Improving fuel efficiency of heavy-duty vehicles (3.5–12 tonnes) in India: Benefits, costs, and environmental impacts

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Key findings – 1/2

- HDVs play a vital role in India's overall freight and passenger movement and thus economic growth; they are also responsible for over 70% of India's total diesel consumption. We find substantial opportunity to improve the fuel efficiency of HDVs in a cost-effective manner.
- We simulate seven efficient technology packages for HDVs using Autonomie, a state-of-the-art vehicle performance simulation platform. The efficient technology packages were drawn from five major areas: engine, transmission and driveline, tires, aerodynamics, and weight reduction.
- Across all HDV types, with efficient technologies, the per-vehicle diesel consumption can reduce by roughly 7% to 28% with a payback period of 1 to 3 years. Engine and tire technologies are found to provide most of this cost-effective efficiency improvement.
- The fleet level HDV diesel consumption can reduce by 9.2% under the least-aggressive technology package (TP1) to 34% under the most-aggressive technology package (TP7) by 2030 — with corresponding reduction in air pollution and greenhouse gas emissions.

Key findings – 2/2

- Given the cost-effectiveness of efficiency improvement, our policy recommendations are as follows: (a) Establish HDV (including under 12 tonnes) fuel efficiency standards, (b) The fuel efficiency standards should be ambitious and provide a long-term pathway for the industry to adapt, (c) Harmonize the fuel efficiency standard revisions with emission standards such as Bharat VI etc., (d) Cultivate testing efforts for heavy duty vehicles, engines, and component systems.
- Note that this study did not include electric HDVs, which could be a promising alternative given the recent developments in the battery technology. They will be covered in our future work.
- This study builds on a previous analysis of Indian heavy-duty vehicles over 12 tonnes, which can be downloaded here: https://ies.lbl.gov/publications/improved-heavy-duty-vehicle-fuel

Outline

- Scope of work
- Summary of vehicle and technology types
- Overview of the efficiency improvement technology
- Methodology
- Vehicle simulations results
- Benefit cost analysis
- Effect on diesel consumption and emissions
- Conclusion
- Policy recommendations
- Future work
- Limitations of the methodology

Scope of work

- Vehicles included in the analysis: HDVs between 3.5 and 12 tonnes
- Focus on diesel-powered trucks and buses
- Fuel efficiency technologies that can be commercialized over the next 10 years
- Time horizon: 2000 – 2050 (model calibrated against historical data for 2000-2016)

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- Baseline technology characterization
- Fuel consumption reduction potential
- Per-vehicle technology costs

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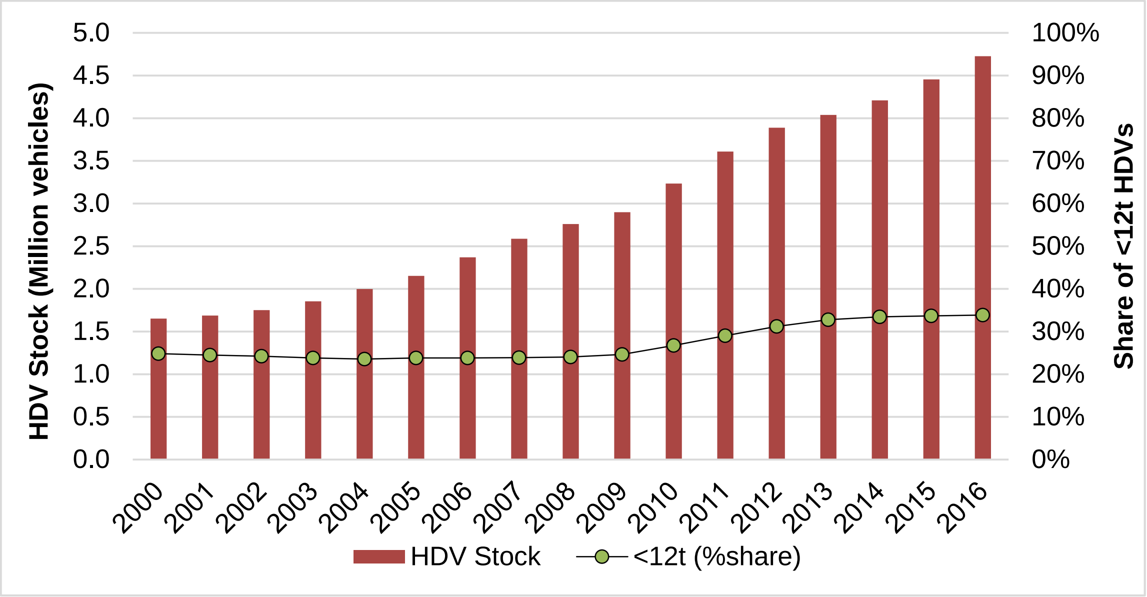
- HDV cost benefit analysis
- HDV fleet model
- Total fleet fuel consumption impacts

Fuel consumption reduction potential and cost-benefit impacts of various technology deployment scenarios

This study builds on a previous analysis of Indian heavy-duty vehicles over 12 tonnes. On August 16, 2017, India regulated HDVs with a GVW of 12 tonnes or greater. Phase 1 went into effect on April 1, 2018, while Phase 2 is effective beginning April 1, 2021.

Vehicle types used in the analysis



Vehicle type	Class	Weight
Rigid truck	LDT (Light-heavy Duty Truck)	3.5 tonnes <GVW*< 7.5 tonnes
	MDT (Medium-heavy Duty Truck)	7.5 tonnes <GVW< 12 tonnes
Transit bus	LDB (Light-heavy Duty Bus)	3.5 tonnes <GVW< 7.5 tonnes
	MDB (Medium-heavy Duty Bus)	7.5 tonnes <GVW< 12 tonnes

* GVW: Gross Vehicle Weight

Areas for on-vehicle efficiency improvements

Truck aerodynamics

Engine efficiency

Driver behavior and telematics*

Auxiliary loads

Transmission and axles

Reducing vehicle empty weight

Rolling resistance

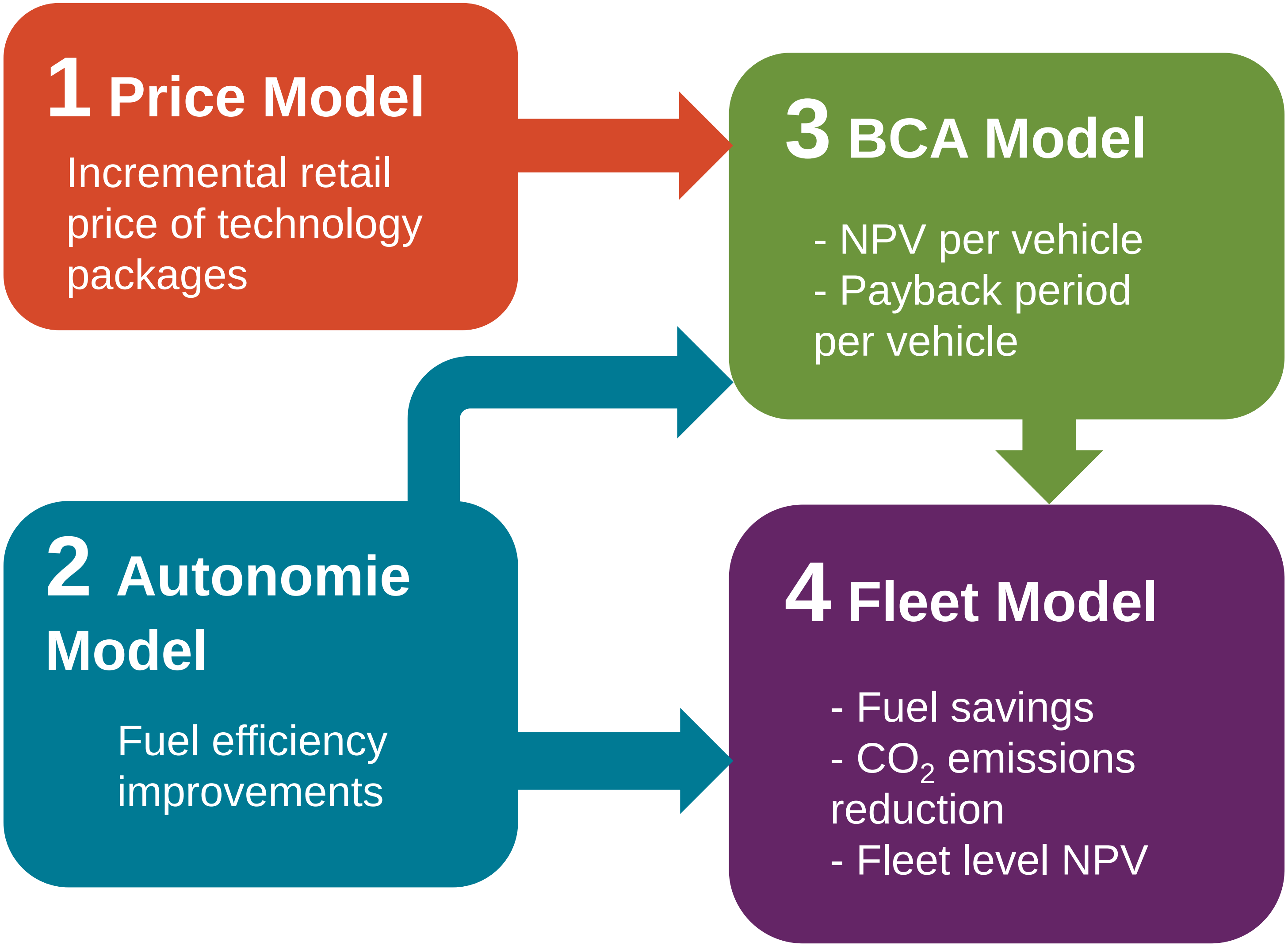
* Not investigated as part of this analysis

