State of the Art on Vehicular Engine Exhaust Emissions Standards and Regulations: a Review

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Abstract. Burning fossil fuels introduced massive quantities of pollutants, leading to many adverse effects on human health. Therefore, regulations to reduce or eliminate exhaust gases and pollutants emissions from fossil fuels began to be issued worldwide in 1970. Automotive emissions issue has been strictly regulated since 1980. Therefore, this article reviewed some significant countries' vehicular emission standards for diesel and gasoline engines. The review began with an overview of considerable diesel and gasoline exhaust emissions, how they are generated, and their impact on the environment and human health, then surveyed the emission standards and regulations for motor vehicles in the United States, Europe, Japan, Australia, China, India and Nigeria. This section discovered that most countries have modelled their regulatory standards using the European and US regulatory models. Since Countries like Japan and Europe have already been following the worldwide harmonised test cycle to rectify the differences in present emission standards followed by different countries, more concerted research is needed for evolution to a shared universal emission standard implementable worldwide so that other countries may introduce the same shortly. Policies to discourage growth in personal automobile use are also potentially most significant. Thus, the review herein has been discussed to have better insight into the status of existing vehicular emission standards, which may be helpful for future improvisation and implementation of vehicular emission standards in Nigeria.

Keywords: emission standards; exhaust emissions; gasoline; diesel; greenhouse effect.

INTRODUCTION

There are about 1.2 billion light-duty vehicles (LDVs) and 380 million heavy-duty vehicles worldwide, and these numbers are growing. The daily demand for liquid fuels per year also exceeds 11 billion litres (23000 million tons oil equivalent [1]. During the energy conversion process, fuel oxidation in combustion occurs. Burning fossil fuels have been linked with its emissions in the form of nitrogen oxides (NO_X), sulfur oxides (SO_X), carbon monoxide (CO), and unburned hydrocarbons. The above emissions negatively influence the environment as automobile emissions lead to global warming, a severe threat to the world [2].

The two predominant forms of motor vehicle emission are major gaseous and particulate air pollutants (which can be found in relatively high amounts in the atmosphere) and so-called air toxics (which are usually found in lower parts of the atmosphere but can have significant health implications) [3]. Diesel and gasoline engine vehicles not only bring economic benefits to us but also pollute the environment, bringing health and safety risks to our lives; because of this, countries and territories developed practical emission regulation standards to reduce the harmful gas emitted by these vehicles from the root.

The human population is projected to exceed 9 billion by 2050, which will increase the calorie intake and push the production of food crops on scarce arable land to its limit. The energy demand will also increase [4]. Fossil fuels provide a significant chunk of the energy requirement; however, depleting reserves, price volatility, and environmental issues preclude their sustainability [5]. For some reasons, including the energy density of petroleum fuels, the internal combustion engine has been the power source of choice for automobiles and most other vehicles. However, with the oil shocks of the past few decades and an increasing awareness of the emissions of air pollutants and greenhouse gases from these vehicles, interest in emission control regulations keep propelling.

The global effort to set up emission control regulations for automobiles dates back to the mid-1960 when tailpipe emissions were identified as a significant source of pollutants in Los Angeles, California and the USA [6]. In early 1970, CO and HC standards were set, followed by measures to control NOx. More and more countries followed the USA in establishing their emission standards and regulations. The introduction of fuel quality norms and stringent emission standards for vehicles are some of the steps taken to reduce the share of vehicular pollution. These emission standards are statutory permissible limits of the pollutants released into the atmosphere from specific sources over a particular period, designed to protect human health and achieve air quality specifications [4]. However, if tailpipe emissions from the escalating vehicles population are not checked, it may invalidate previous achievements. Consequently, this paper reviewed the formulated vehicular emission standards that were covered in some major countries, i.e., the United States of America, Europe, Japan, Australia, China and India, with the intent of controlling diesel and gasoline vehicle engine emissions to understand the present scenario of Nigerian vehicular emission standards.

