



# Implementation of Sustainable Reforms in the Indian Automotive Industry: From Vehicle Emissions Perspective

Revati Borkhade, Subrahmanya Bhat K & GT Mahesha |

**To cite this article:** Revati Borkhade, Subrahmanya Bhat K & GT Mahesha | (2022) Implementation of Sustainable Reforms in the Indian Automotive Industry: From Vehicle Emissions Perspective, Cogent Engineering, 9:1, 2014024, DOI: [10.1080/23311916.2021.2014024](https://doi.org/10.1080/23311916.2021.2014024)

**To link to this article:** <https://doi.org/10.1080/23311916.2021.2014024>



© 2022 The Author(s). This open access article is distributed under a Creative Commons Attribution (CC-BY) 4.0 license.



Published online: 24 Jan 2022.



[Submit your article to this journal](#)



Article views: 4985



[View related articles](#)



[View Crossmark data](#)



Citing articles: 5 [View citing articles](#)



Received 15 June 2021  
Accepted 17 November 2021

\*Corresponding author: GT Mahesha,  
Manipal Institute of Technology,  
Manipal Academy of Higher  
Education, [maresh.gt@manipal.edu](mailto:maresh.gt@manipal.edu)  
Manipal 576 104, India

Reviewing editor:  
Swapnil L. Fegade, Fusion  
Automation Inc, Unites States

Additional information is available at  
the end of the article

## CIVIL & ENVIRONMENTAL ENGINEERING | REVIEW ARTICLE

# Implementation of Sustainable Reforms in the Indian Automotive Industry: From Vehicle Emissions Perspective

Revati Borkhade<sup>1</sup>, Subrahmanya Bhat K<sup>2</sup> and GT Mahesha<sup>1\*</sup>

**Abstract:** The scenario of the Automobile Industry has changed, not only in India but also for the world as a whole. Rise in demand for more sustainable mobility and vehicles with increased usage of renewable energies have given rise to a revolution. This revolution has not only been affecting mankind for better implementation of resources but has also shown tremendous greener and cleaner effects on the flora and fauna of the land as a whole. There has been electrification of vehicles, addition of superior systems to generate lesser harmful effluents and also changing the guidelines of emissions to cleaner and more sustainable ones. The purpose of this paper is to review and state the existence of different pieces of literature for the transition from Bharat Stage-IV (BS-IV) to Bharat Stage-VI (BS-VI). Much has been written about the transition to BS-VI, the difficulties, and the positive effects on vehicle reliability, economy and the environment. In particular, this work explores the parallels between BS-VI and the corresponding Euro norms and their sequence of implementation. The aforesaid transition has increased the number of oil refineries in India that produce BS-VI-compliant fuels, keeping in mind the increased

### ABOUT THE AUTHORS

Revati Borkhade has completed her B.Tech in Automobile Engineering with Minor specialization in Business Management from Manipal Institute of Technology, Manipal, Karnataka. She authored few research papers on composites, and has a keen interest in technology trends.

Subrahmanya Bhat K, is presently serving as Associate Professor in the Department of Chemistry, Manipal Institute of Technology, Manipal. He has over 20 years of teaching and research experience. He has published over 70 research papers, 2 patents and co-edited a book on nanocomposites. His current research interests are on materials science and on composites.

Mahesha Gt, is working as Associate professor in the department of Aeronautical and Automobile Engineering, Manipal Institute of Technology, Manipal and has more than 24 years of teaching experience. He has published more than 15 research articles in reputed journals and his areas of interest are automotive power trains, pollution control, alternative fuels, bio based materials and electric vehicles.

### PUBLIC INTEREST STATEMENT

This review article deals with the transition of the Indian Automotive from Bharat Stage-IV (BS-IV) to Bharat Stage-VI (BS-VI). There has been electrification of vehicles, addition of superior systems to generate lesser harmful effluents and also changing the guidelines of emissions to cleaner and more sustainable ones. The review summarizes the transition from BS-IV to BS-VI. Much has been written about the transition of BS-VI, the difficulties, and the positive effects on vehicle reliability, economy, and the environment. In particular, this work explores the parallels between BS-VI and the corresponding Euro norms and their anticipated effects of implementation. The Indian Automotive Industry is going through the transition from BS-IV to BS-VI and has affected the oil refineries that will produce BS-VI-compliant fuels.

The authors in this review article discuss the need for transition from existing automotive engine emission standards to stringier ones, their advantages and challenges ahead of the original equipment manufacturers, oil refineries and customers.

need for it. This paper explores the current state of the literature and throws light on many of the questions regarding this significant transition. The authors have tried to study the ongoing issues including the stress of inventory management of diesel-run passenger cars, the different refinements required to process and manufacture the BS-VI-compliant vehicles, people's reaction on the changes brought in by the issuing bodies with respect to the norms, to name a few. The focus of the research has been on Bharat Stage emission norms, their implementation challenges and automobile pollution in India to name a few. The authors also discuss the needs, advantages and challenges faced by the industry, producers and customers and conclude that this change is one of the reasons for the decline in car sales in India as it may affect the buying power of the customers.

**Subjects:** Environmental Issues; Environment & Society; Environment & Health; Ecology - Environment Studies;

**Keywords:** Bharat Stage; diesel engines; petrol engines; emissions; NO<sub>x</sub> (Nitrogen Oxides); environment; alternate systems

## 1. Introduction

Governments play a stewarding role in addressing the challenges related to environmental pollution, and are increasingly pledging to achieve sustainable transitions within a predetermined timeline (A.Khodke et al., 2021). For example, the People's Republic of China has indicated to be carbon neutral by 2060 and Japan and the European Union by 2050. The academic community working in the field of sustainability transition research (STR) refers to government's stewarding role in accelerating sustainability transitions as an emergent approach

Various cities across the C40 network have pledged to meet the World Health Organization (WHO) air quality guidelines by 2030. C40 network connects 97 megacities of the world to address threatening issues like climate change and takes bold actions to tackle it. The member cities take actions on local levels to make the agendas of the Paris Agreement achievable. Climate change is perceived as a serious danger to mankind. It is known to be the world's second most critical problem that has had substantial health implications (Ibrahim, 2014). These statistics have led to various weather waves over the past decade and the effects of rising drought on the vegetation area (Dai, 2011; Heyder et al., 2011; Levitus et al., 2012; Li et al., 2009; McKechnie & Wolf, 2010; Meyssignac et al., 2012). The effects of global warming are a natural reaction on the earth's atmosphere. Human activities, especially petroleum energy projects, have contributed to the development of these effects of global warming. This growing greenhouse effect is the result of increased concentrations in the atmosphere and greenhouse gases, i.e. GHGs (Jai Jain, 1993; Saxena, 2009).

The global climate change conference in Kyoto was dedicated to a significant reduction in GHG emissions (Agarwal, 2006). The main greenhouse gases emitted by human activities in the atmosphere are Carbon dioxide(CO<sub>2</sub>), arsenic, nitrous oxide (NO<sub>x</sub>) and fluorine compounds (hydro-fluorocarbons and hydro-carbon sulphide). Transportation accounts for 22% of the total CO<sub>2</sub> emissions in the world. Transportation continues to be a major cause of air pollution in cities, a major public health problem in the world's most developed cities, due to the rapid growth in the population of vehicles and the limited use of pollution control technologies. In developed nations, air pollution causes hundreds of deaths and millions of dollars are spent as medical expenses every year (Du et al., 2020; Faiz et al., 1996; Shao et al., 2021; Sivaloganathan, 1998). According to the World Health Organization reports of 2018, ambient air pollution accounts for an estimated

4.2 million deaths per year due to stroke, heart disease, lung cancer and chronic respiratory diseases (WHO, 2018). There have been efforts to build a better work and rectify the already done damage. The “S2 Home” research project—double safety home—double safety of living (seismic and social/environmental)—pursues Antonino De Masi’s De Masi Mechanical Industries’ development and research strategy on the themes of innovation related to automated mechanics, applied to the realisation of systems and components at the service of users’ health and quality of life. S2 Home aims to achieve a holistic sustainability model that includes both “off-shore” and “off-site” operations. “Off-site” because it uses robotic automation and advanced manufacturing techniques for creating system components between machine shops and off-site (Nava Consuelo, 2020).

