



An Overview of Vehicular Emission Standards

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Abstract: In India, the ambient air quality has been degrading from past few decades especially in urban areas. Vehicular emissions are amongst one of the major reasons for the deterioration of ambient air quality in such areas. This article is an effort to review the vehicular emission standards of the major countries (USA, Europe, Japan and Australia) and compare with Indian emission standards. However, there exists several differences in present emission standards followed by different countries. For instance, emission standards in USA are fuel neutral, while no separate weight categorization exists among light-duty vehicles (LDVs). In Europe, Japan, Australia and India, separate weight categorization and emission limits for both petrol and diesel vehicles are provided. It was observed that different driving test cycles used by different countries are the reasons for numerical differences in vehicular emission standards. To rectify this, a worldwide harmonized test cycle (WHTC) is introduced by United Nations Economic Committee for Europe (UNECE) that would represent real-world driving and verifies that the statutory emission limits are not exceeded during actual driving. Countries like Japan and Europe have already been following the WHTC, while some other countries may introduce the same in near future. Yet the real-world emissions across the world keeps on diverging. In such situation, harmonization of vehicle emission standards worldwide is a bit challenging, based on dynamics of road conditions, driving patterns, environmental conditions, etc. Thus, more concerted research is needed for evolution of a common universal emission standards implementable worldwide so that the uniformity in information and policies available to the common public could be maintained.

Keywords: Vehicular emission standards; Air pollution; India

1. Introduction

The automobile sector is one of the significant sector contributing towards the growth curve of Indian economy. More than 7% of the Indian Gross Domestic Product (GDP) is shared by automobile sector which is anticipated to increase more than 12% by 2026 [1, 2]. Additionally, the escalating demographics along with rise in living standard of the citizens has put a strong pressure on the domestic demand and supply of automobiles. Consequently, India is emerging as one of the world's fastest flourishing hub for passenger cars (PCs) while second largest producer of two-wheelers [3]. However, this rapid growth of Indian automobile sector poses grave challenges to India's energy

security and environmental protection. The intensifying transportation system would dramatically increase India's dependence on fuel import. The core factors that are supposed to control and drive the dynamics of vehicular emissions are monetary growth which include increase in personal vehicle ownership, type of vehicle, technology used in engines and its development, maintenance, the quality of fuel, etc. Therefore, the present scenario of vehicular emissions is highly dynamic and the statutory limits for emission standards are rapidly changing accordingly.

The degrading ambient air quality in India has been the subject of extensive research during the past few decades. Rapid economic expansion and migration of people to urban areas are some of the reasons that could be attributed for the defilement of urban air quality. The urban centers of the nation show alarming levels of criteria pollutants [4].

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The emissions from vehicles in urban areas lead to more than 90% of air pollution, especially in developing countries [5]. Consequently, this jeopardy is mainly urban-centric having significant share of 30–80% of vehicular emissions across the Indian cities [6]. Furthermore, vehicles account for around 5–40% of PM_{10} and 12–90% of NO_x emissions in some cities [7]. The major constituents of vehicular emissions are mainly particulate matter (PM), oxides of Nitrogen (NO_x), hydrocarbons (HCs), carbon monoxide (CO), etc. produced by the incineration of fuels used in the vehicles. In addition, the major potential greenhouse gases (GHGs) are produced from automobiles, i.e., carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) [8, 9]. These emitted pollutants are potential threat to environment and human health and also contribute to trans-boundary pollution. The photochemical reaction between NO_x and HCs is responsible for surface ozone formation. The surface ozone research has been focused even in the first half of twentieth century in Athens to compare with prevailing ozone levels [10]. The persistence of surface ozone concentration showed similar levels in the beginning of twentieth and twenty-first century reflecting that industrialization and increased in situ photochemistry in the Athens did not contribute significantly [11]. The variations in the atmosphere affect the validity of long-term weather change predictions. However, climate is an average of the weather over a reasonably long time. So, climate change means long-term changes which vary slowly, e.g., temperature, rainfall, etc. But the role of short-term changes, e.g., clouds, biogeochemical cycles, remains important which reflects the nonlinear nature of the air pollution problems and its complexity [12]. All these factors can be controlled by improving the air quality of a country.

The Government of India has consistently been working to curtail the menace of decreasing ambient air quality. In this regard, several steps have been taken which include formulation of National Ambient Air Quality Standards (NAAQS), formation of National Air Monitoring Program (NAMP), special action plans like Graded Response Action Plan (GRAP) for major polluting metropolitan cities, LPGs distribution for cooking, etc. [6]. Setting up stringent emission standards for vehicles and introducing fuel quality norms are some of the steps taken to reduce the share of vehicular pollution [6]. In other words, emission standards are statutory permissible limits of the pollutants released into the atmosphere from specific sources over specific period of time. These are designed to protect human health and achieve the air quality standards. However, if the emission of pollutants from the escalating vehicle population is not checked, it may invalidate the achievements of past few decades.

The paper aims to understand the present scenario of Indian vehicular emission standards Vs international

vehicular emission standards. Also, the article reviews the involvement of automobile emission standards for major countries, i.e., United States of America, Europe, Japan, Australia and India. A general comparison of the existing vehicular emission standards has also been discussed in this paper to have better insights on the status of Indian vehicular emission standards. This comparison may be helpful for future improvisation and implementation of vehicular emission standards in India.

2. Evolution of Vehicular Emission Standards

In 1950s, a group of scientists recognized that the peculiar combination of warm climate, bounded landscape and rising population was the prevailing reason behind smog formation in Los Angeles, the State of California. Dr. A.H. Smit discovered that hydrocarbons and NO_x emanating from automobile exhaust emissions react in the presence of sunlight as main constituents in smog formation [13]. Pertaining to such incidents and degradation of air quality of the region, the State of California in 1966 established its first ever automobile emission norms (for HCs and CO only) and formed California Air Resources Board (CARB) to regulate it [14]. The formation of Federal Clean Air Act (CAA) in 1970 authorized the state for the formation and regulation of its own air quality and automobile emission standards [15]. Accordingly, CARB adopted the nation's first emission standard for NO_x , emanating from automobiles, in 1971. USA, in 1968 formulated the vehicular emission standards for rest of the states [16].

Later on, European Nations in 1970s followed by Australia in 1972, and Japan in 1973 started setting up the vehicle emission norms to check the tailpipe emissions in their countries. Emission standards of United States and Europe were considered as main sets of standards later followed by several other countries to meet their NAAQS.

In India, The Air (Prevention and Control of Pollution) Act, 1981 was ordained to regulate the air pollution which provided right to the government to regulate vehicular emission standards and also empowered all the states' pollution control boards to set the standards along with Central Pollution Control Board (CPCB) for air pollutants. Later, the Environment (Protection) Act, 1986 empowered the central government to coordinate the state and central authorities under Water and Air Act for its regulation. Both these acts paved the way for regulation of motor vehicle emissions in India which led to the formation of Ministry of Road Transport and Highways (MoRTH) liable for making vehicular emission standards and implemented under the Motor Vehicles Act, 1989. Indian automobile emission norms were laid down based on European

standards and is known as ‘Bharat Stage (BS)’ Emission Standards [17]

3. Vehicular Emission Standards in USA (Federal Standards)

In USA, the agencies responsible for setting up the statutory emission limits for automobiles and fuel economy standards are CARB, Environmental Protection Agency (EPA), and National Highway Traffic Safety Administration (NHTSA). USA consistently kept amending its automobile emission standards having world’s stringent emission norms for different categories of vehicles. In a recent emission inventory report, EPA has summarized the trends observed in anthropogenic emissions in US during the years 1990–2018. The report stated that light-duty vehicles (i.e., light-duty trucks and passenger cars) accounted for 59%, while medium- to heavy-duty vehicles 23% emissions in the nation [18]. The road to world’s stringent automobile emission standards started from the amendment of CAA, 1970 that empowered US EPA to establish standards for regulation emissions emanating from different automobile sources. Since then, EPA has progressively been working towards regulating the automobile exhaust emissions initially for on-road vehicles and later off-road vehicles like agricultural and construction equipment. In the same year, EPA established emission standards mandatory for new cars to meet the emission norms for NO_x, CO and HCs. EPA is also empowered to regulate the quality of fuels and fuel additives used for automobile sources.

In April 2020, on behalf of Department of Transportation, EPA and NHTSA have issued the rules for amending and establishing CO₂ and fuel economy standards the model year (MY) 2021 for setting new fuel economy standards for the MYs 2021–2026 for PCs and light trucks. This is known as “Safer Affordable Fuel Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks” which has been effective from June 29, 2020 [19]. As a part of the rule, EPA has rescinded the authority of State of California to establish GHGs emission standards with the aim to ascertain ‘One National Program’ for automobile CO₂ emissions and fuel economy standards in the nation. It was ultimately concluded by EPA that the standards fixed in 2012 for MYs 2022–2025 were not suitable anymore and, thus, needed a reformulation. Earlier, the automobile manufacturers had to improve their fuel efficiency by 5% annually for MYs 2020–2025. However, SAFE vehicle rule has relaxed the norms for automobile manufacturers and required them to improve their fuel efficiency only by 1.5% annually for MYs 2021–2026. According to EPA, if the previous standards

were retained, it would have resulted in increased costs of vehicles, and thus forcing people to drive the same older and dirtier vehicles for long time.

The breakthrough was made in the history of US automobile emission standards when the CAA, 1990 introduced new standards to regulate smog pollutants emanating from automobile exhausts Tier 1 emission standards followed by Tier 2 and Tier 3 emission norms, respectively.

3.1. Tier 1 Emission Standards

Tier 1 emission standards were adopted in 1991 and phased-in progressively between 1994 and 1997. These emission standards were applied to all Light-Duty Vehicles (LDVs) with < 8500 lbs gross vehicle weight rating (GVWR) comprising of the weights of vehicle, passengers, goods and/or any other accessories. LDVs in Tier 1 were classified as depicted in Fig. 1.

For PCs and Light Light-Duty Trucks (LLDTs), Tier 1 standards remained effective till 1999; while for Heavy–Light-Duty Trucks (HLDTs), the same was effective until 2004. In Tier 1 standards, the statutory limits were specified for the pollutants NO_x, CO, PM, HCs, Total Hydrocarbon content (THC), and Non-methane hydrocarbon (NMHC). Figure 2 summarizes Tier 1 emission standards for LDVs measured over Federal Test Procedure cycle (FTP-75 test procedure) [20].

To measure the real urban driving emissions, Tier 1 Supplemental Federal Test Procedure (SFTP) standards were introduced and applicable to the emission of CO and mixture of NMHC with NO_x [21]. The SFTP standards were calculated by combining two different cycles US06 and SC03. The US06 cycle measures the emission during highway driving while SC03 cycle was meant for measuring emissions during use of vehicle’s air conditioning system. The combined SFTP was calculated as: $SFTP = 0.35 \times FTP + 0.28 \times US06 + 0.37 \times SC03$ [22]. Figure 3 shows Tier 1 SFTP standards for LDVs.

