Developing pathways for fuel efficiency improvements in HDV sector in India

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Introduction

In the last two decades, India has shown an unprecedented growth in different sectors. With urbanization and industrialization, the energy consumption has increased multi-folds. With this growing mobility, demands for passenger and freight movement have increased the consumption of petroleum products in the road transport sector. Transport sector presently accounts for 17 percent (72 million tonnes of oil equivalent) of the total energy consumed in the country. This is the second largest consumer of commercial energy after the industry sector. The share of transport is largest in consumption of diesel (~70 percent) and petrol (~95 percent). There is a continual shift in the share of railways in freight movement to less fuel efficient road transport mode. Presently, road transport is the most dominant mode of transport with over 50 percent of the freight movements. In passenger transport also, the road-based mobility is the most dominant mode amounting to about 90 percent share in 2010-11.

The sector is expected to grow at a steady rate for the next few decades. With further growth projected in future, the oil import dependency is expected to increase from 76 percent of 141million tonnes (MT) to 93 percent by 2031. This raises important concerns about the energy security in India and emphasizes the need of efficiency improvements in sectors like road transport. The Bureau of Energy Efficiency (BEE), Ministry of Power has notified the first ever fuel efficiency standards for four-wheeled passenger vehicles. However, it is to be noted that heavy-duty vehicles dominate the overall energy consumption in the road transport sector. Therefore, much larger amounts of fuel savings can be made with fuel efficiency improvements in the heavy duty sector.

The current paper analyzes the heavy duty vehicle sector in India. A literature review is carried out to understand the different types of fuel efficiency standards adopted across the world in different countries. The methodologies adopted for evaluation and adoption of HDV fuel efficiency across the world are studied. A survey of different automobile manufacture companies in India was carried out for assessing the key features of the various model categories in the heavy duty sector. Eventually, recommendations are made for pathways to adopt fuel efficiency standards for HDVs in India.

HDV sector in India

There has been a sharp increase in energy demand from the HDV sector in India, mainly because of the increased transport demand and continuous erosion in the share of railways in freight movement and increase in share of less fuel efficient road transport. Road transport is the most dominant mode of transport with over 50 percent of the freight (Figure 1).

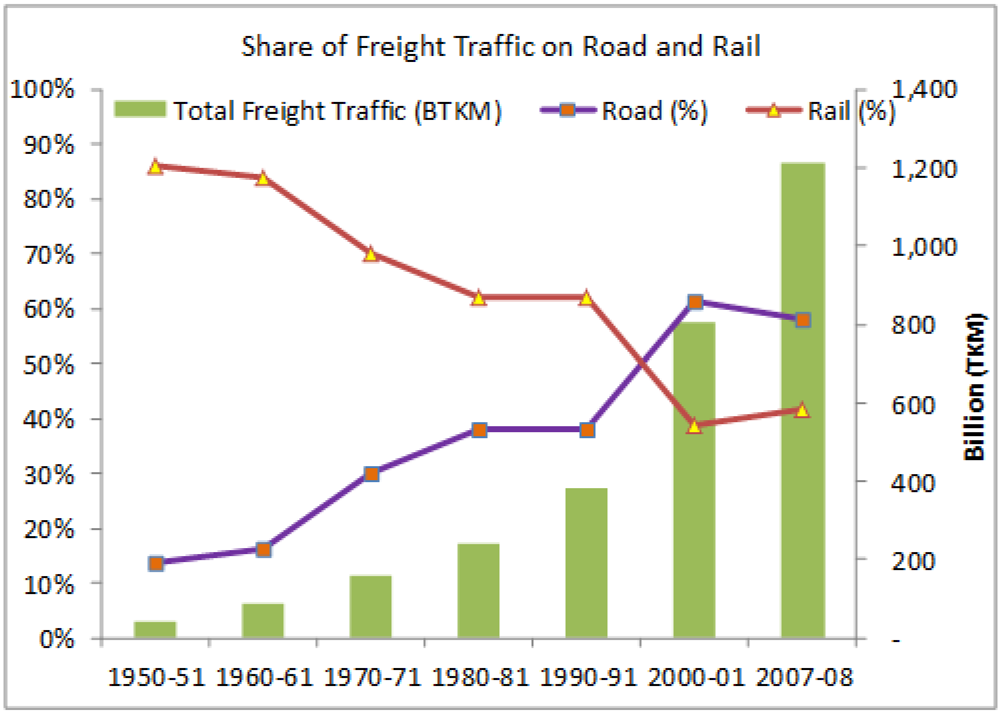

Figure 1: Share of different modes in freight movement in India during (1950-2008)
Data Source: RITES, 2014, PC, MoR, 2012

BTKM: Billion ton kilometer

Even in case of passenger traffic, there is a clear shift from rail to road based movements. The share of road-based transport has gone upto 87 percent in 2008 (Figure 2).

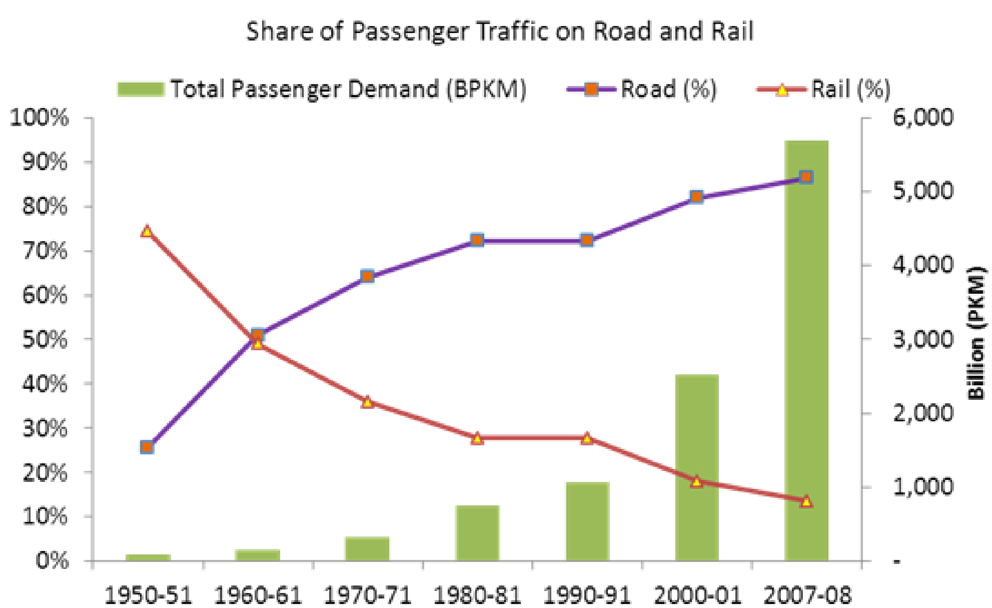

Figure 2: Share of different modes in passenger movement in India during (1950-2008)

Source: Data Source: RITES, 2014, PC, MoR, 2012
BPKM: Billion passenger kilometers

This has led to tremendous demand for heavy duty vehicles both in forms of trucks and buses. Consequently, the HDV sector in India has grown steadily during 1951-1991, and more sharply in the last two decades. By 2011, there are about 7 million trucks and 1.5 million buses registered in India (Figure 3). The Indian market is presently dominated by low-cost light trucks. The market is consolidated, and 90 percent market share can be split between only a few local manufacturers (example:. Tata Motors, Ashok Leyland, Eicher etc.)(KPMG, 2011).