RESULTS AND DISCUSSION

Vehicular engine exhaust emissions

The current tailpipe regulations for gasoline and diesel engines focus on oxides of nitrogen (NOx), carbon monoxide (CO), hydrocarbons (HC) and particulate matter (PM). Facts on how these engine emissions are generated were explained as follows:

CO – carbon monoxide. Carbon monoxide is a colourless, odourless, poisonous gas. It arises mainly in the rich mixture since insufficient oxygen is required to oxidate carbon to harmless carbon dioxide. It is also characterised by having approximately the same density as air. It has been claimed to be chemically active in smog composition.

HC – hydrocarbons. Incomplete combustion leads to unburnt hydrocarbon emissions. Moreover, the surface-to-volume ratio and wall quenching immensely alter and influence the formation of hydrocarbons. Hydrocarbons are released and emitted by exhausts, engine crankcase fumes, and vapour slipping or breaking away from the carburettor. Hydrocarbon content by volume is massively lower than carbon monoxide content.

NOx – nitrogen oxides. NO_X is a byproduct of combustion. It is created when nitrogen and oxygen in the air combine during combustion. More NOX is formed when the cylinder temperature is high. As such, the primary strategy to reduce NOX formation is to lower combustion temperatures in the engine. Nitrogen oxides exist mainly in NO and NO_2, formed at high temperatures. Therefore, the presence of high temperature and the availability of O_2 is the main reason for comprising nitrogen oxides. Pure NO_2 is a toxic, reddish-brown gas with a harsh odour or smell. NO_2 can react with the moisture existing in the air to form nitric acid, damaging materials directly. Many other oxides like N_2O_4, N_2O, N_2O_3, and N_2O_5 are also included in low concentrations, but they break down immediately at ambient conditions of NO_2.

PM – Particulate matter. Particulate matter is the primary general term that includes soot (visible or not) and other small particles (solid or liquid). Dehydrogenation, polymerisation, and agglomeration commonly and frequently form solid particles. Acetylene (C_2H_2) is included as an intermediate product during the combustion process of distinct hydrocarbons. After concurrent polymerisation and dehydration, these acetylene molecules produce and yield carbon particles, the particulate's main elements. These particulates exist in the exhaust gases as solids (ash and carbon) or live in a liquid state.

Carbon Dioxide (CO_2). When considering appropriate functioning, the CO_2 value can be even more significant when complete combustion occurs. However, carbon dioxide is a harmless product of the combustion process. About 21.3 billion tons of carbon dioxide is emitted into the environment every year due to fossil fuel combustion. Natural processes absorb half of the carbon above dioxide. At the same time, the remaining 10.65 billion tons of carbon dioxide is added to the atmosphere yearly, the primary cause of increasing global temperature, popularly known as global warming or the greenhouse effect, as stated by [5, 6].

Impact of the engine exhausts emissions

The human body's breathing range is between 0.3 meters and 2 meters, which is precisely the emission height of vehicle exhaust, posing a threat to human health [7]. Table 1 summarises the environmental and health impacts of these toxic engine emissions, which cause health-related problems such as respiratory disorders, risk of developing cancer and other traumatic ailments and contribute tremendously to economic losses, especially regarding financial resources required for medical assistance to the affected people [8].

Table 1 – Environmental and Health Impacts of Engine Exhaust Emissions

No	Exhaust Emissions	Environmental and Health Effects
1	CO_2	The most prominent greenhouse gas. Increased carbon dioxide content and concentration in the air will increase the earth's surface temperature. As a result, enough ice will melt, leading to an increase in the oceans' level. This phenomenon is known as the "Greenhouse effect."
2	CO	It has harmful health impacts on the human body. CO, when inhaled, replaces oxygen in the bloodstream, where the body's metabolism will not perform and behave appropriately. When inhaled, small CO concentrations lessen physical and mental activity and generate headaches. On the other hand, it has been known to kill within 30 minutes when exposure to a high concentration (> 750 ppm) occurs directly.
3	HC	The most common primary pollutant that produces photochemical smog. It stimulates the eyes and mucosa of the upper respiratory tract, which can cause eye redness, swelling and pharyngitis. On human health basis, it has been discovered that exposure to hydrocarbons cause cancer and tumour. Oxides of nitrogen accompanied by unburned hydrocarbons in sunlight form photochemical oxidants, which have undesirable adverse effects on human health and plants.
4	PM	Reduce atmospheric visibility, and contribute to global warming. It causes chronic lung disease and can even cause cancer. Due to its strong adsorption capacity, it can adsorb various metal dust and pathogenic microorganisms.
5	NOx	The primary pollutant that produces nitrate particulates causes acid rain and destroys the atmospheric ozone. Exposure to NOx concentration can cause respiratory dysfunction. Oxides of nitrogen and other destructive, harmful substances are produced in small portions and can cause air pollution in specific environments. Also, prolonged exposure is health threatening. Nitrogen oxides are also accountable for smog formation (photochemical oxidants), which are the most detrimental to human health.