Efficient technology packages, combining the efficiency improvement technologies

Vehicle	Technology Packages
Rigid truck	Baseline. BS IV engine, bias tires
	TP1. Radial tires+BS VI engine
	TP2. LRR tires+BS VI engine
	TP3. LRR tires+'Advanced Level 1' engine+AMT*
	TP4. LRR tires+'Advanced Level 1' engine+ Advanced AMT
	TP5. LRR tires+'Advanced Level 2' engine+Advanced AMT+1% weight reduction
	TP6. Advanced tires+'Advanced Level 2' engine+Advanced AMT+Moderate truck aero+2.5% weight reduction
	TP7. Advanced tires+'Advanced Level 2' engine+hybrid+Advanced truck aero+5% weight reduction
Transit bus	Baseline. BS IV engine, radial tires
	TP1. BS VI engine
	TP2. LRR tires+BS VI engine
	TP3. LRR tires+'Advanced Level 1 Engine' engine+AMT
	TP4. LRR tires+'Advanced Level 1' engine+Advanced AMT+1% weight reduction
	TP5. LRR tires+'Advanced Level 2' engine+Advanced AMT+2.5% weight reduction
	TP6. Advanced tires+'Advanced Level 2' engine+Advanced AMT+5% weight reduction
	TP7. Advanced tires+'Advanced Level 2' engine+hybrid+7.5% weight reduction

* AMT: automated manual transmission

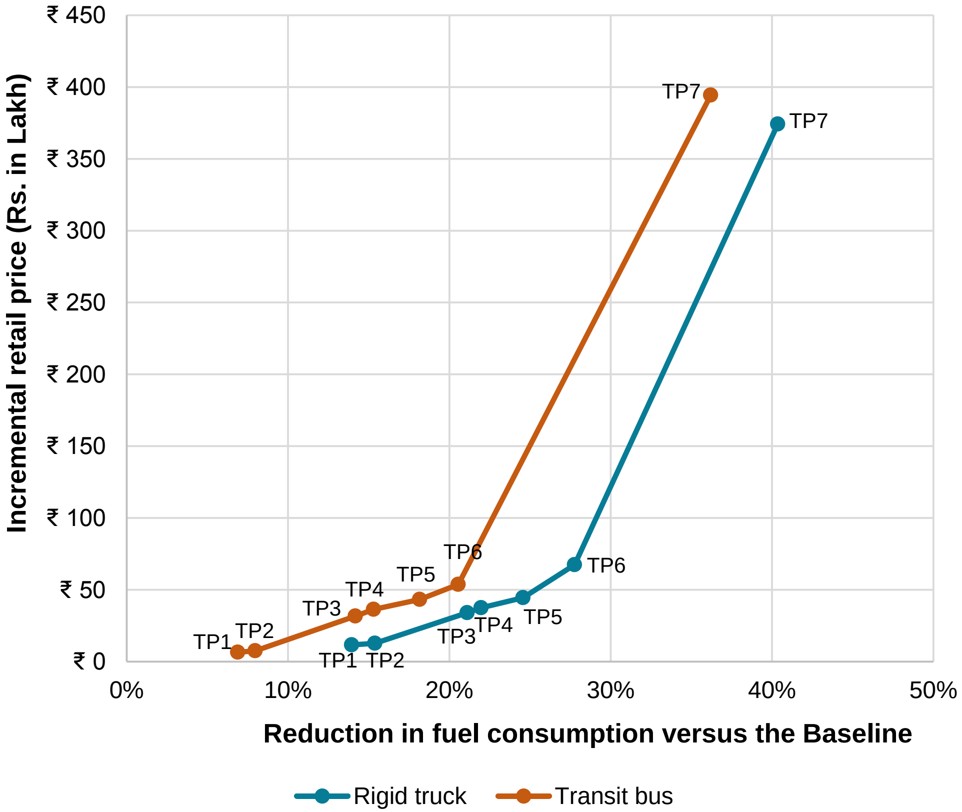
Summary of methodology



*BCA is Benefits Cost Analysis.

Autonomie model results

Incremental retail price versus fuel consumption reduction



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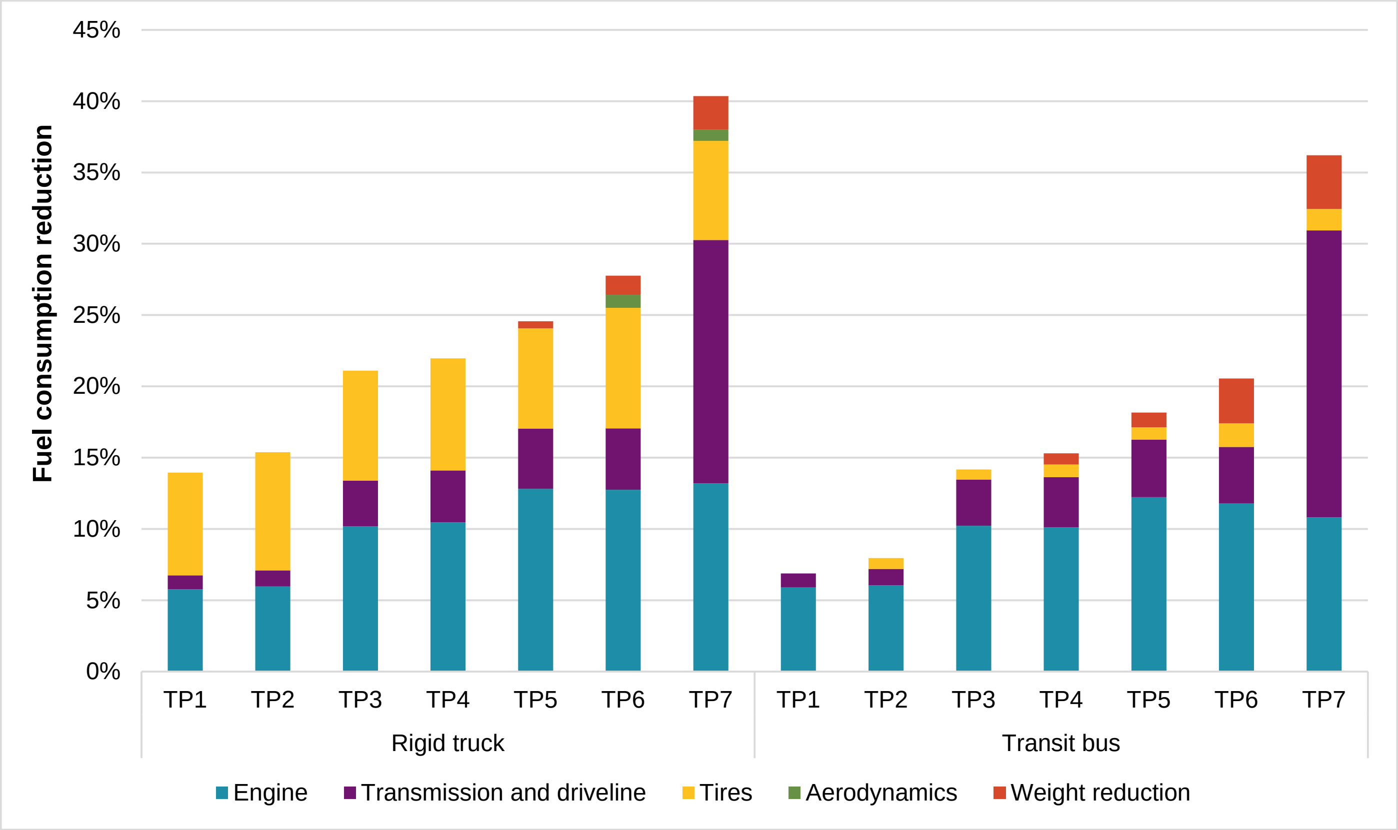
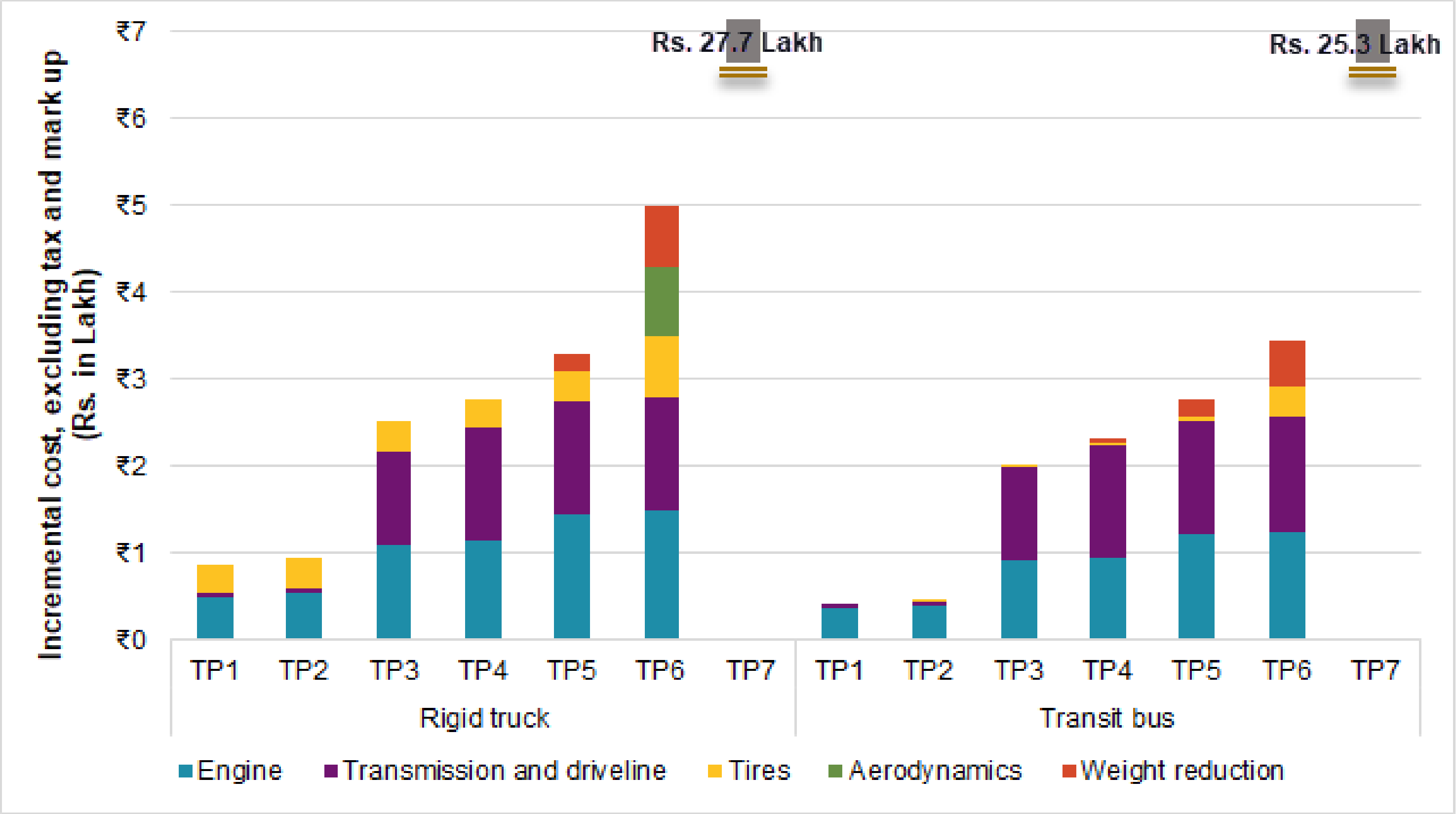
	TP6. Advanced tires+'Advanced Level 2' engine+Advanced AMT+5% weight reduction
	TP7. Advanced tires+'Advanced Level 2' engine+hybrid+7.5% weight reduction

Details of fuel consumption reduction for each technology package



- Engine, transmission, and tire technologies represent the large majority of total fuel savings.

