IOP Conf. Series: Earth and Environmental Science **1347** (2024) 012050 doi:10.1088/1755-1315/1347/1/012050

Carbon monoxide emission and eco-driving for freight sustainability

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Abstract. Carbon monoxide (CO) indirectly causes climate change because it affects the abundance of greenhouse gases such as carbon dioxide and methane. Carbon monoxide is formed because of incomplete combustion in diesel engines. The fate of CO towards achieving freight transportation sustainability is presented. Firstly, the pollutant (CO) emitted by diesel engines from freight vehicles was determined from field studies using the tailpipe emission technique. The effect of the behavioural approach, eco-driving, was also observed for the 304 km trip demonstrated by the drivers of the 40-footer truck. Eco-driving has many advantages, including emitting less CO, saving in fuels, and reducing accidents and traffic summons. Secondly, for freight sustainability, CO should be further reduced by adhering to Euro standards of the European Union for heavy-duty vehicles, which states that the emission should be 1.5 g/kWh. Thirdly, a diesel oxidation catalyst (DOC), which converts CO to CO_2, is an option that can be used. Then fourthly, the decarbonisation of transport using heavy electric trucks also shows some promise, although they are best for moving goods for a short distance. Finally, an efficient logistics system with optimal solutions adopting several measures is suggested for sustainability. These include 'Hub-Spokes' distribution, a polarised fleet, expanded delivery windows and last-mile delivery. Thus, these five steps help decarbonise the transport sector and consequently accelerate the zero carbon emission transition.

1. Introduction

In the combustion chamber, the air is made greater than that of the atmosphere by compressing. Temperature is generated sufficiently, so ignition will occur almost instantly when the diesel fuel is injected into the cylinder. The conversion to the force, which is the mechanical form in nature, occurs when the chemical energy is separated from the fuel by the heating action of the engine [1]. Diesel fuels comprise carbon (C) and hydrogen (H). The complete combustion of diesel fuel would produce water and carbon dioxide in the combustion engine's chambers [2], provided that an ideal thermodynamic equilibrium exists.

However, complete combustion is seldom possible for many reasons, such as the ratio of air to fuel, timing for initiating combustion, sudden air movement in the combustion chamber, combustion form, air–fuel concentration, combustion temperature, and so on. Consequently, some harmful products are generated during combustion. These are carbon dioxide, hydrogen chloride, nitrogen oxide and particulate matter. The estimated amount of exhaust gas constituents upon combustion is shown in figure 1 [3] below.

The figure shows the approximate composition of diesel exhaust gas. Pollutant emissions have a rate of less than 1%, with the four main pollutants of CO, HC, PM and NO_x. The highest proportion of diesel pollutant emission is NO_x (>50%) followed by PM, CO and HC.

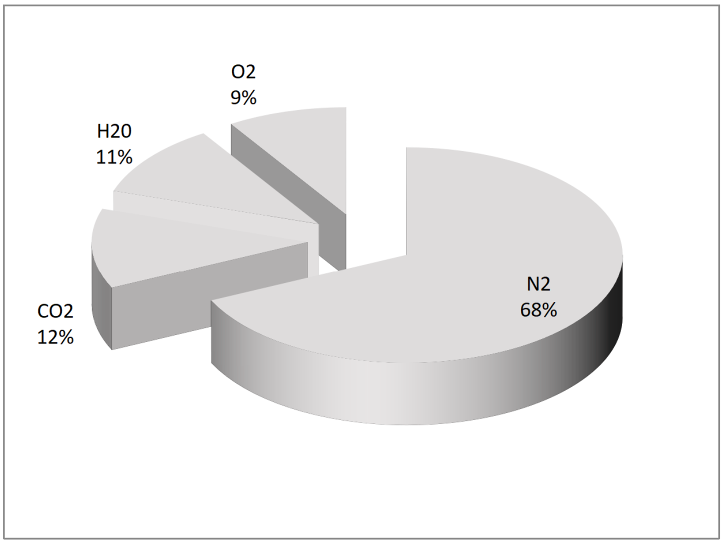

Figure 1. Approximate Composition of diesel exhaust gas [3].