Emission standards and regulations

The most comprehensive system of vehicle emission standards and regulations are those of the US, Japan and Europe [6]. In 1950, Dr A. Smit discovered that hydrocarbons and NOx emanating from automobile exhaust emissions react in sunlight as main constituents in smog formation in Los Angeles, California. As such, the State 1966 established its first-ever automobile emission norms for HCs and CO only. In the same State in 1971, it set its first emission standard for NOx. In 1968, the USA formulated vehicular emission standards for the rest of the states, followed by several other countries [9].

Vehicular Emission Standards in the USA

Emission standards in the USA can be categorised into three stages: the initial stage (before 1977), substantial reduction stage (1978–1993), and super-low emission stage (1994 onwards). Emission standards applicable to 1990 model year vehicles, commonly called Tier 0, required roughly 90% reductions in exhaust HC and CO emissions and a 75 % reduction in NO_X emissions compared to uncontrolled emissions. Tier 1 standards were published in June 1991 and phased between 1994 and 1997. In 1999 the National Low Emission Vehicle Standard (NLEV) was adopted based on California emission regulations. Tier 2 standards were phased in from 2004 to 2009. Tier 2 bars in the US extended the law to heavier vehicles. These medium-duty passenger vehicles were not regulated under the Tier 1 standards and were found to be an essential element for reducing NOx emissions to 70% below Tier 1 levels. One of the super-low emission stage regulations is the Tier 2 standard, which can reduce the levels of sulfur in gasoline from 90% to an average value of 30 ppm. Yet, due to many hindered factors, a new set of emission standards for vehicles and fuels commonly known as the US EPA decided on Tier 3 emission standards in March 2014 [10]. The structure of Tier 3 emission standards formed was similar to the earlier existing Tier 2. In Tier 3 emission standards, the manufacturers were also required to get their vehicles certified to one of the seven available 'certification bins' as depicted in Figure 1. It reduced sulfur content in gasoline by ten ppm, aiming to improve the performance of catalytic converters so that the duration of the vehicle's useful life could be enhanced. Other essential components of Tier 3 were on-board diagnostic systems and emission test fuel [11].

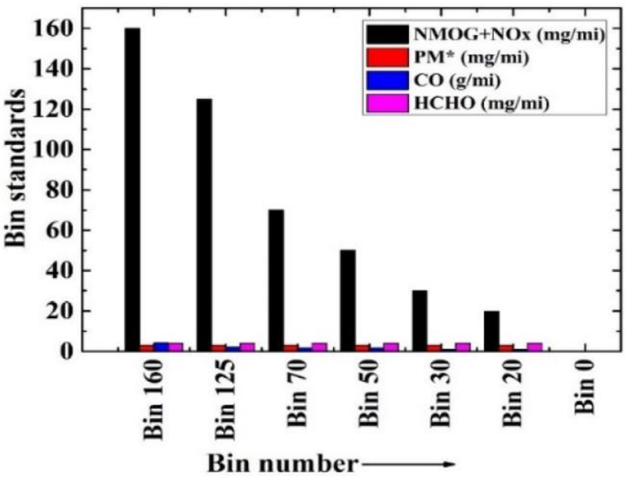

Figure 1 – Tier 3 Certification bin standards [10]

California, while challenging the re-opening of the GHG standards, is now planning for more reductions in GHG emissions beyond 2025. Key strategy elements were drafted to achieve a 40% reduction in overall GHG emissions over 2020 by 2030 [7].