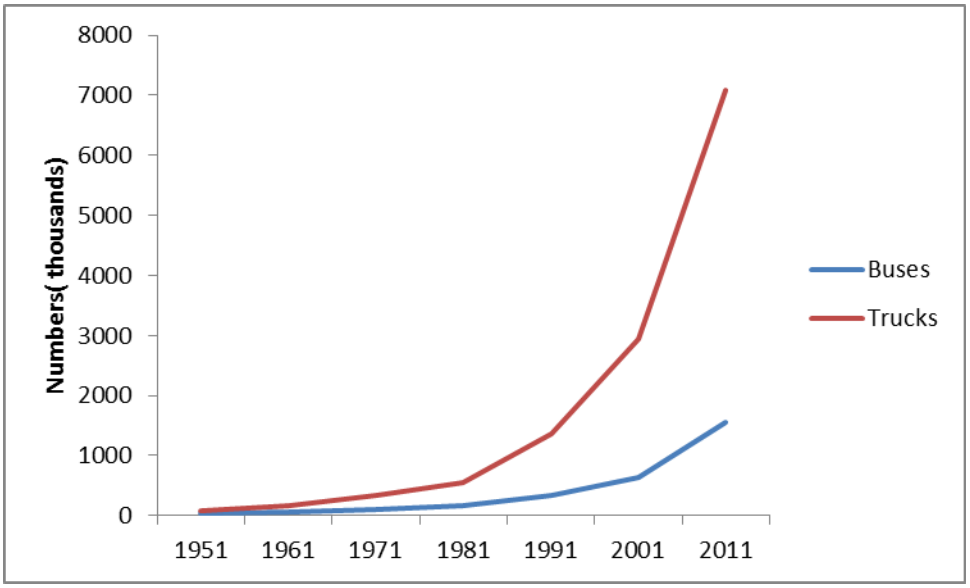

Figure 3: Number of registered HCVs in India during 1951-2011
Data Source: MoRTH, 2013

The Indian HDV market was somewhat affected by the financial crisis in 2008 and 2009. It has, however, recovered after that due to growth in construction and agricultural sectors. From 2007 to 2010, medium and heavy trucks market grew by 15 percent. The demand for buses has also increased as a means of transportation in large cities.

The estimated vehicle category-wise distribution of energy consumption in the road transport sector is shown in Figure 4 (TERI, 2014). Heavy-duty vehicles consume the largest share of the overall energy consumed in the sector (55 percent). Two-wheelers, although very high in numbers (72 percent), have a lesser energy share (18 percent). Cars just account for 13 percent of the total energy consumed in the sector.

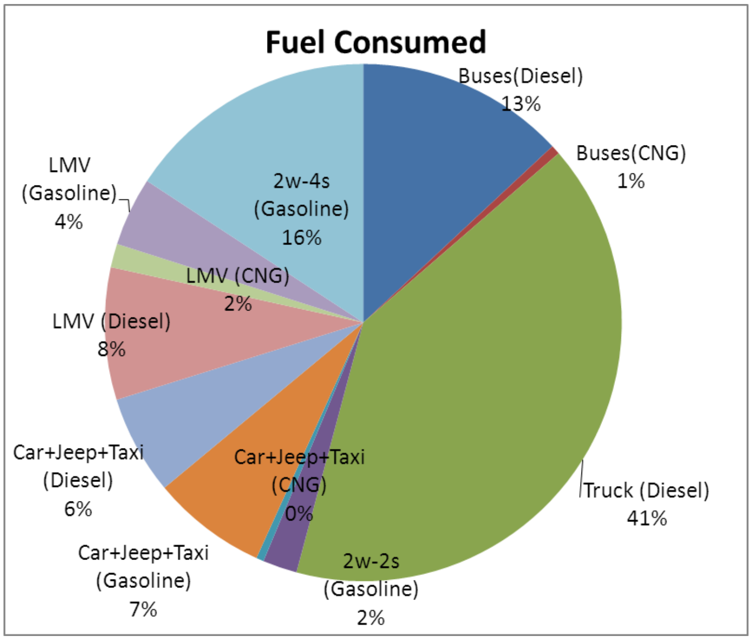

Figure 4: Vehicle category and fuel-wise distribution of energy used in the country during 2010

The share of HDVs is expected to go further up in future with growth in economy and population. Figure 5 shows the energy use forecasted for different vehicle categories using the TERI-MARKAL model. The energy consumption is projected to grow eight-fold during 2010-2030 with the share of HDVs going up from 53 to 67 percent.

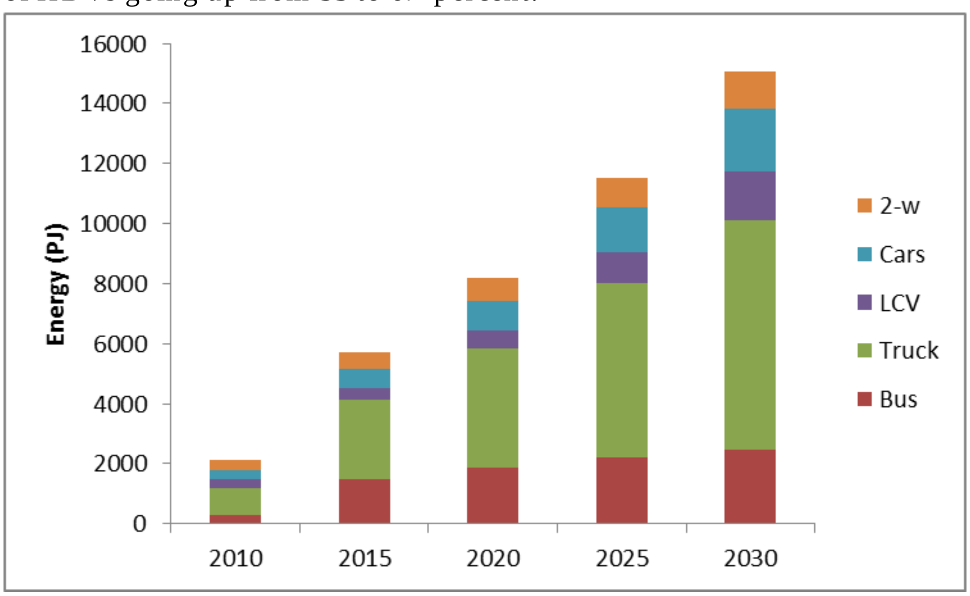

Figure 5: Projected growth of vehicle category-wise energy use in India
Source: TERI-MARKAL model

A 10 percent fuel efficiency improvement from 2020 and 15 percent from 2025, can taper the growth trajectory of diesel consumption significantly. This could lead to a saving of about 65 million tons of diesel annually by the year 2030 amounting to 5000 billion INR (based on 65 Rs/ litre). This clearly emphasizes the need for stringent fuel efficiency norms in the country, which will not only lead to reduction in fuel consumption, but will also reduce our import dependency in the future.