2. Carbon Monoxide (CO) emission

Carbon monoxide gas has no colour or odour. The intake of CO by the lung will cause it to enter the bloodstream and react with haemoglobin, hindering the capacity to deliver O2. Depending on the concentrations of CO, it can cause suffocation, leading to disorientation, affecting the functions of various organs, slowing down reflexes, losing the ability to concentrate and impairing the thinking process [4,5,6,7].

Generally, for complete combustion, the reaction is written as

$$C_xH_y(g)+(x+y/4)\ O_2(g)\rightarrow xCO_2(g)+y/2H_2\ O(l) \quad (1)$$

For propane, however, it can be written as

$$:\ C_3\ H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O \quad (2)$$

Enough air or oxygen needs to be present when burning petrol or diesel. Insufficient air or oxygen will affect fuel burning and likely cause incomplete combustion. It results in the formation of carbon monoxide, carbon and water. When the rich mixture is attained, that is, when excess air factor(λ) is not greater than 1, the concentration CO is at its highest [8]. However, a small amount is produced under lean conditions caused by chemical kinetics [9].

Freight transportation makes up 8% of global greenhouse gas emissions, and carbon emissions may double by 2050 [10]. Figure 2 below shows the average values of CO_2 for various modes of freight transportation. In Malaysia, the transport sector is the second biggest contributor of CO_2 after electricity and heat production [11]. CO_2 emissions from the transport sector represented 28.8 % of total fossil fuel combustion, well above the global average of 24.5% [12]. The following methods henceforth provide the means towards decarbonising sustainability from freight transportation.

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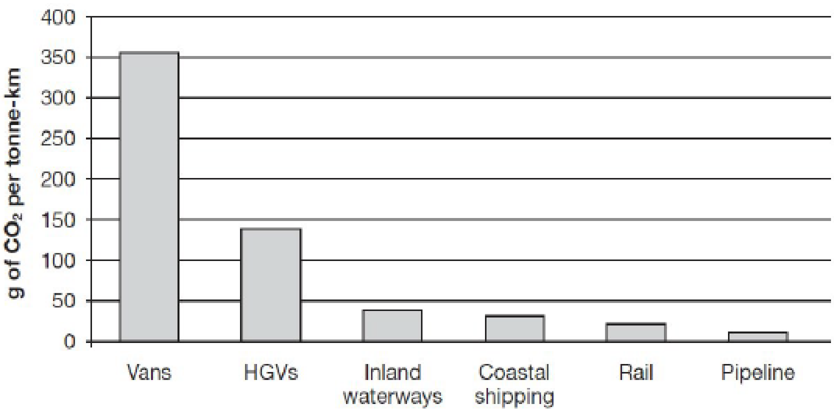

Figure 2. Approximate average values of carbon dioxide intensity values for various modes of freight transport [10].

3. Eco-driving

There are several steps needed in introducing eco-driving in a company. The first step involves building up a state of readiness, making ready with new values for the change and overcoming 'negative' forces in the company. The second step implements eco-driving training and reinvents the drivers' skills accompanied by rewarding schemes; the third step is to develop further and extend the boundaries of eco-driving and integrate it with other activities within the company. Subsequently, by so doing, there are likely long-term changes in driving behaviour, thereby reducing fuel costs. Figure 3 below shows the difference between normal and eco-driving.

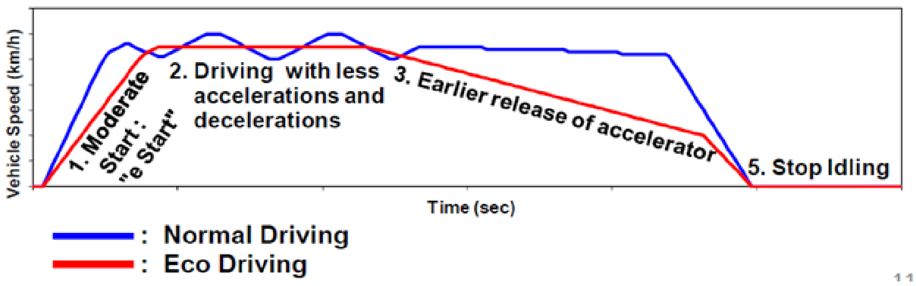

Figure 3. Normal vs. Eco-Driving.