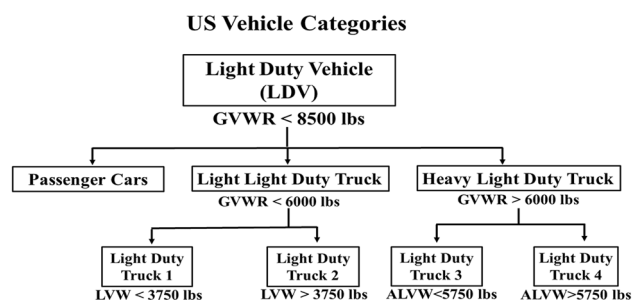


Fig. 1 Categories of vehicles in Tier 1 emission standards (Source: <https://www.epa.gov/emission-standards-reference-guide/vehicle-weight-classifications-emission-standards-reference-guide>)

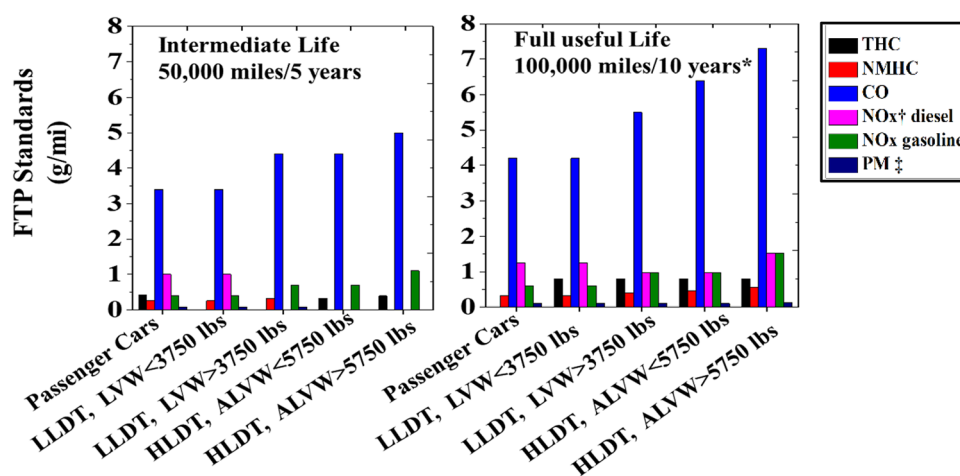


Fig. 2 EPA Tier 1 emission standards for LDVs (passenger cars and light-duty trucks) (FTP-75) (Source: <http://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10009ZL.pdf>)

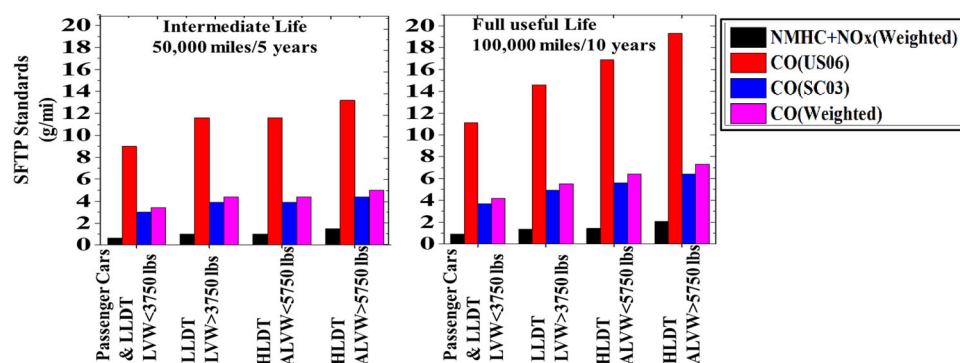


Fig. 3 EPA Tier 1 emission standards for LDVs (passenger cars and light-duty trucks) (SFTP) (Source: <http://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10009ZR.pdf>)

In 1997, before the final phase of Tier 2 emission standards, there was a mutual agreement between north eastern states and auto manufacturers to follow National Light Emission Vehicle (NLEV) Program from the MY 1999 while nationally from the MY 2001 [23]. The program replaced the earlier existing Tier 1 emission standards and was in effect until the final adoption of Tier 2 emission standards. NLEV program was valid only for LDVs (PCs and LLDTs) and it did not include HLDTs (GVWR > 6000 lbs). Also, the program was in harmonization with Low Emission Vehicle (LEV) I of Californian motor vehicle standards.

3.2. Tier 2 Emission Standards

In December 1999, a more stringent update to Tier 1 emission standards was announced by EPA which was planned to be implemented successively through the MYs 2004–2009 with a focus to reduce the NO_x emissions. The applicability of the norms extended further to cover some

heavier vehicle categories. The vehicle categories classified in Tier 2 as per GVWR are shown in Fig. 4. Besides covering all the vehicle categories of Tier 1 standards, Tier 2 emission standards were extended further to include medium-duty passenger vehicles (MDPVs) used for personal transportation having GVWR between 8500 and 10,000 lbs.

Figure 5 shows the Tier 2 emission standards of pollutants measured over FTP-75. The automakers must certify the vehicles to any of the available bins and vehicles certified to a particular bin could not surpass the extent of pollution specific to the bin. However, the automakers fleet as a whole required to meet NO_x emission defined in bin 5 (= 0.07 g/mi). Thus, vehicles having higher fleet average than 0.07 g/mi had to compensate by selling an adequate number of vehicles certified to bin < 5. During phase-in period of Tier 2 standards, the rest of the fleet not complying with 0.07 g/mi mean values were denoted as Interim non-tier 2 vehicles. Those vehicles yet needed to meet one of the available certification bins but with relaxed fleet

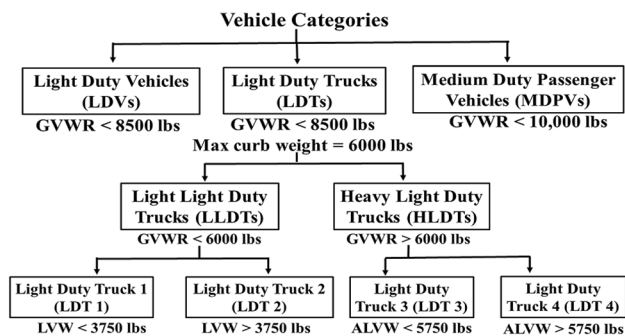


Fig. 4 EPA category of vehicles for Tier 2 emission standards (Source: <https://www.epa.gov/emission-standards-reference-guide/vehicle-weight-classifications-emission-standards-reference-guide>)

average requirements. The full useful life of the vehicle was extended in both the cases of light- and medium-duty vehicles from existing ones. For LDVs and LLDTs, the useful life was protracted to 120,000 miles or 10 years either occurred earlier, while it was 120,000 miles or 11 years for HLDTs and MDPVs [24].

Tier 2 emission standards also had introduced norms for cleaner fuel quality by regulating the levels of sulfur in gasoline and diesel with corporate average of 120 ppm for gasoline with a cap of 300 ppm which had to be met by the refineries in the year 2004. From 2006, the standard was further reduced to 30 ppm with a cap of 80 ppm. While ultra-low sulfur diesel with maximum 15 ppm level came in existence since 2006 for highway purpose.

3.3. Tier 3 Emission Standards

A new set of emission standards for vehicles and fuels was decided by US EPA in March 2014, commonly known as Tier 3 emission standards. The standard was proposed for the MYs 2017–2025 for LDVs, MDPVs and some Heavy-Duty Vehicles (HDVs). The structure of Tier 3 emission standards formed was quite similar to the earlier existing Tier 2. In Tier 3 emission standards also, the manufacturers were required to get their vehicles certified to one of the seven available ‘certification bins’ and manufactured vehicles fleet must meet the average fleet emission standards for a given model year. Tier 3 emission standards considered fuel and vehicle as an integrated system, thus formulated fuel standards similar to Tier 2 program. However, there were several other amendments besides including HDVs up to 14,000 lbs GVWR in Tier 3 program and extension of useful life period of the vehicle to 150,000 miles or 15 years whichever occurred earlier. Apart from all this, one of the interesting aspects of the program was to reduce GHGs emissions from LDVs starting from MY 2017 and the program was known as ‘2017 LD GHG standards’ [25]. Tier 3 standards were in close association with California’s LEV III Program. Finally, the Tier 3 emission standards, 2017 LD GHG standards and LEV III emission standards of California together provided enormous reduction in air pollutants and GHGs emissions and, thus, maintaining the NAAQS. Additionally, these programs would also help the auto manufacturers to design and sell single vehicle for nationwide sales, thus decreasing their cost of compliance. In a nutshell, the main components of Tier 3 emissions standards were:

- (a) emission standards for LDVs, MDPVs and HDVs measured over FTP and SFTP.
- (b) standards for evaporative emissions.

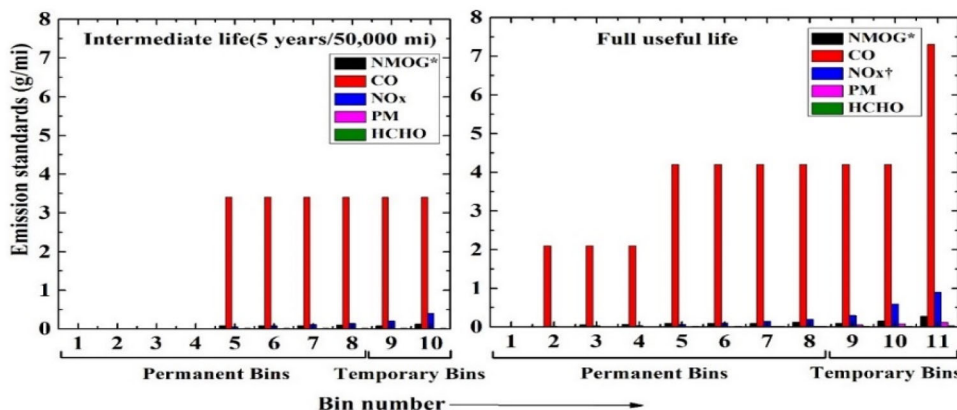


Fig. 5 EPA Tier 2 Emission standards (FTP-75) (Source: <https://nepis.epa.gov/Exe/ZyPDF.cgi/P100SMQA.PDF?Dockey=P100SMQA.PDF>)

- (c) on-board diagnostic systems.
- (d) fuel standards.

3.3.1. Emission Standards for LDVs, MDPVs and HDVs

As stated earlier, Tier 3 emission standards resembled Tier 2 structurally; however, certain new amendments were added keeping ambient air quality standards and public health in view. Figure 6 shows Tier 3 emission standards applicable to vehicles of all weight categories irrespective of fuel type used. One of the main alterations was introducing combined standard for NMOG + NO_x for both certification bins and fleet average standards of vehicles instead of individual standards for Non-methane organic gases(NMOG) and NO_x. Also, the name of bin corresponded to NMOG + NO_x limits measured in mg/mi. The auto manufacturers had to certify their vehicles to one of the seven available certification bins.

The manufactured fleet of the vehicle must also meet NMOG + NO_x fleet average, measured both over FTP and SFTP driving cycles. Figure 7 shows NMOG + NO_x average limits evaluated over FTP and SFTP cycles, respectively. Although the useful life of the vehicle was extended to 150,000 miles or 15 years, yet if the manufacturers wanted to certify their vehicles for 120,000 miles, as in the case of Tier 2 standards, less numerical fleet average would apply calculated by multiplying respective 150,000 miles standard by 0.85 and round it off.

For CO, the SFTP limits decided were 4.2 g/mile throughout the MYs. Also, it was worth noting that the SFTP standard limits for NMOG + NO_x were applied both in cases of lighter and heavier vehicles fleet. PM standards for both FTP and SFTP were applicable for each

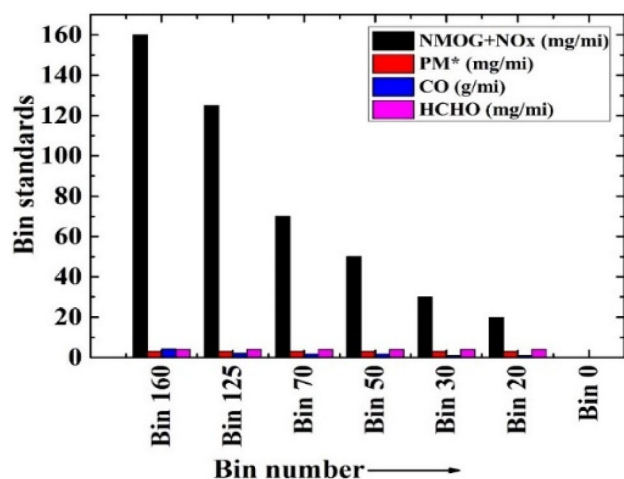


Fig. 6 EPA Tier 3 Certification bin standards (FTP-75) (Source: <https://www.epa.gov/greenvehicles/light-duty-vehicle-emissions#standards>)

vehicle separately instead of vehicle fleet average. The limit for PM measured over FTP was 3 mg/mi for all vehicles in MYs (2017–25) and that evaluated over US06 driving cycle, was decided to be 10 mg/mi over MY 2018 and 6 mg/mi for MY 2019 and later (Fig. 8).

The HDVs were divided into two different categories on the basis of GVWR in Tier 3 emission standards. Vehicles between 8501 and 10,000 lbs were in Class 2b while those between 10,001 and 14,000 lbs were in Class 3 vehicles. Figures 8 and 9 show the emission standards for HDVs measured over FTP and SFTP, respectively. Figure 10 shows Tier 3 HDV fleet average for NMOG + NO_x measured over FTP.

The PM standards measured over FTP in case of HDVs were 8 mg/mi and 10 mg/mi for Class 2b and Class 3, respectively. In Tier 3, exhaust emission standards for HCHO and CO were also established. HDVs did not have requirements of SC03 emissions under the current HDV standards.

