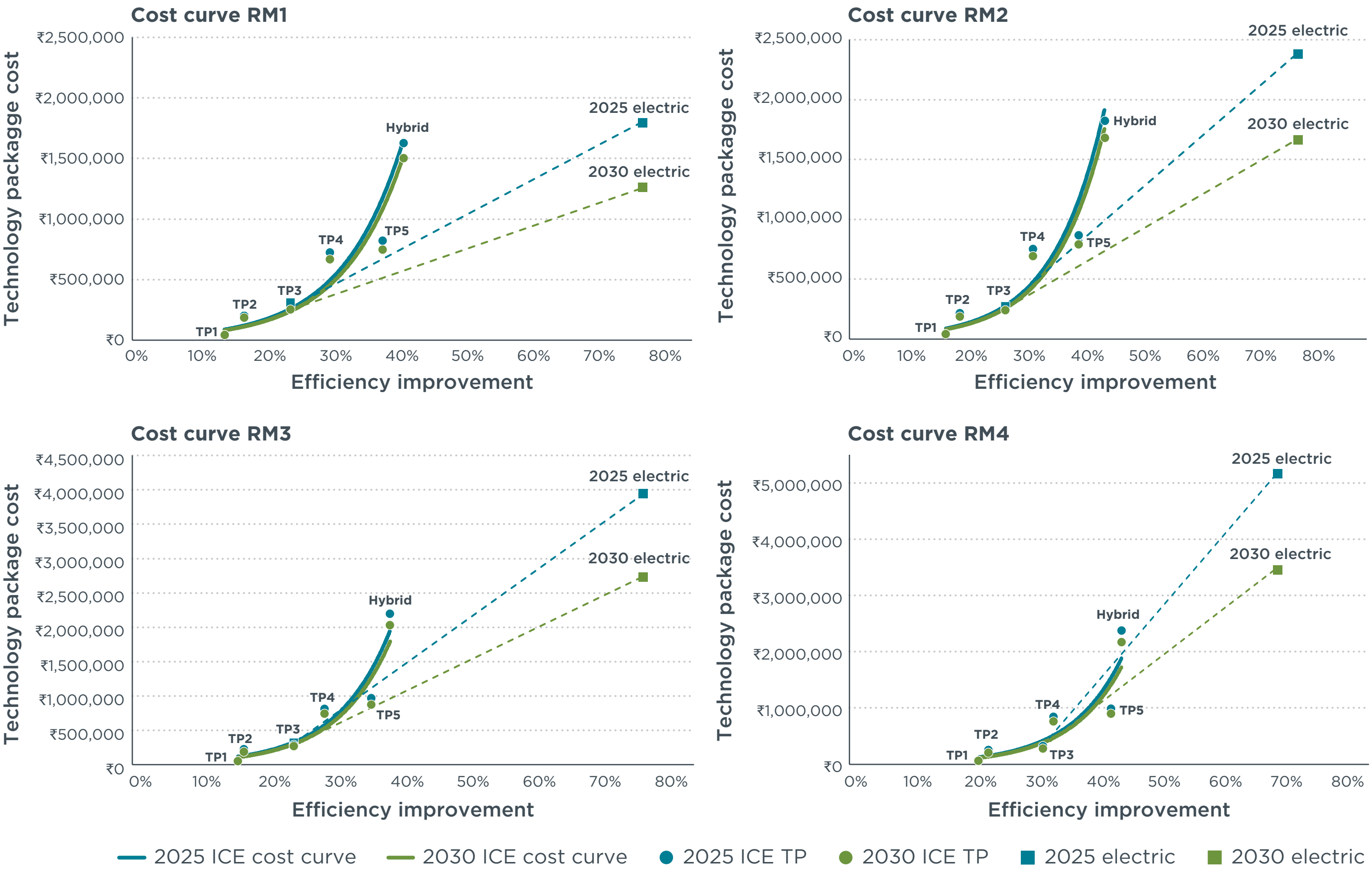


Figure 8. Cost curves for rigid trucks.

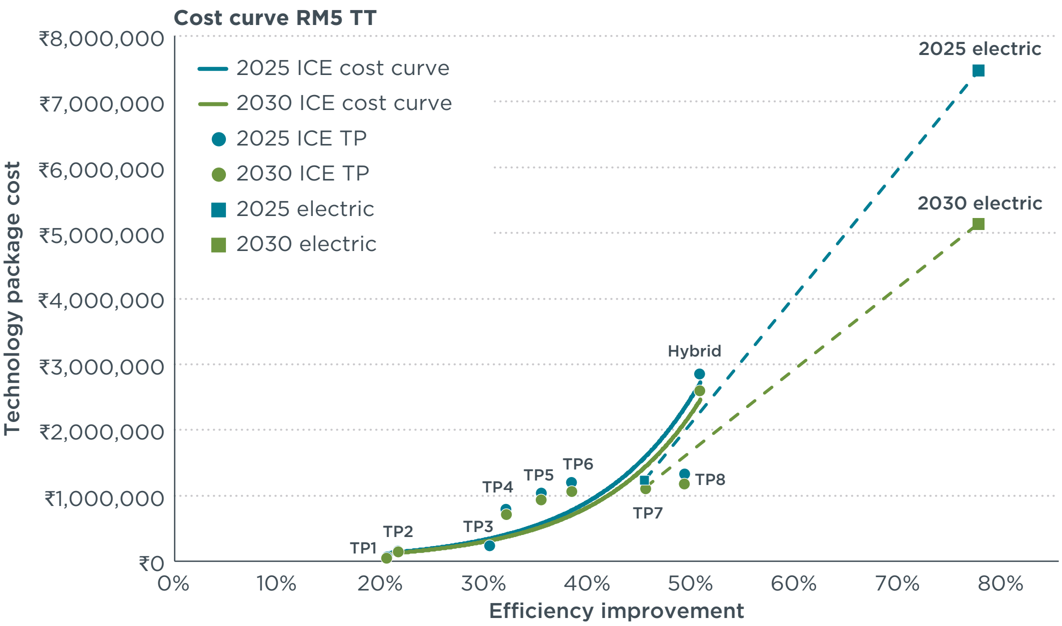


Figure 9. Cost curves for tractor-trailers.

Figure 10 shows the added marginal costs for each reference model under three scenarios: improvement costs for the best-case ICE TP, the hybrid TP, and the electric TP. All the electric models cost more than the best-case ICE and the hybrid models in both 2025 and 2030, with the exception of RM1; for RM1, the electric model costs around 10% less than the hybrid in 2030, but still costs more than the best-case ICE model.

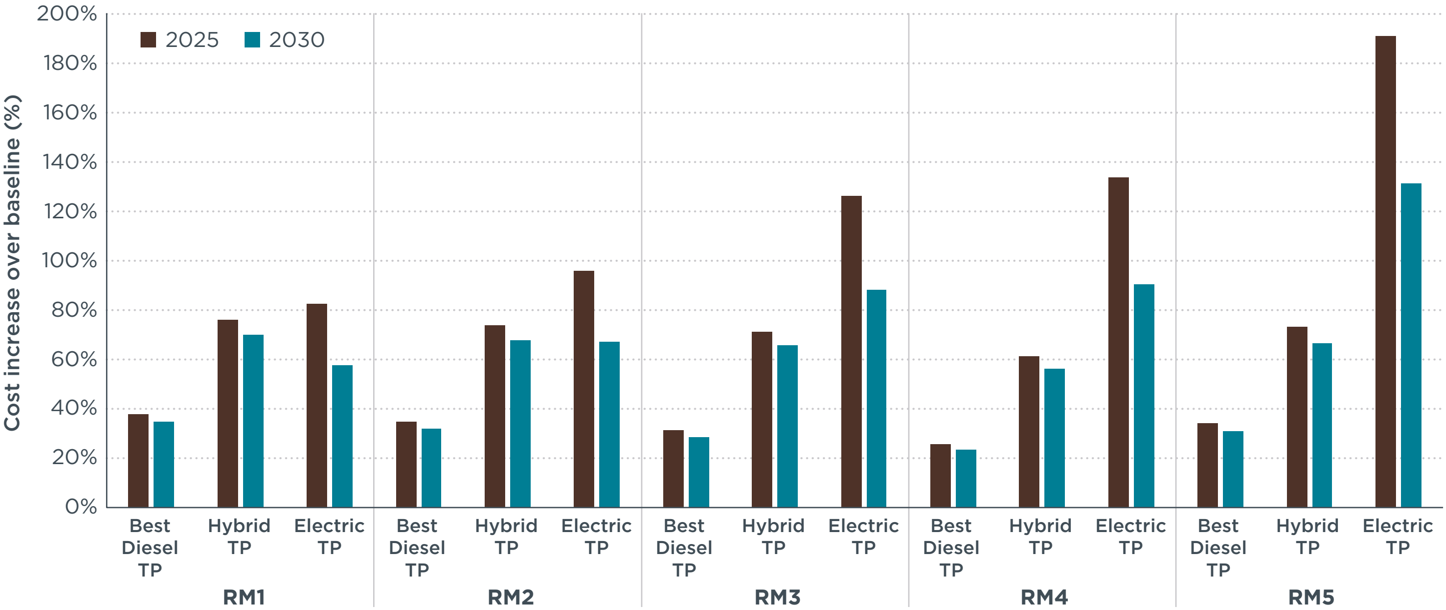


Figure 10. Marginal costs for the best efficiency ICE, hybrid, and electric TPs.

6. PAYBACK PERIOD, LIFETIME SAVINGS, AND MARGINAL COST

This section analyzes the economic performance of the TPs shown in Tables 10 and 11. The payback period for each was determined by calculating the number of years it would take for the annual fuel savings to equal the cost of the TP and the net present value (NPV) of maintenance costs over time. To determine the lifetime savings, the lifetime fuel cost savings resulting from reduced fuel consumption were subtracted from the capital and NPV of maintenance costs over time. The marginal cost of the TP was used to identify the cost-effectiveness of fuel savings relative to the prior package. We also performed a sensitivity analysis to understand the impact of key parameters and assumptions on the findings. Figure 11 illustrates the overall model used.