Along with their low running costs, diesel engines have high efficiency, strength and reliability (Economic Center, 2015). But the key contributors to increasing emissions and many health issues are known to be by diesel engines. In recent years, numerous initiatives have been adopted around the world to reduce the effects of diesel engine emissions on health and comfort of human beings. Also, these adopted changes have been helping to reduce the environmental changes such as smog formation, acid rains, global warming, raising sea level, etc. (Ibrahim, 2014; Zannetti, 1992).

It was also emphasized that carbon monoxide (CO) emissions and oil emissions are the main pollutants from transports, which pose a serious threat to human health and the environment (Bolaji & Adejuyigbe, 2006). Different companies follow different approaches related to fuel and other technologies (viz. energy production, biofuels, hydrogen and fuel cells, energy efficiency and emissions, lightweight carriers, and special materials). Although most people express concern about climate change and the issue of road, the members using carpooling and similar techniques for shorter distances are pretty small in number (DEFRA, 2002). Exhaust extraction is very complex and therefore very difficult to control (Bolaji & Adejuyigbe, 2006). While the failure of some automotive companies to absorb emerging environmental technologies has affected business decisions, recent research has shown that there are global needs for preferred pollution reduction technologies (Whitmarsh & Kohler, 2010).

In India, automotive technology has evolved to meet the pollution and safety rules introduced in association with the Independent Transport Policy which defines the safety rules such as the Safety Road map adopted by CMVR-TSC, jointly. As India’s safety requirements comply with Global Technical Regulations (GTR) and UN Regulators, automotive technology in India is now in line with international standards. India signed UN treaty WP 29/1998 establishing GTRs. India is investing entirely in the body of UN WP 29 and has an impact on it. The GTR represents the driving force and precision of the developed world in a grand way. This paper intends to review the major aftermath and the repercussions of the BS-VI laws on the people as COVID-19 pandemic have taken a toll on not only lives and health of the people but also on the existing laws and the planned norms to be implemented.

In 2019, India was the fourth largest producer of vehicles in the world and the seventh largest manufacturer of passenger vehicles. It is projected that the Indian automotive industry (including production) will surpass Rs.16.16 to 18.18 trillion (US\$251.4–282.8 billion) by 2026. The sector attracted US\$ 24.5 billion to Investment Foreign Direct (FDI) between April 2000 and June 2020, representing ~ 5% of the overall FDI at the time, according to data from the Department of Industry and Trade and Industry (DPIIT). If we look at the strict pollution limits imposed on BS-VI, there is a major problem facing the faltering car industry, which relies heavily on diesel. The adaptation of the newer technologies as per upcoming norms is expected to reduce NO<sub>x</sub> emissions by 67% (Clark et al., 2011; Mirgal, 2017).

In order to implement particle cap numbers, OEMs are expected to use diesel particulate filtrate (DPF) in their engines. The cost of a diesel car increases by about 15% due to the introduction of these packages for after treatment of exhaust gases. Some original equipment manufacturers (OEMs) are moving from diesel to other alternative fuels. Compressed natural gas (CNG), liquified natural gas (LNG), hydrogen-enriched compressed natural gas (HCNG), biodiesel and dimethyl ether (DME) are the fuel sources for new generation passenger and commercial vehicles (Cook et al., 1997; Mirgal, 2017).

The controlled and uncontrolled pollutants lead to many negative effects on human health, classified as short-term and long-term health effects (Agarwal, 2006). There is an estimation of release of 35,000 million tons of CO<sub>2</sub> emissions worldwide, annually. If urgent action is not taken, CO<sub>2</sub> emissions are expected to rise to 41,000 million tons per year by 2020. Along with global warming, increase in CO<sub>2</sub> emissions into the atmosphere promotes sea acidification, harming aquatic ecosystems (Potsdam Institute for Climate Impact Research and Climate, 2012). To address this important situation, India plans to issue a Bharat Stage VI (BS-VI) notice, which was planned to be implemented from 1 April 2020. Other notable examples are mass release rates and certification mechanisms that have been reviewed in BS-VI, compulsory use of OBD for all types of vehicles, increased performance standards, and fuel requirements associated with BS-VI. Also included in the BS-VI study following the analysis of the Volkswagen Scam, In-Service Compliance (real-world driving emissions) using a portable pollution measurement tool (Mirgal, 2017).

The campaign was launched by the Department of Road Transport and Highways to delay the demand for solid fuel for vehicles, tractors, and construction equipment tractors. This comes after demands were made by the Department of Agriculture and Equipment Manufacturers, requesting that the next level of emission standards be introduced from October 2020 onwards. The Department of Transport recommended that the BS-VI regulations apply to construction machinery from 1 October onwards but it will be delayed until April 2021 due to the world pandemic. Given the situation caused by the outbreak of COVID-19 disease in the region, a document for the postponement of BS-VI to 31 March 2021, has been distributed by the Department of Transport. Since the recommendations from the stakeholders have been carefully considered, a definitive decision will be made. During the first quarter of the next fiscal year (2021–2022), the automotive industry is expected to face a decline in sales as the high cost after BS-VI introduction will dent customer sentiment. Insiders and industry analysts, however, thought that in the coming big season, the industry would find relief from rising revenue growth.

Recently, the industry has been hit by a sharp increase in revenue growth. Goods and services tax (GST), strong tax rates, farm stress, stagnant income, and inflation are the result of the economic downturn. Similarly, based on new BS-VI generators, falling prices will boost market confidence in the coming years. India's Daimler AG company has predicted the worst has passed the local truck industry, which could rise by 50–80% by 2021 as economic activity begins to rise. During the January–March quarter in India, the world's largest truck manufacturer expects sales of medium and heavy trucks to be higher than the pre-pandemic period of 2019, as demand returns and continues to increase quarterly. The cost of ownership of BS-VI vehicles towards BS-IV will be substantial. Under current business conditions, the cost will be a major drawback for consumers. Recently, a sharp decline in revenue has affected the industry.

The high rate of GST taxes, farm stress, lower income and thus fewer car sales are the culmination of a decline. Similarly, rising prices based on new BS-VI compatible engines may decline the sales in near future year. The cost of ownership of BS-VI vehicles is going to be higher. Considering the current market conditions, the cost will be a major closure for consumers. According to some experts, continued tension and stress of the decline in employment due to the pandemic of 2019 is going to affect some buying power of a majority of working-class people.

Not only the working class, but also the businesses have been severely affected due to the COVID-19 crisis, aiding to the decline in sales of automobiles. The authors anticipate that this review will be a good start for the other researchers who aspire to conduct study on this historic transition of the automobile sector in India.

This review paper contains background for the emission standards shift taking place in India from BS IV to BS VI, discussion on the regulated automotive exhaust pollutants on the road and the need for Bharat Stage VI. Logical conclusions are drawn on these aspects at the end of the review.

## 2. Background

Transportation is a massive industry that pollutes the atmosphere and causes climate change (Ibrahim A. 2014). Greenhouse gas emissions are significantly increased by transportation pollution, particularly that of vehicles (OECD, 2002). Transportation tends to be a significant source of pollutants in the air because of the exponential rise in traffic. As mentioned earlier according to the WHO report on air quality, air pollution causes hundreds of premature deaths and billions of dollars of health-care costs, thus leading to lower gross domestic product (Faiz et al., 1996; Sivaloganathan, 1998). Oil and diesel internal combustion engines are the major ones used in automotive transportation systems around the world. They are also a major cause of air pollution in urban areas (Bolaji & Adejuyigbe, 2006).