3.3.2. Fuel Standards in Tier 3

The Tier 3 considered vehicle and fuel as integrated system and, thus, included norms for vehicular emission as well as sulfur content of the gasoline. It was noted that the catalytic converter installed in a vehicle to reduce the level of pollutants in exhaust depended greatly on the quality of fuel used. The efficiency of catalytic converters deteriorated severely when they were exposed to significantly high content of sulfur in fuel. Although reducing the levels of sulfur in gasoline ~ 90% to an average value of 30 ppm was required by the oil refineries in Tier 2, yet many scientific studies suggested that this amount of sulfur not only degraded the performance of catalytic converters but also hindered the further reduction targeted by the vehicle emissions to reach Tier 3 standards. Thus, Tier 3 vehicle and fuel standards reduced the content of sulfur in gasoline by 10 ppm average. Apart from facilitating immediate reduction in pollutants from vehicular exhausts, the main aim of reducing sulfur in gasoline was to improve the performance of catalytic converters so that the duration of useful life of the vehicle could be enhanced. Other important components of Tier 3 were on-board diagnostic systems and emission test fuel.

Since beginning although California emissions standards were more stringent than USA, yet their structure of formation remained the same. For LDVs, California emission regulation is known as LEV standards, first adopted by CARB in 1990 for MYs 1994–2003. Later, LEV II emission standards were formed for the MYs 2004–2010 followed by LEV III emission standards for MYs 2015–2025. LEV III emission program is structurally similar to USA Tier 3 emission standards like inclusion of NMOG + NO_x

Fig. 7 EPA Tier 3 NMOG + NOx fleet average (FTP and SFTP standards) (Source: www.gpo.gov/fdsys/pkg/FR-2014-04-28/pdf/2014-06954.pdf)

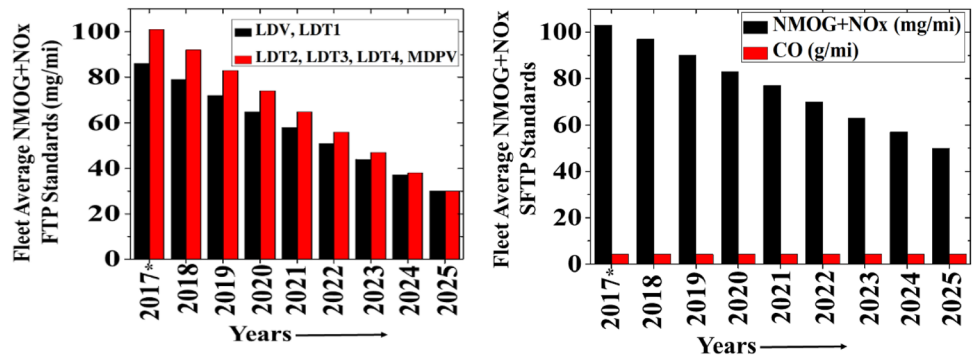


Fig. 8 EPA Tier 3 standards for HDVs (FTP-75) (Source: www.gpo.gov/fdsys/pkg/FR-2014-04-28/pdf/2014-06954.pdf)

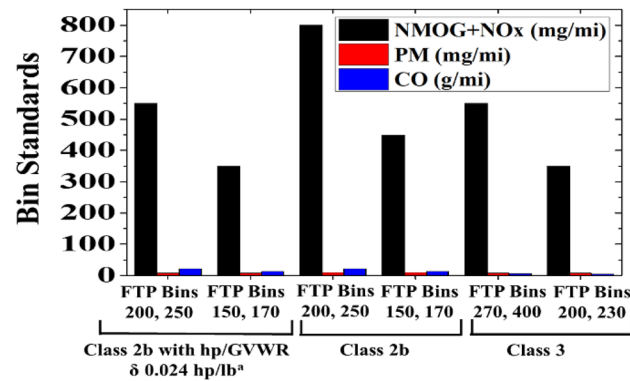
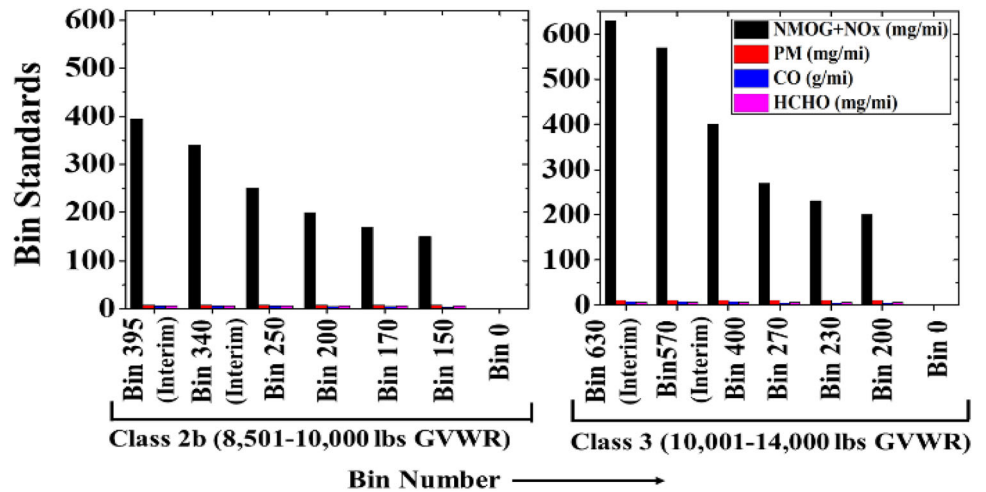


Fig. 9 EPA Tier 3 standards for HDVs (SFTP) (Source: www.gpo.gov/fdsys/pkg/FR-2014-04-28/pdf/2014-06954.pdf)

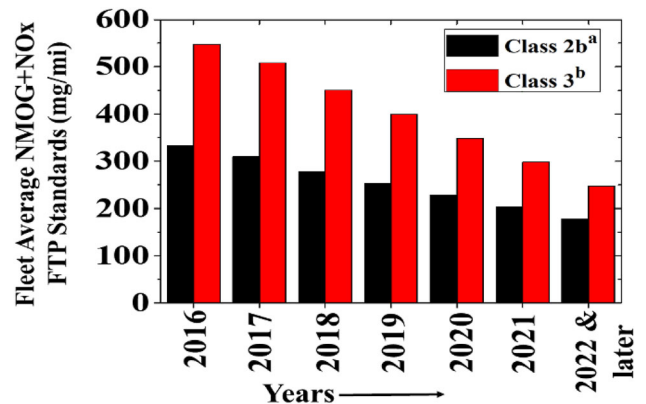


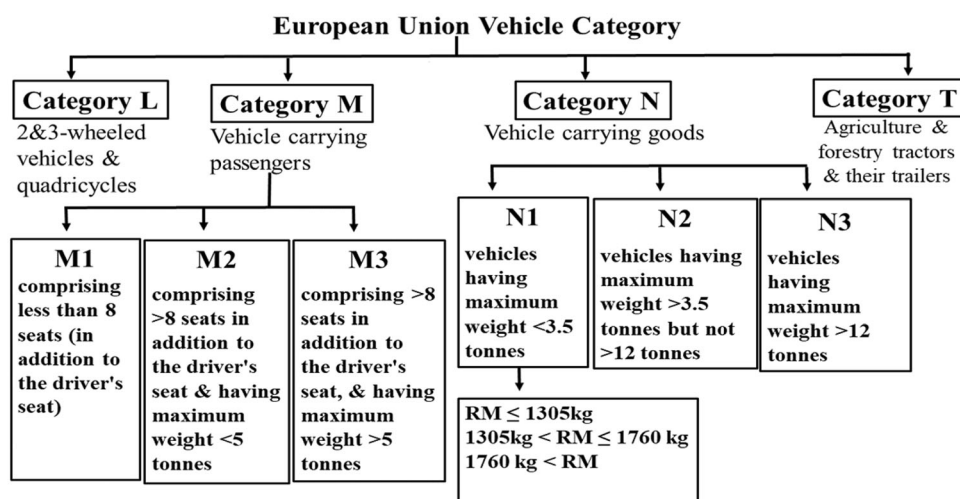
Fig. 10 EPA Tier 3 NMOG + NOx fleet average standards for HDVs (FTP) (Source: www.gpo.gov/fdsys/pkg/FR-2014-04-28/pdf/2014-06954.pdf)

combined standards and formation of corresponding vehicle categories (in case of LEV III) and certification bins (in case of Tier 3 standards). Similar permissible limits were set for all the pollutants in LEV III and Tier 3 emission standards with an aim to harmonize the regulations within USA. Also, the manufacturers are now able to sell the same vehicle within the country which decreases the cost of compliance significantly.

4. Vehicular Emission Standards in European Union

The road transport is one of the significant contributors to air pollutants in the European region. In 2017, the road transport alone contributed for 21% of the total emissions of CO₂ (one of the most important GHGs) in the European

Fig. 11 Vehicle categorization in EU standards (Source: EMEP/EEA air pollutant emission inventory guidebook 2019)



Union (EU) [26]. It was found that PCs and Light commercial vehicles (LCVs) like vans were among the major CO₂ emitters and shared a substantial percentage of 12 and 2.5, respectively, of the total CO₂ emissions, respectively, in the EU [27]. Thus, the reduction of GHGs (mainly CO₂) and protecting the quality of ambient air became the major driving force behind the vehicular emission regulation for the EU. Currently, European Commission regulates emissions emanating from LDVs, HDVs and non-road mobile machinery. However, for each defined vehicle category with varying fuel type, different emission standards apply. European Commission has categorized the vehicles for regulatory purposes for the formation of emission norms. The main categories of the vehicles in EU are as shown in Fig. 11 [28].

Figure 12 represents Euro emission standards for PCs for different fuel type, i.e., gasoline and diesel. Different types of engine are deployed in different vehicles such as positive ignition (PI) and compression ignition (CI) engine and, thus, are meant for different fuels. In PI engines, gasoline is used as fuel while in CI engines, diesel is used. In PI engines spark is used to ignite fuel mixture with air while in CI engines, heat is generated by using compressed air to ignite the fuel. Due to heterogeneous mixture of air and fuel in CI engines, more HCs are produced. The stages of emission standards for LDVs are ranged from Euro 1 to Euro 6, while for HDVs, from Euro I to Euro VI.

4.1. Euro Standards for LDVs

The light category of vehicles means all the vehicles under 3.5 tons, which include both PCs and other LCVs such as vans. The pioneer step for establishing emission norms in Europe was taken in 1970s for PCs under United Nations Economic Committee for Europe (UNECE) Regulation 15

with several amendments, i.e., (a) pre ECE: till 1971, (b) ECE 15-00 and 15-01: 1972–1977, (c) ECE 15-02: 1978–1980, (d) ECE 15-03: 1981–1985, and (e) ECE 15-04: 1985–1992.

The former amendments were applied only to gasoline-fueled vehicles while ECE 15-04 was amended for both gasoline- and diesel-fueled vehicles and the emission norms were based on ECE 15 driving cycle [14].

In 1991, under the Directive 91/441/EEC, Euro 1 emission norms were mandated for PCs only (both gasoline and diesel fueled) [29]. However, it was later upgraded to include both PCs and light trucks through Directive 93/59/EEC. Thus, Euro 1 standards were also known as EC 93. The Euro 1 emission standards became effective from the year 1992–93. Likewise, Euro 2 standards were mandated through Directive 94/12/EC and amended through 96/69/EC to be implemented in the year 1996–97 [30]. The emission norms in both the standards were based on new driving cycle, i.e., ECE 15 (urban) cycle and extra-urban driving cycle (EUDC). Both emission norms regulated

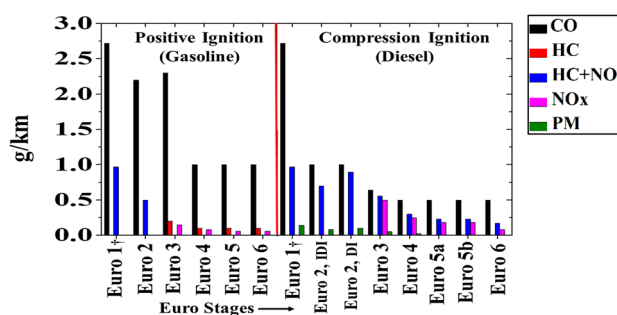


Fig. 12 EU emission standards for passenger cars (Category M₁ and M₂) (Source: <https://www.transportpolicy.net/region/europe/european-union/>)

HC + NO_x and CO levels. However, the level of PM was also regulated in case of diesel vehicles. Unlike Euro 1, Euro 2 standards were also regulated for the emissions from direct-injection (DI) diesel engines to meet the emission requirements until September 30, 1999. After that, the vehicles had to meet the emission requirements for indirect-injection (IDI) diesel engines. All these modifications in the emission requirements made the auto manufacturers to install some conventional technologies with durability requirements in the vehicles like catalytic converters in petrol vehicles.

