VEHICULAR EMISSION AND POSSIBLE MITIGATION FROM HEAVY DUTY VEHICLES (HDV): INSIGHTS FROM MAP-HDV PROJECT

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Abstract

Heavy Duty Vehicles (HDV) which include lorries, trucks and buses (>3.5t), produce significant vehicular emission which is expected to increase due to economic growth and subsequent increase in freight movement in Ireland. Until now, this sector had attracted little attention of environmentalists and policy makers in relation to strategy development and implementation to mitigate the emission levels. In Ireland's National Energy Efficiency Action Plan (NEEAP) it is targeted that a 20% energy efficiency will be achieved from all sectors including transport by 2020. The NEEAP provides a set of policy measures such as, electrification of fleet and eco-driving etc. to improve energy efficiency in transport sector especially passenger cars and buses. As indicated in the recently published 'European Strategy for Low-Emission Mobility' it is necessary to focus on the HDV fleet due to expectation of increase in vehicular emission from this sector due to improved economy. These goals created the imminent need of addressing the issue of tackling vehicular emission from Irish HDV fleet. The goal of the MAP-HDV project is to explore and establish environmental, economic and health impact of the vehicular emission generated from the Irish HDV fleet along with developing an appropriate tool-kit to monitor and calculate future energy consumption and related vehicular emission from the fleet using most advanced simulation tools. Furthermore, research attention will be focussed on exploring and evaluating a set of fleet and demand management tools learned from international and European best practices to mitigate vehicular emission including CO_2 by developing a scenario-based modelling approach. By evaluating the potential environmental and economic impacts and long-term sustainability of multiple measures a suit of the most suitable ones chosen through survey and expert advice will be recommended for possible implementation. The policy implications of these plans will be discussed as well as a guidelines to achieve the aforementioned goals in this sector will be recommended. The project is aligned with multiple important national policies and planning frameworks as well as newest European directives and it is critical to carry out to inform policy makers and practitioners in relation to achieving sustainability in road transport sector in this country. The analysis and results of MAP-HDV will be essential to inform policy in this sector.

Keywords: Heavy Duty vehicles, Emissions, Technology, Policy,

1. Introduction

During the past several decades, there have been more and more debates concerning the gradual increase of global warming and the resulting climate change. The primary source of global warming is increased concentrations of greenhouse gas (GHG) emissions, particularly carbon dioxide (CO_2), which is a product of human activities. The transport sector is one of the inevitable and essential parts of human activities, economic growth and job creation. It has been estimated that the transport sector within the European Union (EU) contributes to 7% of European gross value added / GDP and 7.06% of employment [1]. Despite benefits, transport activities include disadvantages such as enormous energy consumption, increased GHG emissions and decreased air quality. Among all transport modes, one of the primary sources of pollutants has been road vehicles. According to the European Environmental Agency [2], road vehicles account for 82 % of GHG emissions from transportation transport and one-fifth of EU's total GHG emissions. Between road vehicles in Europe, Heavy-Duty Vehicles (HDVs) are responsible for 27 % of CO_2 emissions and almost 5 % of EU's GHG emissions. Overall, emissions from HDVs have increased from 1990 by 25% and projected to increase further [3]. Therefore, several European policies, initiatives, and actions have been launched to address these disadvantages [4]. To reduce GHG emissions and other pollutants, more stringent vehicle emission regulations were adopted in Europe by introducing new standards, alternative fuels, tax exemptions on electric vehicles, etc. Also, a series of initiatives including CO_2 certification, monitoring, and a target for reduction in CO_2 emissions by years 2025 and 2030 were introduced in Europe. Then, as the primary response to stringent vehicle emission regulations of the vehicle and engine manufacturers was the development of new technologies for pollutant emissions reduction. Bearing in the mind that there are numerous and various possible mitigation measures, the paper aims to identify possible solutions and their applicability to reduce emissions from HDVs. This was achieved through a comprehensive and thorough literature review. During the literature review, special attention was devoted to those research articles and projects that highlighted emission reduction from HDVs. The rest of this paper is structured as follows. Section 2 provides the research methodology. Section 3 gives an insight into the findings and discussion. Finally, conclusions and future research are described in Section 4.

2. Methodology

For this paper, relevant research studies, articles published in peer-reviewed journals, conference proceedings were searched from the 'ScienceDirect' domain. The search was performed in June 2019 without limitation on the year of publication. The initial search string was performed by keeping the phrase: "pollution mitigation heavy-duty vehicles". Total 2,425 were found through the initial search. Therefore, the advanced search was performed using title, abstract and keywords in the next iteration. However, very few articles were found in the second search (12). Then, in the third iteration, "heavy-duty vehicle" was used as a keyword in an advanced search of ScienceDirect and 745 articles papers have been found. Based on the results of applied last search string, research articles that studied fuel consumption, potential mitigation measures, and tools for evaluation and monitoring emissions from HDVs have been extracted by first reading the abstracts. Finally, 81 relevant papers were selected in this paper. However, not all the reviewed articles were included in this paper. In addition to research articles, funded research projects and legislations by the European Commission and by other countries were summarized in this research.