Vehicle mitigation systems are already in place and actively established (Whitmarsh & Kohler, 2010). However, the automotive industry has not yet changed its business model to use low-emission technology as the basis for its products (Whitmarsh & Kohler, 2010). The development of environmental friendly power plants and technology is still limited and there is a great scope for the automobile manufacturers and operators to address these issues. The manufacturers also discussed issues such as the provision of legislative provisions, the promotion of technology, the development of multimodal systems, the construction of regulatory mechanisms, and the integration of road infrastructure to reduce impacts (Biswas et al., 2008; Whitmarsh & Kohler, 2010).

Diesel engines are most widely used for heavy commercial vehicles because of their low cost of fuel, energy efficiency, durability, and reliability. They are the primary source of passenger travel, as well as off-road construction equipment such as quarry and mining vehicles, used in trucks, buses, trains, and airlines. Although there are many drawbacks, they impact environmental concerns across the globe. Diesel gas, in particular, contains high levels of particulate matter and NO<sub>x</sub> emissions that are responsible for significant environmental and health issues (Prasad & Bella, 2010). A diesel engine is a self-heating engine in which the air fuel mixture formation happens within the engine. The required air temperature of the fire is greatly compressed inside the heating chamber. This causes the higher temperatures required for diesel fuel to burn automatically when placed in a cylinder. As a result, the diesel engine uses heat to dissipate the chemical energy contained in diesel fuel and to generate mechanical electricity (Bosch, 2005). Various lethal gases formed during the oxidation process from the vehicle engines not only cause degradation of human health but also have a significant effect on the atmosphere and can also worsen climate change crisis. Some of the prominent toxic pollutants exhausted from the combustion process in an engine are:

### 2.1. Carbon monoxide (CO)

The consequence of partial combustion of air fuel mixture is production of carbon monoxide, where the oxidation step does not take place entirely (Ibrahim, 2014). This concentration is strongly reliant on the mixture of air and fuel and is very high, known as a rich mixture, when the air factor ( $k$ ) is less than 1.0 (Wu et al., 2004). While CO is produced during activity by rich compounds, a limited proportion of COs, due to the effects of kinetic chemicals, are also released, considering harsh conditions (Faiz et al., 1996). This will affect the functioning of multiple organs,



leading to reduced focus, sluggish thought, and uncertainty, depending on the concentration of CO in the atmosphere that contributes to confusion (Kampa & Castanas, 2008; Raub, 1999; Strauss et al., 2004; Walsh, 2011). The results indicate that, based on the type and age of the engine/vehicle, the emission control system used and the estimated circumstances under which the vehicle is run, decrease ranges by up to 30%. A 1990 amendment to the US Air Act allowed, due to CO-related health issues, the use of oxygen-rich fuels in major urban areas during the winters (when CO levels are very high) to mitigate this emission.

## 2.2. Hydrocarbons (HC)

Due to heat loss near the tank, hydrocarbon emissions are caused by unheated crude fuel (Ibrahim, 2014). The temperature of the fuel mixture is marginally lower than the centre of the pipe at this stage (Correa & Arbilla, 2008; Demers & Walters, 1999). Thousands of chemicals are composed of hydrocarbons, including alkanes, alkenes and perfumes. Typically, they are described in terms of the  $C_mH_n$  counterpart. The release of HC from exhaust gases is, indeed, at risk of irregular operational conditions (Hiroyuki et al., 2011). A high rate of rapid motor speed shift, crude injection, the excessive volume of the duct channel, and the needle will cause the back flow of a significant amount of unburned fuel (Payri et al., 2009). Hydrocarbons are poisonous and cause tumors in the respiratory system (Diaz-Sanchez, 1997; Krzyzanowski et al., 2005).

The size of diesel contaminants is normally about 15–40 nm long and less than 1 nm wide for around 90% of particulate matters (PM). The absorption of particles into an exhaust gas is the product of a period of combustion (Ibrahim, 2014). They can be obtained from a mixture of very tiny partial charcoal fragments, burnt oil, ash oil, and oil or sulphate lubricating cylinder and water (Demers & Walters, 1999; Maricq, 2007). The majority of particles are the result of incomplete hydrocarbon combustion in petrol and lubricating oils. In the experimental study, 41% gasoline, 7% coal, 25% unburned oil, 14% sulphate and impurities, 13% ash, and other ingredients are the composition of the usual particles of a heavy diesel engine (Bauner et al., 2008; Kittelson, 1998).

## 2.3. Oxides of Nitrogen ( $NO_x$ )

Air, primarily consisting of oxygen and nitrogen, is injected into the fire chamber rapidly during combustion. First, it gets heated and then, at the end of the pressurisation in the fire chamber hot air is mixed with the fuel. Nitric oxide (NO) and nitrogen dioxide ( $NO_2$ ) are called nitrogen oxides ( $NO_x$ ) (Ibrahim, 2014). Approximately 85–95% of  $NO_x$  is NO. It is combined progressively to  $NO_2$  in the after process (Ibrahim, 2014).  $NO_2$  is an amber looking reddish-brown gas (Chong et al., 2010). Road transport is the world's largest source of  $NO_x$  emissions in cities, accounting for between 40% and 70% of  $NO_x$ . Higher temperatures are required for combustion in diesel engines compared to petrol engines because of compression ignition (CI) occurring in such engines (Ibrahim, 2014). Diesel engines count approximately 85% of all  $NO_x$  emissions from mobile sources, mainly in the form of  $NO_x$ . (Lee et al., 2013; Wang et al., 2012). The following technique can be used to reduce emissions from any engine. As mentioned earlier, each engine contains two elements for combustion—air and fuel, which ensures that the control of the amount of fuel and gas used by the unit will be used to decide the key regulation of the fire cycle. ECM will verify the precise quantity of fuel that will be delivered at any time to the engine, ensuring that the discharge of the engine is right (Gagandeep Singh Theti et al., 2016). While these initiatives are expected to greatly reduce diesel engine emissions, more expensive back-up treatment programmes such as Diesel Particulate Filters (DPF) for the retention of exhaust particulate matter and selective catalytic reduction (SCR) for the treatment of  $NO_x$  in vehicles will help analyse the  $NO_x$  production and reduce it. It is thus, treated as a necessary system of treatments (Amit A. Patil, 2019). Table 1 shows the limits for regulated pollutants from the petrol engines as per Bharat stages.

Sustainable mobility can be achieved by converting to much more environment friendly and renewable fuels such as hydrogen, natural gas, biodiesel, etc. In general, due to the lack of safety rules, the use

**Table 1. Petrol engine emission norms (g/km)**

Emission norms	CO	HC	No <sub>x</sub>	PM
BS-III	2.30	0.20	0.15	-
BS-IV	1.00	0.10	0.08	-
BS-VI	1.00	0.10	0.06	00

Ref: (Shelke et al., 2017), "A Review on Bharat Stage Emission Norms".

of hydrogen on-board is limited which makes natural gas and biodiesel as better options to choose (Mirgal, 2017). While the use of pure hydrogen is very dangerous, hydrogen is mixed with a certain amount of compressed natural gas, CNG (5–15% by volume) to support both H<sub>2</sub> and CNG. CNG has a low flame rate so that its temperature is enhanced by the high speed of hydrogen flame in HCNG engines (Markard et al., 2020; Mirgal, 2017; Wei et al., 2008). In 1991, pollution standards were introduced in India, which were later revised in 1996. As part of this redesign, most automotive manufacturers had to make technological advances, such as catalytic converters, to reduce exhaust emissions (Tranfield et al., 2003; Vashisth et al., 2017). Analysis has shown that gas extraction, NO<sub>x</sub> trapping (LNT), and SCR are effective technologies for reducing NO<sub>x</sub> pollution substantially (Du et al., 2020; Ibrahim, 2014; Shao et al., 2021).