Both Euro 3 and 4 emission standards were made mandatory under the Directive 98/69/EC and amended through Directive 2002/80/EC [31]. The Euro 3 standards were to be implemented from 2000–01, while Euro 4 in the year 2005–06. In Euro 3 emission standards, besides HC + NO_x, individual NO_x limits were also added, while gasoline-fueled vehicles remained exempted for PM emission limit until the introduction of Euro 4 standards. For Euro 3 standards, durability or the useful life of the vehicle had been regulated, i.e., 80,000 km or 5 years, while Euro 4 standards were extended to 100,000 km or 5 years (whichever occurred earlier).

Euro 5 standards for gasoline-fueled vehicles were implemented in single phase only. However, the standard was implemented in two phases, i.e., Euro 5a and Euro 5b for diesel vehicles. The latter came into effect in 2011. Euro 5 had new regulation for PM emitting from diesel-fueled PCs. It was made mandatory for these cars to have particle filters to check PM emissions. Furthermore, the emission limit of 6×10^{11} particle number (PN) was included for the very first time in Euro 5b norms. However, new emission norms were introduced as Euro 6 emission standards in September, 2014. Both Euro 5 and 6 emission norms were mandated under Regulation 715/2007 as political legislation while implementing legislation was Regulation 692/2008 [32]. Consequently, any new emission regulation formed for LDVs was stated in the Directive 70/220/EEC with several amendments and subsequently this directive was replaced by Regulation 715/2007 during 1970–2006 [33]. In Euro 5 standards, NO_x and PM emissions were made more stringent for diesel cars. In Euro 6 emission norms, the PM and PN emission limits were kept the same for both diesel- and gasoline-fueled vehicles. Also, the fuel quality norms were regulated in Euro 6 standards to achieve the required PM and PN limits emanating from the vehicles. The fuel having sulfur content < 50 ppm was mandated. However, sulfur-free diesel and gasoline (≤ 10 ppm) were recommended to achieve highest performance for vehicle particle filters. Similar to Euro 4 (i.e., 100,000 km or 5 years), the durability period in Euro 5 and 6 standards was carried forward for ‘in-service conformity’ but the type approval

(done by testing the installed pollution-controlled devices) was extended further to 160,000 km or 5 years.

4.2. Euro Emission Standards for Light Commercial Vehicles

The emission values emanating from LCVs and Light-Duty Trucks (LDTs) were established in the ‘Consolidated Emissions Directive’. From Euro 1–6 emission standards, the N1 Class I vehicles emission standards were similar to PCs for gasoline- as well as diesel-fueled vehicles. However, the further higher weight categories like N1 Class II, Class III and N2 were allowed for higher emissions (Fig. 13).

5. Vehicle Emission Regulation in Japan

Japan was facing serious environmental degradation especially air and water pollution due to its economic expansion during late 1950s–60s [34]. Consequently, in 1962, Smoke and Soot Law was established as Japan’s first pollution control law for controlling dust, SO₂ and smoke emissions from industries. In 1966, the tailpipe exhaust emission regulations in Japan for diesel and gasoline cars were imposed. In 1967, Environmental Quality Standards were introduced under Basic Environmental Pollution Control Law to control the degrading quality of the environment. These regulations became more and more stringent with time [35]. In 1968, then existing Smoke and Soot Law was amended as Air Pollution Control Act in which air pollutants emanating from different sources were regulated. Under this Act, automobile exhaust emission standards (referred as interim standards) were given in 4 sets in 1973, 1975, 1976 and 1978, respectively. These standards were as per CAA, 1970 of USA and tax breaks were given for cars which passed them standards [36]. The 1978 exhaust emission standards regularized the limits for mean and maximum (max) values of CO, HCs and NO_x.

Two emission programs named ‘Automotive NO_x & PM Law’ and ‘Tokyo Retrofit Program’ were implemented to reduce emissions from in-use diesel vehicles. Initially, Ministry of Environment (MOE) adopted the ‘Motor Vehicle NO_x law’ in 1992, to limit the NO_x pollution from then existing vehicle fleets in highly populated cities. This law targeted the removal of old, most polluting vehicles from in-use fleets in some zones. Some amendments were done in this law in June 2000 to include PM control provisions and the law was renamed as the ‘Automotive NO_x & PM Law’ [37]. The Tokyo Government adopted diesel emission regulations, which became effective in October 2003. The Tokyo retrofit program required retrofitting of

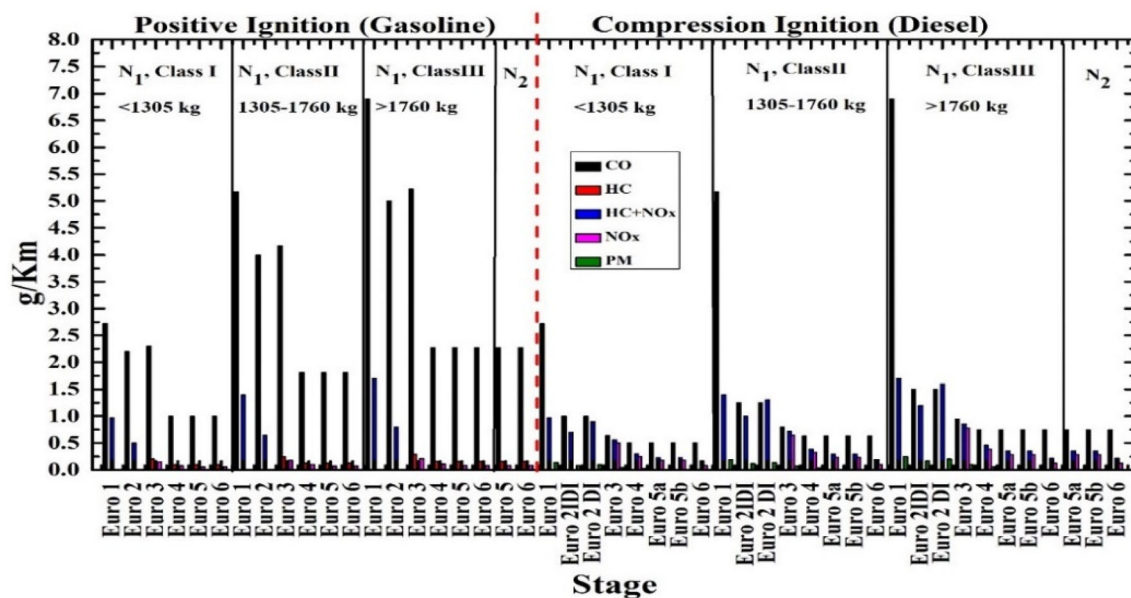


Fig. 13 Euro emission standards for light-duty vehicles (Source: <https://www.transportpolicy.net/region/europe/european-union/>)

older in-use diesel vehicles with PM control devices or replacing them with newer models [38].

Japanese regulations and their phase-in periods are (a) Long-term regulations (1997, 1998, 1999), (b) New short-term regulations (2003, 2004), (c) New long-term regulations (2005), (d) Post new long-term regulations (2009, 2010), and (e) Japan 2018 Target Emission Regulations (2018) [35, 39].

5.1. Emission Standards for PCs and LDTs

The diesel-fueled PCs were divided in two categories as per the equivalent inertia weight (EIW) of the vehicle. The two categories were < 1250 kg and > 1250 kg. Japanese emission legislation consists of two types of standards: 'mean' and 'max'. The 'mean' standards were needed to be in consistence as a production average and as a type approval limit. In case of series production, the 'max' standards should be met by the vehicle as an individual limit whereas sales being less than 2000 vehicles per year, it was needed to be met as type approval.

5.1.1. Category < 1250 kg

After 1978, the emission norms were revised in the year 1986 and successively in 1990 for CO, HC and NOx for diesel PCs. The emission limits for CO and HC remained same in both the years while only NOx limits were revised in the later year. The 1994 emission standards remained same as 1990 emission standards with an additional

emission limits for PM. Later in the year 1997, only NOx and PM emission limits were regulated. More stringent norms were introduced successively in the years 2002, 2005, 2009 and 2018, respectively. NMHCs were considered for the regularization instead of HCs from 2005 onwards.

5.1.2. Category > 1250 kg

For this category of diesel PCs, the mass emission norms were revised in the year 1986 for CO, HC and NOx. The emission limits for CO and HC were same as earlier category of PCs. However, NOx limits were slightly higher. In 1992, the emission limits of CO and HC were kept the same while NOx emission limits were reduced. The revised emission standards of 1994 comprised of same emission limits for CO, HC and NOx with introduction of additional emission limits for PM. NOx and PM emission limits were revised again in the year 1998, while in 2002, more stringent emission norms were introduced for each pollutant. Further, the emission limits for CO and NMHCs (instead of HCs) were kept the same for 2005, 2009 and 2018 emission standards while NOx and PM limits were made more stringent successively. Figure 14 summarizes exhaust emission standards for new diesel-powered PCs. The implementation dates refer to new vehicle models. Figure 15 represents the emission standards for gasoline and LPG PCs for 2009 and later.

Figure 16 shows the emission standards for new diesel-fueled commercial vehicles. The diesel-fueled LCVs were

divided into two categories according to their gross vehicle weight which were ≤ 1700 kg and > 1700 kg.

5.1.3. Category ≤ 1700 kg

The emission norms for this category were revised in the year 1988 for CO, HC and NOx. The emission limits for CO and HC were kept same as diesel PCs in 1986, while the NOx limits were slightly different. In the year 1993, NOx limits were made more stringent with an introduction of additional emission limits for PM. From the year 1997, all the revised limits for years 1997, 2002, 2005, 2009 and 2018 for each pollutant were kept same as for the category < 1250 kg for PCs.

5.1.4. Category > 1700 kg

The 1988 emission standards for diesel-fueled LCVs for CO, HC and NOx were given in ppm instead of g/km. For NOx, the emission limits were different for DI and IDI diesel-fueled vehicles. The CO, HC and NOx limits were revised again in 1993 (in g/km). PM emission limits were also added in the same year. In the year 1997, only NOx and PM limits were revised and made more stringent. The limits were then revised in the year 2003 for all the pollutants. In the following years, i.e., 2005, 2009 and 2019, CO limits were kept same as ≤ 1700 kg category. In 2005, NMHCs replaced HCs and kept same as in ≤ 1700 kg category for subsequent years. NOx and PM limits were slightly higher for the heavier category.

The gasoline- and LPG-fueled LCVs were categorized as Mini ≤ 1700 kg and > 1700 kg (up to 3500 kg) according to their GVW (Fig. 17). In 2009, the emission standard for CO, NMHC, NOx and PM were revised for all categories. In 2019, only NMHC limits were revised and rest all kept same.

5.2. Heavy-Duty Engines

Earlier, emission laws for HDVs were conventionally less stringent in Japan than the corresponding laws in USA and

Fig. 14 Japanese emission standards for diesel passenger cars, g/km (Source: Dieselnets, Japan)

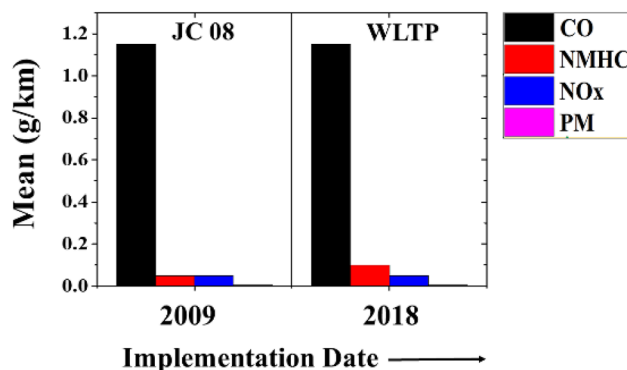
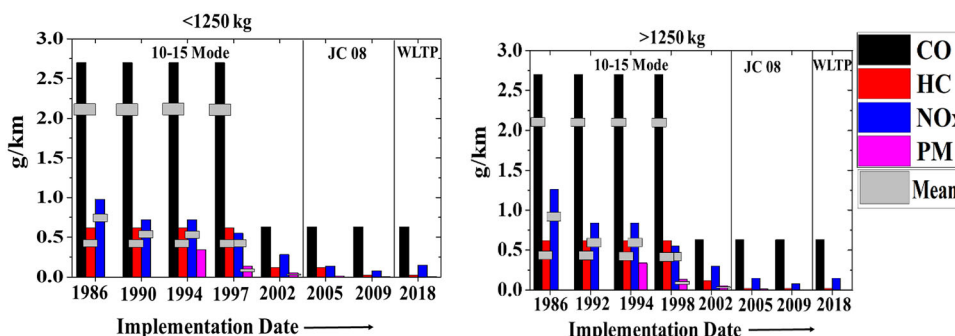


Fig. 15 Japanese emission standards for gasoline and LPG passenger cars, g/km (Source: Dieselnets, Japan)

the EU. However, Japan decided to limit their NOx and PM emissions due to continuous worsening of the air quality. Consequently, in 2003 MOE, Japan decided to implement more stringent emission norms for both LDVs and HDVs from 2005. Further, much more stringent stage was planned for 2009 [40]. Figure 18 shows emission standards for new diesel engines used in heavy commercial vehicles. The heavy commercial vehicle category included the vehicles having GVW > 3500 kg. The CO, HC and NOx emission limits for HDVs were implemented in 1988/1989 and given in ppm. These limits were again revised in 1994 with an introduction of additional emission limits for PM (in g/kWh). For DI and IDI diesel-fueled HDVs, NOx emission limits were set differently in 1988/89 and 1994 standards. In the year 1997, only NOx and PM limits were changed, whereas all the limits were revised in year 2003 with more stringent values. In 2005, NMHC replaced HC limits with same limits for CO while strict limits for NOx and PM. In the year 2009, NOx and PM limits were again revised, while in 2016, only NOx limits were changed and the rest all were same.