Evidence shows that drivers using eco-driving strategies and behaviour have fewer accidents than before adoption. The benefit of eco-driving concerning road safety: driving is safer due to greater anticipation and less erratic and unpredictable behaviour. Figure 4 shows an example of such achievements. It was observed that starting from 2012, despite the increase in the number of trips, the number of accidents per trip kept decreasing at a declining rate.

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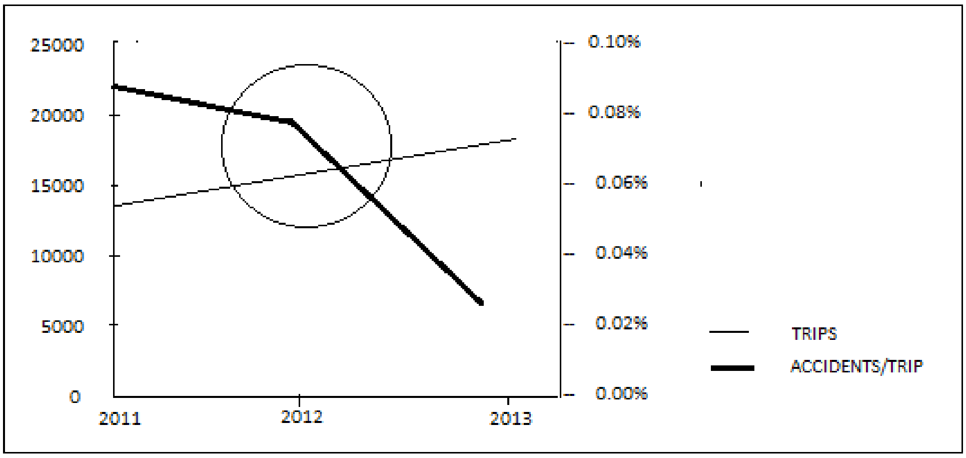


Figure 4. Trips and accidents/trips (%) (2011-2013) [13].

4. Past monitoring results

4.1. Field Study

As part of the Green Logistics study for freight transportation, a field investigation involving the monitoring of CO emissions from the 40-footer truck for the Seremban to Johor Bahru route (a distance of 304 km) was undertaken. This study used the tailpipe emission technique (Direct Sense IAQ (IQ-410) to ascertain the total CO_2 emission for the single trip and within the supply chain. Figures 5 (a) and 5(b) show the vehicle and monitoring instrumentation.

(a) Vehicle Front View (b) Monitoring Instrumentation

Figure 5. Vehicle type and Instrumentation (14).

4.2 Findings from the Study

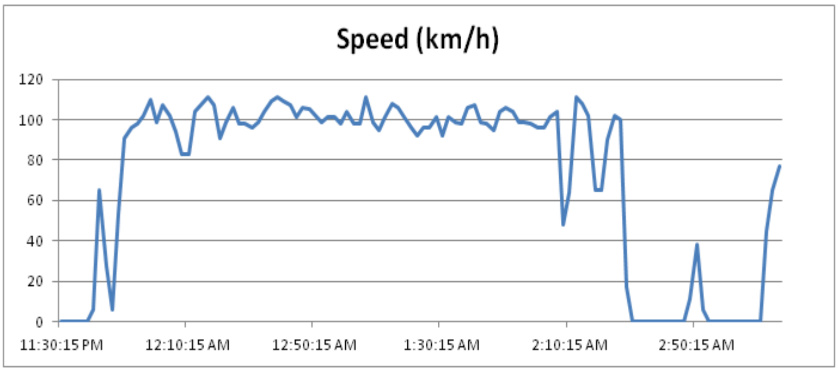
A critical insight is that emissions during some modes (i.e., idling) are generally lower than those during other modes (i.e., acceleration). Another finding is that short-term events substantially influence emissions during a trip. The on-road emissions measurement method demonstrated in this work enables the collection of real-world representative data that can be used to assist in the design and management of air quality monitoring.