Studies also revealed that exposure to diesel fuel pollutants contributes to lung and respiratory illness, and that air pollution can contribute to cancer in humans (Burr & Gregory, 2011; Lewtas, 2007; Lloyd & Cackette, 2001; Sydbom et al., 2001; Whichmann, 2006). Fuel heating harms human health due to increased urban emissions, acid rain, carbon dioxide build up, changes in Earth's temperature balance, to name a few ill-effects. Indeed, 30-year forecasts from 1990 to 2020 indicate that automotive transportation and, as a result, demand for fossil fuels will likely increase, and these emerging emissions will be a major problem (Agarwal, 2006; Venkataraman et al., 2012). Certain health risks are gradually correlated with ultrafine particles smaller than 100 nm in diameter (Brown et al., ; Sun et al., 2003). New research has shown that it can penetrate the membranes of cells, access the blood and even infiltrate the brain (Oberdörster et al., 2004). Further studies found that genetic mutation (particle matter) may result from particles (H. Burtcher, 2014). Environmental problems have increased dramatically in the last decade, especially after the 92<sup>nd</sup> World Conference, which was held to help countries tackle sustainability issues collectively, such as the reduction of carbon reserves underground, major landslides, soil compaction after oil and mineral extraction, etc. (Agarwal, 2006). Table 2 shows regulations laid under Bharat stage norms for diesel engine exhaust emissions.

After careful consideration and study of the various aspects considered by the authors, it was found that the following questions were of great concern to them. These statements could be

**Table 2. Diesel engine emission norms (g/km)**

Emission norms	CO	HC	No <sub>x</sub>	PM
BS-III	0.64	0.50	0.56	0.050
BS-IV	0.50	0.25	0.30	0.025
BS-VI	0.50	0.06	0.17	0.005

Ref: (Shelke et al., 2017), "A Review on Bharat Stage Emission Norms".



a bridge between, not only the existing information about BS norms but can also educate people about the leap frogging in India, and can provide a broader perspective exclusively for new researchers and authors who may be interested in this topic.

1) Detailed information pertaining to the need for comparing the BS with Euro standards the requirements for implementations and the issues that might be faced are studied in the research work.

Ibrahim explains global pollution control legislation and progress in pollution control systems, especially in the case of heavy-duty diesel engines (Henry and Heinke, 1996; Ibrahim, 2014). Conservation of resources, considering the depletion rate has always become the need of the hour. Many governments and organizations are working to stem the tide of bad environmental and social health problems caused by greenhouse gases. In recognition of the harmful impact of diesel pollution on safety and the atmosphere, policymakers have developed requirements for acceptable emission standards. Europe has established Euro rules, which have gradually raised from Euro I to Euro VI since 1993 (Ibrahim, 2014). At the time, the National Capital Region (NCR) was to follow BS-II, while the rest of India followed BS-I. The BS-III and BS-II petrol requirements came into force in April 2005 in 13 major cities and throughout the country, respectively, in line with the 2013 Auto Fuel System. BS-IV and BS-III fuel quality levels have been enhanced in 13 major cities and throughout India since April 2010, as mentioned. BS-IV fuel is currently for sale in India. The Government has agreed to switch the country immediately from BS-IV to BS-VI on 1 April 2020, owing to the alarming rise in air pollution that has threatened the lives of civilians. The decision was made after consultation with the Department of Petroleum and National Gas, Heavy Manufacturing and the Department of Environment and Forestry (Vashisth et al., 2017). New diesel pollution laws will limit non-CO<sub>2</sub> emissions at the same amount as petrol passenger vehicles in the leading regions of the EU, North America, and Japan. This means that, over the next decade, heavy vehicles will take a big step forward in emission control (Fang Yan et al., 2011). Therefore, not only do car manufacturers need to reduce pollution, but they also need to work hard to maintain the driving power of the car (Serrenho et al., 2017; Amit A. Patil et al., 2019). The car export rate in India is currently in BS-IV. The Government of India has decided to switch to the Bharat Stage-VI National Emissions Standards for Cleaner Road Vehicles and Leapfrog in April 2020. (European Commission, 2011; Gagandeep Singh Theti et al., 2016)

2) This literature also studies the parallels between Euro 6 and BS-VI as Euro was considered the baseline for the emission norms in India.

Although the targets for pollution under both processes are similar to Indian driving cycles that need some adjustment as the top speed is very low. Also, India has a wide range of fuels with varying performance. In short, the Euro 6 compliant car should not comply with the BS-VI without technical intervention (Hoekman and Robbins, 2012; Amit A. Patil et al., 2019). BS-VI standards are strong and robust in place of BS-IV requirements, thus reducing emissions (Pothumsetty et al., 2020).

In many European countries, the government is designing luxury cars to ensure that cars emit less air pollution and improve air quality in big cities (Pothumsetty et al., 2020). BS or Bharat Stage Release Rate is a guide developed by the Indian Government to control the amount of air pollution caused by internal combustion engines. The sale and registration of vehicles that do not comply with BS-IV release standards are not allowed in the country from 1 April 2017 ("Somers et al., 2004; Vashisth et al., 2017). BS pollution standards established 17 years downstream are designed to control the air quality of generators and engines. The Central Pollution Control Board is a BS environmental monitoring body that focuses on EU law and rules related to pollution norms (Vashisth et al., 2017).

The Government of India has decided to implement, from April 2020, Bharat Stage VI (BS-VI) release requirements. OEMs are expected to equip their diesel engines after technical attention, EGR programs, and more efficient fuel systems at an additional expense (Lynn Fromm et al., 2017). These regulations will minimize NO<sub>x</sub> emissions by 88% and PM by 66% of the existing BS-IV specifications for diesel-powered commercial vehicles (Lynn Fromm et al., 2017). Pump losses are increased by increased reverse pressure arising from a solid post-treatment system and high requirements for high-pressure Bharat Stage 6 engines. These pump losses are subdivided into the following subclasses.

- Higher EGR requirements also increase pumping losses, particularly when the re-circulated exhaust gas must pass through restrictive coolers.
- Higher fuel injection pressure requirements result in an increased power loss of the fuel pump.
- Elevated Peak Cylinder Pressures (PCPs) due to higher air and EGR specifications raise friction penalties.

Using additional fuel saving technologies for Bharat Stage 6 engines compared to BS-IV engines, BSFC is expected to rise by at least 2–3%. BS-VI engines are projected to be 15–20% more expensive than BS-IV engines, according to a report, and it is also expected that the fuel economy will decrease by 2–3% (Lynn Fromm et al., 2017). BS-VI generators, on average, are projected to be 15–20% costlier (Lynn Fromm et al., 2017). BS-VI engines, although the fuel economy is just 2–3% lower, are projected to be more expensive. The government's decision to stop the level of Bharat Stage (BS) V and switch to the level of BS-VI impacted the economy of two major sectors, namely Fuel & Vehicle Manufacturing. (Franco et al., 2009; Vashisth et al., 2017)