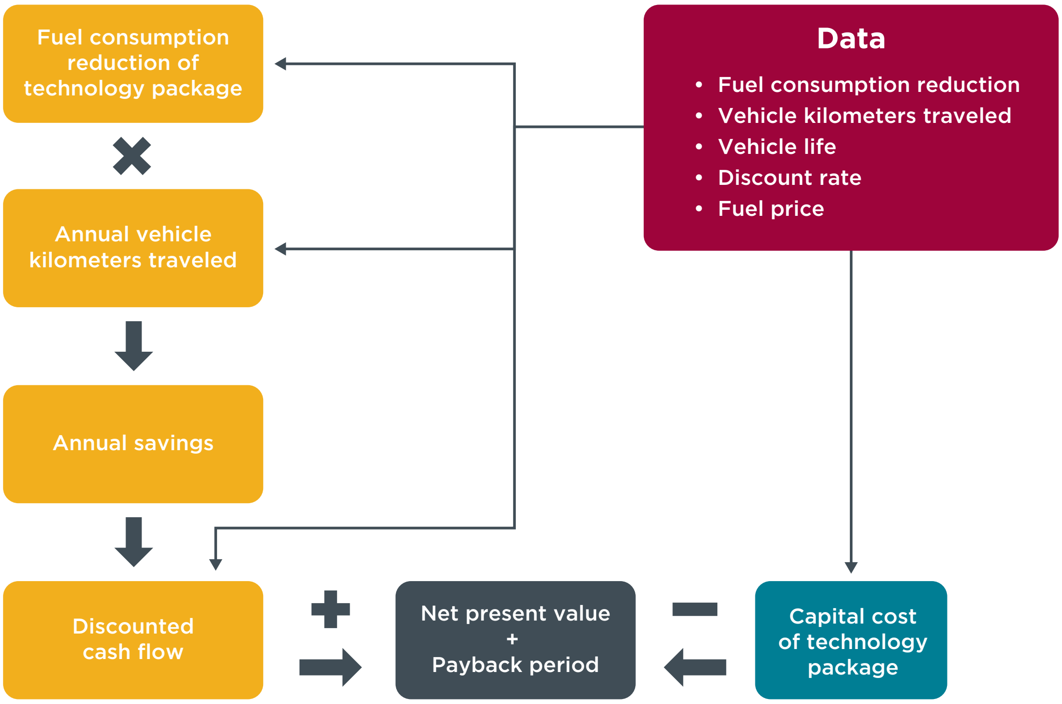


Figure 11. Model used for the cost-benefit analysis.

The various values of parameters in the model were determined based on the authors' best judgment and the literature as follows:

Fuel consumption reduction: Detailed in previous sections for all five reference models and all technology packages.

Vehicle kilometers traveled (VKT): The fuel consumption reduction per km was applied to annual VKT to determine the annual fuel cost savings. Based on Gopal et al. (2017), first-year VKT is 69,000 km for a new rigid truck and 89,500 km for a new tractor-trailer. We assumed similar daily distance for both the tractor-trailer and the 42-tonne truck based on the GPS data collected and used the tractor-trailer VKT for the 42-tonne truck. The VKT for subsequent years decreases and, similar to previous studies, we used the exponential decay function to determine the future VKT:

$$VKT_n = VKT_1 \times (1 - \alpha)^n$$

Where, VKT_n is the VKT in year n, VKT_1 is the first year VKT, n is the evaluation year, and α is the decay factor. α determines how fast the VKT drops with time. We assumed α = 0.07,as used in Gopal et al. (2017).

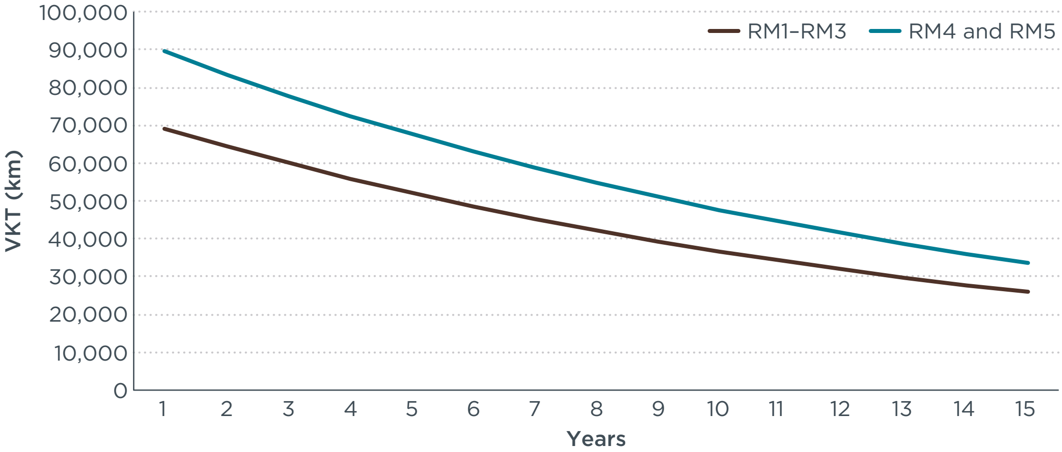


Figure 12. Assumed annual vehicle kilometers traveled.

Vehicle life: The lifetime of both trucks and tractor-trailers was assumed to be 15 years. This is based on the new scrappage policy, which makes it expensive to run commercial vehicles after 15 years of life (PIB Delhi, 2021). We predict this policy will become stricter in coming years and thus used 15 years as the vehicle's useful life.

Discount rate: This is used to assess the present value of future cash flows and is determined by the time value of money. We assumed a 4% discount rate based on Anup et al. (2021).

Charging price: This plays an important role in electric truck benefit assessment. Because there are currently no electric truck charging stations in India, costs were based on assumptions. The electricity tariff was forecasted using the average annual growth rate derived from the commercial electricity tariffs from fiscal year (FY) 2015–16 to FY 2019–20 (Power Finance Corporation, 2022). Service charges and taxes were also added to this tariff to determine the price at the charging point for electric truck operators. The final price at the charge point was evaluated to be ₹18.39/kWh for 2022.

Fuel price: For this crucial parameter, we assumed that future diesel prices will be correlated to the international crude oil price. Therefore, we took the predicted price trajectory for crude oil from the U.S. Energy Information Administration and applied it to recent prices (U.S. Energy Information Administration, 2018). The recent price was from April 2022, ₹93 per liter, and was taken from the Petroleum Planning & Analysis Cell (PPAC) databank.

PAYBACK PERIOD

For each TP, we determined the payback period for the assessment years 2025 and 2030 (illustrated in Figures 13 and 14; payback periods for all technology packages and reference models are tabulated in Appendix C.) Payback periods are shorter for 2030 vehicles than for 2025 vehicles because of lower TP costs and higher fuel prices. In the case of ICE technologies, payback periods are shorter for the heavier trucks due to higher fuel savings. TP1 has the shortest payback period—less than 1 year. The next shortest is for TP3, and in the jump from TP3 to TP4, the payback period increases significantly without much benefit of fuel consumption reduction.

For hybrid trucks, the reduction in fuel consumption is minor and comes with higher costs and a longer payback period. For BETs, the payback period of the electrification package in 2025 is longer than for the ICE packages because of the cost of the battery. The 7.5–12 tonnes segment is most feasible segment to electrify in 2025, with a payback period of about 2 years. In 2030, BETs become attractive for all segments; in most cases, they are more cost effective than improving ICE technology and their payback periods are fewer than 1.5 years.