A key implication of this work is that highway vehicle air quality management strategy should focus on how vehicles are driven rather than how far they are driven. Based on the distance travelled from Seremban to Johor Bahru, it is estimated that the:

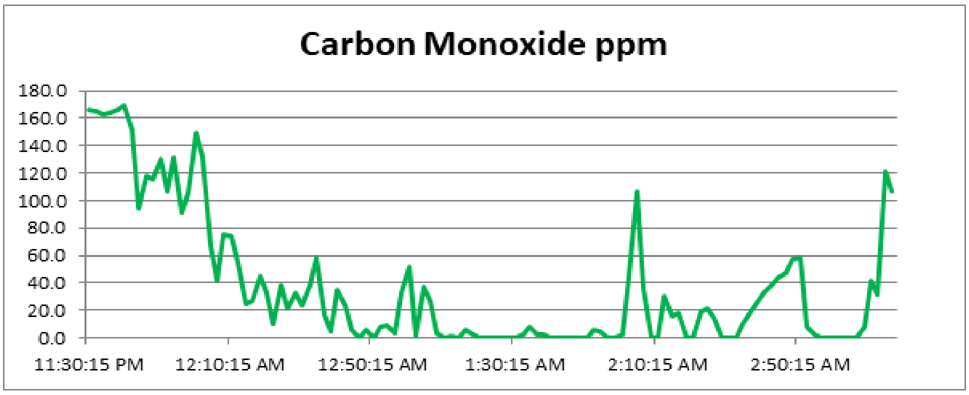
$$\text{Total emissions} = \text{distance x emission factor} = 304 \times 0.94353 \text{ kgCO2 eq/km}$$
$$= 286.672 \text{ kg CO eq}$$

When driving, the engine works hard to overcome wind resistance. Fuel burning is 15% more at 100 km/hr and 25% more at 110 km/hr. However, if the speed is reduced to below 50 km/hr, the engine's gear is lowered, consuming more fuel. Driving at a steady 50 – 90 km/hr is better for achieving optimal fuel economy.

Figures 6 (a) and 6 (b) below show the speed variation with vehicular carbon monoxide (CO) emission. The result of the reduction in the average speed of vehicles, mainly due to traffic buildup, is a marked increase in CO. At low speeds, a dramatic expansion of CO was noticed. A similar increase was observed at high speeds. However, when the speed is maintained at 100 km/hr, at the same time, carbon monoxide emission is reduced and remains constant;



(a) Speed of freight vehicle with time



(b) Emission of carbon monoxide (CO in ppm)

Figure 6. Seremban- Johor Bahru Emission Study (14).

Maintaining a constant speed of 100 km/hr enables a lower emission of CO. Therefore, maintaining a steady rate at low RPM and driving smoothly, using the highest possible gear (80-100 km/hr), will reduce emissions and fuel consumption. Other workers [15] also produced similar results with the eco-driving approach, as shown in Figure 7 below.

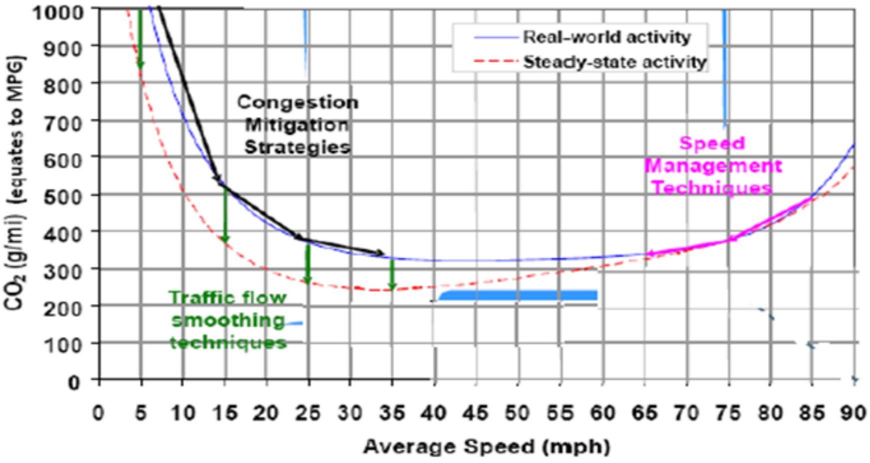


Figure 7. Variation of CO_2 with speed [15].