India is 5 years behind the implementation of European export standards. Currently, BS-VI diesel is being shipped to refineries in India and is approved in the name of the guidelines of BIS 2000. The Indian government was notified in 1999 by orders of the Supreme Court BS-I and BS-II, which closely resembled the details of Euro I and Euro II. It is likely that the fuel injection has completely removed the carburettor with the next solid BS-VI data in India. The regulations for Euro 5 and Euro 6 emissions need to be introduced as soon as possible, as diesel emissions reduce the gap in fuel pollution only at Euro 6 level, with the guarantee of mitigation, as notified by renewable pollution control and control authority (EPCA). The Sulphur level in BS-IV and BS-VI is very low compared to BS III (Diaz-Sanchez, 1997). It is also understandable that the approach to reducing the sulphur content in diesel will have a negative impact on fuel composition. Together, these variables often contribute to vehicle performance and quality of combustion. Automakers take different approaches to solve these problems (Amit A. Patil et al., 2019). Once the BS-VI contamination level is detected, an 89% reduction in particle emissions from two wheeled vehicle's perspective can be realized. NO<sub>x</sub> emissions will also be reduced by 76%. In the case of vehicles, 82% of PM emissions and 68% of NO<sub>x</sub> emissions are proposed to be reduced (Fatah and AbduYusuf, 2019; Vashisth et al., 2017)

It can be inferred from studies that adapting DPF and SCR emissions control strategies must be used to get the maximum benefits and advantages associated with it, in order to skip BS-V and turn directly to BS-VI. The two and three wheeled vehicle systems have to be substituted with the Electronic Fuel Injection System instead of the outdated carburettor System to accommodate the requirements of the BS-VI system. BS-VI would also aim to eliminate particulate matter that was not previously regulated under BS-III or BS-IV (Myers, 2020; Vashisth et al., 2017).

Implementation of a new system of guidelines involves additional expenses. Industry experts agree that the high cost of renovating diesel cars to meet the needs of the BS-VI would certainly

make them more expensive, but it would not drive them far away where consumers would not be able to afford them. Prices for gasoline vehicles are expected to increase from Rs 10,000 to Rs 20,000, while diesel cars can be more expensive from Rs 80,000 to Rs 1,00,000 (Amit Patil et al., 2019; Naik et al., 2017). The price rise for diesel cars is due to more sophisticated vehicles with incorporation of technologies, as the Diesel Particle Filter (DPF) and the Selection Catalytic Reduction System (SCR). SCR injects fuel gases with diesel fluids and lowers the amount of nitrogen oxides ( $\text{NO}_x$ ) released by the exhaust of the vehicle (Pothumsetty et al., 2020). An assumption was made by major truck manufacturer's Daimler Trucks that this could be a major way to close the Indian Market. Also, to keep in mind the unemployment in the working class; it may have an impact on the Indian Automobile sector. Unemployment could directly or indirectly affect the buying powers of the customers, especially in the two-wheeler segment of the industry.

3) This piece of literature studies the change in the composition of fuel used for the newly implemented system BS-VI and overlooks how the fuel has been altered with chemical compositions to fit the demand of BS VI.

Considering that discharge requirements have a significant impact on fuel, these engines use post-treatment extraction methods such as diesel particulate filters (DPFs) in combination with SCR systems. The high sulphur content of BS IV fuel in the range has the potential to poison these systems and has a detrimental effect on their performance. There is, however, some variation. Luxury carmaker Mercedes seems to be using advanced solutions in its pollution control systems, which allows BS-VI diesel cars to run on BS IV fuel supply. There is a very different driving style in both Europe and India. Normal speeds and traffic conditions are very different. Apart from the fact that these two types of discharges are separate, they do not have a large gap (Bosch, 2005; Huizhong Shen et al., 2011)

On the other hand, it is a common condition for diesel engines. In general, even if advanced engine system strategies are used to achieve lower emissions, industrial experts say sulphur poisoning is not a major problem and, as a result, BS-VI petrol vehicles can work safely even with BS IV fuel (Nieuwenhuis and Wells, 1997; Patil et al., 2019). For efficient engine operation, while it is important to use the required fuel, the correct lubricant form also complements the cause. For this reason, it is recommended that only SAPS engine oil (Sulphate Powder, Phosphorus, and Sulfur) be used for all BS VI engine types. The performance of BS IV vehicles for pure fuel does not have any problem, as the main difference between BS IV and BS VI oils is a significant reduction in sulfur content, as mentioned earlier. Also, the use of BS VI fuel can be expected to lead to a slight reduction in the emissions of older engines (Amit A. Patil et al., 2019). The technology of the new BS VI engine often requires slow heating. In addition, the exhaust system will raise the amount of pressure returned to the engine following treatment, meaning that any of these devices, such as particulate filters and traps containing nitrogen oxide ( $\text{NO}_x$ ), will have to undergo a repair procedure including the elimination of fuel filter content. Potential customers are also planning to hang on to the possibility of acquiring a new car, and many have opted to wait until next years to purchase new BS VI-compliant vehicles. Rather than investing in BS IV compliant vehicles, it is reasonable for the customer to wait a while and invest in new BS VI vehicles. The buyer's decision to wait for investment in a new car has created a big problem for car manufacturers, as the stock of non-commercial BS-IV cars has increased because they are unable to sell BS IV cars.

Effective pricing tactics have been introduced to customers in response to competition (Pothumsetty et al., 2020). This would make it increasingly challenging for petrol engines to adhere to the new electronic control unit's (ECU) BS-VI emission specifications. The electrical system and other subsystems are regulated by the ECU. However, to reduce their combined

emissions, diesel engines need a massive improvement in their technology. New developments in diesel cars will increase the price of electric cars (International Energy Agency (IEA), 2012; Pothumsetty et al., 2020; Semakula and Inambao, 2017). As we move towards higher levels of pollution, this is a major challenge in producing cars in a variety of ways. Although reduced exhaust emissions are often associated with complete fuel consumption and efficiency, automotive manufacturers must ensure that they not only reduce the amount of pollution caused by vehicle emissions but also ensure that car manufacturers connect with BS-VI vehicles in such a way that the major operations of the vehicle remain unchanged. Considering all aspects of a premium hatchback, luxury subcompact sedan, or compact sedan, the price difference between diesel and petrol vehicles is estimated at about Rs. 2.5 lakhs (Oxman, 1994; Pothumsetty et al., 2020). This quest to lower the emissions by the introduction of new and more advanced technologies may definitely serve the purpose but will increase the cost of the vehicles, which might be a turndown for a lot of buyers.

### 3. Conclusion

The issues related to the deteriorating conditions of the environment have been on the top of the to-do list of every country. This serious issues not only are affecting the flora and fauna of the planet, but has also started showing issues pertaining to the health of humans. Engine exhaust constituents such as hydrocarbons (HC), oxides of nitrogen ( $\text{NO}_x$ ) and carbon monoxide (CO) among many others have led to health issues ranging from respiratory ailments to Visual Impairments. Major cause of this was found to be the effluents from the vehicles moving contributing to about 22% of the total Carbon dioxide  $\text{CO}_2$  emissions, thus leading to climate change.

Governments around the globe have taken steps to tackle these serious issues. From introducing, on-board diagnostics to the introduction of superior and technological smarter systems to reduce vehicle effluents and thus aid to tackle problems like ozone layer depletion. The use of renewable energy sources in urban infrastructure is an important area of energy supply. In 2019, such sources accounted for 11% (for solar energy) and 22% (for wind energy) of total energy produced in the year. However, these systems need to be more efficient, which can be accomplished by introducing electric automobiles. They have the ability to collect, store, and transfer excess energy to the city's power grid. A smart charging infrastructure is one answer to this challenge ("Gorbunova & Anisimov, 2020). The Government of India has taken steps to revise the existing automobile pollution norms and upgrade them. This transition was from the Bharat Stage IV to the newly introduced Bharat Stage VI emission norms. BS standards have been drawn in parallel to the Euro Emission norms.

The implementation of the new BS laws was supposed to be effective in the year 2020. The transition faced a little delay as the country was hit by the Covid-19 pandemic. One of the reasons for the decline in car sales in India is due to this transition of Bharat stages (from BS IV to BS VI) as it may affect the buying power of the customers.