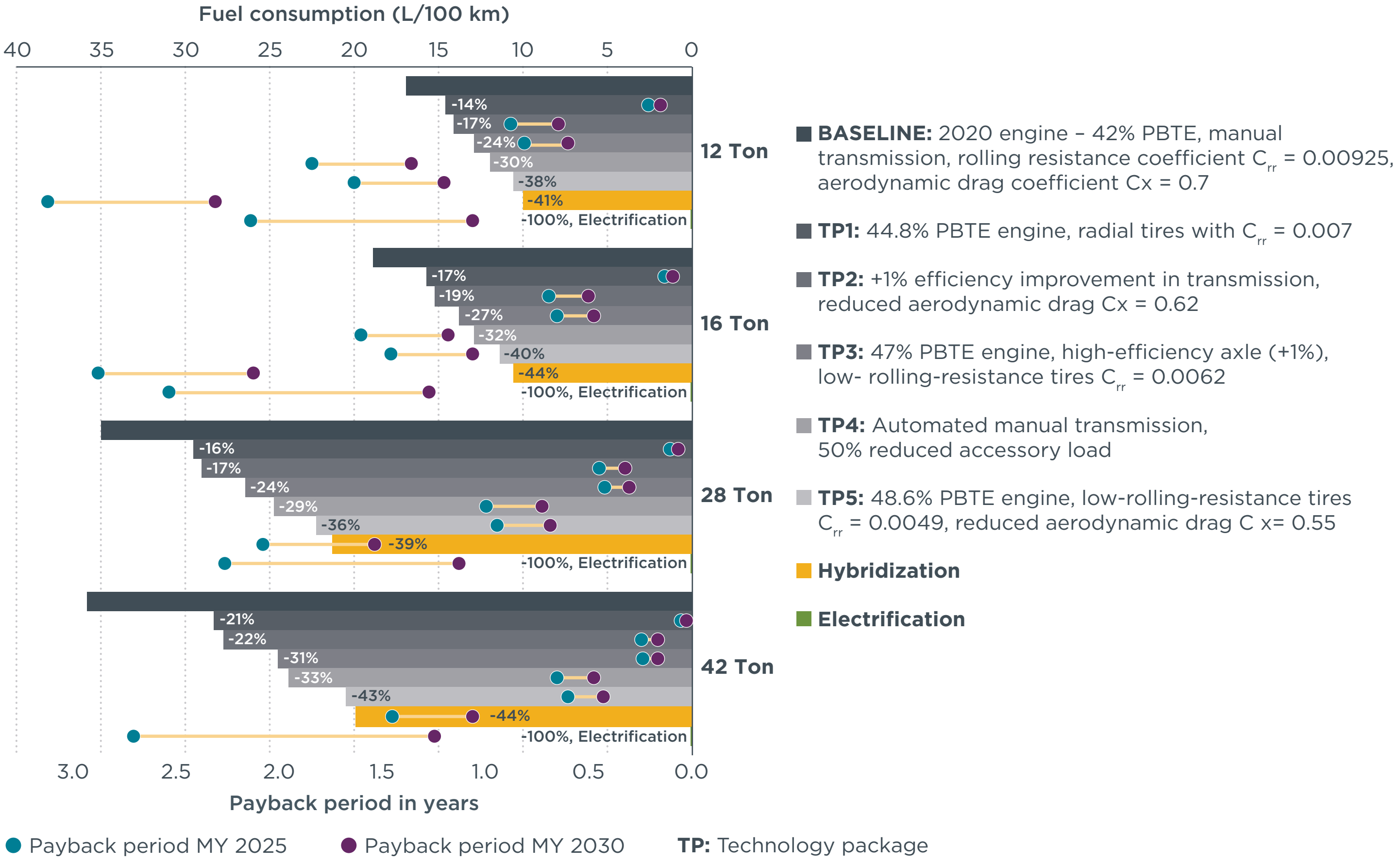


Figure 13. Fuel consumption reduction and payback periods for the rigid truck TPs.

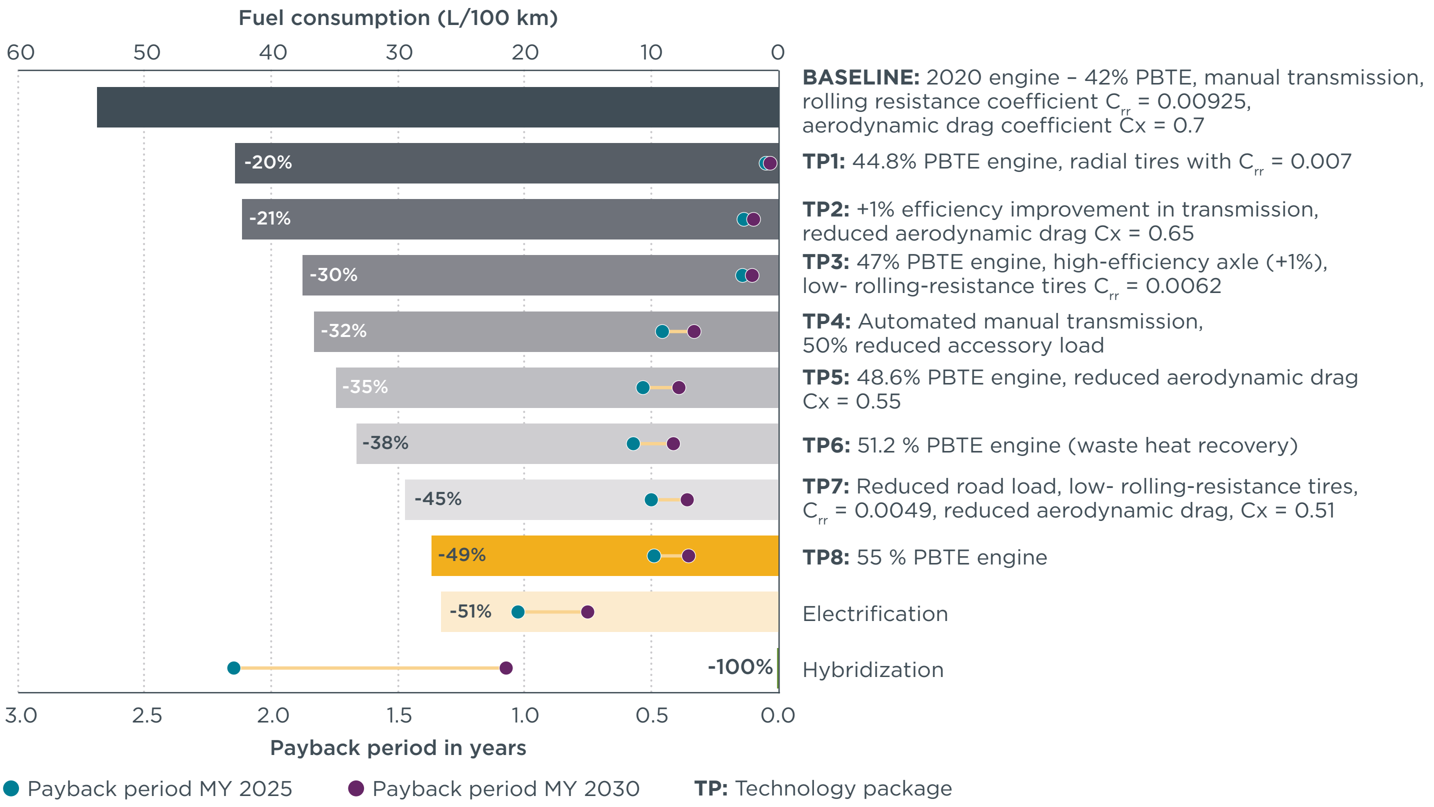


Figure 14. Fuel consumption reduction and payback periods for the tractor-trailer TPs.

LIFETIME SAVINGS

Lifetime savings were determined by taking the NPV of future savings from reduced fuel consumption and deducting the initial investments in the TPs. Lifetime savings for rigid trucks and tractor-trailers are illustrated in Figure 15 and 16, respectively.

We find that the TPs provide incremental savings due to reduced fuel consumption. Overall savings are higher in 2030 than in 2025 because of higher fuel costs and lower costs for TPs. Lifetime savings are equal to or only slightly higher for TP4 than TP3, which suggests that TP3 is an optimum package for the medium-term relative to package cost. Electrification offers more lifetime savings for all trucks in 2025 except for the heavy GVW vehicles, RM4 (42 tonnes) and RM5 (55 tonnes), and this is due to large battery costs. When deployed in 2030, lifetime savings from electrification are significantly higher for all truck segments.

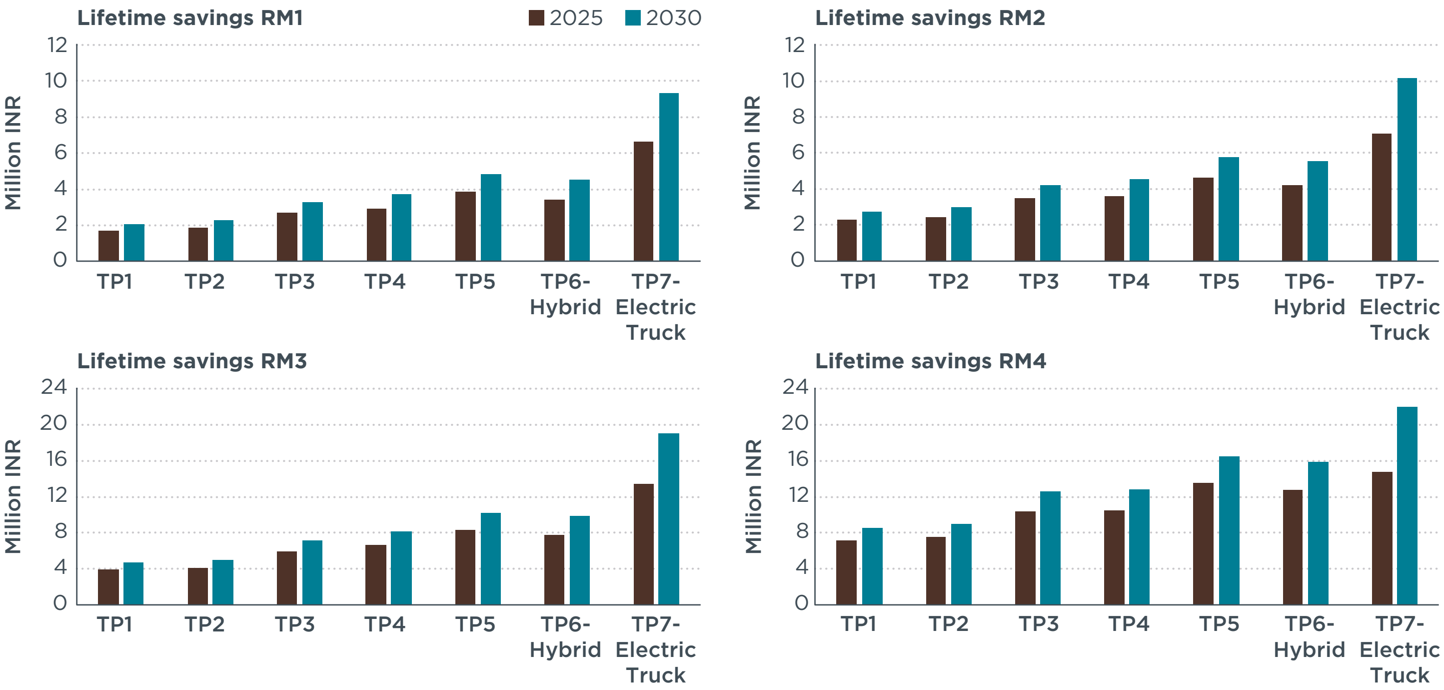


Figure 15. Lifetime savings for rigid trucks.