TERI conducted a survey of all models under heavy duty vehicle categories for their various technological features. Some of the findings are attached in Annexure-I.

Factors causing energy loss in HDVs

The factors which play an important role in defining the fuel consumption depend on actual road load driving conditions. Equation 1 shows the force or power required to propel a vehicle which is broadly comprised of four terms describing tire rolling resistance, aerodynamic drag, acceleration, and grade effects:

FRL = mg.Crr + 0.5Cd.A.ρa.V2 + m(dV/dt) + mgsin(θ) -----------------------(1)

where mg is vehicle weight, Crr is tire rolling resistance, A is the frontal area, Cd is a drag coefficient based on the frontal area, ρa is the air density, V is the vehicle velocity, m is vehicle mass, t is time, and θis the road gradient (uphill positive). NRC, 2010 reports the approximate energy loss caused in HDVs due to various factors (Table 1).

Table 1: Energy loss in vehicles caused due to various factors and potential energy savings

Types	Urban / Intercity (percent)	Potential of energy savings(percent)
Engine losses	60	28
• *Heat rejection*	26	
• *Exhaust heat*	24	
• *Gas exchange*	4	
• *Friction*	1.5	
• *Engine accessories*	2.5	
Aerodynamic losses	4–10 / 21	11.5
Drivetrain losses	5–6 / 2	7
Braking losses	15–20 / 0-2	
Auxiliary loads	7–8 / 4	
Rolling resistance	8–12 / 13	11

Source : NRC, 2010

Table 1 shows that engine losses account for maximum followed by braking losses, losses due to aerodynamics, rolling resistance, loads, and drivetrains. This also shows the potential of energy savings as estimated by NRC, 2010 in the different categories. This clearly shows the need for a stringent policy to have fuel efficiency standards for the HDV sector in India to claim significant savings in fuel which is mainly imported in the country.

Literature review

A review of literature was carried out to understand the status of adoption of fuel efficiency standards in different countries across the world.

State of FES at global level

Fuel efficiency standards for HDVs are not very old across the world and they are significantly more challenging to adopt because of the presence of diverse fleets in terms of vehicle size and configuration as well as usage patterns. However, many countries in the world have made progress and adopted fuel efficiency standards for these vehicles. Japan was the first country to introduce such standards in 2005, even though they will not take effect until 2015. The US adopted HDV efficiency standards that will apply to vehicles starting in the model year 2014.

Canada has standards equivalent to the US, and Mexico is currently undergoing active discussions to do the same. In 2009, Europe initiated research work on heavy-duty commercial vehicle carbon dioxide emission regulations and plans to complete carbon dioxide emissions testing regulations at the end of 2013, and shall perform certification of the European heavy-duty vehicle carbon dioxide emissions at the beginning of 2016. China adopted an “industry standard” for HDVs in 2011 and has proposed a national fuel consumption standard for HDVs (Zheng, 2011). The following section summarizes the status of HDV efficiency programme around key countries of the world.

i. Japan

Japanese vehicle fuel economy regulations are part of the “Law Concerning the Rational Use of Energy” (Energy Conservation Law). Since 1998, energy efficiency standards under the Energy Conservation Law are developed using a ‘top runner’ approach and the fuel efficiency targets, expressed in kilometers per liter of fuel (km/ L), are based on the gross vehicle weight (GVW) category. Manufacturers must ensure that in each financial year the average fuel economy of their vehicles in each weight category meets the standard. Flexibilities exist that allow manufacturers to accumulate credits in one weight category for use in another. While the fuel economy targets are mandatory, the penalties for missing the targets are minimal. The adoption of the standards is supplemented by introduction of financial incentives. For an example, vehicles that surpass the fuel economy/ emission standards may become eligible for reductions in vehicle tax. The fuel economy standards for heavy vehicles have been formulated and will be effective from 2015.

ii. China

In 2012, China’s Ministry of Industry and Information Technology (MIIT) put forward a proposal for a National Fuel Consumption Standard for new commercial heavy-duty vehicles (HDVs). The proposed standard is a set of limits on the fuel consumption for new commercial trucks, dump trucks, tractors, coaches, and buses with gross vehicle weight of over 3,500 kg. The standard would take effect from July 1, 2014 onwards. The National Standard sets fuel consumption limits following a step function, using gross vehicle weight as the utility parameter. The proposed standards tighten vehicle consumption limits for tractors, trucks, and coach by an average of 10.5 percent to 14.5 percent. Nearly 50 percent current models cannot meet the proposed fuel consumption limits. However, with the advent of newer vehicles based on fuel efficiency standards, HDV fuel consumption is expected to reduce by 11 percent by 2015 resulting in savings of 5- 6 million tons of annual oil consumption) (http:/ / transportpolicy.net/).

iii. USA

The U.S. Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA) jointly adopted the global warming emissions and fuel efficiency standards for medium- and heavy-duty vehicles (M/ HDV) and engines in 2011. The standards apply to vehicles manufactured during 2014-2018. The final USEPA standards are in the form of the mass of emissions from carrying a ton of cargo over a distance of one mile (g/ ton-mi). Similarly, the final NHTSA standards are in terms of gallons of fuel consumed over a set distance. Finally, for engines, EPA is adopting standards in the form of grams of emissions per unit of work (g/ bhp-hr), the same metric used for the heavy-duty highway engine standards for criteria pollutants today. Similarly, NHTSA is finalizing standards for heavy-duty engines in the form of gallons of fuel consumption per 100 units of work (gal/ 100 bhp-hr).

iv. Canada

Canada also formulated and adopted the heavy-duty fuel efficiency standards (almost the same as the U.S. heavy-duty GHG standards) in February 2013. However, most of the HDVs used in Canada are imported and compliance strategies need to be different than from those that will be used in the U.S.

v. Mexico

Mexico is in the process of developing heavy-duty fuel efficiency standards. Ultra-low sulfur diesel and advanced emissions technologies are the prerequisites as fuel efficiency improvements rely on these technologies.

vi. Europe

In the second phase of the European Climate Change Program (ECCP2), it was recognized that HDV fuel efficiency has significant potential of improvement. Since then, European Union has initiated the process of development and testing certification procedure for HDV fuel efficiency and expected to launch the formal program in place by 2020. The research was initiated in 2009 on heavy-duty commercial vehicle CO2 emission regulations.

Table 2 shows various features of HCV fuel efficiency standards across different countries in the world.