Vehicular Emission Standards in Europe

The control of pollutants has a long history of regulatory work since the mid-1960 in European Union. The initiatives to implement national emission regulations independently by France and Germany were seen as barriers to free trade by other European Community members, as such opposed. Sequel to this, the implementation of European emission regulations was delayed until early 1990 [4]. Light duty vehicles were the first regulated in 1970 to conform to the Economic Commission for Europe (ECE) Regulation. The regulation was later amended four times (ECE 15-01 in 1974, ECE 15-02 in 1977, 15-03 in 1979, and ECE 15-04 in 1984) and applied to gasoline and diesel-fueled light-duty vehicles [6]. The Union later introduced the first two regulation standards (Euro I) and (Euro II) in 1992 and 1996 to reduce particulate and gaseous emissions for heavy-duty vehicles. It later approved the Euro IV (2009), Euro V (2014), and Euro VI (2016) regulations. The emission values emanating from passenger car diesel engines are established in Figure 2. However, Euro VI technology has been proven to have 65 to 70% additional NOx reduction capacity [9].

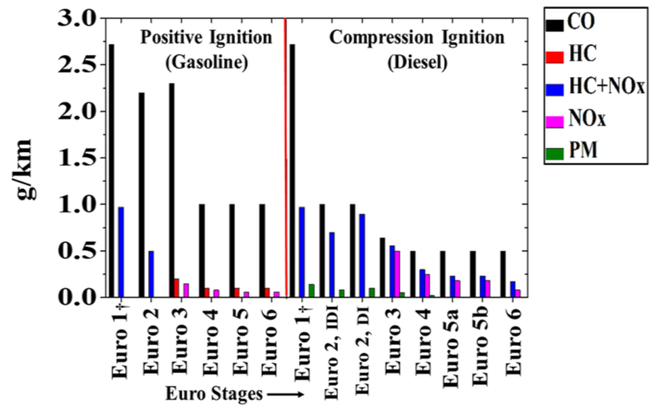

Figure 2 – Evolution of European emission standards for passenger car diesel engines [9]

Euro VI has set the fuel standards for the nation. Still, the Union's strategy for low-emission mobility now aims to limit transport-related greenhouse gas (GHG) emissions by 2050 to be at least 60% lower than in 1990. In line with the aim, a legislative proposal was adopted in late 2017, targeting reductions in average fleet CO2 emissions from new LD vehicles in 2025 by 15% and 30% in 2030, compared to New European Drive Cycle (NEDC)-based CO2 limits of 95 g/km for passenger cars and 145 g/km for light commercial vehicles in 2020. The CO2 emissions testing will be done using the World-Harmonized Light-Vehicle Test Procedure (WLTP) starting in 2021 to address some of the issues related to the testing procedure [5].

Vehicular Emission Standards in Japan

Japan's Ministry of Environment established its first tailpipe emissions 1966 for diesel and gasoline to cope with increasing environmental degradation. The first vehicular control measures concerning CO emissions were enacted in 1969 and extended to HC and NOx emissions in 1973. These standards involved concentration and mass emission limits relative to driving cycles specific to Japan and were revised review for light-duty vehicles in 1991. The Japanese emission standards for gasoline, diesel passenger cars, diesel light commercial vehicles, and diesel heavy commercial vehicles are depicted in Figures 3–6, respectively. Rules were applicable differently in the case of diesel and gasoline-fueled vehicles for different weight categories [12]. The two types of diesel passenger cars were those less than 1250 kg and those greater than 1250 kg. The diesel-fueled light commercial vehicles were divided into two categories according to their gross vehicle weight: those less than 1700 kg and those more incredible than 1700 kg [13].