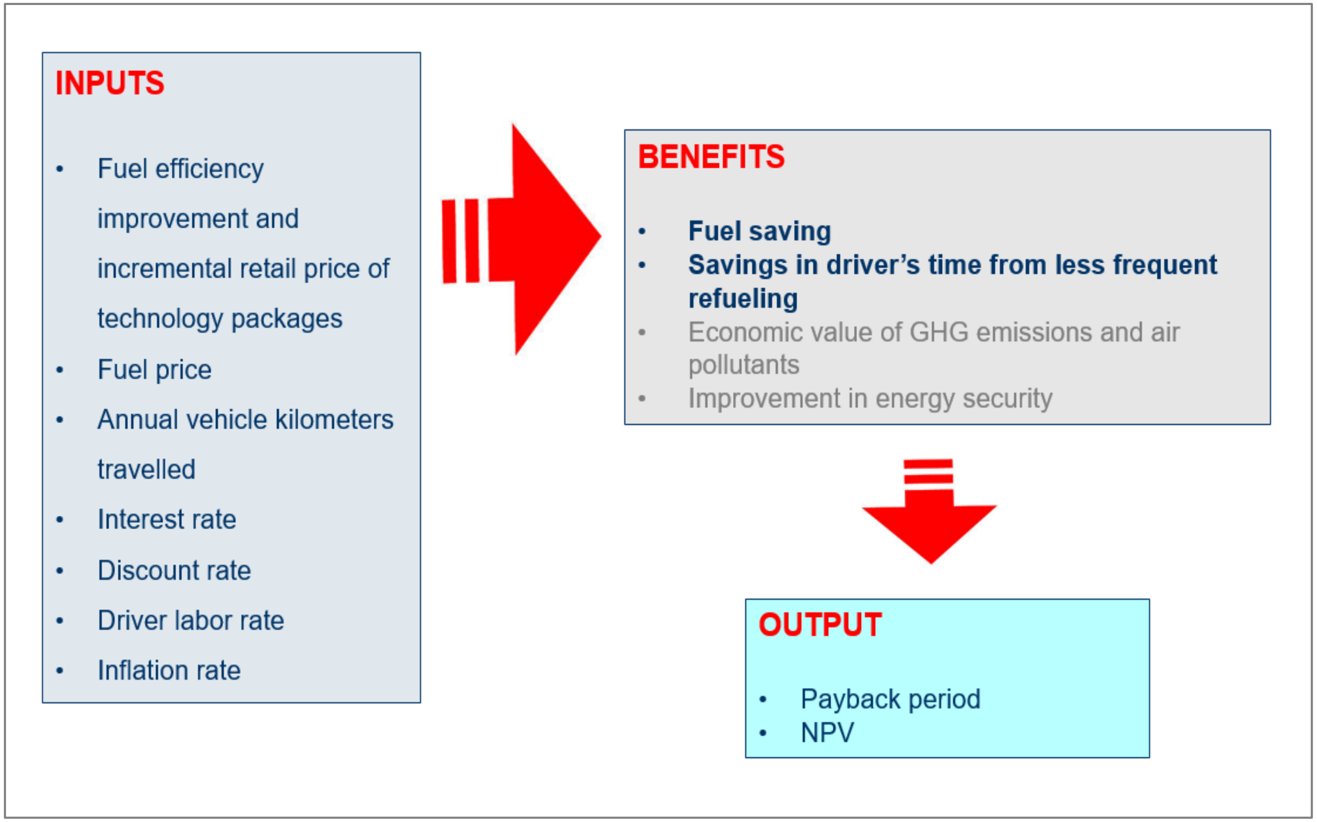
Details of cost breakdown for each technology package



- TP7 adds the relatively expensive hybrid-electric system.

Benefits-cost analysis (BCA)

General structure of the HDV BCA model



Source: Karali et al. (2017)

'Net benefits' is calculated by summing the costs and benefits of each technology package over the lifetime of the vehicle and converted into a net present value (NPV) using a discount rate. The payback period (in years) for each technology package is calculated using the cumulative savings provided by that technology package relative to the baseline.

HDV BCA model – India main assumptions

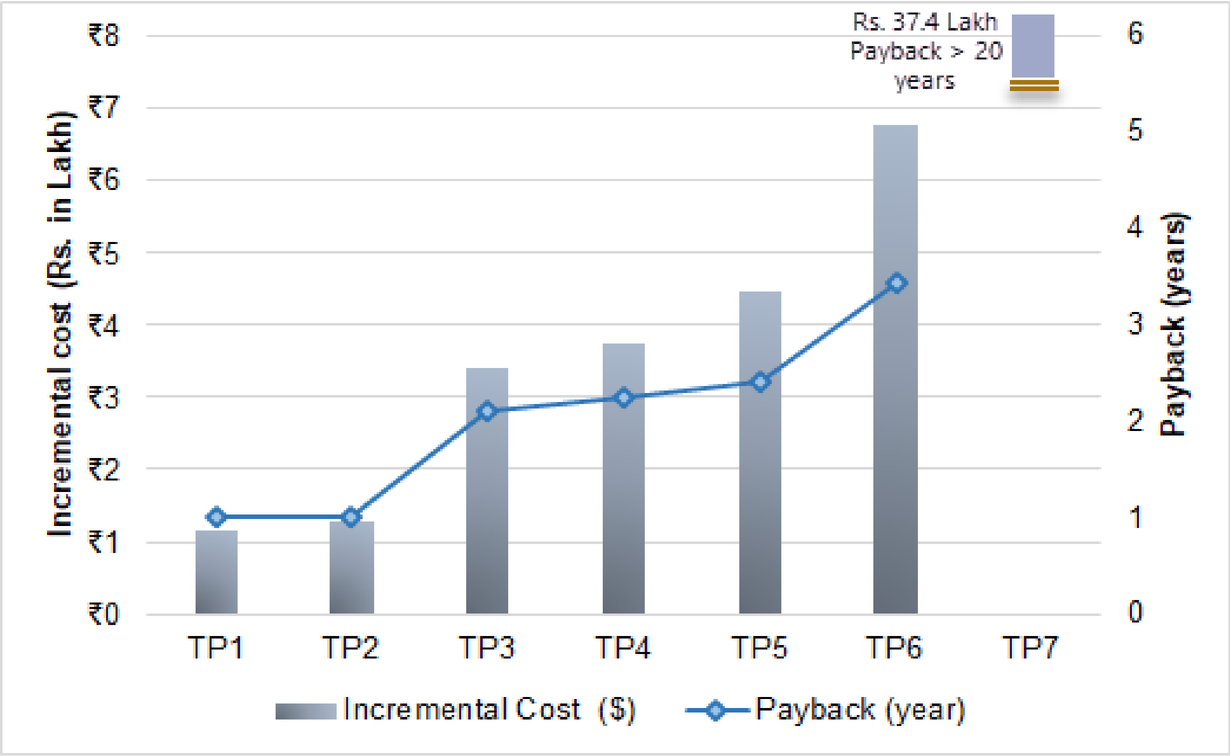
	Rigid truck		Transit bus	
	LDT	MDT	LDB	MDB
Fuel efficiency (km/L)	4.91	4.44	4.94	4.55
Annual vehicle km traveled (VKT) (km)	35,000	65,000	114,425	114,425
Average lifetime (years)	14	14	12	12
Tank volume (liters)	160	160	160	160
Fuel dispensing rate (liter/min)	76	76	38	38
Refueling fixed time (min/refill)	3.5	3.5	3.5	3.5

Diesel price (Rs/L)	₹65
Driver labor rate (Rs/hour)	₹63
Discount rate (%)	6.25%
Depreciation rate (%)	16%
Interest rate (%)	12%
Markup rate (%)	20%