Figure 19 shows the emission standards for new gasoline- and LPG-fueled engines for heavy commercial vehicles. All standards for heavy-duty gasoline and LPG engines were published for the pre-2018 time frame.

Fig. 16 Emission standards for diesel light commercial vehicles GVW \leq 3500 kg (\leq 2500 kg before 2005) (Source: Dieselnets, Japan)

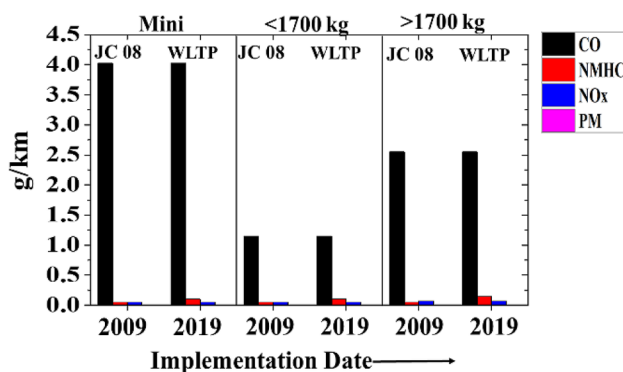
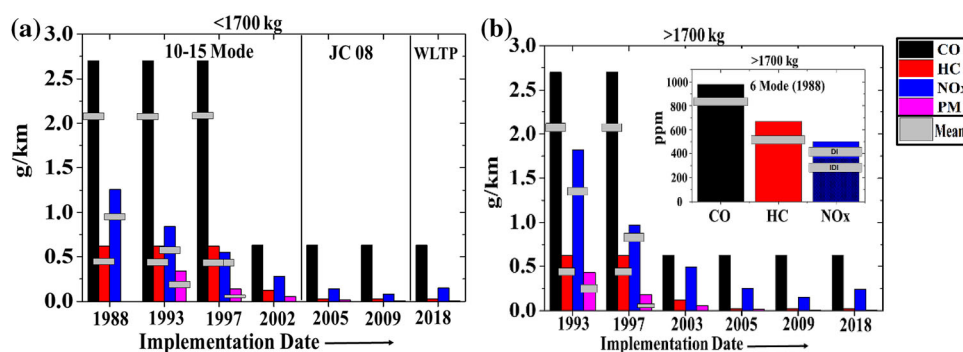


Fig. 17 Emission standards for gasoline and LPG light commercial vehicles, g/km GVW \leq 3500 kg (Source: Dieselnets, Japan)

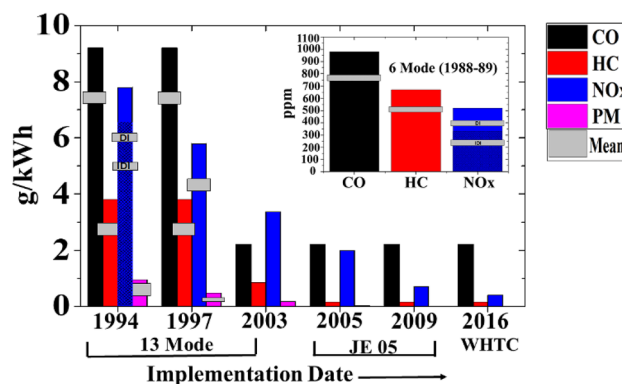


Fig. 18 Emission standards for diesel engines used in heavy commercial vehicles GVW $>$ 3500 kg ($>$ 2500 kg before 2005) (Source: Dieselnets, Japan)

6. Vehicular Emission Standards in Australia

The vehicular pollution has been a serious concern in Australia also especially in densely populated urban centers. Studies have shown that about 70% of urban air pollution in Australia was attributed to vehicles [41]. Moreover, around 80% CO, 60–70% NO_x and 40% of HC emissions were emanating from automobile exhausts [42]. To curb this situation, Australia implemented vehicle emission standards since 1970s for petrol-fueled light vehicles.

The automobile exhaust emission standards in Australia were codified as Australian Design Rules (ADRs) regulated under the Motor Vehicle Standards Act, 1989 for both exhaust emissions and safety. The regulatory authorities for development and implementation of emission standards in Australia are National Road Transport Commission (NRTC) and Department of Infrastructure and Transport. Australia has adopted the Euro standards as their base, while US and Japanese emission standards were also considered for designing their emission standards. In the year 1999, the Government of Australia introduced several environmental proposals under ‘Measures for a Better Environment’ which staged implementation of Euro 2 and

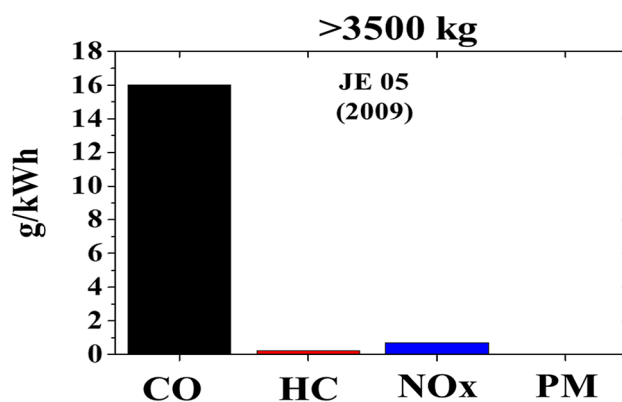


Fig. 19 Emission standards for gasoline and LPG engines for heavy commercial vehicles, g/kWh (GVW $>$ 3500 kg) (Source: Dieselnets, Japan)

Euro 3 for petrol vehicles and Euro 2, Euro 3 and Euro 4 for diesel vehicles. Figure 20 represents the emission limits of pollutants for petrol-fueled PCs during 1976–2016.

Idle CO test was used for checking the emissions with limits defined in % by volume. In 1974, these emission limits were revised under ADR 27. The new limits (g/test) were measured for CO over new emission test cycle ECE

'Big Bag' in addition to existing emission limits. The emission limits for HC were also included in this standard. ADR 27 A/B/C were introduced in the years 1976, 1982 and 1983, respectively, to regularize the emission limits for HC, CO and NO_x measured over US FTP-72 emission cycle (g/km). The 1986 emission standards implemented under ADR 37/00 (replacing ADR 27), introduced more stringent emission limits for HC and CO measured over new emission test cycle US FTP-75. The exhaust emission standards were revised again in the year 1997 under ADR 37/01. New ADR 79/00 was introduced in the year 2003 which substituted then existing ADR 37/01 corresponding to Euro 2 emission standards. From 2003 onwards, the emission limits for new petrol passenger cars were based on corresponding Euro standards. The revised versions of ADR79/00 were named as ADR79/01, ADR79/02, ADR79/03 and ADR79/04 that were introduced successively in the years 2005, 2008, 2013 and 2016 equivalent to Euro 3, Euro 4, Euro 5 and Euro 6 standards, respectively. Emission limits for PM were introduced in ADR79/03. NMHC limits were also regularized in addition to HC limits. The emission limits were kept same for all the pollutants in third and fourth revision of ADR79/00.

Figure 21 represents the emission limits of pollutants for diesel-fueled HDVs during 1995–2011. In Australia, the diesel-fueled HDVs were regularized for their exhaust emanations since 1976. In the year 1976, the smoke emission requirements were introduced under ADR 30/00 based on European regulations (UN ECE Reg 24/00). However, alternative standards such as US EPA, 1974 and British standards, 1971 were also provided in case of import of vehicles from these countries. Later in the year 1995, the emission limits for diesel heavy-duty vehicles were introduced under ADR70/00. The pollutants regularized in this standard were CO, HC, NO_x and PM with limits in g/kWh unlike PCs. These standards were based on Euro I standards and tested for emissions using 13 mode ESC (Engine

Steady-state Cycle) test. The accepted alternative standards were US EPA 1991 and Japan 1994.

The revised smoke emission standard was introduced under ADR 30/01 in the year 2002–03 based on UN ECE Reg 24/03 and US EPA 1998 as an accepted alternative. ADR80/00 analogous to Euro III standards replaced the older standards in 2002. Two test cycles, i.e., ESC and ETC (Engine Transient Cycle) were used to test the emissions. ESC and ETC limits were given for CO, NO_x and PM while ESC limits only for HC and ETC limits were for NMHC. ADR80/02 was introduced in the year 2007 with more stringent emission limits comparable to Euro IV standards. The third revision, ADR80/03 was introduced in the year 2010 based on Euro V standards. The emission limits for CO, HC and PM were kept same, whereas NO_x limits made more stringent. In case of diesel vehicles, diesel engines in Australia were being imported from Europe, USA and Japan. Thus, Japan and USA emission standards for HDVs were acceptable as alternative standards.

7. Vehicular Emission Standards in India

As in other countries, vehicular emissions contribute significantly to air pollution in India which has drawn attention of the researchers, policymakers and stakeholders since past few decades. Thus, there is continuous need to reduce vehicular emissions. The regulatory authorities had already determined the gravity of the situation and started working towards controlling the tailpipe emissions. Switching to unleaded petrol, using CNG as fuel for commercial passenger vehicles in Delhi [43] and setting the idle emission limits (PUC—Pollution Under Controlcheck) that came in effect in 1991 [44]. The Air Act 1981 and Environment Act 1986 gave right to Indian government to form and regulate automobile emission standards [45, 46]. However, under Motor Vehicles Act 1988 and Rules 1999, the Ministry of Road Transport and Highways (MoRTH) is the apex body of the nation to implement automobile emission standards. Further, MoRTH sets up different committees like Automotive Industry Standards Committee (AISC), Central Motor Vehicle Rule-Technical Standing Committee (CMVR-TSC) and Standing Committee on Implementation of Emission Legislation (SCOE) for the formulation of emission standards.