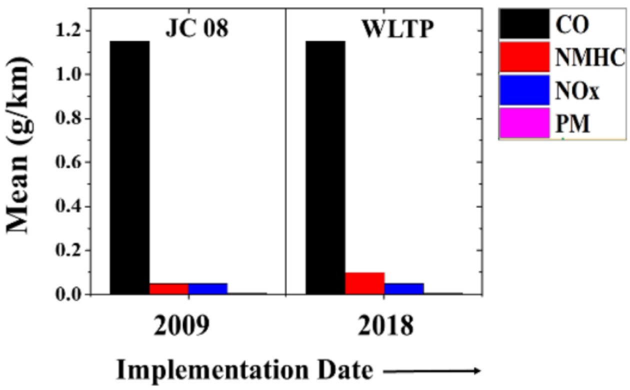

Figure 3 – Japanese emission standards for gasoline vehicles [13]

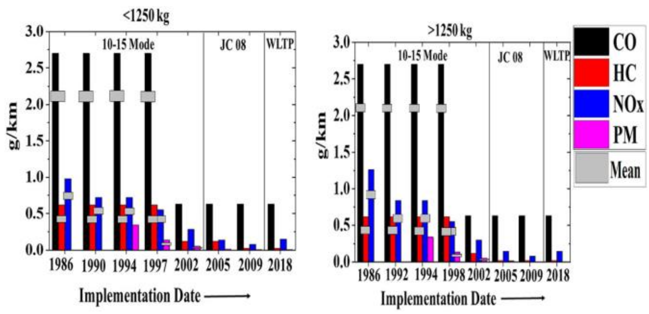

Figure 4 – Japanese emission standards for diesel passenger cars [13]

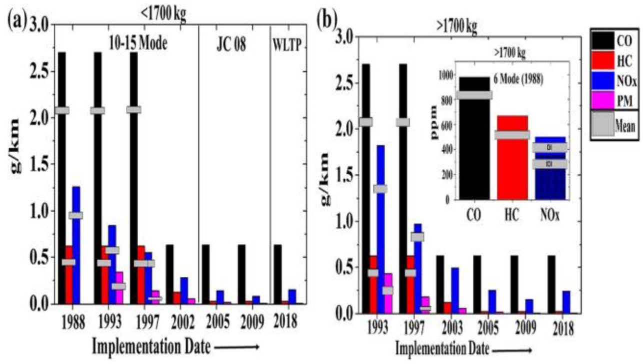

Figure 5 – Japanese emission standards for diesel light commercial vehicles [13]

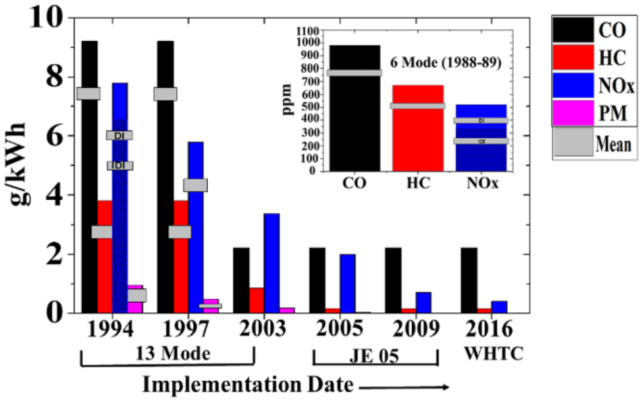

Figure 6 – Japanese emission standards for diesel heavy commercial vehicles [13]

Vehicular Emission Standards in Australia

In Australia, Vehicle emission standards started in 1970 for petrol-fueled light vehicles. Vehicular emissions in the country became a severe concern after studies have shown that about 70% of urban air pollution was attributed to cars. Furthermore, about 80% of CO, 60–70% of NOx and 40% of HC emissions were reported to emanate from automobile exhausts [14]. As such, Australia initially adopted the Euro standards as their base, but the US and Japanese emission standards were also considered for designing their emission standards. The government of Australia in 1999 introduced several environmental proposals under 'Measures for a Better Environment'. The proposal staged implementation of Euro 2 and Euro 3 for petrol vehicles and Euro 2, Euro 3 and Euro 4 for diesel vehicles. Figure 7 represents the Australian emission standard for petrol-fueled cars from 1972 to 2016 [8].