$$vkt_{age} = vkt_{1styear} * e^{-\alpha * age}$$

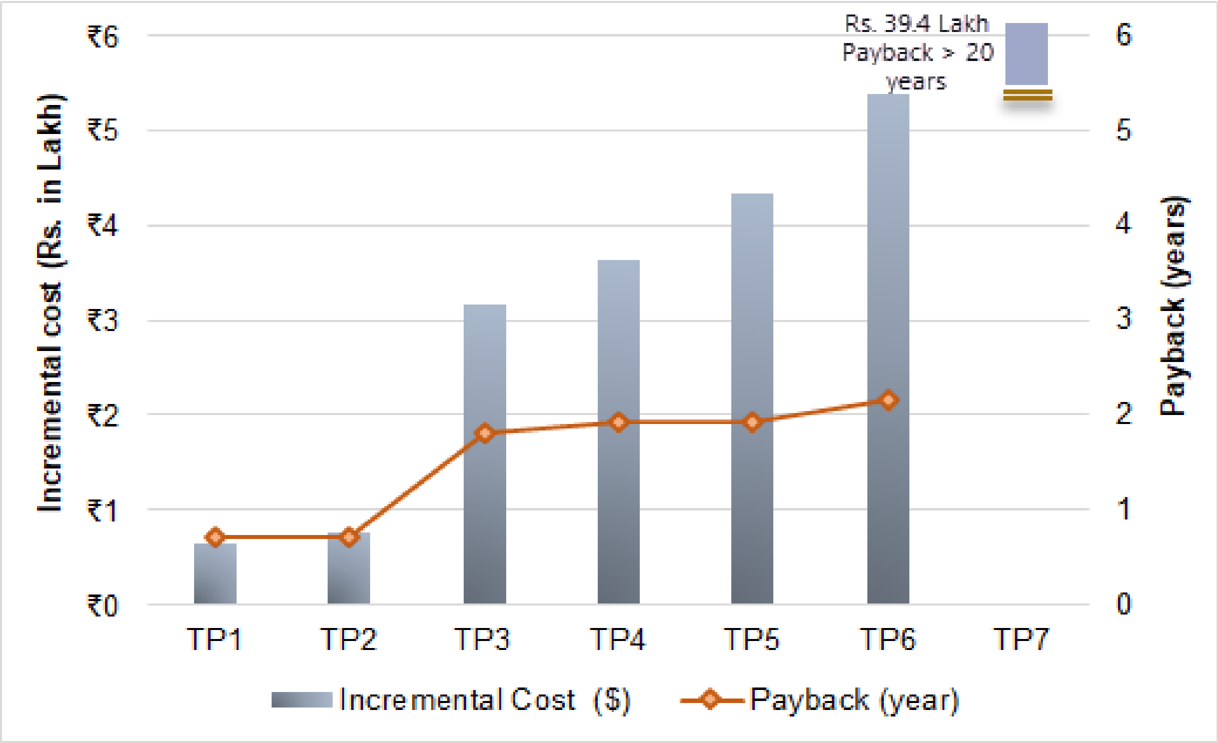
where vkt_{age} represents the annual VKT of the vehicle at a certain age
$vkt_{1styear}$ is the annual VKT of the vehicle in its first year
age is the age of the vehicle
α is a decline parameter that controls how fast VKT declines over time.
the parameter α as 0.07 for both trucks and buses.

Payback period is within 2-3 years for rigid trucks



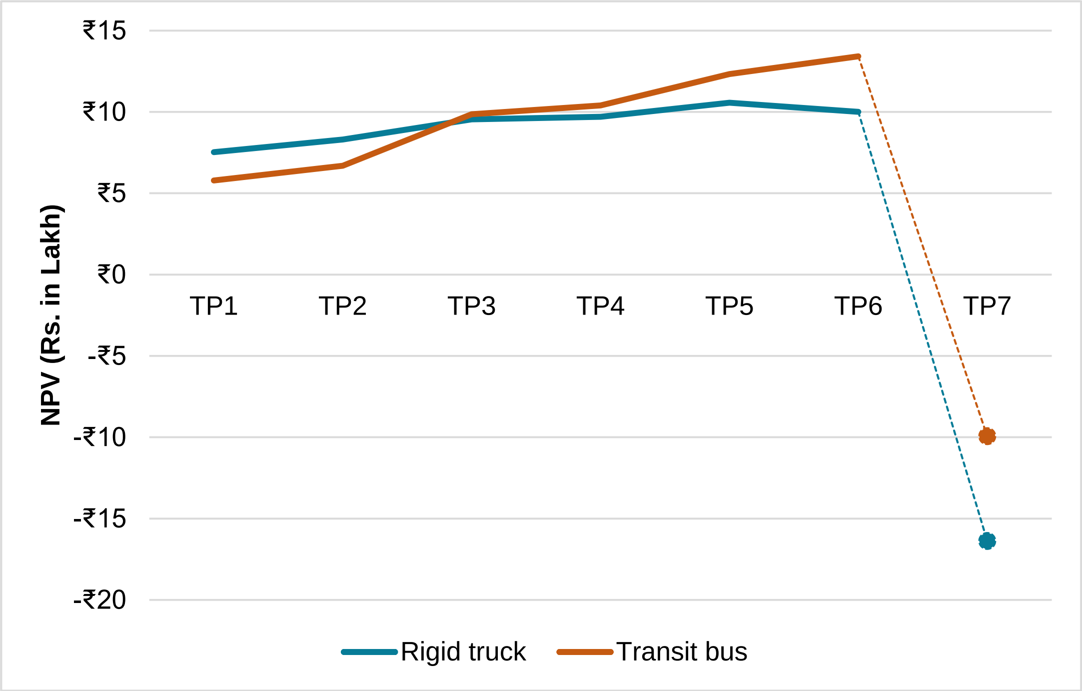
- Payback periods for the 11.9-tonne rigid truck with each technology package, assuming one-time upfront payment.
- TPs improve the fuel economy of these vehicles by 14% (TP1) to 28% (TP6) and provide a return on the initial capital investment within about one year (TP1) to three years (TP6).
- The payback time with TP7—which adds the relatively expensive hybrid-electric system—is over 20 years and thus longer than the vehicle lifetimes.

Payback period is within 2-3 years for transit buses



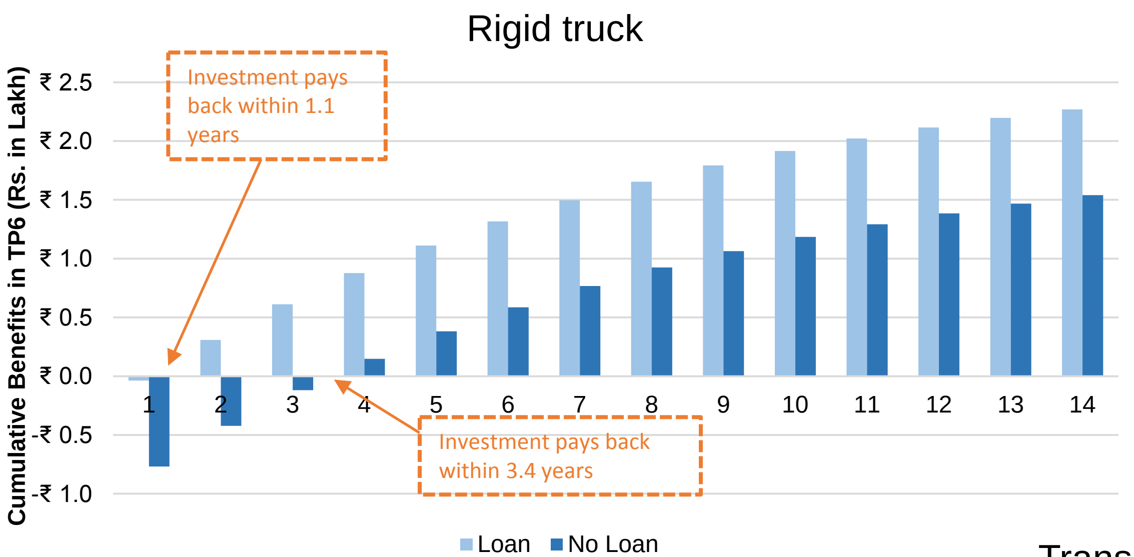
- Payback periods for the 7.5-tonne transit bus with each technology package, assuming one-time upfront payment.
- TPs improve the fuel economy of these vehicles by 7% (TP1) to 21% (TP6) and provide a return on the initial capital investment within about one year (TP1) to three years (TP6).
- The payback time with TP7—which adds the relatively expensive hybrid-electric system—is over 20 years and thus longer than the vehicle lifetimes.

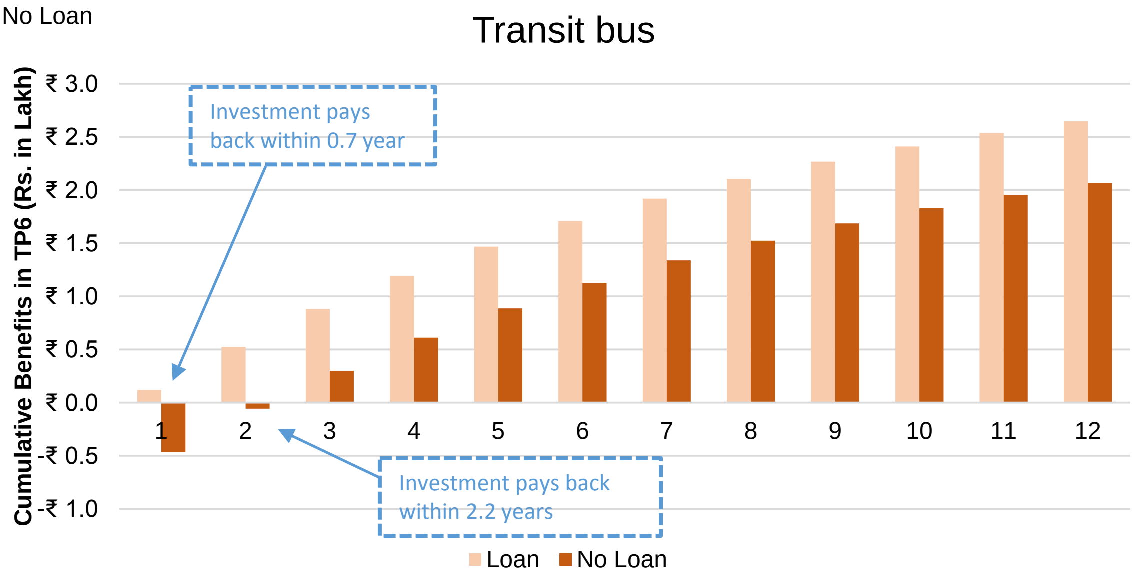
Net Present Value (NPV)



- From the customer point of view, the most attractive technology packages are TP5 for the rigid truck and TP6 for the transit bus, because they provide the highest NPV over the vehicle lifetime.