5. Regulation and technologies

5.1 Euro emissions standards for heavy-duty vehicles

Environmental and human health must be protected against pollutants from point and non-point sources. The effects can be detrimental as greenhouse gases cause global warming and far-reaching impacts on human health due to emissions from moving sources such as diesel-powered trucks. Concerned governments have put up standards for emission control. As in the case of European countries, the standards have evolved from 1993 from Euro 1 to Euro V1, becoming more stringent each year.

As Directive 70/156/EC stated with reference mass ≤2,610 kg, Euro standards concerning carbon monoxide are shown below (Table 1). These are the limits in mass per energy (g/kWh). Compared to the Euro I standard, the Euro VI standard for CO has decreased by 66 %. The implementation of the Euro VI standard for heavy-duty vehicles in Europe has been in effect since September 2014 [16].

Table 1. Euro standards of the European Union for heavy-duty vehicles [16]

Euro I	4.5	Euro IV	1.5
Euro II	4	Euro V	1.5
Euro III	2.1	Euro VI	1.5

5.2 Technologies and the Logistics

5.2.1 Diesel oxidation catalyst (DOC)

CO and HC are oxidised to form CO_2 and H_2 O (Eqns. 3 and 4) in the DOC. Oxygen comprises from two to seventeen per cent of diesel exhaust by volume. In the combustion chamber, there is no reaction between the oxygen and the fuel. It is readily consumed in DOC (Figure 8) [17,18,19].

$$CO + 1/2\ O_2 \rightarrow CO_2\ CO + 1/2\ O_2 \rightarrow CO_2 \quad (3)$$

$$C_3\ H_6 + 9/2\ O_2 \rightarrow 3\ CO_2 + 3H_2\ OC_3\ H_6\ + 9/2\ O_2 \rightarrow 3\ CO_2 + 3H_2\ O \quad (4)$$

$$NO + 1/2\ O_2 \rightarrow NO_2NO + 1/2\ O_2 \rightarrow NO_2 \quad (5)$$

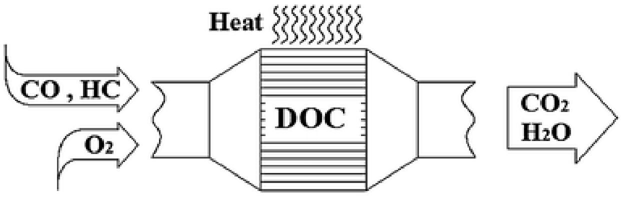


Figure 8. Diesel oxidation catalyst (DOC).

The continually stricter standards for emission values make vehicle manufacturers work on improving the quality of pollutant emissions from vehicles. Many studies performed over the years have made some progress. These studies include modifications of the engines, a system of controlled fuel injections, and advances in improving fuel properties. The measures fail to reduce to the required standards. It is left to the option of controlling it as after-treatment steps. The emissions from the vehicles can then meet the criteria. Pollutants can be eradicated when they leave the engine just before contacting the ambient air.

5.2.2 Heavy electric trucks

Europe's heavy (≥ 16 tonnes) electric truck market has grown. Many in the freight industry elsewhere have made arrangements to shift to electric. Truck manufacturers are developing electric vehicles due to the growing pressure from legislatures, environmental concerns, and to gain economic benefits.

Due to EV truck batteries' limitations in mileage range, they are best for moving goods across short distances. This situation is often due to the need for charging infrastructure. Thus, trucking companies are trying to develop EV trucks that travel short distances and use them at ports and intermodal logistics facilities. It is possible to have zero-emission for short-haul fleets if EV tracking is adopted.