Table 2 Heavy-Commercial Fuel Efficiency Standards by Region

Feature	Japan	U.S.	China	EU
Regulation Timing	Adopted in 2006, effective starting 2015	Adopted in 2011, effective from 2014, early compliance allowed in 2013 (EPA and NHTSA 2011a)	Proposed in 2012. Program to start in 2014	Development and testing of certification procedure underway
Metric/Units	Kilometers per liter	(g) CO2/ payload ton-mile and gallons/1,000 payload ton-miles (short tons)	Liters per 100 kilometers	NA
Reference Fuel Efficiency Level (Tractor-Trailer)	Average for 2002 tractor-trailer with GVW > 20 tons3 was 1.8 km/l	Average for Class 8 sleeper cab high roof tractor-trailer in 2010 was 9.3 gal/1000 ton-miles (short tons) (2.4 km/l) (EPA and NHTSA 2011a)	1.2, 1.6, and 2.4 km/l for a 49 ton GCW tractor-trailer tested in city, rural, and motorway segments	Average of 3.27 km/l for all long-haul trucks in 2010
Target Fuel Efficiency (Tractor-Trailer)	2.01 km/l by 2015 (Daisho 2007) for GVW>20 tons	7.3 gal/1,000 ton-miles (3.06 km/l) by 2014 (short tons) for Class 8 w/ sleeper cab and high roof	42 l/100 km (2.38 km/l) by 2014 for 40-43 tons GCW	3.86 km/l found to be cost-effective for long-haul
Test Cycles	JE05 (transient) and Interurban Mode (steady state cycle with 80 kph speed and road grade from -5 percent to +5 percent)	HHDDTS Transient Cycle and 55-mph and 65-mph steady state cruise cycles	UN World-wide Transient Vehicle Cycle, modified to match driving patterns in China	
Cycle Weighting	90 percent JE05 and	Transient 5 percent, 55-	Road (rural) 10 percent and	No weighting necessary for

(Tractor-Trailer)	10 percent Interurban Mode for GVW > 20 tons	mph cruise 9 percent and 65-mph cruise 86 percent for sleeper cab	highways 90 percent for semi-trailer towing more than 25 tons	mission-based cycles
Test Payload (Tractor-Trailer)	20 tons (half of maximum allowed payload)	19 short tons (17.2 tons)	Maximum allowed payload	Certification testing to be at average payload
Test Method	Simulation, using engine fuel consumption map and transmission specs; standard trailer	Simulation; standard engine, transmission; standard trailer depending on cab roof height	Chassis testing for basic vehicle; choice of simulation or chassis testing for variants	Simulation based on actual vehicle values; standard trailer depending on intended use
Treatment of Aerodynamics and Rolling Resistance	Standard values for Cd and Crr, depending on vehicle category	Manufacturer testing to determine Cd (coast down preferred); Crr for the steer and drive tire determined per ISO 28580	Manufacturer testing to determine tractive load (coast down preferred); otherwise standard value used for Cd and standard formula used for Crr	Manufacturer testing to determine Cd (constant speed test preferred); Crr values from tire labels as specified by EC directive No 1222/2009
Regulating Agency	Ministry of Economy, Trade and Industry (METI)	National Highway Traffic Safety Administration (NHTSA) for fuel efficiency; Environmental Protection Agency (EPA) for GHG emissions	Ministry of Industry and Information Technology (MIIT)	NA

Source: Therese Langer and Siddiq Khan, 2013

Methodologies to formulate fuel efficiency standards

A review of literature was also carried out to document the different methodologies used to formulate fuel efficiency standards across various countries.

i) Footprint-based approach

Footprint-based approach used in US allows policy makers to regulate GHG emissions (g/ mile) instead of fuel economy (km/ l). In this new approach, individual vehicle fuel economies, which are actually measured in terms of GHG targets are based on the size of the vehicles. So according to this approach, each automaker has a customized fuel economy target based on the average size of their vehicle fleet. This new approach was developed in the US in April 2006 by the National Highway Traffic and Safety Administration (NHTSA) of the Department of Transportation (DOT), which adopted a reformed CAFE scheme based on vehicle size defined by light-truck footprints (which is the area between four wheels). A relationship or formula correlating fuel economy targets with vehicle sizes was applied and modified targets were worked out. Previously, the corporate average fuel economy (CAFE) program maintained two fixed standards, one for passenger cars and the other for light trucks.

In Japan and China, fuel economy standards are based on a weight classification system, where vehicles must comply with the standard for their weight class. Fuel economy standards in the Republic of Korea are based on an engine size classification system.

However, in the case of HDV standards based on fuel consumed per unit of payloads (g/ ton-mile) makes more sense. Based on the same approach, separate standards for engines and vehicles are adopted in US to ensure improvements in both. Moreover, separate standards for fuel consumption, CO2, N2O, CH4 and HFCs.

ii) Top runner approach

Under Japan's "Front Runner" program, the most efficient vehicles of one year become the standard of the next year, thus ensuring that vehicles become increasingly efficient over time. To set the baseline the vehicle which has achieved the highest fuel efficiency amongst all commercially available heavy vehicles in each category in the given financial year is selected. Based on this, the target fuel efficiency standard value is determined after evaluating the following factors:

- Fuel efficiency improvement due to technological development (ongoing and planned R&D)
- Effect of working around exhaust gas emission regulation on fuel efficiency within the period from 2002 (long-term control level) to 2015 (2009 exhaust gas emissions control level).
- Effect of fuel properties on fuel efficiency

iii) Stage-wise standard approach

In China, an independent research laboratory conducted studies to estimate the fuel consumption level of the new vehicles from the existing fleet of HDVs. This data was used as a baseline for setting an industry standard (stage-I industry standard) for HDV fuel consumption which was adopted in January 2012. The fuel consumption limits were set for three types of HDVs: tractors, straight trucks and coaches, requiring manufacturers to report the fuel consumption performance of all new models applying for type approval (from February 1, 2012). And by July 2012 it was mandated that all new models applying for type approval must not exceed the set fuel consumption limits. The next stage (Stage II national fuel consumption standard) of the HDV fuel consumption standard was then proposed in September 2012 for five types of HDVs (tractors, straight trucks, dump trucks, city buses, and coaches) after the Chinese ministry collected more fuel consumption data through additional testing, simulations using the latest models and through the database of the new vehicles appearing for type approval. Hence, the second stage HDV fuel consumption standards in China were based on a broader set of fuel consumption data. This proposed national fuel consumption standard is to be implemented for new HDV models applying for type approval starting from July 1, 2014; by July 1, 2015, all new commercial HDVs manufactured in China (except for specialized vocational vehicles) are required to comply with the National Standard. Both the standards (stage I and II) were weigh- based fuel consumption standards.

India

The recently introduced corporate average fuel consumption (CAFC) standards in India for cars are based on the corporate average kerb weight (CAKW) of the vehicles sold by the manufacturers. These mandatory CAFC for 2015-16 standards for cars is calculated as per the formula described below:

$$CAFC = 0.0025 * CAKW + 3.171$$

While, the standard for 2020-21 (assuming availability of Euro V fuel) is:

$$CAFC = 0.0023 * CAKW + 2.753$$

However, this proposal has been met with criticism from various quarters stating that it is too weak both in terms of international standards and in terms of improvements already anticipated in the automobile industry in India. It is expected that the industry will make enough autonomous improvements to surpass the prescribed standards.