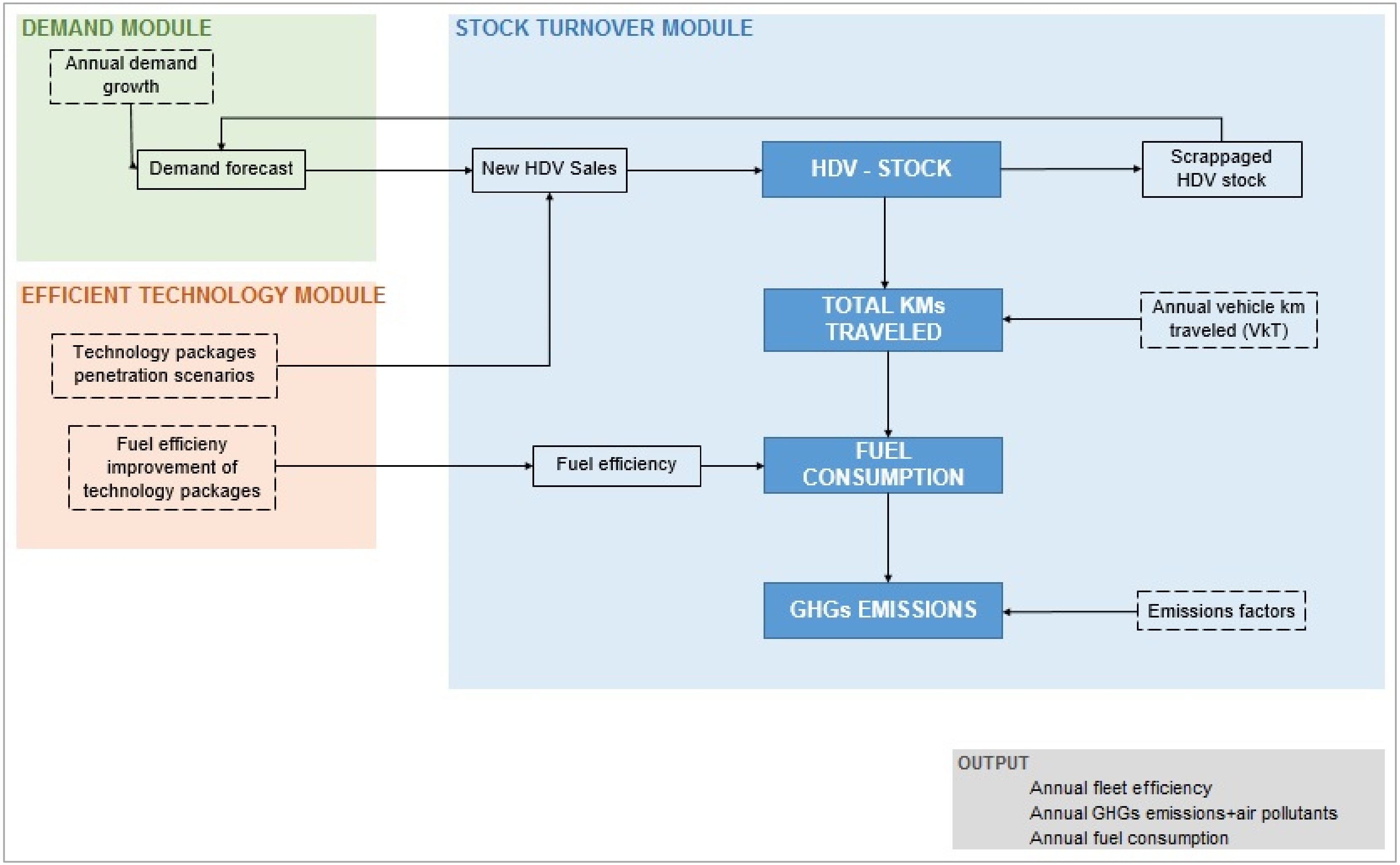
Cumulative benefit with loan and without loan in TP6 example.



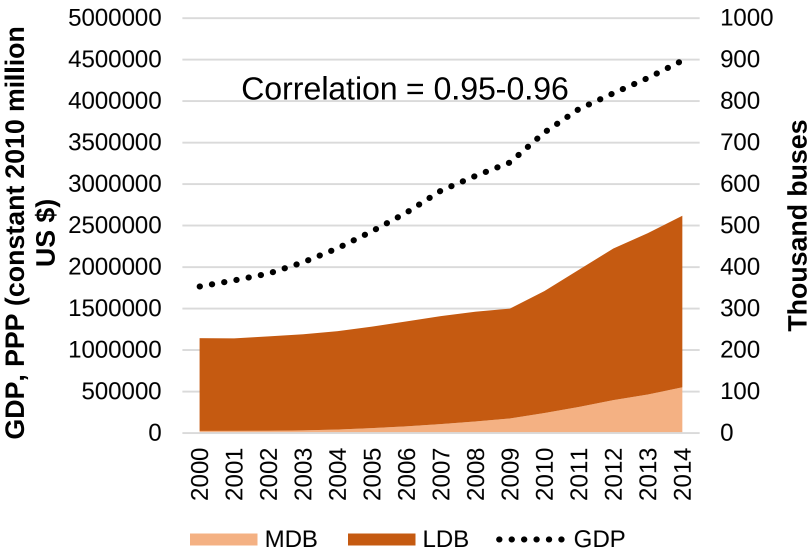


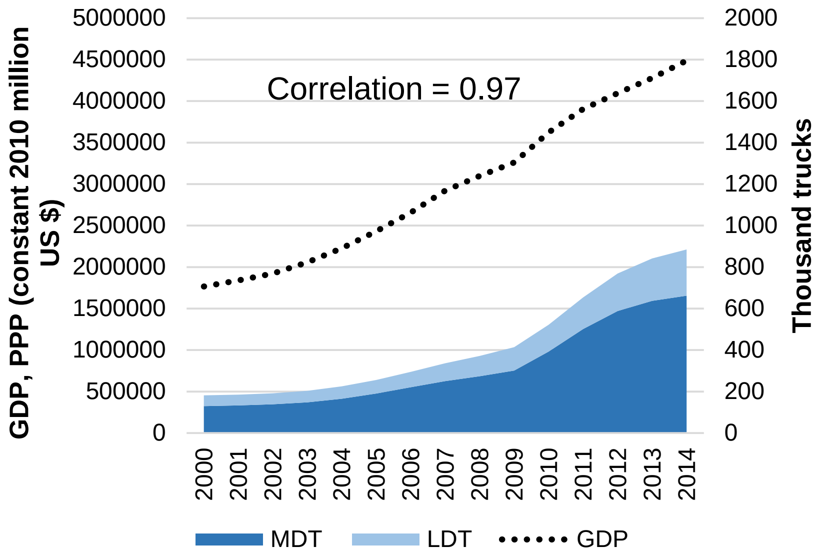
Fleet Model

HDV fleet energy model



Correlation of HDV (3.5-12t) demand with GDP using data from 2000 to 2014





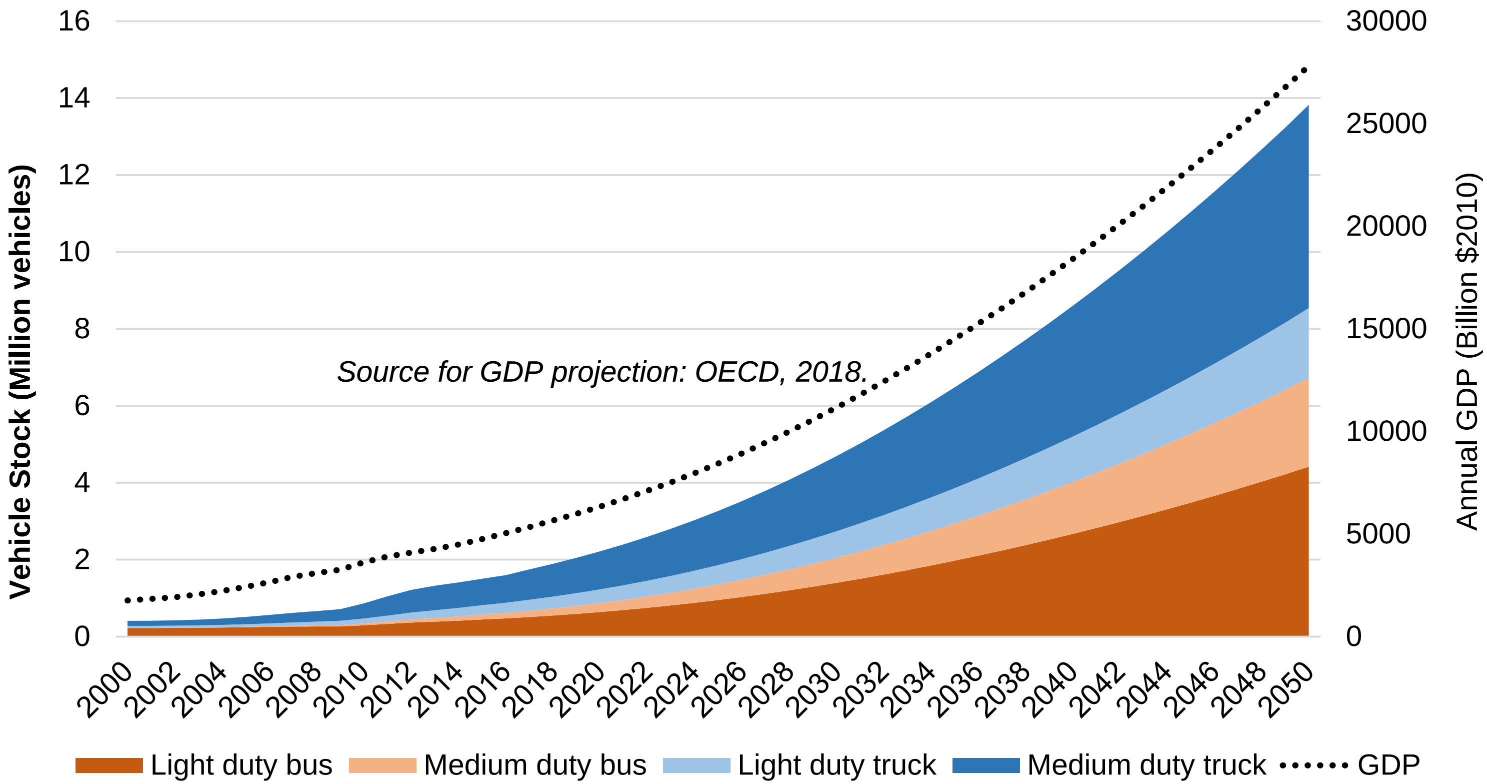
$$LDT\ Stock = -87{,}423.1 + 0.066 * GDP$$

$$MDT\ Stock = -277{,}427.8 + 0.199 * GDP$$

$$LDB\ Stock = 1{,}466{,}596.3 + 0.189 * GDP$$

$$MDB\ Stock = 768{,}905.2 + 0.113 * GDP$$

HDV (3.5-12t) stock growth



- In 2050 the number of HDVs under 12 tonnes will be 13.8 million, an increase of 8.7 times from 2016 as follows: 7.1 million rigid trucks (total of LDTs and MDTs) and 6.7 million transit buses (total of LDBs and MDBs).