A proposed solution to reduce the cost of EV ownership is to consider EV conversion services, converting an internal combustion engine vehicle into an EV by removing the powertrain and replacing it with a battery motor, controller and battery management system.

The other solution involves battery swapping by providing the EV owner with a new battery every time they visit a battery swapping centre. This reduces the purchasing cost by eliminating the cost of the batteries, which comprise 40%-50% of the EV's total cost.

6. Freight sustainability

There are several ways to the successful execution of Green Logistics: using green technology, packaging, storage, transportation, and reverse logistics. Green Logistics should be geared towards efficient systems for reducing the carbon footprint of this industry. An efficient system must also consider the whole perspective of freight sustainability (Figure 9).

To promote an efficient logistics system for freight sustainability, an optimal solution to sustainability in environmental, financial and societal settings has to be achieved. It requires the implementation of the following steps:

a) Hub and spoke distribution
The form of transport topology optimisation is where traffic planners organise routes as a series of 'spokes' connecting outlying points to a central 'hub'. As compared to the point-to-point model, the requirement is for fewer routes. However, since it is centralised, any changes in day-to-day demand need appropriate handling.

b) Polarised fleet,
It means creating the geographical concentration of logistics companies to create synergies and economies of scale. It makes possible the interaction between inland locations and seaports. This leads to the developing of a large logistics pool consisting of several logistics zones. The ports and inland areas can complement each other's existence and not compete.

c) Expanded delivery windows
A specific period when the customer expects to receive their parcel is called a delivery time window. Delivery time is the total time calculated from ordering the product to delivery time. Integrating tools like dedicated route planning and optimisation software can help optimise the delivery process and shortest multi-stop delivery paths for increased productivity.

d) Last-mile delivery
The final part of the product's journey as it moves from the warehouse shelf to the back of a truck and the customer's doorstep. As a share of the total shipping cost, this last-mile delivery cost is substantial, comprising 53% of the overall. For more efficient freight transportation to deliver, the crowd sourcing model is adopted to ease last-mile delivery woes.

Regarding encouraging other green practices, it is best to add up with proper support. The initiatives include reverse logistics, route and load optimisation, green supply and purchasing.

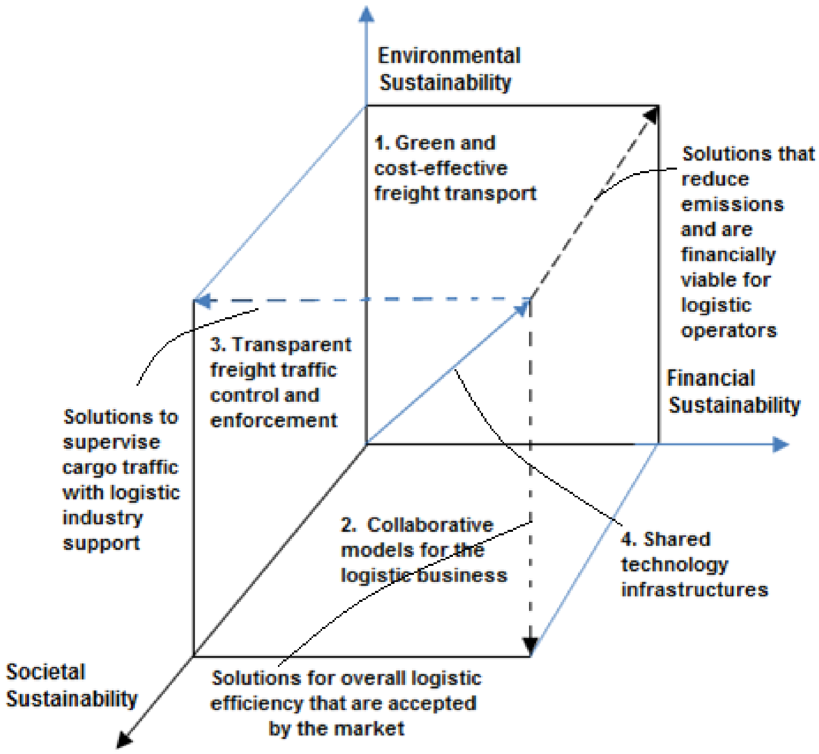


Figure 9. Freight Sustainability [14].