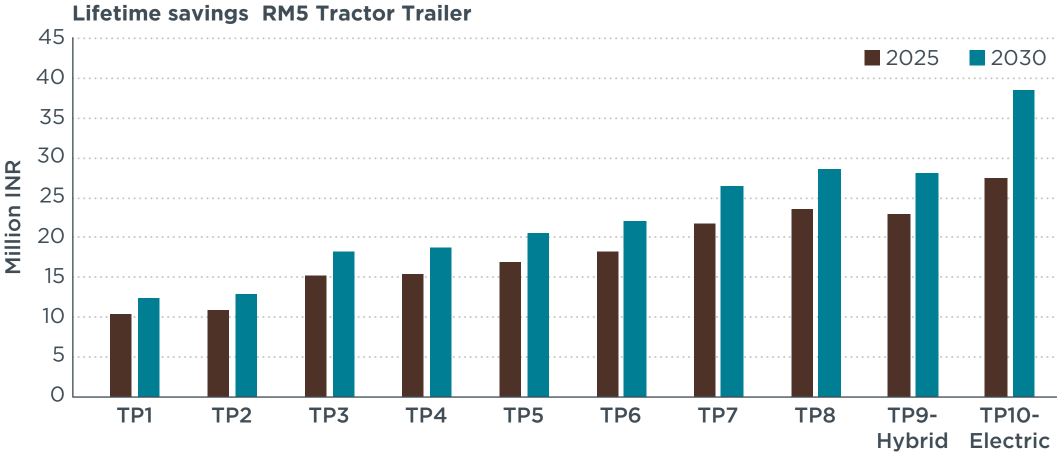


Figure 16. Lifetime savings for the tractor-trailer.

SENSITIVITY ANALYSIS

Because all economic assumptions introduce uncertainty, we performed a sensitivity analysis to check two boundary scenarios: a Best Case in which the three crucial assumptions regarding TP cost, diesel price, and charging price are favorable, meaning that diesel prices are high and both technology and charging costs are low; and a Worst Case where the costs of technology and charging are high and the diesel price is low. To avoid many iterations, we illustrate the impact only on a mid-GVW truck, the 28-tonne RM3. The two scenarios are illustrated for payback period and lifetime savings in Figures 17 and 18, respectively.

Best Case Scenario: We assumed the TP cost was 20% lower than our baseline estimates to account for factors outside of this study's scope such as supply and price of raw materials, labor costs, profit margin, and more. The higher diesel price corresponds to the high price scenarios of the U.S. EIA's crude oil price forecast. The price for BET charging was kept favorable by assuming a lower value of service charge growth on the base electricity price. The payback period and savings vary slightly for the low-cost packages, which provide low fuel savings. The most impact is on BETs, given the high package cost and increased savings. Under favorable conditions, the payback period shrinks to less than 2 years in 2025 and less than 1 year in 2030.

Worst Case Scenario: We assumed the TP cost was 20% higher than our baseline estimates to account for uncertainty and previously mentioned factors that might result in higher costs than estimated. The lower diesel price corresponds to low price scenarios of the U.S. EIA's crude oil price forecast. The price for BET charging was assumed to be higher due to higher value of service charge growth on the base electricity price. Low fuel prices decrease the annual savings and thus it takes more time to recover the higher technology package cost. The high charging price also reduces the benefits of BETs but only slightly. In the worst case, TP3 has a payback period of just over 6 months, while BET payback rises to more than 2.5 years, both in 2025. In 2030, electrification is feasible with a payback period of fewer than 1.5 years, even under worst-case conditions.

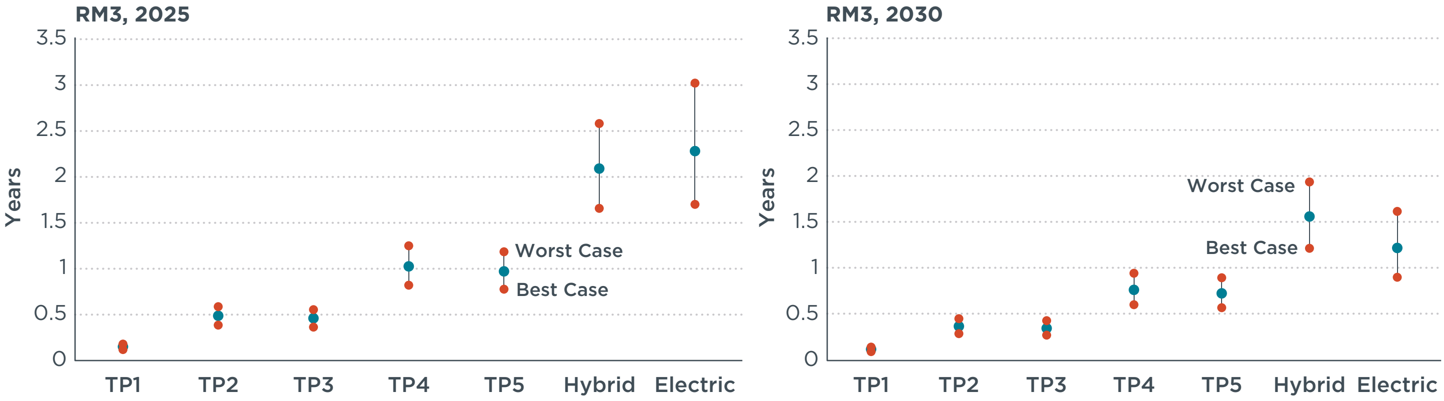


Figure 17. Payback periods under Best Case and Worst Case Scenarios.

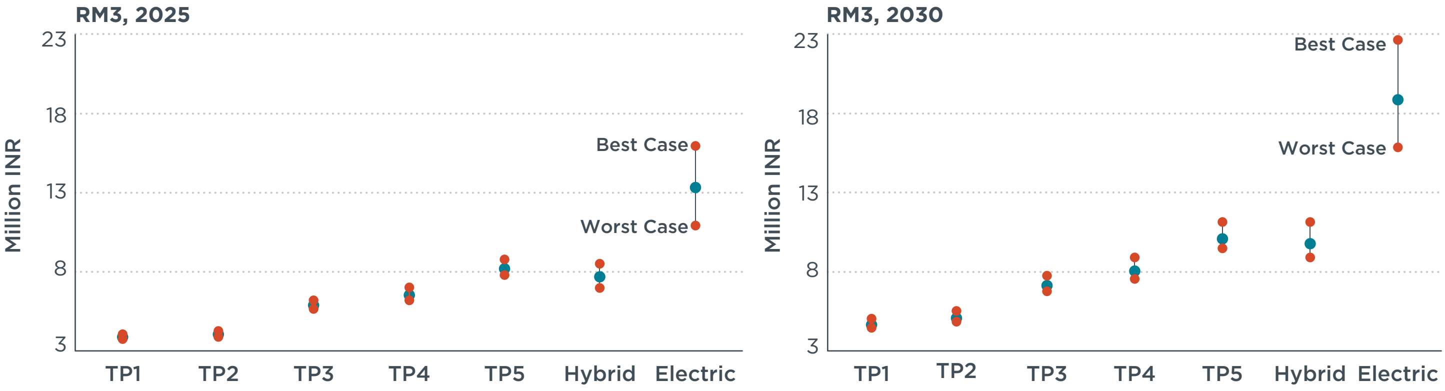


Figure 18. Lifetime savings under Best Case and Worst Case Scenarios.

7. POLICY TARGETS AND BENEFITS

We used ICCT's Roadmap model (ICCT, 2022) to evaluate policy scenarios that could bring about the improvements detailed above. The Roadmap model projects the emissions and fuel consumption from 2022–2070 based on input scenarios, and we assessed the impact on carbon emissions and oil demand under three policy scenarios: Business as Usual (BAU), Moderate Ambition, and High Ambition. Each scenario demonstrates the likely impacts of two policy levers, more stringent ICE fuel consumption standards and BET sales requirements; for each scenario, associated standard stringency and BET penetration levels are summarized in Figure 19; detailed assumptions by year are in Appendix D.

BAU: Policy advancement is weak and slow. ICE vehicle efficiency improvement of 0.5% per year until 2070 is assumed. BET sales are based on data used in a previous ICCT study of HDVs (Sen & Miller, 2022).

Moderate Ambition: TP3 is deployed in 2025 due to its cost-effectiveness with sales-weighted average fuel consumption reduction of 27%. There are no further improvements assumed in the ICE, as the focus of manufacturers shifts to BETs. We assume a 10% sales requirement for BETs from 2030 onward based on Gode et al. (2021), and the sales pick up gradually after that to achieve 70% sales by 2050 and then continue further until 100% electrification.

High Ambition: After the initial improvement in ICE trucks, the focus shifts to accelerated deployment of BETs. ICE vehicles reach peak fuel consumption reduction of 40% sales-weighted average in 2030 and thereafter have no further improvement and are phased out using ambitious BET sales requirements. BETs are introduced in 2025 at 3% sales share, and that reaches 30% by 2030, 60% by 2035, and 90% by 2040 before ultimately getting to a 100% share in 2045 (Sen & Miller, 2022).