The pioneer step regarding the formation of vehicular emission norms in India was first taken for gasoline vehicles in 1991 and subsequently for diesel vehicles in 1992 [44]. Since then, the emission limits were made more stringent, while other pollutants were brought under the emission regulation. The Indian emission standards also

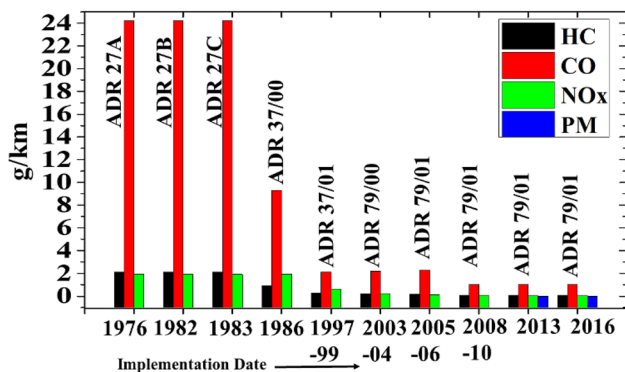


Fig. 20 Emission limits of pollutants for petrol-fueled PCs from 1972 to 2016 (Source: https://www.infrastructure.gov.au/vehicles/environment/emission/files/Emission_Standards_for_Petrol_Cars.pdf)

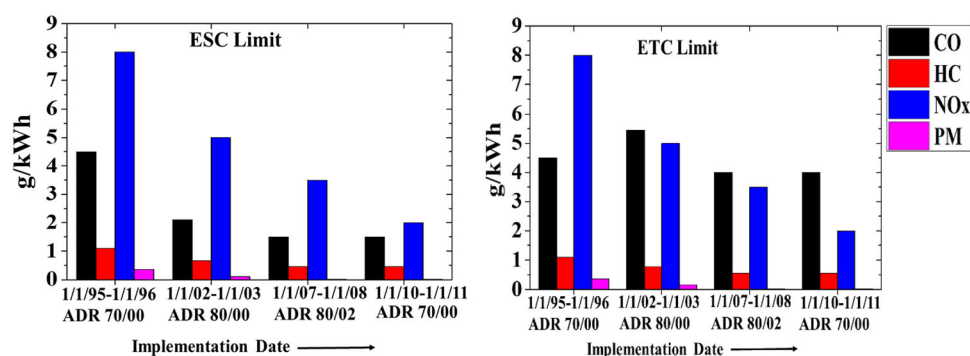


Fig. 21 Emission limits of pollutants for diesel-fueled HDVs from 1995 to 2011 (Source: https://www.infrastructure.gov.au/vehicles/environment/emission/files/Standards_for_Diesel_HDVs.pdf)

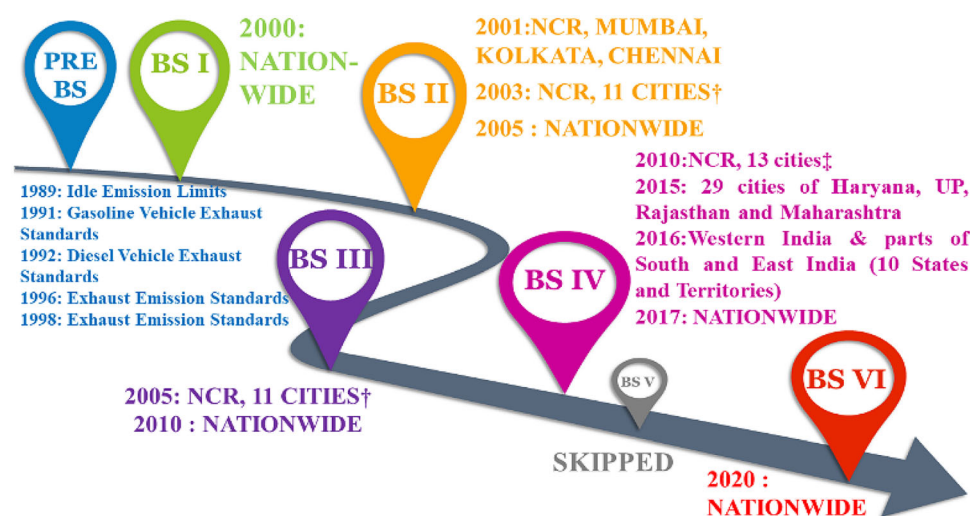


Fig. 22 Timeline representing implementation of emission norms in India (Source: <https://www.siam.in/technical-regulation.aspx?mpgid=31&pgidtrail=33>)

known as Bharat Stage Emission Standards, parallel to European Emission standards adopted by Government of India in the year 2000 for HDVs and 4-wheeled LDVs. However, for 2- and 3-wheeled vehicles, India's own emission regulations apply. The regulated pollutants for vehicular emissions are HC, CO, NO_x and PM. The implementation of the emission regulations for 4-wheeled vehicles in India is shown in Fig. 22.

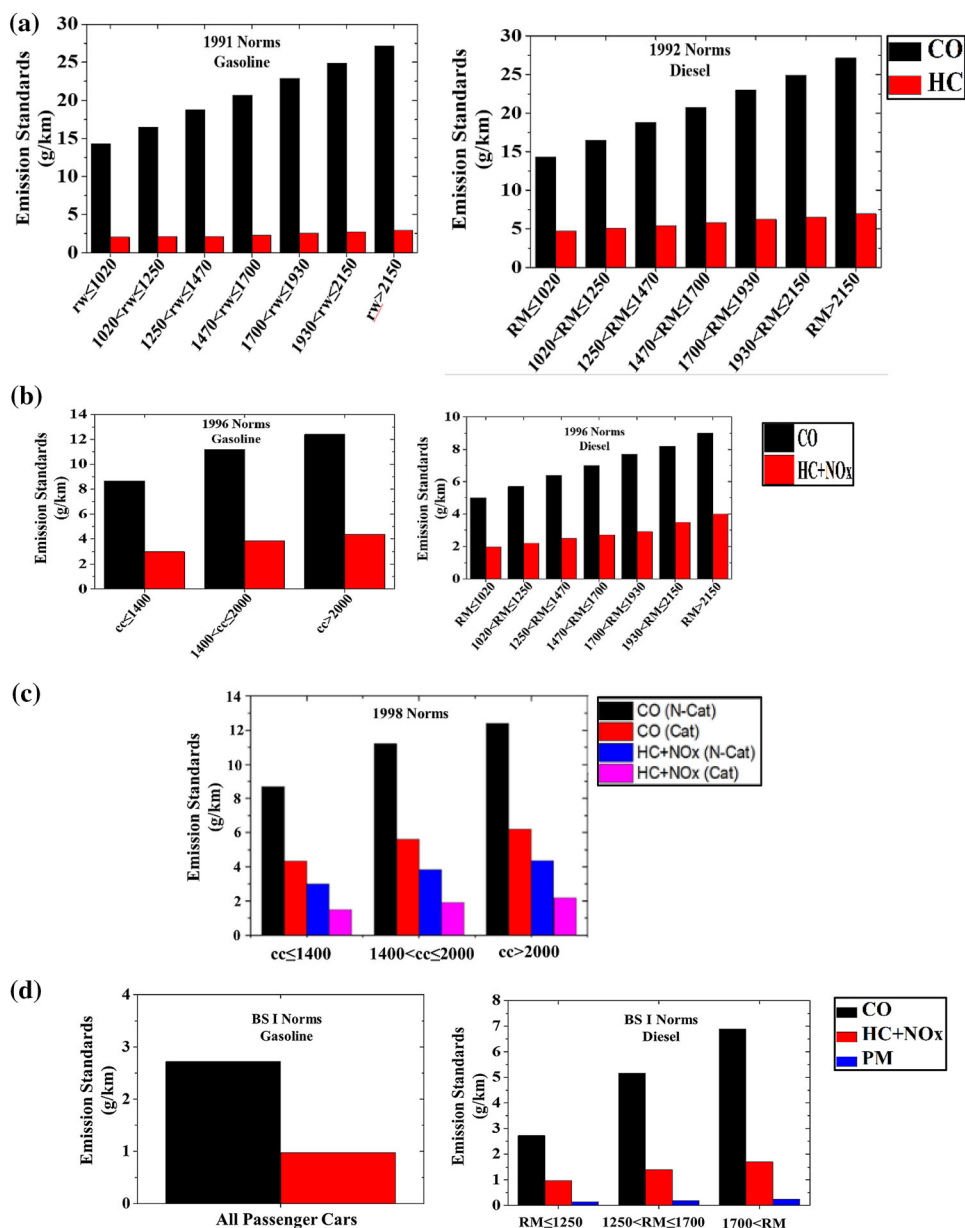
7.1. Indian Emission Standards for LDVs

Prior to the adoption of European emission standards, only 6-seater PCs (Gross Vehicle Weight, GVW \leq 2500 kg) were regularized in the category of LDVs. The vehicle categories in Indian emission standards were similar to Euro standards. The 1991 gasoline exhaust standards and 1992 diesel vehicle standards were applied to PCs having GVW $<$ 2.5 tons. The former emission standard was regularized for CO and HC limits only while the latter for CO

and HC + NO_x limits. The CO limits were same in both gasoline- and diesel-fueled vehicles (Fig. 23a). Further, these mass emission norms for gasoline as well as diesel vehicles were revised in 1996. For gasoline vehicles, the categorization was changed as per the engine capacity while for diesel vehicles, it was kept same as 1992 diesel emission norms (Fig. 23b). In 1995, catalytic converters were made mandatory for the new unleaded gasoline PCs. Consequently, 1996 mass emission norms for gasoline vehicles were revised in 1998 as 'vehicles with catalytic converter' and 'vehicles without catalytic converter' for same vehicle category (Fig. 23c).

In the year 2000, the first emission stage known as India 2000 (BS-I) equivalent to Euro 1 was implemented nationwide for LCVs with GVW \leq 3500 kg. For gasoline passenger vehicles, the standards were made without categorization of the vehicles. However, diesel-fueled PCs and LCVs were categorized as per the reference mass (RM) of the vehicle (similar to Euro 1). Consequently, all diesel-

Fig. 23 Emission Norms in India for LDVs **a** 1991 Gasoline Norms and 1992 Diesel Vehicles Norms, **b** 1996 Norms for Gasoline- and Diesel-Fueled Vehicles, **c** 1998 Norms, **d** BS-I Norms for Gasoline- and Diesel-Fueled Vehicles, **e** BS-II Norms for Gasoline- and Diesel-Fueled Vehicles, **f** BS-III Norms for Gasoline- and Diesel-Fueled Vehicles, **g** BS-IV Norms for Gasoline- and Diesel-Fueled Vehicles and **h** BS-VI Norms for Gasoline- and Diesel-Fueled Vehicles. (Source: Indian Emission Regulations Booklet, ARAI, 2018)



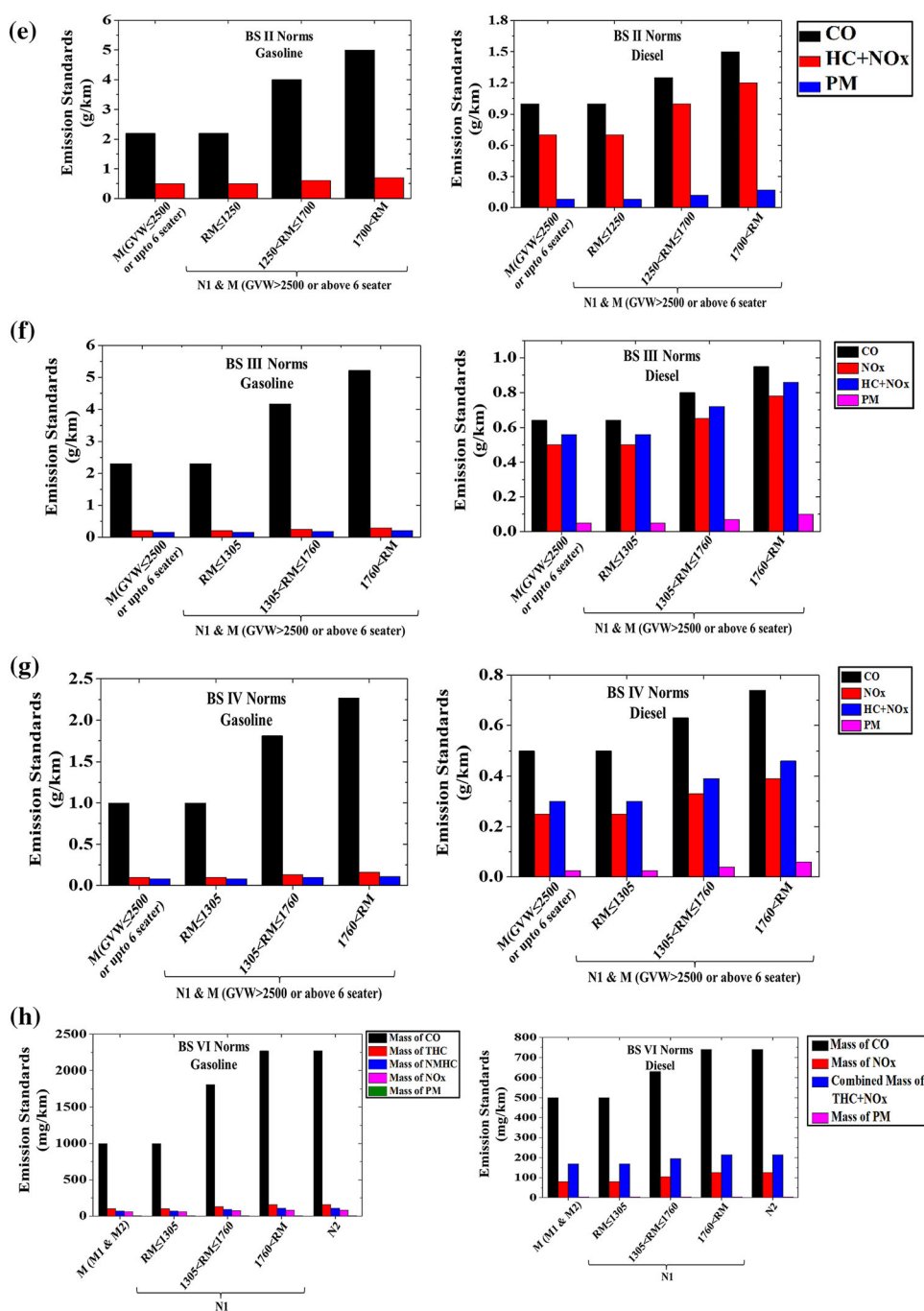
fueled vehicles ($GVW \leq 3500$ kg) were divided into 3 subclasses as $RM \leq 1250$, $1250 < RM \leq 1700$ and $1700 < RM$ (Fig. 23d). The pollutants under consideration were CO, HC + NO_x (gasoline and diesel vehicles) and PM (diesel vehicles only). The higher weight categories of diesel vehicles were allowed to emit more. For the very first time, evaporative emission test limit (2 g/test) was introduced to check the evaporative loss of HCs from the fuel system having PI engines [47].