HDV India Fleet model – other main assumptions

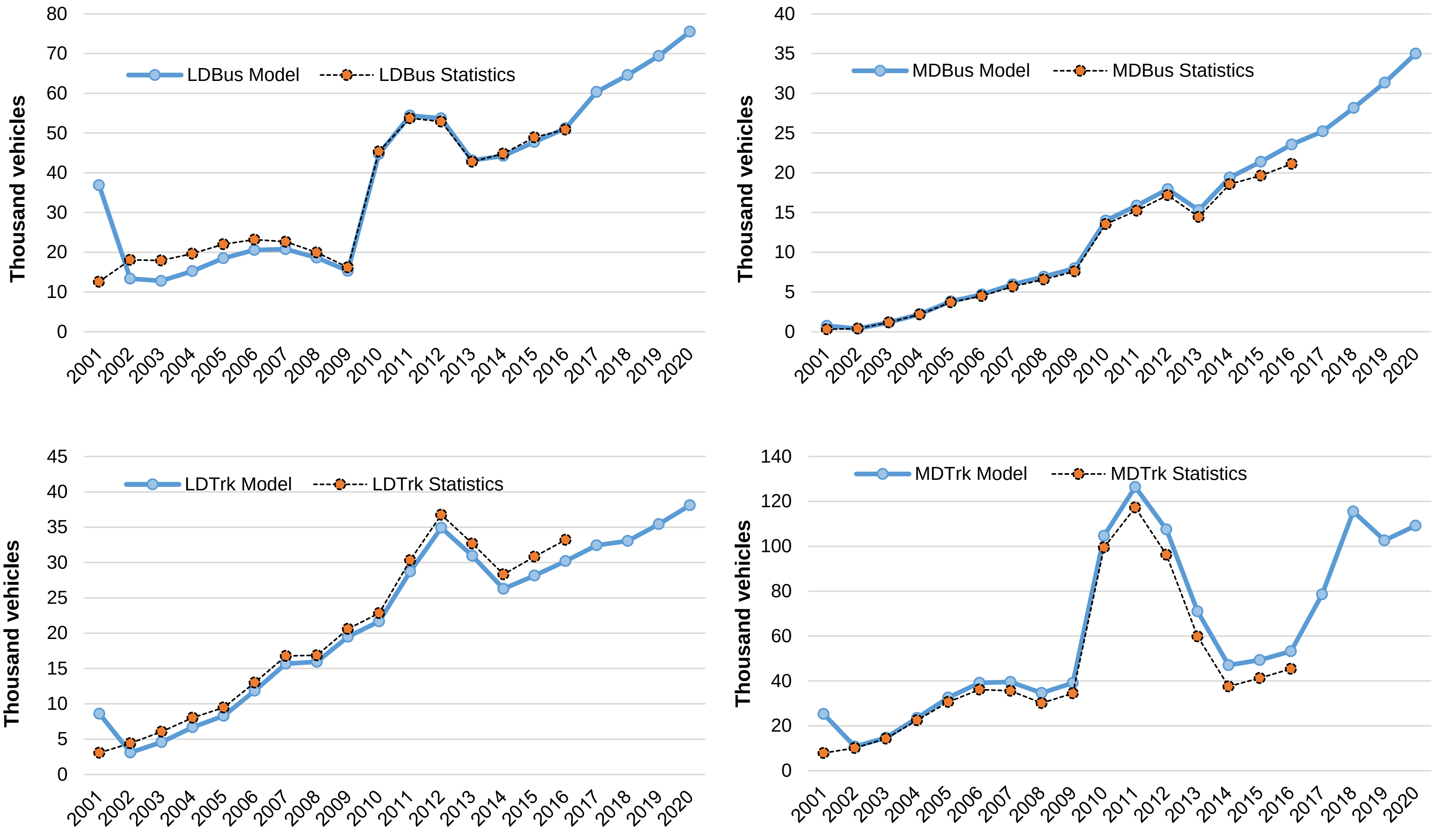
	Rigid truck		Transit bus	
	LDT	MDT	LDB	MDB
Average fleet fuel efficiency (km/L)	4.09	4.09	4.67	4.12
Annual vehicle km traveled (VKT) (km)	35,000	65,000	114,425	114,425
Median lifetime (years)	15	15	15	15
Utilization rate (%)	70%	70%	90%	90%

$$survival(t) = 1 - 1/(1 + e^{-\beta(t-t_0)})$$

where t_0 is the median lifetime of the vehicle
t is the age in a given year
β is a growth parameter that determines how fast vehicles are retired around t_0.

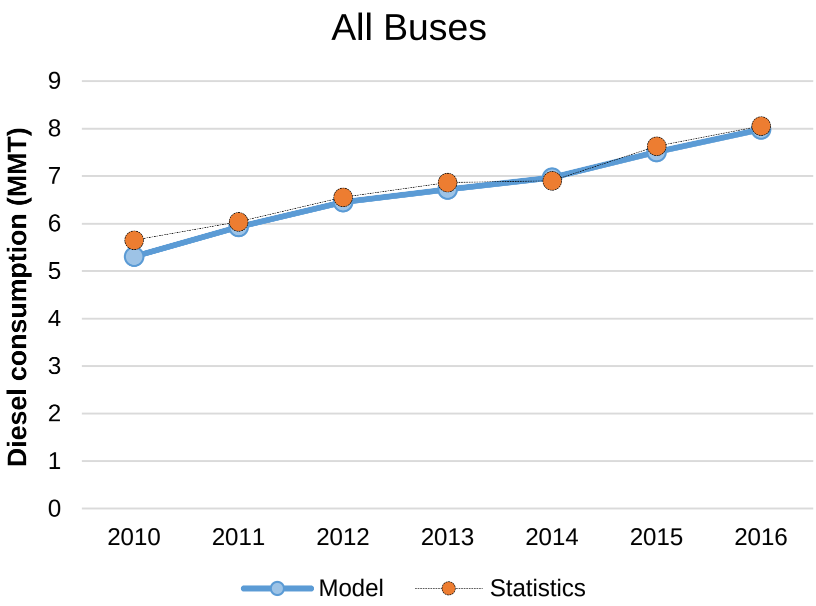
The parameter β is applied as 0.20 for new rigid trucks, 0.20 for new light duty buses, and 0.25 for new medium duty buses.

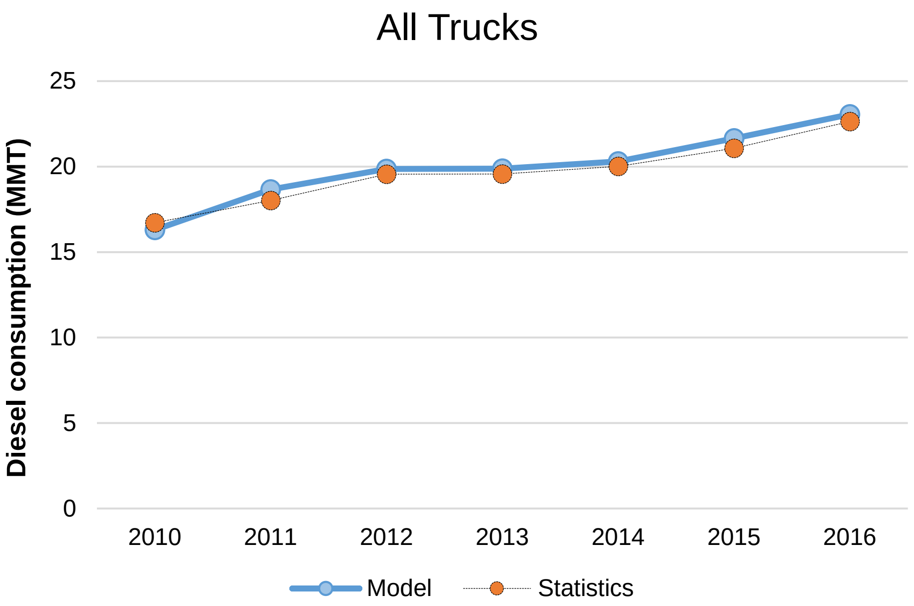
Sales validation of the model



VKT and fuel efficiency parameter validation with historical diesel consumption

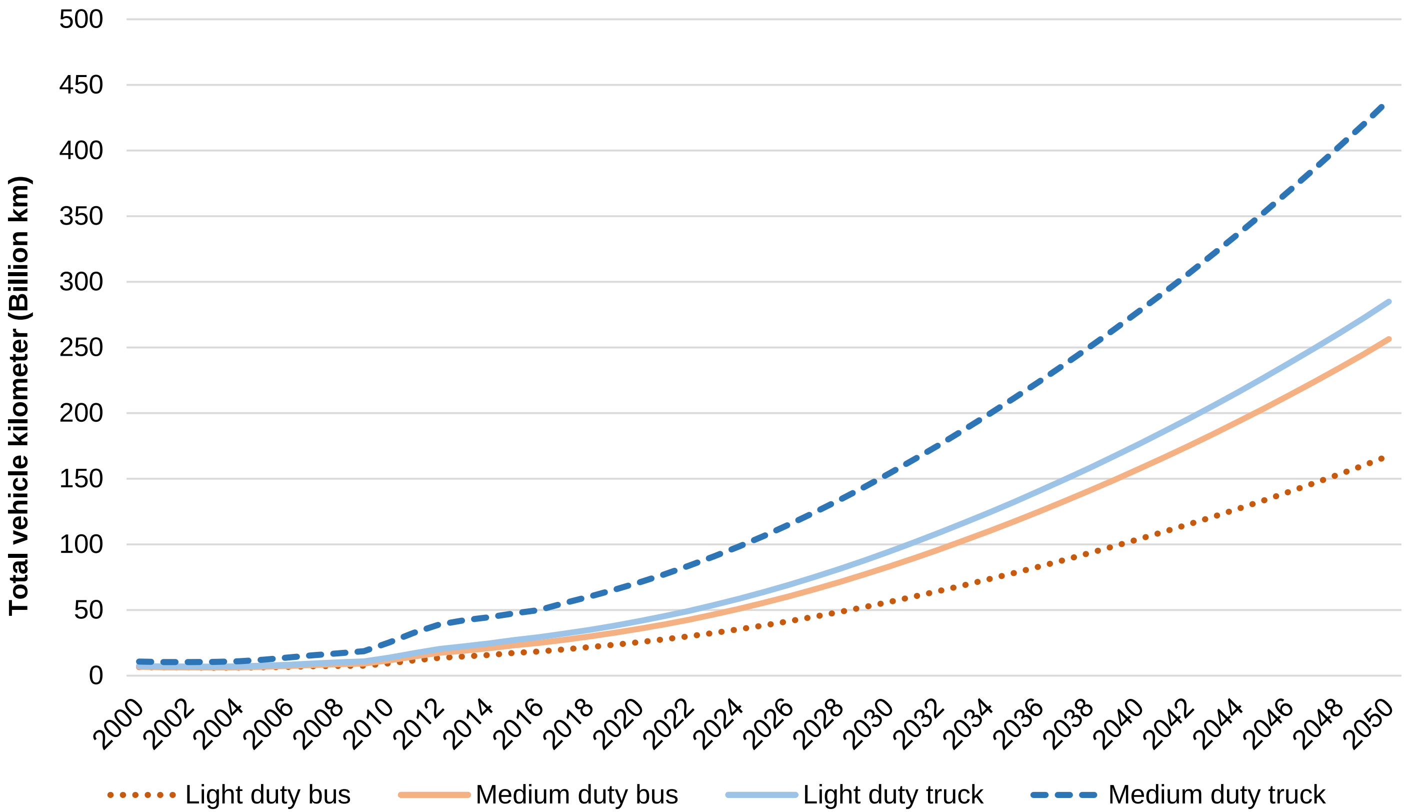
Validation includes all buses and trucks, i.e., both under and over 12 tonnes.