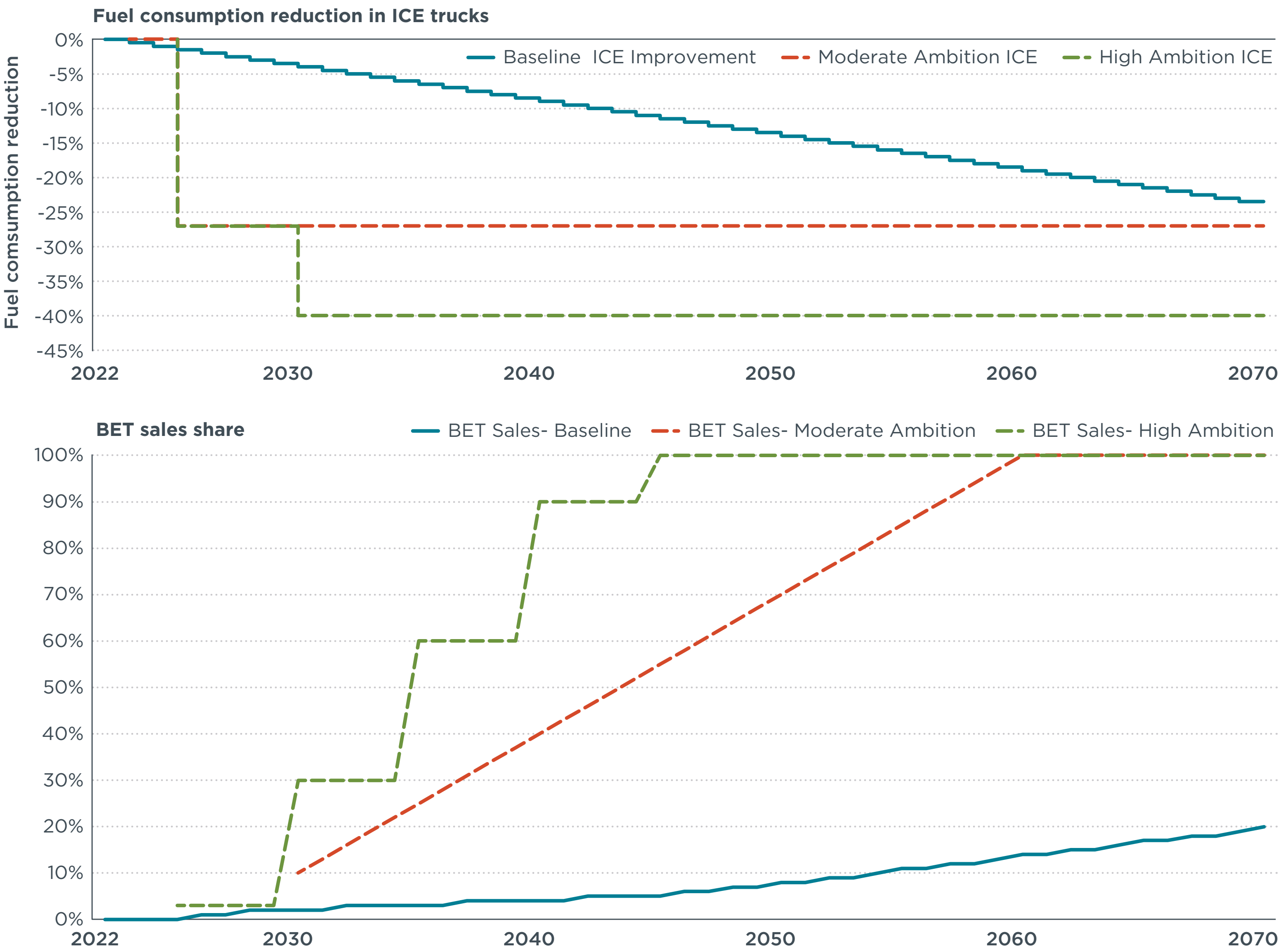


Figure 19. Details of the policy scenarios analyzed for CO_2 and oil consumption reduction.

IMPACT ON CARBON EMISSIONS

As shown in Figure 20, under the BAU scenario, the well-to-wheel CO_2 emissions from HDTs in 2070 are over four times higher than the 177 MT in 2022. Under the Moderate Ambition scenario, annual emissions plateau until 2040 and then decline. In the High Ambition scenario with 30% sales of BETs in 2030, the impact is significant and maximum annual emissions from HDTs is reached in 2029. The three dashed curves show the scenarios with only ICE vehicle sales and zero electric trucks; it is evident that without BETs, the emissions trajectory will not reverse. Figure 21 illustrates how the High Ambition scenario reduces cumulative emissions between 2022 and 2070 by about 75%.

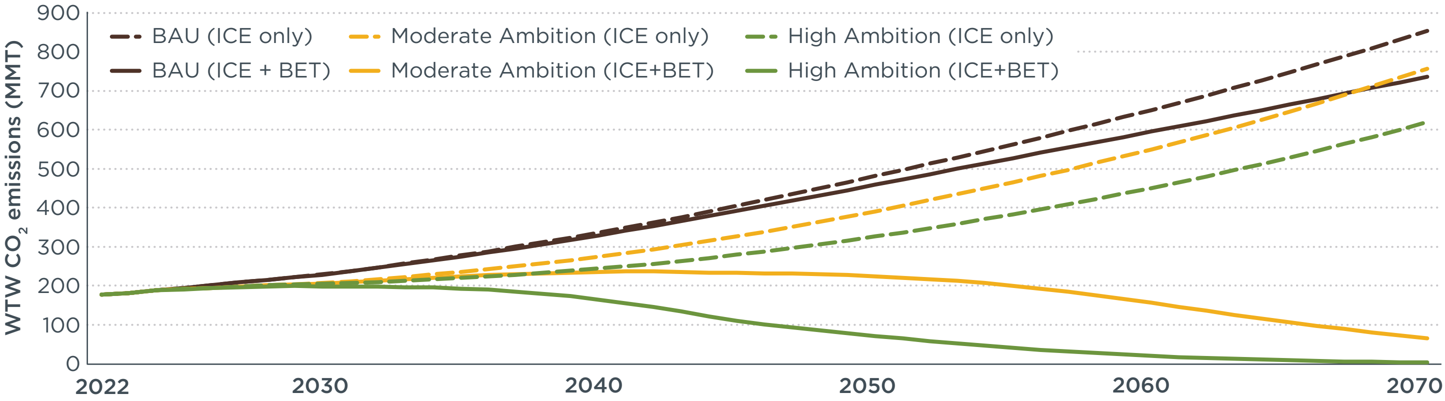


Figure 20. Annual CO_2 emissions from HDTs under the three scenarios.

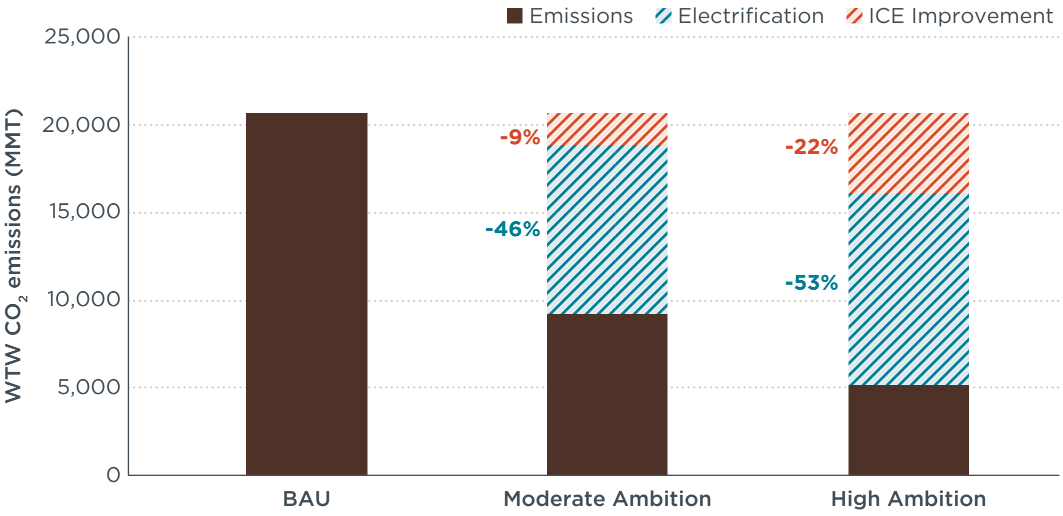


Figure 21. Cumulative CO_2 emissions from HDTs in India between 2022 and 2070 under the three scenarios.

IMPACT ON OIL CONSUMPTION

Under the BAU scenario, oil consumption from HDTs rises by more than four times to 194 MToe in 2070, as illustrated in Figure 22. The Moderate Ambition scenario reduces this oil consumption by about 89% in 2070, and the High Ambition scenario reduces it completely with mix of ICE improvement and BET sales over the years. ICE technology improvements can provide oil consumption reduction up to only 16%, and the rest needs to come from BETs.