3. Review of Literature

The literature is divided into five parts: fleet management policies, demand management policies, evaluation and monitoring tools, projects related to emission reduction, and legislations.

3.1 Fleet Management Policies

This section covers the use of alternative technologies in terms of vehicles, fuel, engine, and strategies to reduce emissions from HDVs.

Alternative Vehicle Technology

One of the alternative technologies is use of Hydrogen fuel cells to reduce emissions and fuel consumption. For Australian market where zero emissions are desirable, hydrogen fuel cells can be a good option for HDVs [5]. According to Kinnon et al. [6], air quality can only be improved with 50% to 100% introduction of fuel cell electric vehicle (FCEV) technology in HDVs. According to Liu et al. [7], based on the five scenarios with fuel cell vehicles, GHG generated by the whole fleet will decrease by 13.9% and for heavy-duty trucks, GHG will decrease by nearly one-fifth when compared with no fuel cell vehicles. Further, technologies related to renewable energy should be used to achieve significant CO_2 mitigation [8]. Further, Keller et al. [9] have shown that adoption of alternative fuel vehicles in the HDVs in the absence of carbon taxes leads to 3% of emission reduction. Furthermore, electric trucks powered by overhead lines also known as trolley trucks [10] have potential to reduce CO_2 emissions. According to Anderhofstadt and Spinler [11] potential measures for reduction of emissions from diesel-powered heavy-duty trucks in Germany are introduction of battery electric (BE), fuel cell electric (FCE), compressed natural gas (CNG) and liquefied natural gas (LNG) technologies.

Alternative Engine Technology

Zhang et al. [12] highlighted that hybrid and CNG/LNG technologies are better options than the Euro V diesel engines to mitigate NOx emissions. Further, hydrotreated vegetable oil (HVO) in Euro III and Euro IV heavy-duty engines produce less emission when compared with diesel fuel [13]. Likewise, CNG prototype engine produces lower emissions (CO_2, NOx and CO) when compared to the Euro V engine [14]. Thiruvengadam et al. [15] pointed out that advanced technologies in natural gas engines produce significantly less NOx and PM emissions. Based on the weight class and driving cycle of trucks, compressed natural gas (CNG) produces 13–15% less CO_2 emissions than diesel trucks, while advanced vehicle technologies options in CNG trucks can reduce CO_2 around 28–35% in short-term and 41–51% over the long term [16].

Combustion Techniques and Exhaust Aftertreatment Technology

In terms of internal combustion engines, Karavalakis et al. [17] have found that new stoichiometric combustion natural gas (NG) engines with three-way catalysts (TWCs) in urban areas can reduce THC, NMHC, CH_4, and NOx emissions. Also, in the United States, many HDVs installed selective catalytic reduction with ammonia (SCR) technology to achieve the 2010 emission standard of NOx. Dixit et al. [18] have estimated emissions of eight heavy-duty diesel trucks by using three different exhaust aftertreatment systems (ATS) –i.e., cooled exhaust gas recirculation (CEGR) plus a diesel particulate filter (DPF), CEGR and DPF plus advanced engine controls, and CEGR and DPF plus SCR system. The results indicate that PM emission factors and selected non-regulated emissions were reduced for all control technologies and driving conditions. Further, greenhouse gas (nitrous oxide) were observed to be within detection limits, while NOx emission factors were depended on the control technology, engine calibration, and driving mode. The recovery of exhaust heat is an appropriate option to improve the efficiency of internal combustion engines and to lower their emissions [19]. One of the promising options among all the waste heat recovery (WHR) technologies is Thermoelectric Generators (TEG) [20]. Muralidhar et al. [20] have confirmed that significant fuel savings and CO_2 emissions reduction can be achieved with the TEG in HDVs. Moreover, fuel consumption and CO_2 emissions can be reduced with the introduction of Organic Rankine Cycle Waste Heat Recovery (ORC-WHR) in diesel HDVs [21].