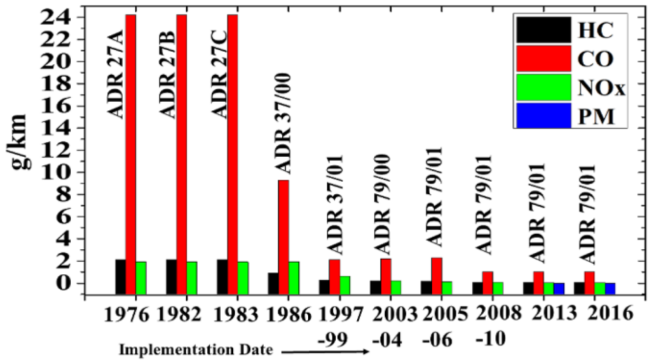

Figure 7 – Emission standard of pollutants for petrol-fueled PCs [8]

Vehicular Emission Standards in China

China attaches great importance to controlling the urban environmental pollution caused by vehicles. Statistics show that the number of diesel trucks in China increased from 14.272 million in 2012 to 16.909 million in 2017, with an average annual growth rate of 3.45% [13]. While heavy diesel vehicles bring economic benefits, there are also cases of environmental pollution caused by emissions. Therefore, China has formulated automobile emission regulations to control the emission of pollutants from motor vehicles. The limits of pollutants discharged and strictness on exhaust emissions under three different national standards are shown in Figure 8 [1]. The lower the value, the more stringent the emission limits. It can be seen that the National VI standard is the strict standard.

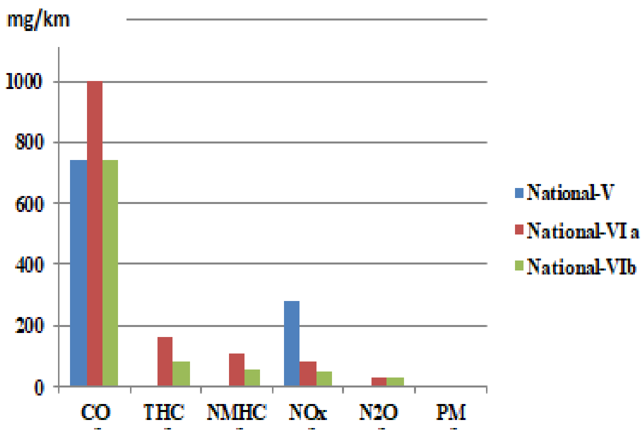

Figure 8 – Histogram of China's pollutant emission limits [1]

The Chinese Ministry of Industry and Information Technology finalised the new energy vehicle (NEV) mandate policy. NEVs include plug-ins and full-battery electric and fuel-cell vehicles. The approach expands on California's ZEV credit system. In this regard, auto manufacturers are required to generate 10% of NEV credits in 2019 and 12% in 2020. It is a five-year Plan titled "New progress in ecological civilisation construction, continuous improvement of ecological environment and living environment, and continuous reduction of pollutant emission". To comply with this standard, automobile enterprises adopt effective emission control technology to reduce the harmful gas emitted by vehicles from the root [1]. With the joint efforts of all of us, the target could be achieved quickly.

Vehicular Emission Standards in India

As in other countries, The Air Act 1981 and Environment Act 1986 gave the right to the Indian government to form and regulate automobile emission standards. 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 [15]. Vehicle categories in Indian emission standards were similar to Euro standards. 2000 the first emission stage, India 2000 (BS-I), was implemented Nationwide. It's equivalent to Euro 1. BS-II emission standards were implemented in 2001 in four metro cities, then nationwide in 2005. The next series, BS-III emission norms, were executed for M and N1 categories of vehicles in 2005 in NCR and 11 other cities, then nationwide in 2010 [16].