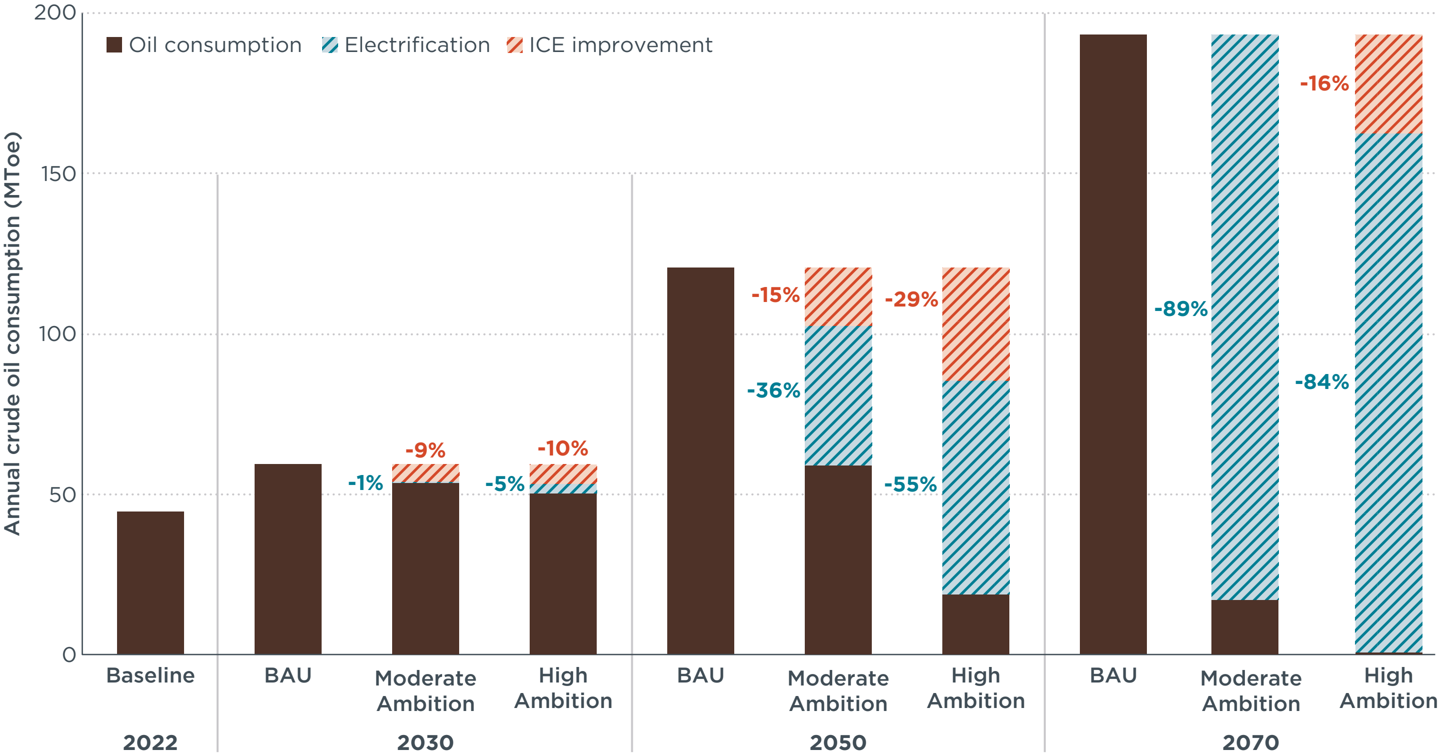


Figure 22. Crude oil consumption from HDTs under the three scenarios.

We also determined the impact on India's overall annual oil demand projection (see Figure 23). According to IEA's data, the crude oil demand for India is projected to be around 470 Mtoe in 2050. Under the High Ambition policy scenario, the HDT sector can reduce this annual oil demand by 22% in 2050.

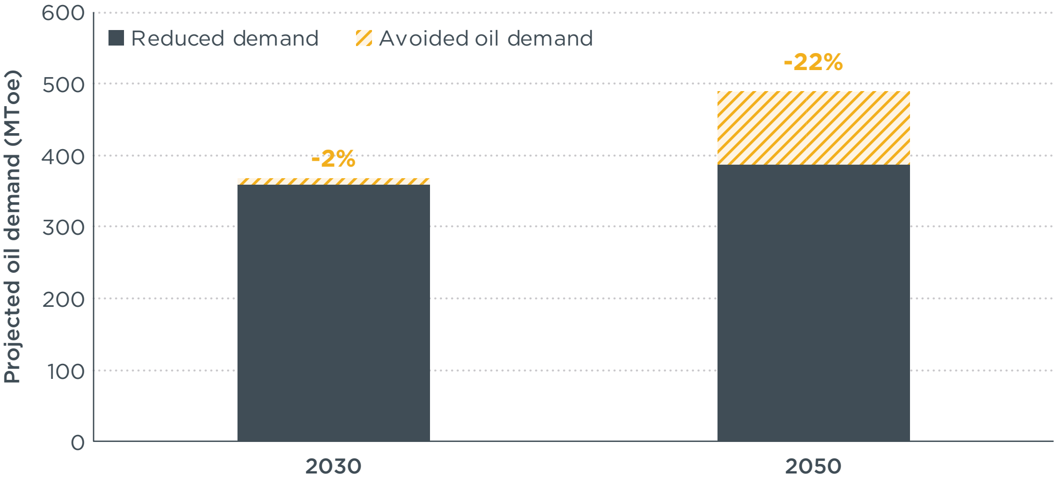


Figure 23. Impact of the High Ambition scenario on projected oil demand in India.

8. SUMMARY OF FINDINGS AND POLICY IMPLICATIONS

This study analyzed the technology potential and cost-effectiveness of fuel consumption reduction technologies for HDTs in the 2025–2030 time frame. TPs for five different vehicle segments were analyzed in terms of baseline fuel consumption, technology potential, cost, and cost-effectiveness. That was followed by analysis of the economic and emissions benefits of stricter fuel consumption standards to promote HDT efficiency.

With respect to technology potential in the near term (2023), our estimates show that best-in-class, currently available technologies for engines and tires can reduce fuel consumption by approximately 14%–21% for rigid trucks and 21% for tractor-trailers. These technologies can be implemented with minimal impact on cost and with a payback period of less than 1 year (see TP1 in Figures 13 and 14). In particular, tires in India are presently under Stage 2 of the Automotive Indian Standards (AIS) 142:2019, which allows for fuel efficient new radial tires with a maximum rolling resistance of up to 0.007. However, the standards also allow bias tires with a rolling resistance of 0.0095. These bias tires, although cheaper, result in higher efficiency losses. Thus, **phasing out bias tires is an immediately available and economical step toward reducing the fuel consumption from HDTs**.

We also found that additional technologies could be available and adopted in the 2025 time frame, and these could reduce fuel consumption by up to 31% for rigid trucks and 30% for tractor-trailers. These additional technologies include a 47% efficiency engine and about 2% improvement in the transmission and axle along with tires with rolling resistance of 0.0062 (see TP3 in Figures 13 and 14); together these have a payback period of about 10 months for rigid trucks and just 3 months for tractor-trailers.

In the long term (2030), for pure ICE power train, TP5 for rigid trucks reduces fuel consumption up to 43%. TPs with more advanced technologies and payback periods shorter than 14 months could reduce fuel consumption by up to 43% for rigid trucks (see TP5 in Figure 13); this includes a 48.6% PBTE engine with low-rolling-resistance tires and reduced aerodynamic drag (C_{rr} = 0.0049 and Cx = 0.55), automated manual transmission, and high-efficiency axle. Similarly, for tractor-trailers, up to 45% fuel consumption reductions could be achieved with a pure ICE technology package (see TP8 in Figure 14) that combines a very high-efficiency engine using waste heat recovery (55% PBTE) with low-rolling-resistance tires, even lower aerodynamic drag (C_{rr} = 0.0049 and Cx = 0.51), automated manual transmission, and high-efficiency axle. This engine technology is presently under research and development. We note that this technology package essentially exhausts all the technology potential available. As the fuel and emissions reductions required by India's goals go beyond the potential of ICE technologies, hybrids and BETs will be necessary.

The results suggest the following implications for policies promoting alternative power trains:

After TP3, it becomes more cost effective to focus on BETs. The technology cost curves illustrate that as additional improvement in ICE technology becomes more costly, the same effort toward accelerated electrification will return greater economic and environmental benefits.

For the vehicles analyzed, hybridization does not offer a significant benefit over ICE for long-haul HDTs. Hybrid technology is best-suited for drive cycles with a high share of transient driving, like urban delivery trucks. In this study, drive cycles were more focused on long haul and regional delivery, and the share of urban and transient driving was smaller. We found that hybrid trucks offer up to 4% fuel consumption reduction in rigid trucks and 2% reduction in tractor-trailers. Thus, for HDTs that run mostly on highways, instead of investing in hybrids, investing in complete electrification would be more cost-effective in the long term.

The upfront cost for BETs is higher than for ICE trucks, but that comes with lower energy costs. Additionally, it is expected that battery costs will be lower by 2030 and that will make BETs more economically appealing in all circumstances. Further:

- The electrification package has a payback period of around 2.4 years for rigid trucks in 2025 and this comes down to about 1.2 years in 2030. For the tractor-trailer, the payback period for the electrification package is 2.2 years in 2025 and it drops to 1.1 years in 2030.
- BETs up to 40 tonnes offer benefits up to 1.9 times higher than the best-case ICE trucks, while HDTs greater than 40 tonnes offer savings about 1.3 times higher than the best-case ICE.

Among all segments, tractor-trailers provide the most opportunity for fuel consumption reduction benefits—up to 49%—and lifetime savings of up to INR 28 million. This is due to high fuel consumption and high vehicle kilometers traveled and it makes tractor-trailers attractive for electrification despite the high upfront cost.

India could potentially reduce the oil demand from the HDT sector by almost 84% by 2050 and 100% by 2070. This analysis shows that India could reduce fuel consumption from HDTs in both the near- and long-term. This will have benefits for energy security and carbon emissions. We found that ICE improvement alone cannot reduce emissions in line with India's climate ambitions; BET sales must complement ICE improvements to mitigate the sector's oil consumption and CO_2 emissions growth. As illustrated in Figure 22, under the High Ambition scenario, electrification will be responsible for 55% and 84% of reduced oil demand in 2050 and 2070, respectively. ICE improvement alone only provides 16% reduction by 2070.

India can change the emissions trajectory from HDTs as early as 2029 in the High Ambition scenario and by 2038 in the Moderate Ambition scenario. With stringent HDT fuel efficiency standards in combination with a BET sales mandate, India could reduce the oil demand from HDT by 100% by 2070. This would result in a 22% reduction in projected overall oil demand for the country in 2050. Reduced oil consumption would reduce the need for oil imports and strengthen energy security.