After exploring the technicalities of the BS-VI standards put forward by the Bharat Stage Emissions Standards (BSES), it is proposed that with the implementation of the BS-VI, the  $\text{NO}_x$  would be reduced by 67%. For the effective implementation of new norms, OEMs must equip their vehicles with exhaust after-treatment systems that increase the cost of the vehicle by 15–20% in the Indian market context. While exploring the aftermath of the implementation of the BS-VI norms, Diamler has anticipated improvement in the employment count of the Indian automobile sector. This research work also compares the timelines followed by the Euro and the Bharat stage standards to introduce the advanced stages, keeping in mind the air quality index of the respective

countries and regions. There is a mention of using SAPS engine oil to prevent failures of the engine equipped with DPF and SCR technology.

#### Funding

The authors received no direct funding for this research.

#### Author details

Revati Borkhade<sup>1</sup>

Subrahmanya Bhat K<sup>2</sup>

ORCID ID: <http://orcid.org/0000-0002-7948-8621>

GT Mahesha<sup>1</sup>

E-mail: [mahesh.gt@manipal.edu](mailto:mahesh.gt@manipal.edu)

ORCID ID: <http://orcid.org/0000-0001-9477-8996>

Swapnil L. Fegade Reviewing editor

<sup>1</sup> Department of Aeronautical and Automobile Engineering, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal, India.

<sup>2</sup> Department of Chemistry, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal, India.

#### Disclosure statement

No potential conflict of interest was reported by the authors.

#### Citation information

Cite this article as: Implementation of Sustainable Reforms in the Indian Automotive Industry: From Vehicle Emissions Perspective, Revati Borkhade, Subrahmanya Bhat K & GT Mahesha, *Cogent Engineering* (2022), 9: 2014024.

#### References

- Agarwal, A. K. (2006). Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. *Progress in Energy and Combustion Science*, 33(3), 233–271. <https://doi.org/10.1016/j.pecs.2006.08.003>
- Bauner, D., Laestadius, S., & Lida, N. (2008). Evolving technological systems for diesel engine emission control: Balancing GHG and local emissions. *Clean Technologies and Environmental Policy*, 11(3), 339–365. <https://doi.org/10.1007/s10098-008-0151-x>
- Biswas, S., Verma, V., Schauer, J. J., & Sioutas, C. (2008). Chemical speciation of PM emissions from heavy-duty diesel vehicles equipped with diesel particulate filter (DPF) and selective catalytic reduction (SCR) retrofits. *Atmospheric Environment*, 43(11), 1917–1925. <https://doi.org/10.1016/j.atmosenv.2008.12.040>
- Bolaji, B. O., & Adejuyigbe, S. B. (2006). Vehicle emissions and their effects on natural environment – A review. *Journal of the Ghana Institution of Engineers*, 2006, 35–41. <https://doi.org/10.1088/1757-899X/1080/1/012004>
- Bosch. (2005). *Emissions-control technology for diesel engines*.
- Burr, M., & Gregory, C. (2011). Vehicular exhaust. *Encyclopedia Environ Health*, 49, 645–663. <https://doi.org/10.1007/s10098-014-07939>
- Burtscher, H. (2014). Physical characterization of particulate emissions from diesel engines: A review. *Journal of Aerosol Science*, 36(7), 896–932. <https://doi.org/10.1016/j.jaerosci.2004.12.001>
- Challenges and opportunities for Indian automotive industries (<https://www.livemint.com/Industry/b5VcxRbUqSjDLySxI4Cr0O/BS-VI-Challenges-and-opportunities-for-Indias-auto-industr.htm>)
- Chong, J. J., Tsolakis, A., Gill, S. S., Theinnoi, K., & Golunski, S. E. (2010). Enhancing the NO<sub>2</sub>/NO<sub>x</sub> ratio in compression ignition engines by hydrogen and reformat combustion, for improved after treatment performance. *International Journal of Hydrogen Energy*, 35(16), 8723–8732. <https://doi.org/10.1016/j.ijhydene.2010.06.008>
- Clark, N. N., Kern, J. M., Atkinson, C. M., & Nine, R. D. (2011). Factors affecting heavy-duty diesel vehicle emissions. *Journal of the Air & Waste Management Association*, 52(1), 84–94. <https://doi.org/10.1080/10473289.2002.10470755>
- Consuelo, N. (2020). Advanced design for manufacturing of integrated sustainability “off-shore” and “off-site” prototype – MVP “S2\_HOME”. *Civil Engineering Journal*, 6(9), 1752–1764. <https://doi.org/10.28991/cej-2020-03091580>
- Cook, D. J., Mulrow, C. D., & Haynes, R. B. (1997). Systematic reviews: Synthesis of best evidence for clinical decisions. *Annals of Internal Medicine*, 126(5), 376–380. <https://doi.org/10.7326/0003-4819-126-5-199703010-00006>
- Correa, S. M., & Arbillia, G. (2008). Carbonly emissions in diesel and biodiesel exhaust. *Atmospheric Environment*, 42(4), 769–775. <https://doi.org/10.1016/j.atmosenv.2007.09.073>
- Dai. (2011). Drought under global warming: A review. *WIREs Climate Change*, 2(1), 45–65. <https://doi.org/10.1002/wcc.81>
- DEFRA. (2002) *Survey of public attitudes to quality of life and to the environment*. Department for Environment, Food and Rural Affairs.
- Demers, D., & Walters, G. (1999). “Guide to exhaust emission control options” BAeSAME
- Diaz-Sanchez, D. (1997). The role of diesel exhaust particles and their associated polyaromatic hydrocarbons in the induction of allergic airway disease. *Allergy*, 52, 52–56. <https://doi.org/10.1111/j.1398-9995.1997.tb04871.x>
- Du, M., Hall, G. L., Franklin, P., Musk, A. W. (Bill), Mullins, B. J., de Klerk, N., Elliott, N. S. J., Sodhi-Berry, N., Brims, F., & Reid, A. (2020). Association between diesel engine exhaust exposure and lung function in Australian gold miners. *International Journal of Hygiene and Environmental Health*, 226, 113507. <https://doi.org/10.1016/j.ijheh.2020.113507>
- European Commission (2011), “Climate change: Report. Europe: Directorate-General for Communication”, Brussels
- Faiz, A., Weaver, C. S., & Walsh, P. W. (1996). Air pollution from motor vehicles: Standards and technologies for controlling emissions. <https://doi.org/10.1596/0-8213-3444-1>
- Fatah, A., & AbduYusuf, F. L. I. (2019). Effect of cold start emissions from gasoline-fueled engines of light-duty vehicles at low and high ambient temperatures: Recent trends Case Studies in Thermal Engineering, 141, 100417. <https://doi.org/10.1016/j.csite.2019.100417>
- Franco, C. D., Elia, A., Spagnolo, V., & Scamarcio, G. (2009). Optical and electronic NO<sub>x</sub> sensors for applications in mechatronics. *Sensors*, 9(5), 3337–3356. <https://doi.org/10.3390/s9050337>
- Gagandeep Singh Theti, R. J. Y., More, K., & Utage, A. S. (2016). Implementation of Bharat Stage VI norms for