Technologies to improve fuel efficiency

There are several technologies available for improvement in fuel economy in HDV sector. The technologies can be grouped into categories of Power Train improvements and technologies for reducing load specific fuel consumption. There are technologies for improving the efficiency of diesel engines and technologies for transmissions and drive axles. Moreover, there are hybrid power train technologies hybrid power trains that can reduce fuel consumption in HDVs.
The vehicle technologies for reducing Load-Specific Fuel Consumption mainly focus to reduce vehicle engine losses which happen mainly due to heat transfer to the coolant and exhaust heat loss. The rest is used to power the vehicle and auxiliaries. The main areas of energy losses are aerodynamics, auxiliary loads, rolling resistance, vehicle mass (weight), and idle reduction. Significant research has happened over the years across the world to improve aerodynamics, reduce vehicle weight, and improve tire quality. **Table 5** summarizes the technologies that can be applied in improving the fuel economy in HDV sector.

Table 5: Summary of technologies to improve fuel economy in HDVs

S.No	Technology type	Intervention	Description
1	Power Train Technologies	Turbochargers	Turbochargers (turbines and compressors with improved efficiencies) Dual-stage turbocharging with inter-cooling Mechanical Turbocompound (by employing a power turbine to the exhaust stream to extract wasted energy) Electric Turbocompound (similar to mechanical turbocompound where the power turbine drives an electrical generator to supplement the engine output for electrical accessories or can be used to charge a hybrid system battery.
		Low-Temperature Exhaust Gas Recirculation	Exhaust Gas Recirculation (EGR) reduces NOx formation and leads to more advanced injection timing and increases engine efficiency
		Electrification of Engine-Driven Accessories	Conversion of engine driven accessories to electric power. (more effect in short-haul/ urban applications and lesser in line-haul applications)
		Engine Friction Reduction	Friction reduction in some cases may develop issues with durability/ performance. Friction losses could be more during cold starts and under light load operation. ,
		Improved Work Extraction from Combustion Process	Improved combustion processes (involving improvements in compression ratio, expansion ratio, combustion chamber shape, injection spray pattern, injection pressure, injection timing, injection rate shaping, air/ fuel mixing, peak cylinder pressure limit, air/ fuel ratio, and EGR rate). Improved combustion chamber design, and improved

			materials can allow more precise control of rate of heat release (combustion) as well as higher combustion temperatures, resulting into improved thermal efficiency. More accurate and timed injection of fuel and increase in injection pressure.
2	Vehicle Technologies for Reducing Load-Specific Fuel Consumption	Aerodynamics	Day cab roof deflector (4-7 percent) Sleeper roof fairing (7-10 percent) Standard Chassis skirt (3-4 percent) Cab extender (2-3 percent)
		Auxiliary loads	Improved auxiliary systems Use of electric drives instead of direct mechanical drives
		Rolling resistance	Improved Tires Tire Pressure Maintenance and Effects Tire/ Wheel Alignment
		Vehicle mass (weight)	Lightweight materials and structures (Aluminium composite panels)
		Idle reduction	Automatic Shutdown/ Startup Systems Battery-powered idle reduction systems
3	Driver support systems		Eco-Roll for taking advantage of the vehicle's kinetic energy during downhill driving

Figure 6 shows the fuel consumption reduction possible through various interventions in HDVs (as reported in NRC, 2010). The engine improvements can also lead to a significant reduction of 11-23 percent. Other parameters have a role to play in reducing fuel consumption from the HDVs. Hybrid engines also have a great potential in reducing fuel consumption.

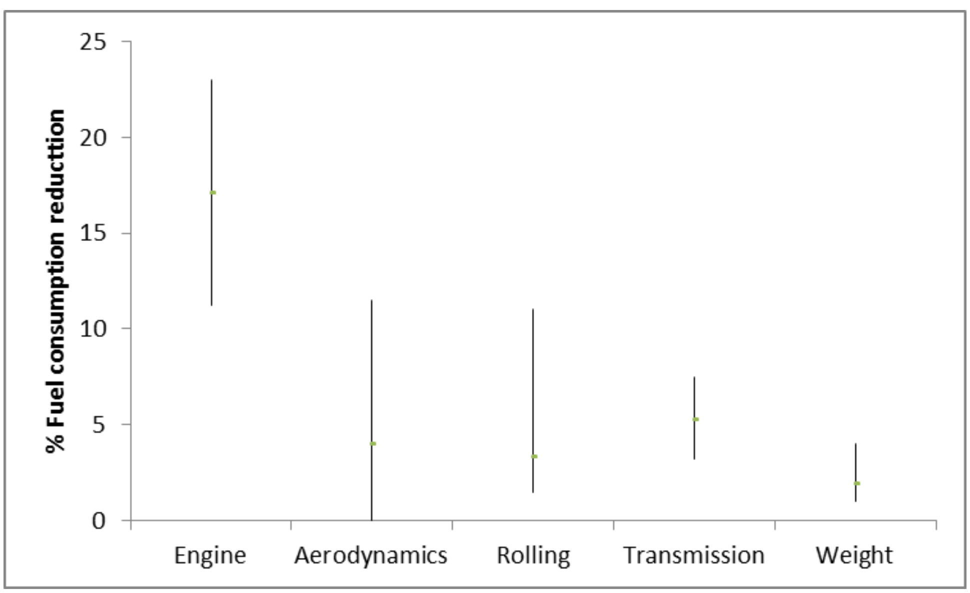

Figure 6: Possible fuel consumption reductions through various technologies in HDVs
Source: NRC, 2010

Conclusion

Energy security is already an important issue in India and considering the growth trajectory and geo-political situations, it is expected to become even more important in future. The share of road transport has risen tremendously over the years and HDVs are one of the important consumers of energy in the road transport sector in India. This paper analyzed the technical features of the different HDV models available in the country. The paper also analyzed the factors which are responsible for energy losses in the system.

A review of literature suggests that while there are many countries in the developed and developing world which have either already established the fuel efficiency norms for the sector or are in the process of developing them. India has just announced its first-ever automobile fuel efficiency norms for cars in 2014. However, its effects on the overall fuel consumption are going to be very small considering the lower share in the overall energy mix. However, fuel efficiency improvements in HDVs can result in substantial savings of the fuel (in the order of 65 MT annually by the year 2030) .This calls for introduction of fuel efficiency norms for HDVs in India. In this paper, literature has also been reviewed to understand the potential of various interventions in improving fuel efficiency from the sector. Further, simulation exercises need to be carried out to understand the effect of different interventions in India specific fleet of HDVs. This paper can be the first step in the direction to formulate and adopt fuel efficiency standards for HDVs in India. It is recommended that BEE should now set up a working group on discussing and formulating the fuel efficiency standards for HDVs in India.