Further in the series, BS-IV emission standards were implemented in 2017 nationwide, which is analogous to Euro 4 emission standards. BS-V emission standards were skipped to provide updated technologies in meeting previous norms at affordable costs so that the nation would be at par with countries like Europe and USA regarding vehicular emission norms and improving the overall ambient air quality. BS-VI emission norms, a derivative of Euro 6, were implemented in April 2020 nationwide with a similar framework. These steps for controlling India's vehicular emissions are depicted in Figure 9 [1]. The implementation of BS-IV is to keep up with the G-20 countries. The standards apply to light and heavy-duty vehicles and two and three-wheeled vehicles.

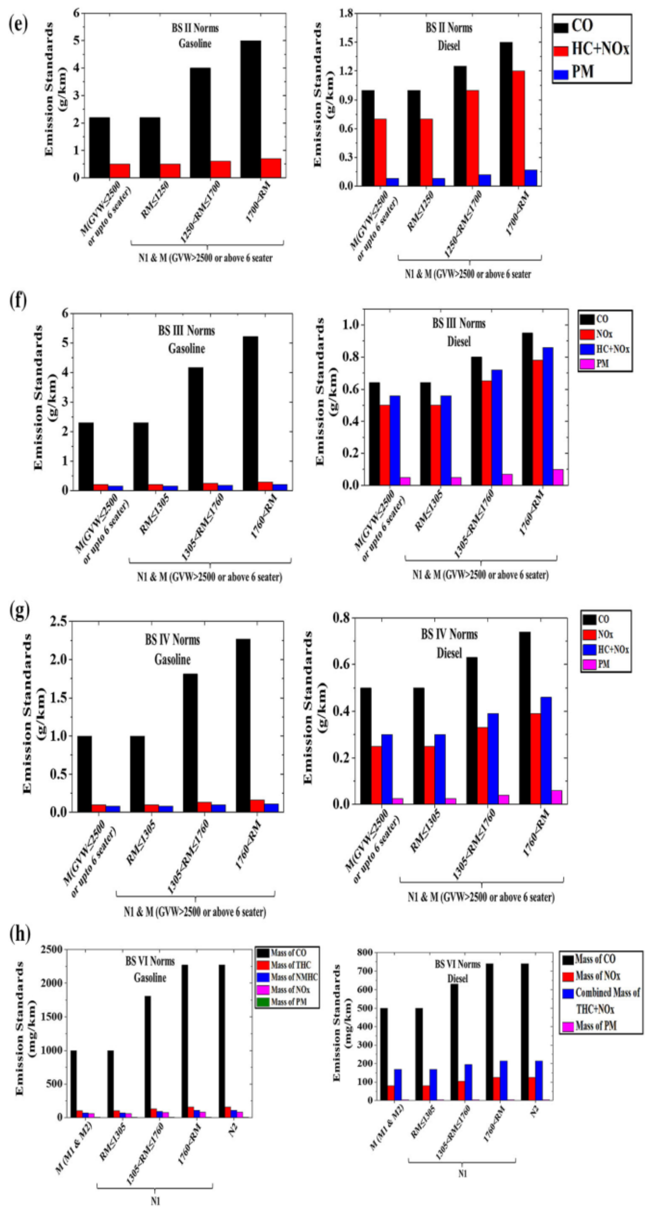

Figure 9 – Steps for Controlling Indian's Vehicular Emissions [1]

Vehicular Emission Standards in Nigeria

Transport-related pollution in Nigeria is significant, with possibly severe health consequences. Authors [17] reported that pollution at traffic intersection is threatening and that motor vehicle remains the dominant sources of urban air pollution. Unfortunately, much attention is given to general industrial pollution and pollution in oil industries, with little reference to damage of pollution caused by mobile transportation sources of air pollution. Author [18] added that the increase in portable transportation sources is propelling, thus resulting in high congestion on Nigerian city roads and an increase in the concentration of pollutants in the air, which may likely offset a portion of the expected reductions. A result from a comparative study of emission figures for two major cities in Niger Delta and Lagos revealed that the concentrations of total suspended particulates, NOx, SO_2, and CO in those areas were above the FEPA recommended limit [18]. This has drawn the attention of researchers, policymakers and stakeholders to contribute significantly to air quality in Nigeria. National Environmental (air quality control) regulations, 2021 under National Environmental Standards and Regulations Enforcement Agency has set up rules to improve the nation's air quality to an extent that would enhance the protection of flora and fauna, human health, and other resources affected by air quality deterioration. It stated that Emissions from road vehicles should be by the provisions of the Vehicular Emissions from Petrol and Diesel Engines Regulations depicted in Table 2 [19].