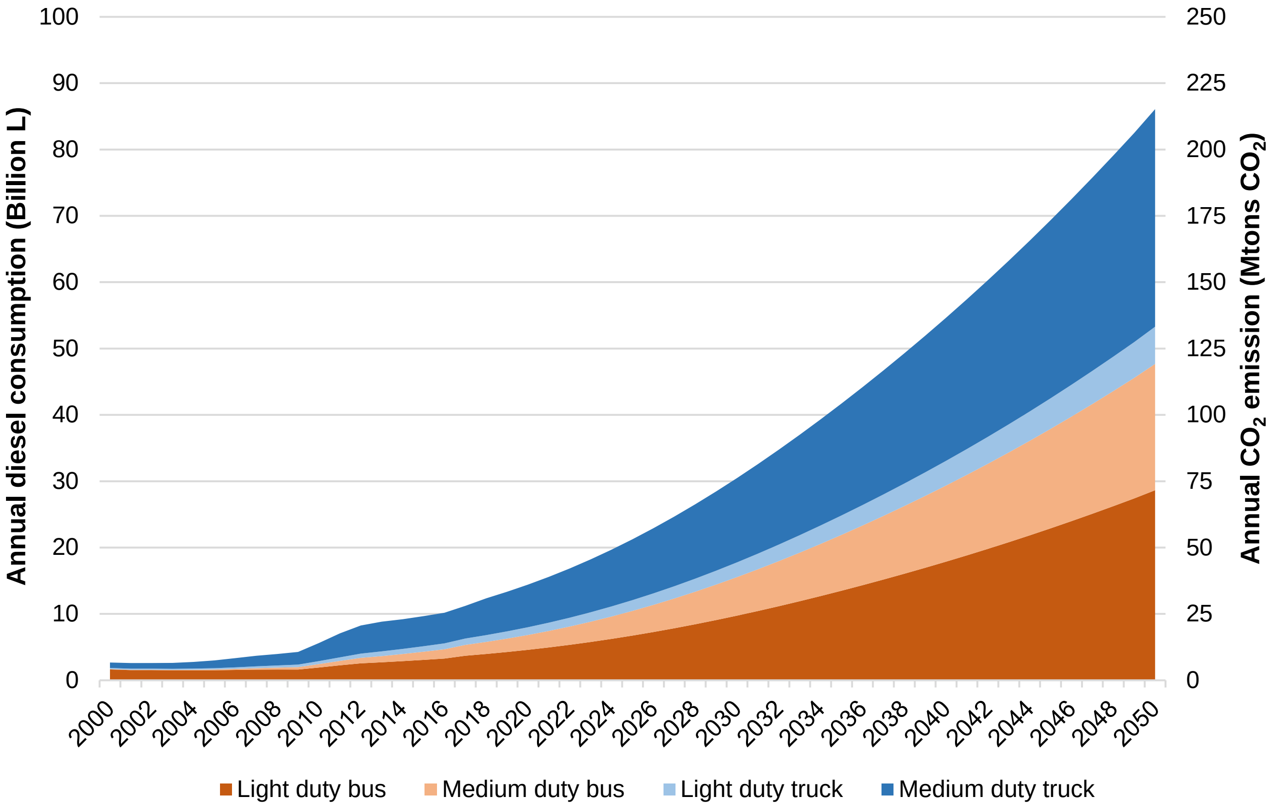


Source for historical data: PNG, 2018; PPAC, 2013.

Annual Total VKT by HDV (3.5-12t) type

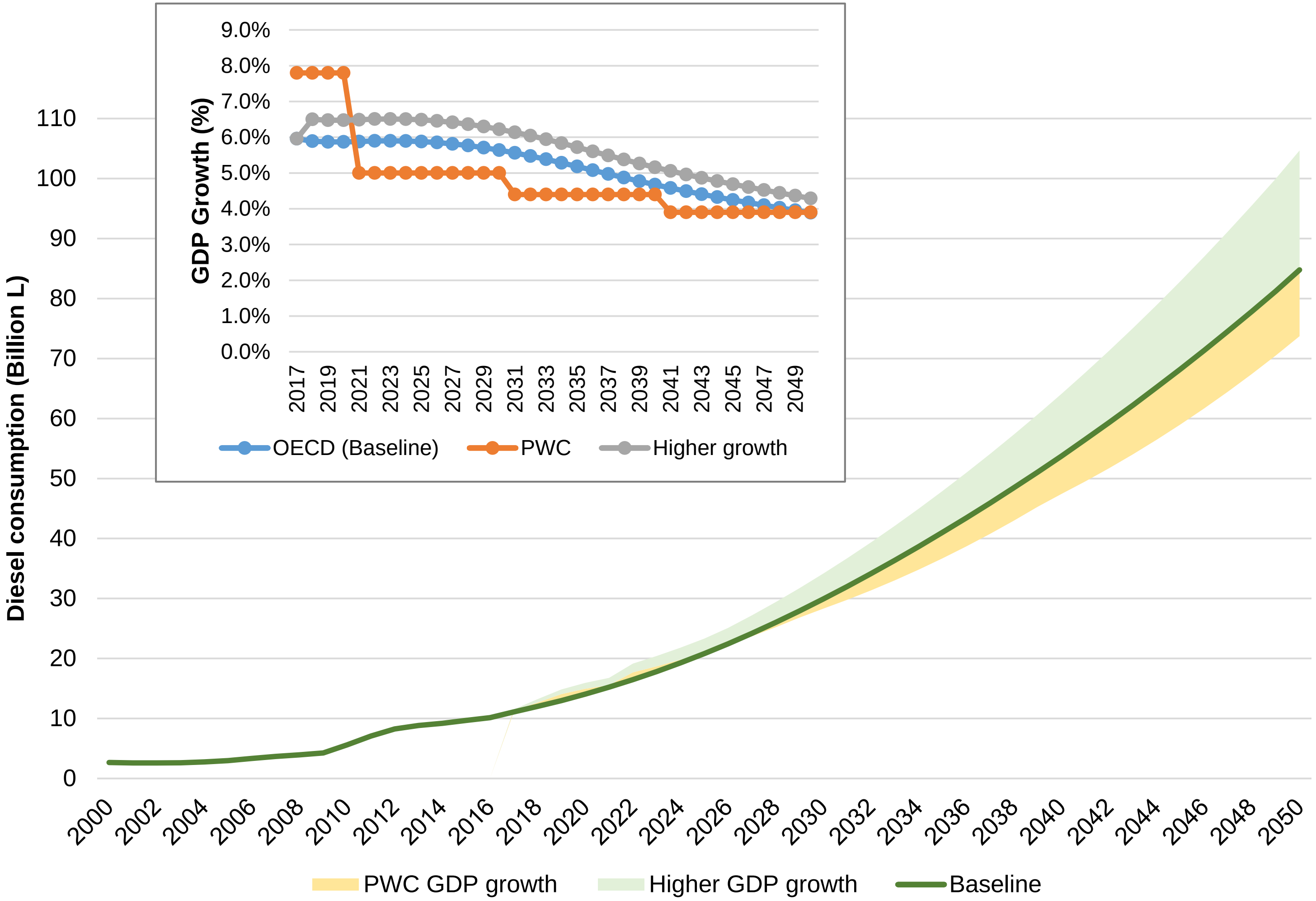


Baseline: annual total diesel consumption and CO_2 emission by HDV (3.5-12t) type