Acknowledgments

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Annexure –I Survey of HDV industry in India

TERI carried out a survey of different automobile manufacturers to understand the various features and technologies available across different models in the HDV sector. Broadly, the heavy duty vehicles (HDV) are classified under three classes based on their use: Tractor (to provide high traction effort), truck (to pull or carry goods/ weights) and bus (to carry passengers). There are 18 tractor manufacturing companies in India, while eight companies manufacture trucks and buses. The survey was carried out for different models under the three categories of trucks, buses, and tractors. Each of the HDV categories is further classified into four different categories depending on their Gross Combination Mass (GCM): N1 (< 3.5 MT), Medium Goods Vehicle (MGV) (3.5 – 7.5 MT), N2 (7.5-12.0 MT) and N3 (>12.0 MT). A majority (99 percent; 225 models) of the Tractor models in India are in the category N1, while majority of truck (80 percent; 139 models) and bus (37 percent; 55 models) models are in the category of N3 (Figure A1). A significant percentage of buses also falls in N2 and MGV categories also.

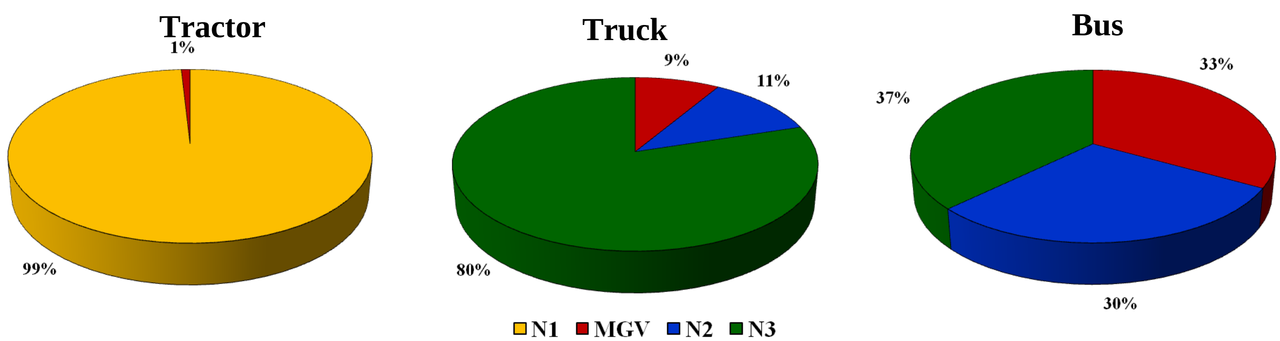

Figure A1: Different categories of HDVs based on GCM.

Models were also checked for their transmission systems. Gear transmissions system is an important component affecting the fuel economy in HDVs. More gears enable fuel savings since the driver has more flexibility to operate the truck and keep the engine at higher efficiency levels. Manual transmission systems are generally found to be more fuel efficient mainly because of the lack of torque converter.

94 percent of tractor models and 30 percent of truck models are having more than 6 front gears whereas only one bus model is having more than 6 front gears (Figure A2). 77 percent of tractors have eight front gears while 42 percent of truck and 42 percent bus models have six front gears.

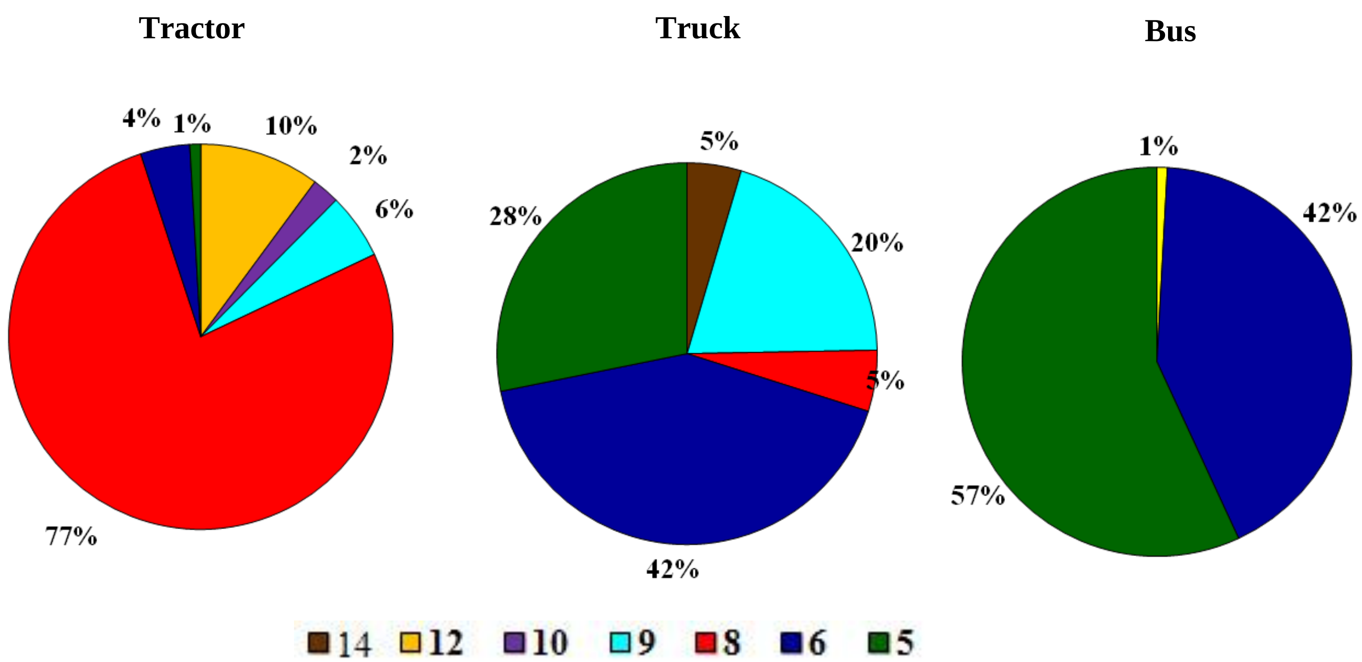

Figure A2 Distribution of front gears in different HDVs.

All models of tractor and truck use diesel as fuel, while, 17 percent of buses are powered by compressed natural gas (CNG) and the rest work on diesel. Two-axle powered HDVs are more common than four-axle powered ones (Figure A3) under all classes of HDVs. 91 percent, 66 percent and 96 percent of tractor, truck, and bus models are two-axle powered, respectively.