- small and medium duty CI engines. *International Journal of Current Engineering and Technology*. E-2277 – 4106, P- 2347 – 5161. <http://inpressco.com/category/ijcet>
- Gorbunova, D., & Anisimov, I. A. (2020). Assessment of the use of renewable energy sources for the charging infrastructure of electric vehicles. *Emerging Science Journal*, 4(6), 539–550. <https://doi.org/10.28991/esj-2020-01251>
- Henry, J. G., & Heinke, G. W. (1996). *Environmental science and engineering*. Prentice- Hall.
- Heyder, U., Schaphoff, S., Gerten, D., & Lucht, W. (2011). Risk of severe climate change impact on the terrestrial biosphere. *Environmental Research Letters*, 6(3), 034036. <https://doi.org/10.1088/1748-9326/6/3/034036>
- Hiroiyuki, Y., Misawa, K., Suzuki, D., Tanaka, K., Matsumoto, J., Fujii, M., & Tanaka, K. (2011). Detailed analysis of diesel vehicle exhaust emissions: Nitrogen oxides, hydrocarbons and particulate size distributions. *Proceedings of the Combustion Institute*, 33(2), 2895–2902. <https://doi.org/10.1016/j.proci.2010.07.001>
- Hoekman, S. K., & Robbins, C. (2012). Review of the effects of biodiesel on NOx emissions. *Fuel Processing Technology*, 96, 237–249. <https://doi.org/10.1016/j.fuproc.2011.12.036>
- Huizhong Shen, H., Tao, S., Wang, R., & Wang, B. (2011). Global time trends in PAH emissions from motor vehicles. *Atmospheric Environment*, 45(2011), 2067e2073. <https://dx.doi.org/10.1016%2Fj.atmosenv.2011.01.05>
- Ibrahim, A. (2014). The pollutant emissions from diesel-engine vehicles and exhaust aftertreatment systems. *Clean Techn Environ Policy*, 17, 15–27. <https://doi.org/10.1007/s10098-014-0793-9>
- International Energy Agency (IEA). (2012). *CO2 emissions from fuel combustion highlights*. France.
- Jai Jain, P. C. (1993). Greenhouse effect and climate change: Scientific basis and overview. *Renewable Energy*, 3(4–5), 403–420. [https://doi.org/10.1016/0960-1481\(93\)90108-S](https://doi.org/10.1016/0960-1481(93)90108-S)
- Kampa, M., & Castanas, E. (2008). Human health effects of air pollution. *Environmental Pollution*, 151(2), 362–367. <https://doi.org/10.1016/j.envpol.2007.06.012>
- Kern, F., & Rogge, K. S. The pace of governed energy transitions: Agency, international dynamics and the global Paris agreement accelerating decarbonisation processes? *Energy Research & Social Science*, 22, 13–17. <http://www.sciencedirect.com/science/article/pii/S2214629616301992>
- Khodke, A., Watabe, A., & Mehdi, N. (2021). Implementation of accelerated policy-driven sustainability transitions: Case of Bharat Stage 4 to 6 leapfrogs in India. *Sustainability*, 13 (8), 4339. 2021. <https://doi.org/10.3390/su13084339>
- Kittelson, D. B. (1998). Engines and nanoparticles: A review. *Journal of Aerosol Science*, 29(5–6), 575–588. [https://doi.org/10.1016/S0021-8502\(97\)10037-4](https://doi.org/10.1016/S0021-8502(97)10037-4)
- Krzyzanowski, M., Kuna-Dibbert, B., & Schneider, J. (2005). *Health effects of transport-related air pollution*. WHO.
- Lee, T., Park, J., Kwon, S., Lee, J., & Kim, J. (2013). Variability in operation based NOx emission factors with different test routes, and its effects on the real-driving emissions of light diesel vehicles. *Science of the Total Environment* 461–462, 377–385. <https://doi.org/10.1016/j.scitotenv.2013.05.015>
- Levitov, S., Antonov, J. I., Boyer, T. P., Baranova, O. K., Garcia, H. E., Locarnini, R. A., Mishonov, A. V., Reagan, J. R., Seidov, D., Yarosh, E. S., & Zweng, M. M. (2012). “World ocean heat content and thermosteric sea level change (0–2000 m)”, 1955–2010. *Geophysical Research Letters*, 39, 10603. <https://doi.org/10.1029/2012GL051106>
- Lewtas, J. (2007). Air pollution combustion emissions: Characterization of causative agents and mechanisms associated with cancer, reproductive, and cardiovascular effects. *Mutation Research/Reviews in Mutation Research*, 636(1–3), 95–133. <https://doi.org/10.1016/j.mrrev.2007.08.003>
- Li, Y., Ye, W., Wang, M., & Yan, X. (2009). Climate change and drought: A risk assessment of crop-yield impacts. *Climate Research*, 39, 31–46. <https://doi.org/10.3354/cr00797>
- Lindley, A. A., & McCulloch, A. (2005). Regulating to reduce emissions of fluorinated greenhouse gases. *Journal of Fluorine Chemistry*, 126(11–12), 1457–1462. <https://doi.org/10.1016/j.jfluchem.2005.09.011>
- Lloyd, A. C., & Cackette, T. A. (2001). Diesel engines: Environmental impact and control. *Journal of the Air & Waste Management Association*, 51(6), 809–847. <https://doi.org/10.1080/10473289.2001.10464315>
- Marica, M. M. (2007). Chemical characterization of particulate emissions from diesel engines: A review. *Journal of Aerosol Science*, 38(11), 1079–1118. <https://doi.org/10.1016/j.jaerosci.2007.08.001>
- Markard, J., Geels, F. W., & Raven, R. (2020). Challenges in the acceleration of sustainability transitions. *Environmental Research Letters*, 15(8), 081001. <https://doi.org/10.1088/1748-9326/ab9468>
- McKechnie, A. E., & Wolf, B. O. (2010). “Climate change increases the likelihood of catastrophic avian mortality events during extreme heat waves. *Biol Lett*, 6 (2), 253–256. <https://doi.org/10.1098/rsbl.2009.0702>
- Meyssignac, Cazenave, A., & Meyssignac, B. (2012). Sea level: A review of present-day and recent-past changes and variability. *Journal of Geodynamics*, 58, 96–109. <https://doi.org/10.1016/j.jog.2012.03.005>
- Mirgal, N. (2017). Indian automotive industry towards Bharat Stage-VI emission norms: A technical review. *IJERAT*, 3(11), 2454–6135. <https://doi.org/10.7324/ijerat.2017.3155>
- Myers, S. L. (2020). *China’s pledge to be carbon neutral by 2060: What it means-the new york times*. 23 Sept 2020. New York: The New York Times co. [www.nytimes.com/2020/09/23/world/asia/china-climate-change.html](http://www.nytimes.com/2020/09/23/world/asia/china-climate-change.html)
- Naik, S., Johnson, D., Fromm, L., Koszewnik, J., Redon, F., Regner, G., & Abani, N. (2017). Achieving Bharat Stage VI emissions regulations while improving fuel economy with the opposed-piston engine. *SAE International Journal of Engines*, 10(1), 0056. <https://doi.org/10.4271/2017-26-0056>
- Nieuwenhuis, P., & Wells, P. (1997). *The death of motor-ing? Car making and automobility in the 21st century*. John Wiley & Sons. <https://doi.org/10.1016/j.jclepro.2015.02.084>
- Oberdörster, G., Sharp, Z., Atudorei, V., Elder, A., Gelein, R., Kreyling, W., & Cox, C. (2004). Translocation of inhaled ultrafine particles to the brain. *Inhalation Toxicology*, 16(6–7), 437–445. <https://doi.org/10.1080/08958370490439597>
- Organisation for Economic Co-Operation and Development (OECD) (2002), “Strategies to reduce