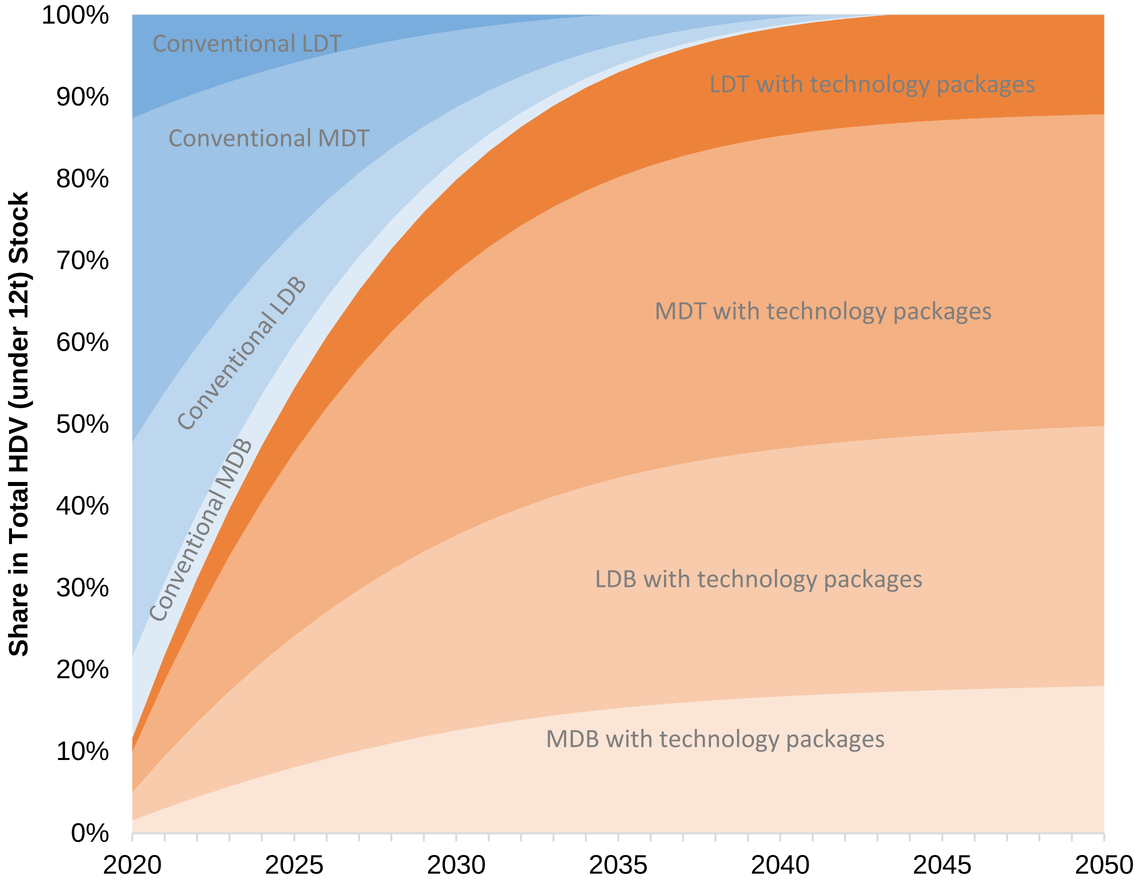


- Baseline scenario results indicate that Indian HDVs under 12 tonnes would require 30.5 billion liters of diesel to meet demand in 2030, increasing to around 86 billion liters in 2050.
- Correspondingly, CO_2 emissions from these HDVs increase by a factor of 3 in 2030 and a factor of 8.5 in 2050, compared to the 2016 level.

Annual total diesel consumption sensitivity to different GDP growth rates

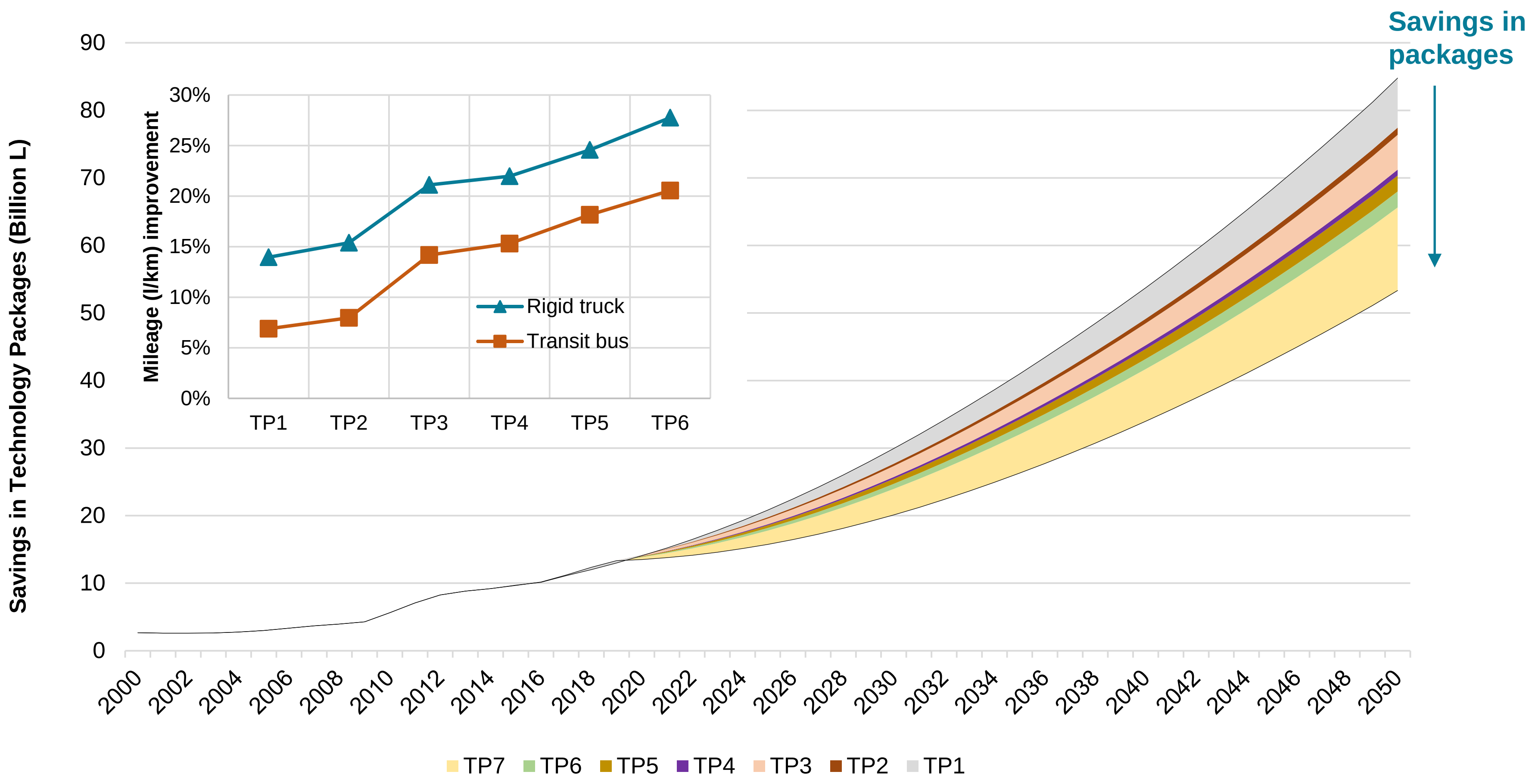


Penetration of technology packages in TP scenarios



- Total share of vehicles with TPs covers 11.4%, 50%, and 92% of the HDV stock in 2020, 2025, and 2035, respectively.
- All HDVs in the fleet have TPs in 2050.

Annual diesel consumption reduction from each technology package



- Reductions compared with the baseline are about 10% (TP1), 11% (TP 2), 17% (TP3), 18% (TP4), 21% (TP5), 24% (TP6), and 38% (TP7) in 2050.

Conclusion

- India has substantial opportunity to improve the fuel efficiency of HDVs of 3.5 to 12 tonnes using cost-effective technologies.
- Our analysis reveals that per-vehicle fuel consumption reductions between roughly 7% and 28% are possible with technologies that provide a return on the initial capital investment within 1 to 3 years.
- Across all of the technology packages and vehicle types, engine and tire technologies provide the most cost-effective efficiency improvements.
- Projected diesel savings range from 9.2% under the least-aggressive package (TP1) to 34% under the most-aggressive package (TP7) in 2030—with corresponding CO_2 emissions reductions. In 2050, the range of savings is 10% (TP1) to 38% (TP7).
- Given the cost-effectiveness of efficiency technologies, establishing fuel efficiency standards for this category of HDVs in the near future, combined with the over 12 tonne category, will make a large impact in the overall fuel consumption, imports, GHG emissions, and air pollution.

Policy recommendations

- **Establish fuel efficiency standard:** Setting up fuel efficiency standards for all HDVs in the near future will make a large impact in the overall fuel consumption, imports, air pollution, and GHG emissions.
- **Develop fuel efficiency regulatory norms with long term targets:** Early signaling of efficiency targets gives industry sufficient time for research, development, and deployment of new and improved technologies. Similarly, it would be advantageous for the industry to align the staging of fuel efficiency standards with the emission standards schedule.
- **Cultivate testing efforts for heavy duty vehicles, engines, and component systems:** Accelerating efforts to: (a) develop and implement testing campaigns will provide the data critical for better fuel efficiency regulations and real-world benefits, (b) make the standardized test results widely accessible.
- **Develop complementary policies for alternative fuel and electric vehicles.** Reaching a significant share of alternative powertrain technologies, such as electric buses and trucks, in the on-road fleet by 2050 could be another pathway for a large impact fuel and emissions impact.

Future work

- Future work may be
  - combining the results in this analysis with the authors' previous work on over 12 tonnes HDV category to see the combined impact of HDV fuel efficiency improvement on national scale.
  - studying/evaluating electrification of HDV fleet in India including (1) practical and economical implications, (2) energy security and environmental impacts, and (3) power system impacts.
  - updating market analysis for sales of new HDVs using fiscal year 2017-2018 data.

Limitations of the methodology

- Obtaining accurate vehicle-specific data for parameters such as aerodynamic and rolling resistance drag takes time and resources that are beyond the scope of this study. As such, the technology potential analysis uses estimates for these drag coefficients based on our previous work on HDV fuel efficiency in India and the authors' best judgment.
- As in our previous work that examines HDVs greater than 12 tonnes, India-specific costs for the various fuel-saving technologies are estimated based on values derived from US and EU-based research. Given that vehicle technology costs are typically less expensive in these other markets, the costs in this study are likely conservative.
- Benefits costs analysis performed in this study does not include the economic value of reductions in non-GHG pollutants, as well as the economic value of improvements in India energy security, due to uncertainty around input data.
- Even though impact of different HDV stock growths in the fleet analysis is captured in sensitivity analysis, the stock growth, particularly in the medium and long term, may have independent drivers other than GDP.
- This study does also not address the use case of HDVs. HDVs between 3.5-12 tonnes have a greater diversity of use cases, which will require significantly more data and nuanced technical analysis.

- Download Full Report (3.5-12 tonne) here:
  https://ies.lbl.gov/publications/improving-fuel-efficiency-heavy-duty
- Download >12 tonne Report here:
  https://ies.lbl.gov/publications/improving-fuel-efficiency-heavy-duty

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