REFERENCES

Anup, S., Deo, A., & Bandivadekar, A. (2021). *Fuel consumption reduction technologies for the two-wheeler fleet in India*. International Council on Clean Transportation. https://theicct.org/publication/fuel-consumption-reduction-technologies-for-the-two-wheeler-fleet-in-india/

Automotive Research Association of India (ARAI). (2019, February). *Evaluation of tyres with regard to rolling sound emissions and/or to adhesion on wet surfaces and/or to rolling resistance*. https://hmr.araiindia.com/api/AISFiles/AIS_142_F_f385df6f-da24-4777-822a-ee49fd92776c.pdf

Basma, H., & Rodríguez, F. (2021). *Race to zero: How manufacturers are positioned for zero-emission commercial trucks and buses in Europe*. International Council on Clean Transportation. https://theicct.org/publications/race-to-zero-ze-hdv-eu-dec21

Buysse, C., Sharpe, B., & Delgado, O. (2021). *Efficiency technology potential for heavy-duty diesel vehicles in the United States through 2035*. International Council on Clean Transportation. https://theicct.org/publication/efficiency-technology-potential-for-heavy-duty-diesel-vehicles-in-the-united-states-through-2035/

Cabinet approves India's Updated Nationally Determined Contribution to be communicated to the United Nations Framework Convention on Climate Change. (2022, August 3). Pib.gov.in. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1847812

Centre for Economics and Business Research. (2022, December 26). *World Economic League Table 2023*. https://cebr.com/reports/world-economic-league-table-2023/

Chaturvedi, V., & Malyan, A. (2022). Implications of a net-zero target for India's sectoral energy transitions and climate policy. *Oxford Open Climate Change*, *2*(1). https://doi.org/10.1093/oxfclm/kgac001

Dahodwala, M., Joshi, S., Dhanraj, F., Ahuja, N., Koehler, E., Franke, M., & Tomazic, D. (2021). Evaluation of 48V and High Voltage Parallel Hybrid Diesel Powertrain Architectures for Class 6-7 Medium Heavy-Duty Vehicles. *SAE Technical Paper Series*. https://doi.org/10.4271/2021-01-0720

Dallmann, T., & Bandivadekar, A. (2016). *India Bharat Stage VI emission standards*. International Council on Clean Transportation. https://theicct.org/publication/india-bharat-stage-vi-emission-standards/

Delgado, O., & Li, H. (2017). *Market analysis and fuel efficiency technology potential of heavy-duty vehicles in China*. International Council on Clean Transportation. https://theicct.org/publication/market-analysis-and-fuel-efficiency-technology-potential-of-heavy-duty-vehicles-in-china/

Delgado, O., & Lutsey, N. (2014). *The U.S. SuperTruck Program: Expediting development of advanced HDV efficiency technologies*. International Council on Clean Transportation. https://theicct.org/publication/the-u-s-supertruck-program-expediting-development-of-advanced-hdv-efficiency-technologies/

Delgado, O., & Lutsey, N. (2015). *Advanced tractor-trailer efficiency technology potential in the 2020–2030 timeframe*. International Council on Clean Transportation. https://theicct.org/publication/advanced-tractor-trailer-efficiency-technology-potential-in-the-2020-2030-timeframe/

Delgado, O., Miller, J., Sharpe, B., & Muncrief, R. (2016). *Estimating the fuel efficiency technology potential of heavy-duty trucks in major markets around the world*. International Council on Clean Transportation. https://theicct.org/publication/estimating-the-fuel-efficiency-technology-potential-of-heavy-duty-trucks-in-major-markets-around-the-world/

Delgado, O., Rodríguez, F., & Muncrief, R. (2017). *Fuel efficiency technology in European heavy-duty vehicles: Baseline and potential for the 2020–2030 timeframe*. International Council on Clean Transportation. https://theicct.org/publication/fuel-efficiency-technology-in-european-heavy-duty-vehicles-baseline-and-potential-for-the-2020-2030-timeframe/

Garg, M., & Sharpe, B. (2017). *Fuel consumption standards for heavy-duty vehicles in India*. International Council on Clean Transportation. https://theicct.org/publication/fuel-consumption-standards-for-heavy-duty-vehicles-in-india/

Gode, P., Bieker, G., & Bandivadekar, A. (2021). *Battery capacity needed to power electric vehicles in India from 2020 to 2035*. International Council on Clean Transportation. https://theicct.org/publication/battery-capacity-needed-to-power-electric-vehicles-in-india-from-2020-to-2035/

Gopal, A. R., Karali, N., Sharpe, B., Delgado, O., Bandivadekar, A., & Garg, M. (2017). *Improved heavy-duty vehicle fuel efficiency in India, benefits, costs and environmental impacts*. https://doi.org/10.2172/1398495

Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles, 49 C.F.R. § 523, 534, 535 (2011). https://www.govinfo.gov/content/pkg/FR-2011-09-15/pdf/2011-20740.pdf

India Inflation Calculator: World Bank data, 1958-2023 (INR). (n.d.). Www.in2013dollars.com. Retrieved April 23, 2023, from https://www.officialdata.org/india/inflation

India's Stand at COP-26. (2022, February 3). Pib.gov.in. https://pib.gov.in/PressReleasePage.aspx?PRID=1795071#:~:text=The%20message%20conveyed%20by%20India

Jin, L., Delgado, O., Gadepalli, R., & Minjares, R. (2020). *Strategies for deploying zero-emission bus fleets: Development of real-world drive cycles to simulate zero-emission technologies along existing bus routes*. International Council on Clean Transportation. https://theicct.org/publication/strategies-for-deploying-zero-emission-bus-fleets-development-of-real-world-drive-cycles-to-simulate-zero-emission-technologies-along-existing-bus-routes/

Mao, S., Basma, H., Ragon, P.-L., Zhou, Y., & Rodríguez, F. (2021). *Total cost of ownership for heavy trucks in China: Battery electric, fuel cell, and diesel trucks*. International Council on Clean Transportation. https://theicct.org/publication/total-cost-of-ownership-for-heavy-trucks-in-china-battery-electric-fuel-cell-and-diesel-trucks/

Mao, S., & Rodríguez, F. (2021). *Race to zero: How manufacturers are positioned for zero-emission commercial trucks and buses in China*. International Council on Clean Transportation. https://theicct.org/publication/race-to-zero-how-manufacturers-are-positioned-for-zero-emission-commercial-trucks-and-buses-in-china/

Meszler, D., Delgado, O., Rodríguez, F., & Muncrief, R. (2018). *EU HDVs: Cost effectiveness of fuel efficiency technologies for long-haul tractor-trailers in the 2025-2030 timeframe*. International Council on Clean Transportation. http://theicct.org/publications/cost-effectiveness-of-fuel-efficiency-tech-tractor-trailers

Meszler, D., Delgado, O., Rodríguez, F., & Muncrief, R. (2022). *EU HDVs: Cost effectiveness of fuel efficiency technologies for long-haul tractor-trailers in the 2025-2030 timeframe*. International Council on Clean Transportation. https://theicct.org/publication/eu-hdvs-cost-effectiveness-of-fuel-efficiency-technologies-for-long%E2%80%91haul-tractor%E2%80%91trailers-in-the-2025%E2%80%912030-timeframe/

Meszler, D., Delgado, O., & Yang, L. (2021). *Heavy-duty vehicles in China: Cost-effectiveness of fuel-efficiency and CO2 reduction technologies for long-haul tractor-trailers in the 2025–2030 timeframe*. International Council on Clean Transportation. https://theicct.org/publication/heavy-duty-vehicles-in-china-cost-effectiveness-of-fuel-efficiency-and-co2-reduction-technologies-for-long%E2%80%91haul-tractor%E2%80%91trailers-in-the-2025-2030-timeframe/

Ministry of Petroleum and Natural Gas. (2021). *Indian Petroleum and Natural Gas Statistics 2019-20*. https://mopng.gov.in/files/TableManagements/IPNG-2019-20.pdf

Ministry of Road Transport and Highways. (2022). *Central Motor Vehicles (Nineteenth Amendment) Rules*.

NITI AAYOG, RMI, & RMI India. (2021). *Fast tracking freight in India: A roadmap for clean and cost-effective goods transport*. https://www.niti.gov.in/sites/default/files/2021-06/FreightReportNationalLevel.pdf

Power Finance Corporation. (2022). Pfcindia.com. https://pfcindia.com/Home/VS/29

Ricardo Strategic Consulting. (2021). *E-Truck Virtual Teardown Study Final Report*. https://theicct.org/wp-content/uploads/2022/01/Final-Report-eTruck-Virtual-Teardown-Public-Version.pdf

Road Transport & Highways Minister, Shri Nitin Gadkari Announces Vehicle Scrapping Policy. (2021, March 18). Pib.gov.in. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1705811

Sathiamoorthy, B., Narla, A., & Bandivadekar, A. (2021). *Market analysis of heavy-duty vehicles in India for fiscal years 2019–20 and 2020–21*. International Council on Clean Transportation. https://theicct.org/publication/market-analysis-of-heavy-duty-vehicles-in-india-for-fiscal-years-2019-20-and-2020-21/

Sen, A., & Miller, J. (2022). *Emissions reduction benefits of a faster, global transition to zero-emission vehicles*. International Council on Clean Transportation. https://theicct.org/publication/zevs-global-transition-benefits-mar22/

Sen, A., Miller, J., Bandivadekar, A., Sharma, M., Nagar, P., Singh, D., & Callahan, J. (2021). *Understanding the emissions impacts of large-scale vehicle electrification in India*. International Council on Clean Transportation. https://theicct.org/publication/understanding-the-emissions-impacts-of-large-scale-vehicle-electrification-in-india/

Sharpe, B., & Basma, H. (2022). *A meta-study of purchase costs for zero-emission trucks*. International Council on Clean Transportation. https://theicct.org/wp-content/uploads/2022/02/purchase-cost-ze-trucks-feb22-1.pdf

Sharpe, B., & Delgado, O. (2016). *Engines and tires as technology areas for efficiency improvements for trucks and buses in India*. International Council on Clean Transportation. https://theicct.org/publication/engines-and-tires-as-technology-areas-for-efficiency-improvements-for-trucks-and-buses-in-india/

Siemens. (2020). *Simcenter Amesim*. https://www.plm.automation.siemens.com/global/en/products/simcenter/simcenter-amesim.html