- greenhouse gas emissions from road transport: Analytical methods". OECD
- Oxman, A. D. (1994). Systematic reviews: Checklists for review articles. *BMJ: British Medical Journal*, 309(6955), 648–651. <https://doi.org/10.1136/bmj.309.6955.648>
- Payri, F., Bermudez, V. R., Tormos, B., & Linares, W. G. (2009). Hydrocarbon emissions speciation in diesel and biodiesel exhausts. *Atmospheric Environment*, 43(6), 1273–1279. <https://doi.org/10.1016/j.atmosenv.2008.11.029>
- Pothumsetty, R., Viswam, N., & Thomas, M. R. 2277–3878. 8. S. (2020). Bharat Stage IV to VI -challenges and strategies.
- Prasad, R., & Bella, V. R. (2010). A review on diesel soot emission, its effect, and control. *Bull Chem React Eng Catal*, 5(2), 69–86. <https://doi.org/10.9767/bcrec.5.2.794.69-86>
- Raub, J. A. (1999). Health effects of exposure to ambient carbon monoxide. *Chemosphere: Global change. Science*, 1, 331–351.
- Saxena, A. K. (2009). *Greenhouse gas emissions—estimation and reduction*. Asian Productivity Organization.
- Semakula, M., & Inambao, P. F. (2017). The effects of exhaust gas recirculation on the performance and emission characteristics of a diesel engine – A critical review *International Journal of Applied Engineering Research*, 12 (23),13677–13689. 2017. <http://www.ripublication.com>
- Serrenho, A. C., Norman, J. B., & Allwood, J. M. (2017). The impact of reducing car weight on global emissions: The future fleet in Great Britain. *Supplementary Materials*, 375(2095). <https://doi.org/10.1098/rsta.2016.0364>
- Shao, M., Lingxiang, Y., Xiao, C., Deng, J., Yang, H., Xu, W., Chen, Y., Liub, X., Ni, J., & Pan, F. (2021). Short-term effects of ambient temperature and pollutants on the mortality of respiratory diseases: A time-series analysis in Hefei, China. *Ecotoxicology and Environmental Safety*, 215, 112160. <https://doi.org/10.1016/j.ecoenv.2021.112160>
- Shelke, S., Raut, P., Sonaiya, H., & Yadu, S. (2017). A review on bharat stage emission norms. *International Journal for Scientific Research & Development*, 5 (1), 508–512. <http://www.ijserd.com/articles/IJSRDV5I10420.pdf>
- Sivaloganathan, S. (1998). Case report: Death from diesel fumes. *Journal of Clinical Forensic Medicine*, 5 (3), 138–139. The World Bank, Washington. [https://doi.org/10.1016/S1353-1131\(98\)90033-5](https://doi.org/10.1016/S1353-1131(98)90033-5)
- Somers, C. M., McCarry, B. E., Malek, F., & Quinn, J. S. (2004). Reduction of particulate air pollution lowers the risk of heritable mutations in mice. *Science*, 304 (5673), 1008–1010. <https://doi.org/10.1126/science.1095815>
- Strauss, S., Wasil, J. R., & Earnest, G. S. (2004). Carbon monoxide emissions from marine outboard engines. *Society of Automotive Engineers*, 2004(32), 0011. <https://doi.org/10.1007/s10098-014-0793-9>
- Sun, C., Ritchie, S. G., & Oh, S. (2003). Inductive classifying artificial network for vehicle type categorization. *Computer-Aided Civil and Infrastructure Engineering*, 18 (3), 161–172. <https://doi.org/10.1016/j.envpol.2007.06.012>
- Sydbom, A., Blomberg, A., Parnia, S., Stenfors, N., Sandstrom, T., & Dahlen, S. E. (2001). Health effects of diesel exhaust emissions. *European Respiratory Journal*, 17(4), 733–746. <https://doi.org/10.1183/09031936.01.17407330>
- The Impact of Implementation of Bharat stage VI and the key challenges (<https://www.prnewswire.com/news-releases/India-commercial-vehicle-industry-fy-2019-the-impact-of-implementation-of-bharat-stage-vi-bs-vi-key-challenges-from-leapfrogging-bs-iv-to-bs-vi-300913353.html>)
- The Potsdam Institute for Climate Impact Research and Climate (2012), “Turn down the heat: Why a 4\_C warmer world must be avoided.” The World Bank, Washington Tony Fountain
- Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing. *British Journal of Management*, 14, 207–222 .
- Vashisth, D., Kumar, N., & Bindra, M. (2017). Technical challenges in shifting from BS IV to BS-VI automotive emissions norms by 2020 in India: A review. *Archives of Current Research International*, 8, 1–8. 2454-7077. <https://doi.org/10.9734/ACRI/2017/33781>
- Venkataraman, S. V., Iniyar, S., & Goic, R. (2012). A review of climate change, mitigation and adaptation. *Renewable and Sustainable Energy Reviews*, 16(1), 878–897. <https://doi.org/10.1016/j.rser.2011.09.009>
- Walsh, M. P. (2011). Mobile source-related air pollution: Effects on health and the environment. *Encyclopedia of Environ Health*, 3, 803–809. <https://doi.org/10.1016/B978-0-444-52272-6.00184-7>
- Wang, X., Wasterdahl, D., Jingnan, H., Wu, Y., Yin, H., Pan, X., & Zhang, K. M. (2012). On-road diesel vehicle emission factors for nitrogen oxides and black carbon in two Chinese cities. *Atmospheric Environment*, 46, 45–55. <https://doi.org/10.1016/j.atmosenv.2011.10.033>
- Wei, Z., Jiangming, M., Yunting, F., Xiankai, L., & Hui, W. (2008). Effects of nitrogen deposition on the greenhouse gas fluxes from forest soils. *Acta Ecologica Sinica*, 28(5), 2309–2319. <https://doi.org/10.1080/10473289.2001.10464315>
- Whichmann, H. E. (2006). Environmental pollutants: Diesel exhaust particles. *Encyclopedia Respir Med*, 1, 96–100.
- Whitmarsh, L., & Kohler, J. (2010). Climate change and cars in the EU: The roles of auto firms, consumers, and policy in responding to global environmental change. *Cambridge Journal of Regions, Economy and Society*, 3(3), 427–441. <https://doi.org/10.1093/cjres/rsq008>
- Wu, C. W., Chen, R. H., Pu, J. Y., & Lin, T. H. (2004). The influence of air-fuel ratio on engine performance and pollutant emission of an SI engine using ethanol-gasoline-blended fuels. *Atmospheric Environment*, 38 (40), 7093–7100. <https://doi.org/10.1016/j.atmosenv.2004.01.058>
- Yan, F., Winijkul, E., Jung, S., Bond, T. C., & D. G. Streets. (2011). Global emission projections of particulate matter (PM): I. Exhaust emissions from on-road vehicles. *Atmospheric Environment*, 45 (28), 4830–4844. <https://doi.org/10.1016/j.atmosenv.2011.06.018>
- Zannetti, P. (1992). *Air pollution modeling*. VanNostrand Reinhold Publications.



© 2022 The Author(s). This open access article is distributed under a Creative Commons Attribution (CC-BY) 4.0 license.

You are free to:

Share — copy and redistribute the material in any medium or format.

Adapt — remix, transform, and build upon the material for any purpose, even commercially.

The licensor cannot revoke these freedoms as long as you follow the license terms.

Under the following terms:

Attribution — You must give appropriate credit, provide a link to the license, and indicate if changes were made.

You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.

No additional restrictions

You may not apply legal terms or technological measures that legally restrict others from doing anything the license permits.

***Cogent Engineering* (ISSN: 2331-1916) is published by Cogent OA, part of Taylor & Francis Group.**

**Publishing with Cogent OA ensures:**

- Immediate, universal access to your article on publication
- High visibility and discoverability via the Cogent OA website as well as Taylor & Francis Online
- Download and citation statistics for your article
- Rapid online publication
- Input from, and dialog with, expert editors and editorial boards
- Retention of full copyright of your article
- Guaranteed legacy preservation of your article
- Discounts and waivers for authors in developing regions

**Submit your manuscript to a Cogent OA journal at [www.CogentOA.com](http://www.CogentOA.com)**