Table 2 – Nigerian Vehicular Petrol and Diesel Engine Emissions Regulation

Mobile Source	Emission Standard									
	Tailpipe Concentration (%)					Emission Factor (g/km)				
	PM	Soot	CO	NOx	VOC	PM	Soot	CO	NOx	VOC
Gasoline	-	-	-	-	-	-	-	13	1.6	1.2
Gasoline with catalysts	-	-	-	-	-	-	-	3.5	0.6	0.3
Diesel	-	-	-	-	-	0.4	-	0.9	1.0	0.3
Light Duty Truck, LDT (Gasoline)	-	-	-	-	-	-	-	15	1.8	2.0
LDT (Gasoline with Catalysts)	-	25	-	-	-	-	-	10	1.0	0.8
LDT (Diesel)	-	40	-	-	-	0.5	-	8.0	1.2	0.45
Heavy Duty Truck, HDTB	-	40	-	-	-	0.9	-	9.0	12	2.0
Motorcycles/Tricycles	-	45	-	-	-	0.3	-	14	0.6	2.6

CONCLUSIONS

Tailpipe emissions regulation for gasoline and diesel engines focuses on carbon monoxide (CO), oxide of nitrogen (NOx), hydrocarbon (HC) and particulate matter (PM). Tailpipe emissions from gasoline and diesel engine pose several health concerns. Once in the atmosphere, nitrogen oxides react with volatile organic compounds (VOCs) in sunlight to form ozone. Ozone is a harmful, reactive, corrosive gas contributing to many respiratory problems, particularly for children and older people. Developments of regulatory standards have dramatically reduced a reasonable percent of these emissions from uncontrolled levels. The emission standards of the United States and Europe were considered the primary standards, later followed by several other countries. USA vehicular emission standards are analogous to Californian emission standards consisting of 3 phases, i.e., Tier 1, Tier 2 and Tier 3 – the European vehicular emission standards comprised six stages of stringent emission norms. The initial stage was Euro 1 emission levels based on the universal application for gasoline vehicles, followed by Euro 2 standards for NOx control in some larger cars and light commercial vehicles. Cold start emission control become the main focus of pollutant control for Euro 3-compliant vehicles. Gasoline standards change little from Euro 4 to Euro 5, with only a 25% reduction in NOx, and Euro 6 is identical to Euro 5. Euro 5 and 6 emission control technologies are strongly influenced by CO_2 emission standards that aim to reach a target of 95 grams per kilometre in 2020. Japanese vehicle emission standards were based on European emission standards and regulated LDVs and HDVs.

Australia had adopted the Euro standards as their base. Though, USA and Japanese emission standards were also taken into account. India and China have established their emission standards parallel to European vehicular emission standards. The emission standards have been applied in five stages: BS-1/I, BS-2/II, BS-3/III, BS-4/IV and BS-6/VI (skipping the BS-5/V stage). Nigerian National Environmental Standards and Regulations Enforcement Agency also introduced Petrol and Diesel Engines Regulations standard in 2021. Generally, the US, Japan and Europe have been proven and concluded to have the most comprehensive vehicle emission standards. Though compliance with stricter emission standards usually involves higher initial and operating costs, more stringent emission standards should be developed to achieve a reasonable percent reduction in overall tailpipe emissions to meet up with the European Union's laid plan on greenhouse gases drop to 40, 60, and 80% by 2030, 2040, and 2050. Furthermore, the optimal level of emission standards varies among countries, which causes market disruption. As such, universal standards should be set at a level nearly all vehicles can meet, even though this worldwide harmonisation is challenging based on the dynamics of road conditions, driving patterns and environmental conditions.

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