US Dollar to Indian Rupee Spot Exchange Rates for 2013. (2022, March 14). *Exchange Rates*. https://www.exchangerates.org.uk/USD-INR-spot-exchange-rates-history-2013.html

U.S. Energy Information Administration. (2018). *Annual Energy Outlook 2023*. https://www.eia.gov/outlooks/aeo/data/browser

U.S. Environmental Protection Agency, & National Highway Traffic Safety Administration. (2016). *Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles - Phase 2: Regulatory Impact Analysis*. U.S. Environmental Protection Agency. https://nepis.epa.gov/Exe/ZyPDF.cgi/P100P7NS.PDF?Dockey=P100P7NS.PDF

Xie, Y., & Rodríguez, F. (2021). *Zero-emission integration in heavy-duty vehicle regulations: A global review and lessons for China*. International Council on Clean Transportation. https://theicct.org/publication/zero-emission-integration-in-heavy-duty-vehicle-regulations-a-global-review-and-lessons-for-china/

APPENDIX A. DRIVE CYCLES

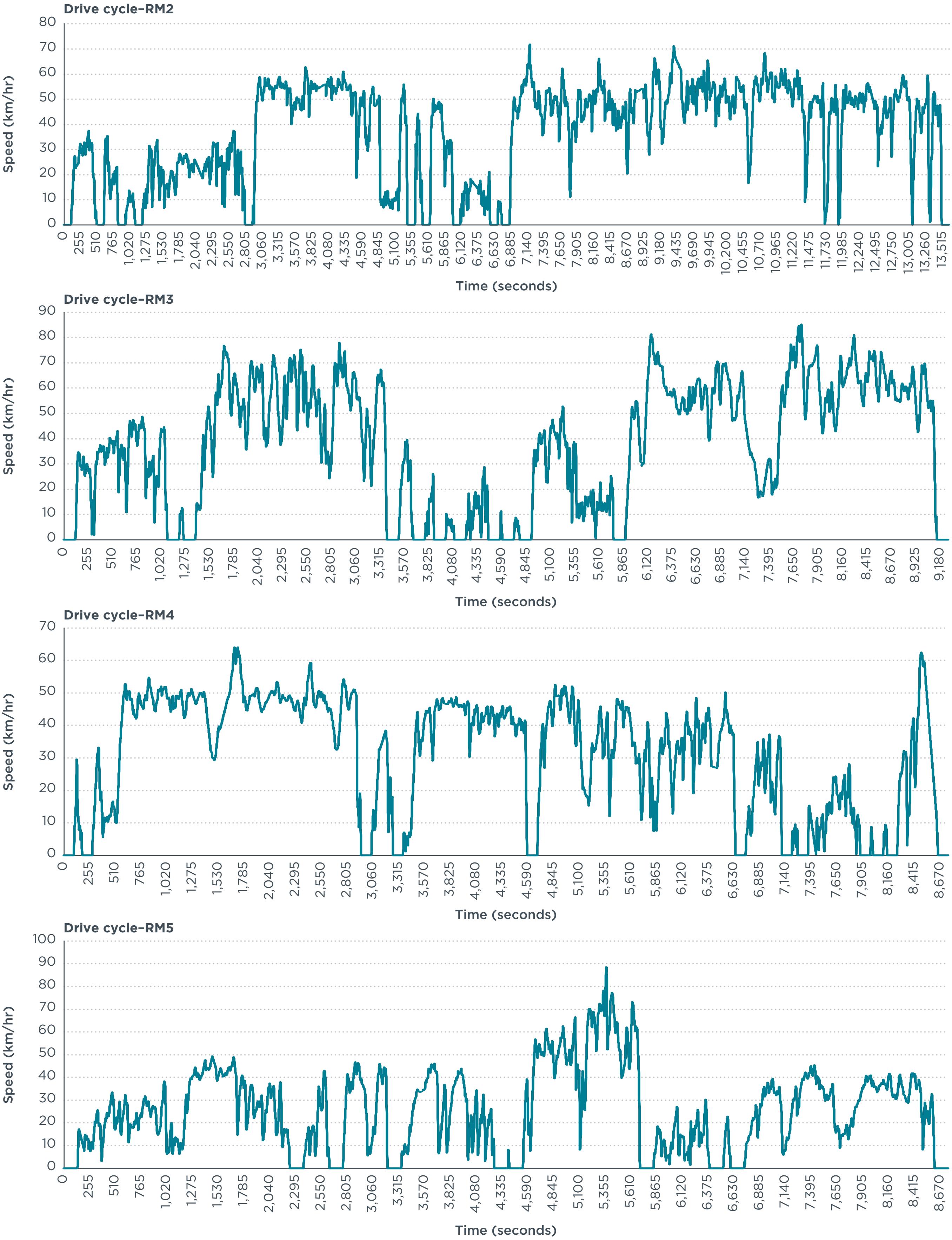


Figure A1. Cycle for reference models

APPENDIX B. COST ASSESSMENT

Improved engine efficiency costs for the reference models, other than those discussed in Section 4. The dotted lines in the figures below represent the efficiency improvement steps.

Figure B1. Engine efficiency improvement costs for RM2, RM3, and RM4.

Rolling resistance reduction costs for the reference models, other than those discussed in Section 4. The dotted lines in the figures below represent the efficiency improvement steps.

Figure B2. Rolling resistance improvement cost curves for RM3, RM4, and RM5.

APPENDIX C. DETAILED PAYBACK PERIODS

Table C1. Payback periods for assessment year 2025 (in years)

Technology Package	RM1	RM2	RM3	RM4	RM5
TP1	0.3	0.2	0.1	0.1	0.1
TP2	0.9	0.7	0.5	0.3	0.1
TP3	0.8	0.7	0.5	0.3	0.2
TP4	1.9	1.6	1.0	0.7	0.5
TP5	1.7	1.5	1.0	0.6	0.5
TP6	N/A	N/A	N/A	N/A	0.6
TP7	N/A	N/A	N/A	N/A	0.5
TP8	N/A	N/A	N/A	N/A	0.5
Hybrid	3.1	2.9	2.1	1.5	1.0
Electric	2.2	2.6	2.3	2.7	2.2

Table C2. Payback periods for assessment year 2030 (in years)

Technology package	RM1	RM2	RM3	RM4	RM5
TP1	0.2	0.1	0.1	0.1	0.0
TP2	0.7	0.5	0.4	0.2	0.1
TP3	0.6	0.5	0.3	0.2	0.1
TP4	1.4	1.2	0.8	0.5	0.3
TP5	1.2	1.1	0.7	0.5	0.4
TP6	N/A	N/A	N/A	N/A	0.4
TP7	N/A	N/A	N/A	N/A	0.4
TP8	N/A	N/A	N/A	N/A	0.4
Hybrid	2.3	2.1	1.6	1.1	0.8
Electric	1.2	1.4	1.2	1.4	1.1

APPENDIX D. POLICY SCENARIOS

Table D1. Scenarios for evaluation of CO_2 and oil consumption reduction

	Baseline		Moderate Ambition		High Ambition	
Years	**ICE improvement**	**BET sales-**	**ICE improvement**	**BET sales**	**ICE improvement**	**BET sales**
2022	0%	0%	0%	0%	0%	0%
2023	0.5%	0%	0%	0%	0%	0%
2024	1.0%	0%	0%	0%	0%	0%
2025	1.5%	0%	27%	0%	27%	3%
2026	2.0%	1%	27%	0%	27%	8%
2027	2.5%	1%	27%	0%	27%	14%
2028	3.0%	2%	27%	0%	27%	19%
2029	3.5%	2%	27%	0%	27%	25%
2030	4.0%	2%	27%	10%	40%	30%
2031	4.5%	2%	27%	13%	40%	36%
2032	5.0%	3%	27%	16%	40%	42%
2033	5.5%	3%	27%	19%	40%	48%
2034	6.0%	3%	27%	22%	40%	54%
2035	6.5%	3%	27%	25%	40%	60%
2036	7.0%	3%	27%	28%	40%	66%
2037	7.5%	4%	27%	31%	40%	72%
2038	8.0%	4%	27%	34%	40%	78%
2039	8.5%	4%	27%	37%	40%	84%
2040	9.0%	4%	27%	40%	40%	90%
2041	9.5%	4%	27%	43%	40%	92%
2042	10.0%	5%	27%	46%	40%	94%
2043	10.5%	5%	27%	49%	40%	96%
2044	11.0%	5%	27%	52%	40%	98%
2045	11.5%	5%	27%	55%	40%	100%
2046	12.0%	6%	27%	58%	40%	100%
2047	12.5%	6%	27%	61%	40%	100%
2048	13.0%	7%	27%	64%	40%	100%
2049	13.5%	7%	27%	67%	40%	100%
2050	14.0%	8%	27%	70%	40%	100%
2051	14.5%	8%	27%	73%	40%	100%
2052	15.0%	9%	27%	76%	40%	100%
2053	15.5%	9%	27%	79%	40%	100%
2054	16.0%	10%	27%	82%	40%	100%
2055	16.5%	11%	27%	85%	40%	100%
2056	17.0%	11%	27%	88%	40%	100%
2057	17.5%	12%	27%	91%	40%	100%
2058	18.0%	12%	27%	94%	40%	100%
2059	18.5%	13%	27%	97%	40%	100%
2060	19.0%	14%	27%	100%	40%	100%
2061	19.5%	14%	27%	100%	40%	100%
2062	20.0%	15%	27%	100%	40%	100%
2063	20.5%	15%	27%	100%	40%	100%
2064	21.0%	16%	27%	100%	40%	100%
2065	21.5%	17%	27%	100%	40%	100%
2066	22.0%	17%	27%	100%	40%	100%
2067	22.5%	18%	27%	100%	40%	100%
2068	23.0%	18%	27%	100%	40%	100%
2069	23.5%	19%	27%	100%	40%	100%
2070	24.0%	20%	27%	100%	40%	100%