BS-II emission standards were implemented in four metro cities in 2001 while nationwide in 2005. The BS-II norms were regularized for the pollutants similar to BS-I with more stringent limits. The emission limits of gasoline-fueled vehicles were based on Evaporative Emission Test

(2 g/test). In BS-II emission norms, all the LCVs in M and N1 categories were considered as shown in Fig. 11. The vehicles were subcategorized in 3 classes, Class I ($RM \leq 1250$), Class II ($1250 < RM \leq 1700$) and Class III ($1700 < RM$) similar to BS-I diesel vehicles. Figure 23e shows the BS-II emission norms for gasoline- and diesel-fueled vehicles.

Further in the series, BS-III emission norms were implemented for M and N1 categories of vehicles in NCR and 11 other cities in 2005, while nationwide in 2010. The categorization of the vehicles remained same as BS-II norms while subcategorization was changed as Class I ($RM \leq 1305$), Class II ($1305 < RM \leq 1760$) and Class III ($1760 < RM$) (Fig. 23f). The pollutants CO, HC, HC +

Fig. 23 continued



NO_x, NO_x and PM were considered for regularization. The Evaporative Emission Test of 6 g/test was additionally introduced beside 2 g/test limit. The emission limits for heavier categories of diesel vehicles were kept higher than the lighter ones. With similar framework, BS-IV emission standards were implemented nationwide in 2017. However, the pollutants limits were made stringent in this norm (Fig. 23g). BS-V emission standards were skipped and BS-VI emission norms were implemented nationwide from April 2020. BS-VI emission norms are applicable for M1,

M2, N1 and N2 categories of vehicles. Until BS-IV, PM emission limits were limited to diesel vehicles only. However, in BS-VI norms, PM emission limits have been applied to gasoline-fueled vehicles also. A new category of pollutant emission limit has been introduced in BS-VI emission norms, i.e., PN with a limit of 6×10^{11} for gasoline- as well as diesel-fueled vehicles, but it has not been implemented as yet. The regulation of PN standards may be considered in future (Fig. 23h).

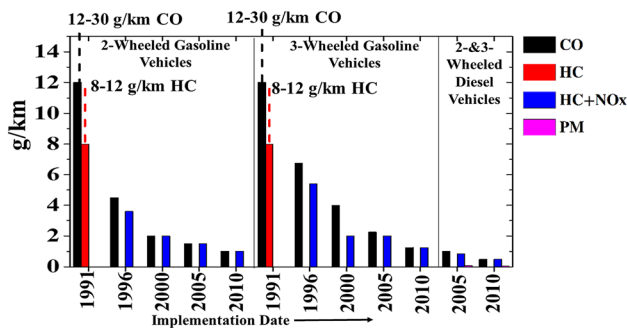


Fig. 24 Emission standards for 2- and 3-wheeled vehicles, g/km (Source: Indian Emission Regulations Booklet, ARAI, 2018)

At every stage, the standards were set differently based on the types of fuel along with weight categories. It is quite evident that the norms were more relaxed for diesel-fueled vehicles. However, with successive introduction of stringent norms, the gap between the pollutant emission limits for diesel and petrol vehicles got reduced significantly. The implementation of BS-VI emission norms has been targeted mainly to reduce this gap. Consequently, the vehicles need to be fitted with emission control devices like diesel particulate filter to meet the PN and PM permissible emission limits and equipped with an on-board diagnostic system to check the emission levels of CO, NMHC, NOx and PM.

7.2. Emission Standards for 2- and 3-Wheeled Vehicles

The 2-wheeled vehicles largely regulate the dynamics of road transport and emissions in India. The number of 2-wheeled vehicles on road outweighs any other category in India. Thus, the implementation of BS-VI emission

norms is also targeted towards this category of vehicles nationwide. For emission regulation of this category, India does not follow European emission standards model.

The emission standards for 2- and 3-wheeled vehicles were initially implemented in the year 1991 for CO and HC only (Figs. 24, 25). Successively, other parameters like HC + NOx, NOx, PM were also considered for emission regulation. BS-IV emission standards for 2- and 3-wheeled vehicles were implemented in 2014 and 2015, respectively. Besides HC + NOx, individual NOx standards were introduced for 2-wheeled vehicles. Evaporative emission standards were introduced in BS-IV emission standards in which the vehicles must qualify the permissible limit of either 2 g/test or 6 g/test.

Slight relaxation was provided in HC + NOx permissible limit if the vehicles qualify for 2 g/test evaporation test limit. In 2016, it was decided by the authorities to implement new emission standards nationwide to curtail the problem of increasing urban air pollution and related health damages. Thus, more stringent BS-VI standards have been implemented nationwide by skipping BS-V standards.

Individual HC emission norms have been introduced unlike other stages which regulated HC + NOx limits together. For evaporative emission test, all gasoline-fueled vehicles are needed to qualify for evaporation limit of 1.5 g/test without any relaxation in HC emission limit.

Earlier, India used to measure the emissions of 2- and 3-wheeled vehicles by Indian Driving Cycle (IDC) unlike Europe that uses ECE and Worldwide-harmonized Motorcycle Test Cycle (WMTC) for emission testing. However, in BS-IV standards, it was mandatory for gasoline-fueled vehicles to undergo WMTC for type approval, while the diesel-fueled vehicles continued to follow IDC.

Additionally, the ongoing BS-VI standards also follow the same pattern for emission testing. In the case of

Fig. 25 BS-IV and BS-VI emission standards for 2- and 3-wheeled vehicles, g/km (Source: Indian Emission Regulations Booklet, ARAI, 2018)

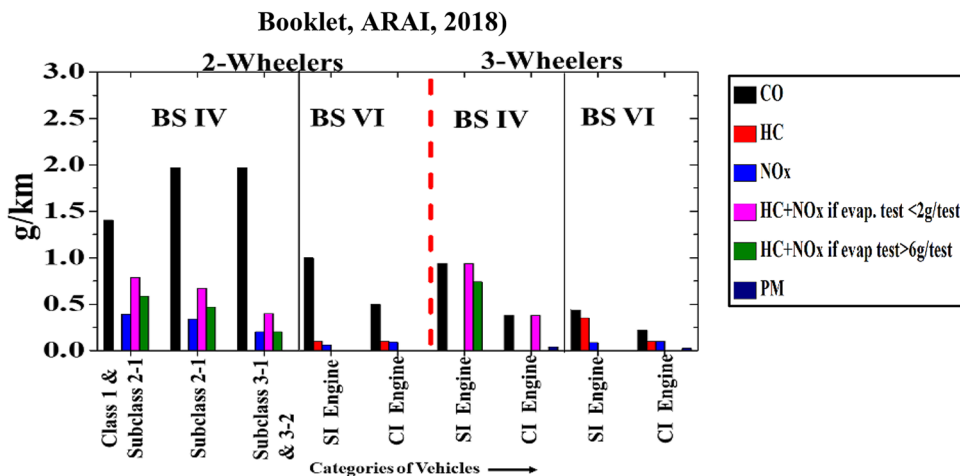
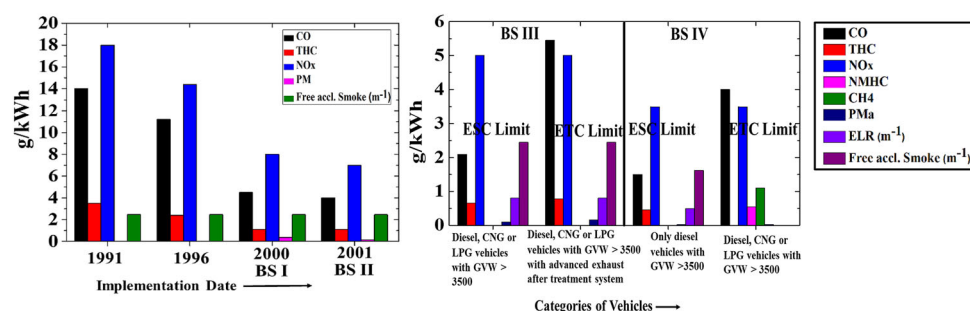


Fig. 26 Emission Standards for HDVs (GVW > 3500 kg) (Source: Indian Emission Regulation Booklet, ARAI, 2018)



3-wheeled vehicles, both BS-IV and BS-VI continue to follow IDC for type approval.

7.3. Emission Standards for HDVs

Heavy-duty vehicles include vehicles having GVW > 3500 kg (diesel, CNG or LPG fueled) with their emissions being regulated since 1991. For HDVs, the emission limits were defined only for CO, THC and NO_x as per 1991–1992 emission norms. In contrast to LDVs, a new emission category of free acceleration smoke was applicable for HDVs. Free acceleration smoke test means the test conducted by accelerating the vehicle abruptly (but not violently) from idle to full speed with the stationary vehicle in neutral gear [48]. In case of HDVs, the unit of emission limits were g/kWh instead of g/km or mg/km. These emissions were revised with more stringent values in 1996 (Fig. 26). For HDVs, BS-I emission norms were implemented in 2000 nationwide while BS-II emission norms were implemented in Delhi-NCR region since October 2001 with almost comparable pollutant emission limits.

BS-III emission standards were implemented in 2005 and the HDVs were categorized into two different categories, i.e., Diesel, CNG or LPG vehicles with GVW > 3500 and Diesel, CNG or LPG vehicles with GVW > 3500 with advanced exhaust after treatment system. In BS-III emission norms, a new emission limit was added for ELR (European Load Response) smoke beside CO, THC and NO_x, PM and Free smoke acceleration (Fig. 26). ELR smoke test consists of transient load steps at different speeds, and are run concurrently [48]. BS-IV emission standards for HDVs were implemented in several stages and finally implemented nationwide in 2017. For BS-IV emission norms, HDVs were categorized into two different categories, i.e., only Diesel vehicles with GVW > 3500 (with ESC cycle) and Diesel, CNG or LPG vehicles with GVW > 3500 (with ETC cycle). CH₄ and NMHC were regularized for the latter category besides the other specified pollutants (Fig. 26). BS-VI emission standards for HDVs have been implemented nationwide in April 2020. For HDVs, an additional pollutant emission limit of 10 ppm for NH₃ has been introduced in BS-VI emission

norms. The drive cycles used for testing emissions from HDVs have changed from ECE R49 (up to BS-II) followed by ESC and ETC (BS-III and BS-IV) and finally to WHSC and WHTC in BS-VI standards.

8. Indian Perspective of Automobile Emission Standards

Recently, India has witnessed the implementation of new vehicle emission standards BS-VI, implemented nationwide by skipping BS-V standards. India has also planned to phase-in several other parameters under BS-VI emission regulation in the upcoming years. For the very first time, the vehicles in India would be tested under Real Driving Emission (RDE) cycle (planned to be implemented from 2023) using portable emission monitoring system (PEMS) that would provide real-world emissions data. This step will help in abridging the existing gap between emissions occurring during the time of certification by type approval and conformity of production with the real world. Prior to BS-VI, India continued to allow diesel-powered LDVs to emit significantly high amount of NO_x and PM compared to gasoline powered vehicles. However, in BS-VI emission norms, the introduction of stringent fuel specifications and reduction of permissible limits of pollutants from diesel and gasoline will be helpful for fuel neutral standards.