7. Conclusion

Ironically, efficiency in achieving complete combustion contributes to CO_2 (greenhouse gas), notwithstanding that. Therefore, the alternatives are better vehicle technology and improvements, such as low-emission vehicle standards and supplementary technologies. Low carbon fuel alternatives (i.e., low carbon fuel standard, biofuel procurement, etc.) are better. Better road design, route planning and optimisation for freight vehicles are needed. Intermodal freight initiatives will improve transportation system efficiency. Regarding the challenge of providing better charging infrastructure for EVs, relevant parties must recognise the need to share and build their critical mass and be willing to participate. All commercial and passenger vehicles must move as one. Meanwhile, since diesel vehicles are still used for moving goods in the logistics industry, adopting after-treatment is necessary. It is still viable despite the pollutant CO, among others.

8. References

[1] Bosch, 2005. Emissions-control technology for diesel engines. Robert Bosch GmbH, Germany.
[2] Prasad R and Bella V R 2010 A review on diesel soot emission; its effect and control, Bull, *Chem. React Eng. Catal.* **592** 69-86
[3] Khair M K and Majewski W A 2006. Diesel emissions and their control, SAE International

IOP Conf. Series: Earth and Environmental Science **1347** (2024) 012050 doi:10.1088/1755-1315/1347/1/012050

[4] Raub J A 1999 Health effects of exposure to ambient carbon monoxide, Chemosphere; global change, Science **1** 331-351
[5] Kampa M and Castana E 2008 Human health effects of air pollution, *Environ Pollut* **151** 362-367
[6] Walsh M P 2011 Mobile source related to pollution: Effects on health and the environment, *Encyclopedia of Environ Health* **3** 803-809
[7] Strauss S Wasil J R Ernest G S 2004 Carbon monoxide emissions from marine outboard engines, *Society of Automotive Engineers* 32-0011
[8] Wu C W, R H Chen, R H, Pu, J Y Lim TH 2004. The influence of air-fuel ratio on engine performance and pollutant emission of a-Si engine using ethanol-gasoline-blended fuels, *Atmos Environ* **38** 7093-7100
[9] Faiz A, Weaver C S, Walsh P W 1996 Air Pollution from motor vehicles: standards and Technologies for controlling emissions. The World Bank: Washington
[10] McKinnon A C 2007b 'CO_2 Emission from Freight Transport in the UK' Commission for Integrated Transport, London
[11] Solaymani S 2022 Front. Environ. Sc, Sec. Env.l Economics and Management Vol 9
[12] International Energy Agency -IEA (2019) CO_2 Emissions from fuel combustion Paris IEA
[13] Nippon Express 2014 ASEAN Working Group on Eco-Driving Seminar KL
[14] Hassan R 2015 Green Logistics A report on Green and Reverse Logistics in Supply Chains MITRANS-MOHE
[15] Barth M and Bonboonsomsin K 2008 Energy and Emission Impacts of a Free-way based Dynamic Eco-Driving System, Transportation Research, Part D. Environment, Elsevier Press.
[16] Delphi 2012 Worldwide emissions standards-heavy duty and off-highway vehicles (Delphi, Michigan)
[17] Chen M and Schirmer K 2003 A modelling approach to the design optimisation of catalytic converters of I. C. engines. In: Proceedings of ICEF03 2003 fall technical conference of the ASME internal combustion engine division ICEF2003-729
[18] Wang T J, Baek S W and Lee J H 2008 Kinetic parameter estimation of a diesel oxidation catalyst under actual vehicle operating conditions, *Ind Eng Chem Res* **47** 2528-2537
[19] Yu B K and Kim M Y 2013 Modelling the selective catalytic reduction of NO_x by ammonia over a Vanadia-based catalyst from heavy-duty diesel exhaust gases, *Appl. Therm. Eng*. **50** 152-158.