Alternative Fuels & Strategies

Besides the combustion improvement techniques and the exhaust aftertreatment technology, emissions from a diesel engine can also be reduced with alternative fuels. For example, the involvement of oxygenates into diesel fuels represents an additional measure for the reduction of smoke emission from a diesel engine. Wang et al. [22] concluded that fuel blended with biodiesel, dimethyl carbonate and high cetane number could reduce PM emission to an extremely low level that is capable of meeting the Euro IV or even stricter emission standards without applying an aftertreatment device. Based on the comparison of HDVs fuelled with natural gas and hydrogen fuel mixtures, reduction of CO, CO_2, NOx and HC emissions can be reached through the addition of hydrogen in natural gas [23]. Sharafian et al. [24] have estimated the implication of replacing diesel HDVs with LNG HDVs on Well-to-Wheel GHG emission in Canada and BC from 2014 to 2050. Results have shown the potential of GHG emission reduction in Canada and BC only if methane emissions are maintained at one gramCH_4/kgLNG (the low emissions case). Besides the technological improvement of vehicles and alternative fuels, one of the specific and potential transport measure for GHG emission reduction is eco-driving. Ayyildiz et al. [25] have presented that fuel consumption and CO_2 emissions from HDVs were significantly decreased after the training.

3.2 Demand Management Policies

Operational Strategies

Low Emission Zones: To improve the air quality limit values, low emission zones (LEZs) have been introduced [26]. Panteliadis et al. [27] have confirmed a significant decrease in NO_2, NOx, PM10, elemental carbon and absorbance concentrations after the implementation of LEZs in Amsterdam. Optimization of weight: Weight reduction –i.e., the application of lightweight components is one of the strategies for reduction of pollutant emissions and increment in fuel savings, specifically the truck market [28].

Management Strategies

Efficient vehicle routing was highlighted in the literature as one of the possible ways of reducing fuel consumption and emissions from HDVs. Based on the optimization approach for winter HDVs services, results in [29] have shown that a reduction of route length leads to lower fuel consumption (diesel) and CO_2 emissions.

3.3 Evaluation and Monitoring Tools

It is important to compute actual or / expected fuel consumption and emission before the implementation of any policy [30]. Techniques such as calculation models, bench tests, vehicle tests, and chassis dynamometer tests are used to compute emission factors [31]. Graham et al. [31] reviewed GHG emissions for different HDVs and engines using chassis dynamometer testing, and on-road testing of HDVs, and engine dynamometer testing.

Chassis Dynamometer test

The chassis dynamometer test is performed on an indoor bench under simulated work conditions. Since the test is unaffected by weather and other traffic conditions, this test provides improved accuracy, repeatability, and comparability for the measurements [32]. Numerous papers related to the measurement of emission factors from HDVs equipped with-or-without different control strategies and aftertreatment systems using the chassis dynamometer test are found in the literature.

On-road test

Some of the on-road tests such as PEMS (for NOx,CO,CO_2), PN-PEMS (to measure PN emission), global positioning system (GPS), data acquisition and a Quantum Cascade Laser Infra-Red (QCL-IR) (for NO, NO_2, NH_3, N_2O and NH_3) and Engine Control Unit (ECU) are used to measure real-time emissions [33](7).

Calculation and Simulation models

COPERT is a popular software to compute emissions. COPERT 4 can be used to review emissions and develop potential emission mitigation strategies [30]. Further, models such as PROGRESS (computer PROGramme for Road vehicle EmiSSions evaluation) code, ADVISOR simulator, Passenger car and Heavy-duty Emission Model (PHEM), COPERT and HBEFA were used to estimate emissions factors from HDVs equipped with different technologies and under different conditions. Likewise, several emission calculation models such as MODEM, PHEM, VeTESS, CMEM, ADVISOR, MOVES, EMPA, TEE, COPERT 4 and VERSIT +) were analysed in [34]and compared for HDVs, COPERT and MOVES in research studies.

3.4 Projects Related to Emission Reduction

Research attention is being focussed in Europe and outside to monitor, calculate and reduce the vehicular emission from GHG fleet. In 2005, Sturn and Hausberger [35] reported combined findings from the COST Action 346, the EU project ARTEMIS (Assessment and Reliability of Transport Emission Models and Inventory Systems) and 'Handbook on Emission Factors for Road Transport'(HBEFA). The report utilised emission model PHEM to calculate emissions and concluded that regular updates of the emission factors based on measurements for the actual engine technologies is highly relevant.

HBEFA and COPERT (COmputer Programme to calculate Emissions from Road Transport) are the two reference vehicle emission models in Europe where COPERT is used to report National Emission Inventories (NEI) of the EU member states. The project team has reported the emissions from public transport and passenger cars using COPERT using Environmental Protection Agency (EPA) funded Greening Transport project [36]. Moreover, VECTO (Vehicle Energy Consumption Calculation Tool) is a recently developed simulation tool to quantify the fuel consumption and CO2 emissions from HDVs based on the vehicle longitudinal dynamics. Development and upgradation of VECTO were the parts of LOT 4 [37], LOT 2 [38] and LOT 3 [39] projects. In relation to monitoring emission, the evaluation of the methodology (VECTO) proposed for the monitoring and certification of CO2 emissions from HDV in Europe has been investigated (Zacharof et al. [40]).