The new standard may also consider regulation of PN emitting from vehicular exhaust in future. To maintain the same, vehicles must be equipped with effective emission control technologies. The phased out BS-IV emission standards for LDVs in comparison to its analogous Euro 4 emission standards had an evident implementation gap as India officially started to control its automobile emissions in 1991 only. However, the gap helped the country to provide the updated technologies in meeting the norms at affordable costs to its citizens. Thus, the decision of skipping BS-V was one of the significant steps so that the nation should be at par with countries like Europe and USA in terms of vehicular emission norms and improving the overall ambient air quality. BS-VI, a derivative of Euro 6 has been implemented on 01st April, 2020

nationwide, prohibiting the selling and purchasing of BS-IV vehicles completely. However, due to nationwide lockdown owing to COVID-19 pandemic, some relaxations were given [49].

Still, there remains several challenges in the way of BS-VI implementation. For instance, the share of emissions from the old vehicle fleet on Indian roads cannot be neglected. There are ~ 50 lakhs light-duty vehicles more than 20 years old and ~ 34 lakhs over 15 years old [50]. Thus, fleet renewal as per BS-VI emission standards, especially for commercial vehicles will prove to be phenomenally beneficial. Working in the same direction, the Government of India in August 2021 has launched 'Vehicle Scrappage Policy' which aimed at removal of unfit and polluting vehicles in phased manner [51]. As per the policy, after expiration of the registration certificate of vehicles, they have to go through a mandatory fitness test. The identified unfit vehicles will be scrapped and deregistered. However, this policy will additionally require an effective and severe monitoring to ensure that the old vehicles are being identified and removed from the Indian vehicle fleet. The second major problem is poor conditions of roads in the cities resulting in repeated halts and congestion. A recent NITI Aayog report states that many Indian cities are being consistently classified as world's most congested cities where average speed of the vehicles is ~ 50 – 60% lower than the designed speed [52]. Accordingly, fuel loss and idling emissions as per Indian scenario are needed to be looked upon while driving emission tests.

8.1. Factors Responsible for Vehicular Emissions and Their Mitigation Approaches

Figure 27 illustrates the major factors that are responsible for controlling the dynamics of vehicular emissions in a country. In India, the rising living standards of the people in urban areas have resulted in increasing private ownership of vehicles while use of public transport has severely

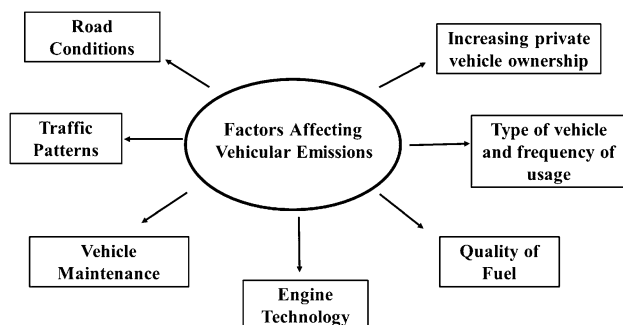


Fig. 27 Illustration of factors controlling the dynamics of vehicular emissions

eroded in recent years. Also, it was projected that the share of public transport would drastically reduce from 75.7% (2000–01) to 44.7% (2030–31) [53]. Moreover, the COVID-19 pandemic has severely hit the shared mobility mode of urban commute. In this regard, the big companies have to take lead and encourage their staff to use more and more public transport either by offering incentives or allowing the strategy of work from home as and when possible. The government can offer some relaxation in taxes of companies for using public transport. The vehicle's specification, quality of fuel used and frequency of their usage are also accountable for automobile emissions. The emission standards are framed to tackle the emissions arising from vehicles and fuel. However, the frequency of vehicle usage is still to be monitored and controlled. The technology used in engines for capturing higher particulate emissions and pollutants is most sought factor in any vehicle. However, more advanced the technology, costlier will be the vehicle. Thus, more research and development is needed that will suit our evolving emission standards and be affordable at the same time. The condition/age of the vehicles also affect the level of its emissions. Thus, periodic maintenance and proper certification of the vehicles are needed. But in India, the system of inspection and maintenance is disorganized [54]. Central Motor Vehicle Rules (CMVR), 1989, states that it is mandatory for all transport vehicles to go through a fitness test each year after two years of initial registration. However, the non-transport vehicles are not required to go through any fitness test for first 15 years of its life. Sometimes, either the inspection centers are not properly equipped with required instruments or the staff are not skilled or trained. Additionally, there lacks a mechanism where these inspection/PUC centers can undergo for auditing and performance check.

9. Comparative Summary of Present Emission Standards in Different Countries

Presently, USA is following Tier 3 emission standards for both LDVs and HDVs analogous to Californian LEV III emission standards. The emission limits for PCs and LDVs in USA and California are given in mg/mi or g/mi (in case of CO) but for the sake of comparison, the units are converted to g/km. In case of USA emission standards, no separate categorization of PCs in LDVs category has been made. However, a different category was made just for the comparison in Table 1. In Tier 3 and LEV III emission standards, pollutants regulated for emissions are CO, HCHO, NMOG + NO_x and PM, irrespective of the fuel used. It should be noted that USA and Californian vehicle emission norms do not define emission limits separately for

Table 1 Comparative summary of emission standards presently being followed in different countries

Category	Recent emission standard pollutants	USA		Japan	Australia	Europe	India
		USA Tier 3	California LEV III	–	ADR79/04	Euro 6	BS-VI
PCs (referred as LDVs in USA and California)	CO	0–2.610	0.621–2.610	0.63(1.15)	(1.0)	0.5 (1.0)	0.5 (1.0)
	HC	–	–	–	(0.1)	– (0.10)	– (0.1)
	NOx	–	–	0.15, 0.05	(0.06)	0.08 (0.06)	0.08 (0.06)
	HC + NOx	–	–	–	–	0.17 (–)	0.17 (–)
	HCHO	0–0.002	0.002	–	–	–	–
	NMHC	–	–	0.024 (0.1)	(0.068)	–	– (0.068)
	NMOG + NOx	0–0.099	0.012–0.099	–	–	–	–
	PM	0–0.002	0.006	0.005, 0.005	(0.0045)	0.005(0.005)	0.0045, (0.0045)
	PN	–	–	–	–	6×10^{11} (6×10^{11})	6×10^{11} (6×10^{11})
	LDVs	CO	0–2.610	0.621–2.610	0.63, 1.15–4.02	–	0.5–0.74(1.0–2.27)
HC		–	–	–	–	– (0.1–0.16)	– (0.1–0.16)
NOx		–	–	0.15–0.24, 0.05–0.07	–	0.08–0.125(0.06–0.082)	0.08–0.125, (0.06–0.082)
HC + NOx		–	–	–	–	0.17–0.215 (–)	0.17–0.215 (–)
HCHO		0–0.002	0.002	–	–	–	–
NMHC		–	–	0.024, 0.1–0.15	–	– (0.068–0.108)	– (0.068–0.108)
NMOG + NOx		0–0.099	0.012–0.099	–	–	–	–
PM		0–0.002	0.006	0.005–0.007, 0.005–0.007	–	0.005 (0.005)	0.0045, (0.0045)
PN		–	–	–	–	6×10^{11} (6×10^{11})	6×10^{11} (6×10^{11})
HDVs		Recent emission standard/pollutants	Tier 3	LEV III	–	ADR80/03	Euro VI
	CO	0–4.536	1.988–4.536	2.22, (16)	1.5–4.0	1.5	4.00
	HC	–	–	–	0.46–0.55	0.13	–
	NOx	–	–	0.4, (0.7)	2.0	0.4	3.50
	HCHO	0–0.004	0.004	–	–	–	–
	NMHC	–	–	0.17, (0.23)	–	–	0.55
	NMOG + NOx	0–0.391	0.093–0.391	–	–	–	–
	CH4	–	–	–	–	–	1.10
	PM	0–0.006	0.037–0.075	0.01, 0.01	0.02–0.03	0.01	0.03
	PN	–	–	–	–	8×10^{11}	–

NO_x, HC and NMHC. Additionally, there is no consideration for PN in their emission standards (Table 1). Only USA and California regulate the emission limits for HCHO. The ranges specified in the Table 1 indicate minimum and maximum values for various bins/classes/categories.

Similarly, European Union presently have Euro 6 emission standards for PCs and LDVs, while Euro VI for HDVs. The regulated pollutants for diesel- and gasoline-fueled PCs are CO, HC, NO_x, HC + NO_x, PM and PN while LDVs are regulated for all these pollutants including NMHC. All the emissions are measured in g/km for PCs and LDVs while in g/kWh for HDVs. Japan and Australia have its own emission limits, the basis of which lies in Euro emission standards.

Indian emission standards which are analogous to European emission standards for LDVs (PCs and other LCVs) have equal magnitude of emissions defined for different pollutants. For HDVs, the emission standards set on the basis of Euro standards have different magnitudes.

10. Summary

Since vehicular emissions are one of the significant factors in deteriorating ambient air quality of the nations across the world, the origin and evolution of vehicular emission standards came into existence. The pioneer step in this regard dates back to 1960s when NO_x and VOCs emanating from the vehicles were found responsible for Los Angeles photochemical smog. Perceiving the seriousness of the situation, the state of California established the first ever vehicular emission norms in 1966 and formed California Air Resource Board to look after these regulations. The Californian vehicular emissions standards evolved in three major stages of increasingly stringent emission norms starting with LEV I, LEV II to LEV III for different weight categories of vehicles. Similarly, the Clean Air Act 1970, empowered USEPA to form such emission regulations for rest of the country. USA vehicular emission standards are analogous to Californian emission standards consisting of 3 phases, i.e., Tier 1, Tier 2 and Tier 3.

The main drivers for the formation of European vehicular emission standards were degrading ambient air quality and increasing CO₂ emissions from the vehicles. The European vehicular emission standards comprised of six stages of stringent emission norms. The initial stage was Euro 1/I (LDVs/HDVs) (1992) which transformed into present Euro 6/VI(2015) with considerable reductions in levels of different pollutants. The rules were applicable differently in case of diesel- and gasoline-fueled vehicles for different weight categories. Euro VI also set the fuel standards for the nation. However, the EU emission

standards cannot be compared directly to USA emission standards due to difference in their test procedures.

To cope with increasing environmental degradation, Ministry of Environment, Japan established their first tailpipe emissions in 1966 for diesel and gasoline PCs. Japanese vehicle emission standards were based on European emission standards and regulated both LDVs and HDVs.

Australia implemented vehicular emission standards since 1970s for petrol-fueled light vehicles. The emission standards were codified as ADRs. Although Australia had adopted the Euro standards as their base, USA and Japanese emission standards were also taken into account. Both LDVs and HDVs were regulated for emissions in Australia under ADR 79 and ADR 80, respectively.

In India, the steps for controlling their vehicular emissions dates back to 1990s. Since 2000, India has established its emission standards parallel to European vehicular emission standards for 4-wheeled LDVs and HDVs and has its own set of standards for 2- and 3-wheeled vehicles. The Indian vehicular emission standards have been applied in five different stages namely BS-1/I, BS-2/II, BS-3/III, BS-4/IV and BS-6/VI (skipping the BS-5/V stage).

In Tier 3 and LEV III emission standards of USA and California, pollutants measured for vehicular emissions are CO, HCHO, NMOG + NO_x and PM, irrespective of the type of fuel used. There is no separate standard for NO_x, HC and NMHC. In European Union, in-use emission standards are Euro 6 for PCs and LDVs while Euro VI for HDVs. The measured pollutants are CO, HC, NO_x, HC + NO_x, PM and PN for diesel- and gasoline-fueled vehicles. Beside all these, LDVs are regulated for NMHC. Japan and Australia have its own emission limits, the basis of which lies in Euro emission standards. Indian emission standards which are analogous to European emission standards for LDVs (PCs and other LCVs) have equal magnitude of emissions defined for each pollutant. However, regulation of PN standards may be considered in future in India. For HDVs, although the standards were set on the basis of Euro standards, yet the magnitudes were kept different. The level of stringency of vehicle emission limits are based on a standard test procedure conducted in a laboratory that simulates actual driving or usage pattern. To simulate traffic conditions of one's own nation, different countries perform different types of test procedures resulting in different values of emissions.

Thus, there exists several differences in present emission standards followed by different countries. To rectify this, a worldwide harmonized test cycle is introduced by United Nations Economic Committee for Europe that would represent real-world driving and verifies that the statutory emission limits are not exceeding during actual driving. Countries like Japan and Europe have already been

following the WHTC, while some other countries may introduce the same in near future. Yet the real-world emissions across the world keeps on diverging. In such situation, harmonization of vehicular emission standards worldwide is a bit challenging, based on dynamics of road conditions, driving patterns, environmental conditions, etc. Thus, more concerted research is needed for evolution of a common universal emission standards implementable worldwide.

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