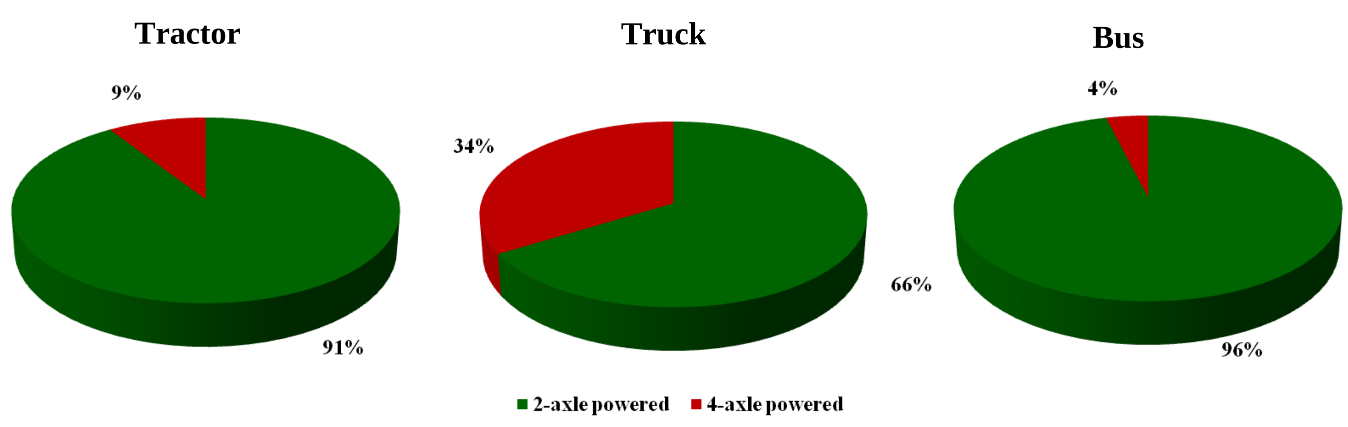

Figure A3: Categorization of HDVs based on number of axle.

The vehicle length of 50 percent of all tractor models is below 3.5 m whereas the vehicle length of most of the truck (90 percent) and bus (68 percent) models are in the range of 5.0 to 10.0m (Figure A4). The data reveals that average vehicle length is higher in buses, while width is found to be higher in trucks.

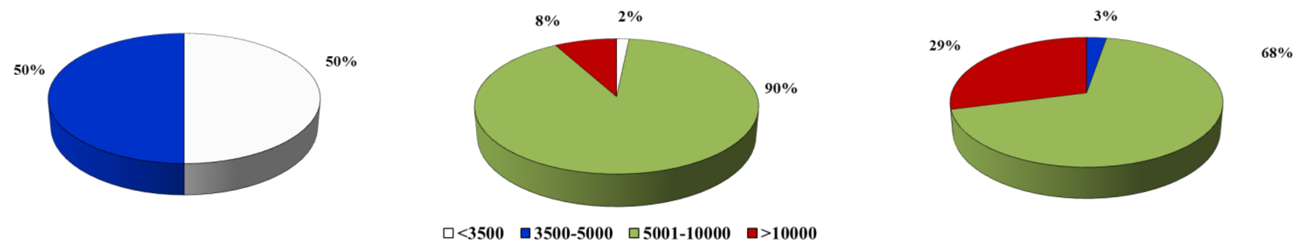

Figure A4: Classification of different HDVs based on vehicle length (mm)

Out of 227 models of tractor, 226 have wheelbase less than 2.5m. The majority of truck models (51 percent) have a wheelbase in the range of 2.5-4.0 m whereas majority of the bus models (43 percent) have a wheelbase greater than 5.0m (Figure A5).

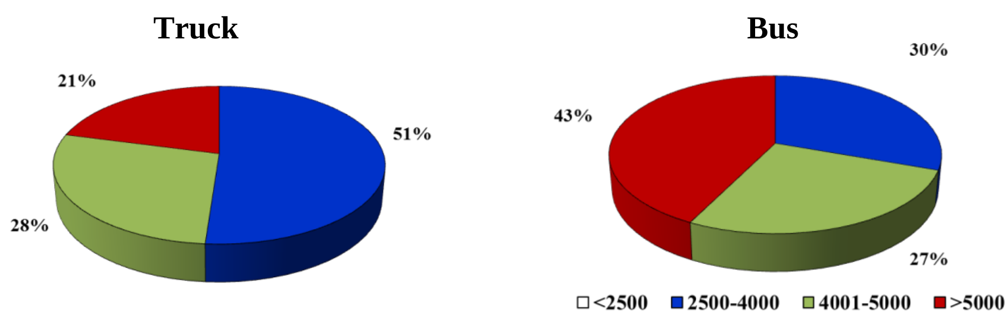

Figure A5: Classification of Truck and Bus models based on wheelbase (m)

The majority of tractor (82 percent) and bus (62 percent) models have the engine displacement in the range of 2001-4000 cc, while majority of truck models (71 percent) have the engine displacement in the range of 4001 – 8000 cc (Figure A6).

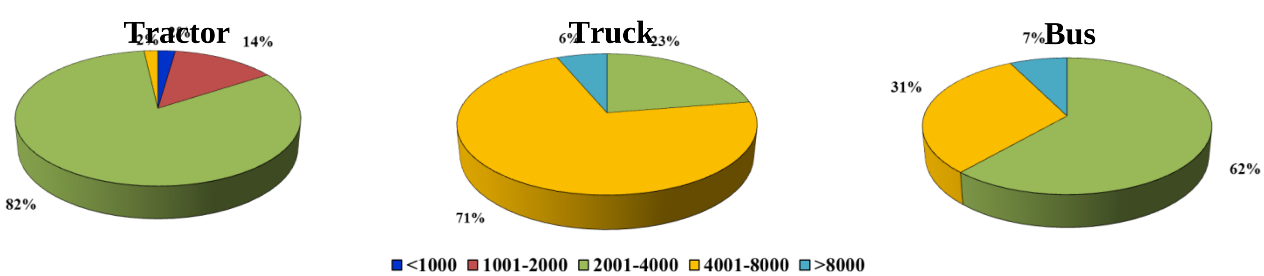

Figure A6: Classification of different HDVs based on engine displacement (cc).

However, engine power of truck models with engine displacement >8000cc is significantly higher than that of bus models (Figure A7) although engine powers of different models of tractor are at par under different classes of engine displacement. Figure 9 indicates that the engine powers of truck models are higher than those of bus models under different classes of engine displacement.

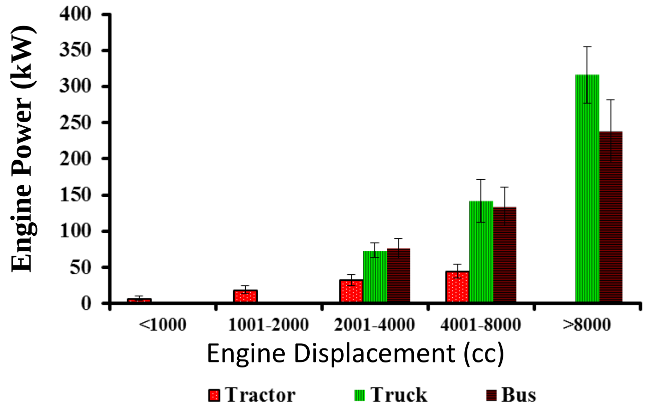

Figure A7 Engine power versus engine displacement in different HDVs.

Depending on the number of engine cylinders, tractors can be classified into four categories. Maximum numbers of tractor models (68 percent) are with 3-cylinders (Figure 10). On the other hand, models of truck and bus could be divided into 2 categories, based on the number of cylinders. Most of the truck (64 percent) and bus (72 percent) models are with 6-cylinders (Figure A8).

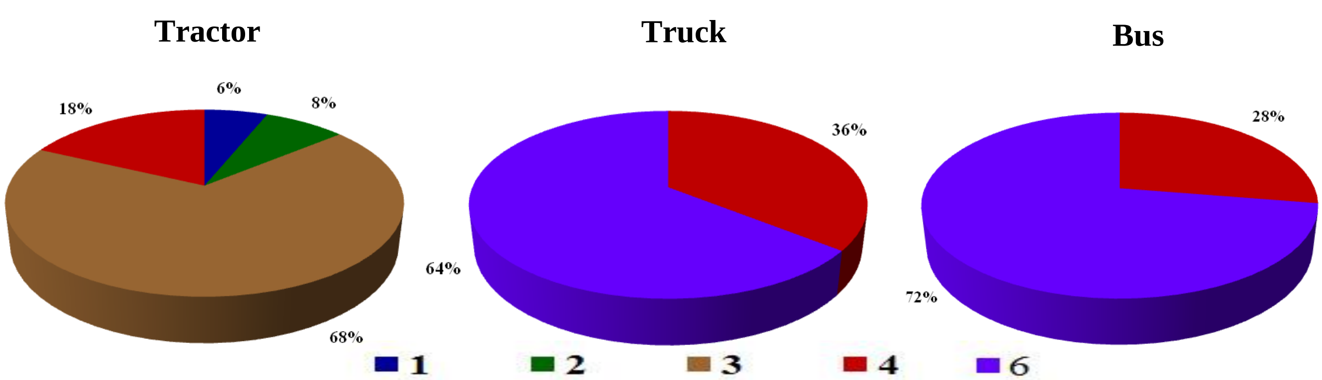

Figure A8: Distribution of engine cylinder among different categories of HDVs.

Engine power of 3-(12.2 to 55.9 kW) and four-cylinder (22.37 to 61.89 kW) tractors are more diverse than others (Figure A9), whereas the ranges of engine power of six-cylinder truck (52.19 to 382 kW) and bus (62 to 315 kW) models are much wide. All models of tractors and buses have two and four valves per cylinder respectively. Truck models have four- and six-valve engines.

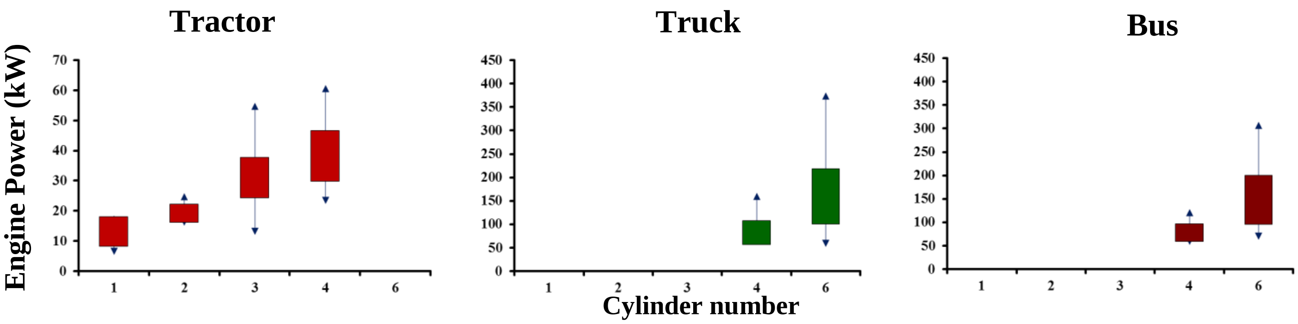

Figure A9 Engine power of different HDVs with different cylinder number.

Among the HDV, average engine power of trucks (138.4 kW) is significantly higher than others. Engine power of different HDV followed the order: Truck (138.4 ± 61.4 kW)>Bus (108.1 ± 49.5 kW)> Tractor (30.3 ± 9.23 kW). The average GCM of trucks (24.11 ± 12.04 Mt) is also significantly higher than other HDVs. The average GCM of different HDVs followed the order: Truck (24.11± 12.04 MT) > Bus (10.95 ± 4.67 MT) > Tractor (2.09 ± 0.44 MT). All tractor models follow the Term III emission standard; while most models of the truck (89.08 percent) and bus (72.30 percent) follow the BSIII emission standard (Figure A10).

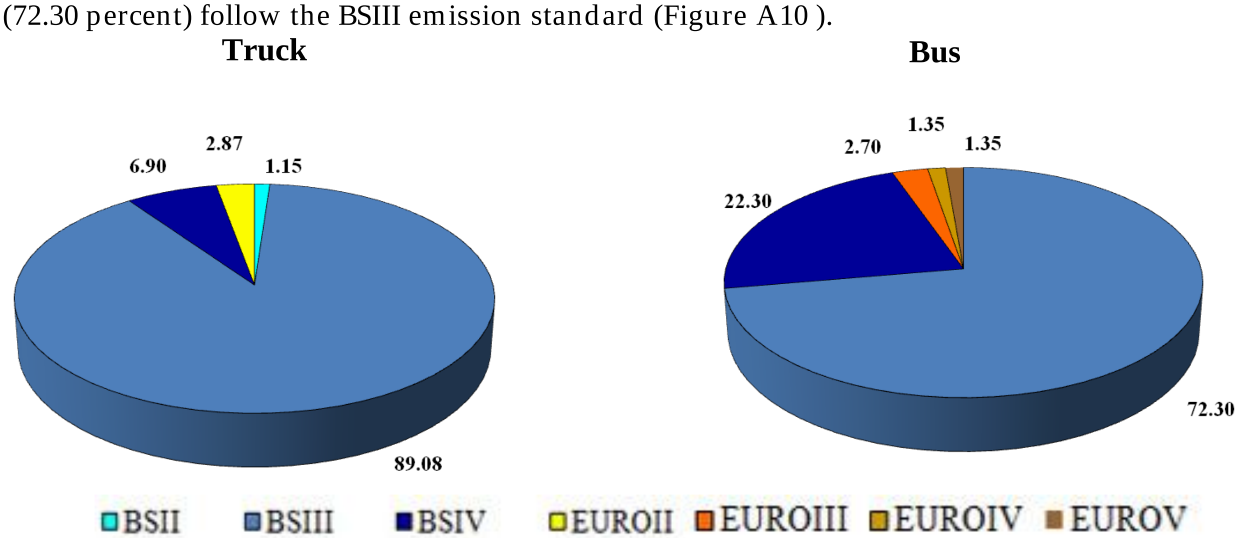

Figure A10 percentage of truck and bus models under different emission standard category.