In the UK, the Green Logistics project investigated estimating and forecasting environmental and economic impacts of logistics using existing data such as freight survey CSRGT (Continuing Survey of Road Goods Transport) data. This multi-university project investigated several key research areas in this field including the pollution mitigation measures such as: vehicle rerouting & scheduling according to prevalent traffic conditions; investigating scopes of modal shift; looking into loading of vehicles etc.[41], In other European studies, for emission reduction in urban areas, Low Emission Zones (LEZ) has been investigated which looked into diverting traffic from congested urban arterials and concluded that it is not easy to calculate or estimate the effect of these measures on air quality due to day to day variations and effects of meteorological conditions [42].

Many of the European Union and other non-European countries have implemented education-based strategies to reduce GHG emission from HDVs. Eco-driving is one of the widely adopted methods for passenger cars compared to HDV to reduce emissions. The KEY project [43] in the Finland, is the first project for Eco-driving. Since 1995, starting with Finland (KEY project), then Netherlands, Germany and many other European countries have adopted eco-driving in HDV. ECOeffect [44] focused on developing an eco-driving training scheme in the Czech

Republic, Poland and Romania. This project concluded that one-day training program and correct monitoring would result in 5 to 9% reduction in fuel consumption. Likewise, projects such as ECOWILL [45], ECODRIVEN [46], TREATISE [47], and FLEAT [48], ACTUATE [49] focused on reducing the emission using eco-driving. Some survey-based studies [50] some simulations [51,52], some modelling-based studies [53] have analysed the effectiveness of eco-driving in the freight sector. Eco-Driving Training (EDT) is a key aspect of its implementation and some researchers have looked into EDT in terms of standardisation (ECOWILL [45]), implementation (SAFED [54]). In Ireland, in the National Mitigation Plan (2017), an education initiative (Measure T-22) related to encouraging eco-driving for heavy duty vehicles (including freight) through incentivising has been proposed for consideration[55].In Germany, Rothengatter and Doll [56] pointed out that higher user charge on the whole network of federal roads for HDVs with a given level on improved service of the railways could be a solution to reduce emissions. Further, for diesel HDVs additional measures were proposed within three cities of China (Shanghai, Nanjing and Wuxi in Jiangsu): increase the population share of natural gas and battery electric buses, phase out all pre-Euro III trucks registered before 2007, and retrofit Euro III diesel trucks by adding SCR systems [57].

3.5 Policies and Legislation

Ireland's national target is to reduce GHG emissions by 20% from 2005 levels by 2020 following the European National Emissions Ceilings (NEC) Directive. In addition, the new NECD (2016/2284/EU) [58] would require Ireland to reduce NOx (oxides of nitrogen) and particulate matter levels by 49% & 18% respectively from 2005 levels for the period of 2020-2030. At European level, European Commission (EC) has developed policies and undertaken strategies such as, 'HDV strategy' (COM (2014) 285) [59] adopted in 2014 and the 'low-emission mobility strategy' COM/2016/0501) adopted in 2016 to reduce externalities such as air pollution from HDV sector. At National level, National Policy Framework (NPF) on Alternative Fuels Infrastructure for Transport in Ireland - 2017 to 2030 developed by DTTaS indicates eco-driving technique to be a possible measure to reduce GHG emission [60]. The National Mitigation Plan (NMP) published by Department of Communications, Climate Action and Environment (DCCAE) in 2017 reiterates that the growth in the economy may increase the pollution and GHG emission from HDV fleet in Ireland [61]. In addition to alternative fuels, both NPF and NMP indicates exploring other options including, eco-driving techniques. The EPA-United States introduced Cleaner Truck Initiative (CTI) on November 13, 2018, to update emission standard for NOx from HDVs and their engines. However, the details regarding the emission standards are still not available and expected to publish it by early 2020 [62].

Following the legislative proposal on 17th May 2018 by the European Commission, a new EU regulation 2019/1242 will be enforced from 14th August 2019, setting new standards for CO2 emission for new heavy-duty vehicles. This legislation focused on reducing CO2 emissions from new trucks by 15% lower in 2025 compared to 2019. The new regulation aims at providing incentives to encourage zero and low emission vehicles [63]. The regulation also helps to reduce fuel consumption costs for smaller and medium enterprises (SMEs) and consumers and to uphold the leadership of EU suppliers and manufacturers in technology.

Conclusions and future work

Over the last decade, the primary and intensive topic of research among scholars is the reduction of energy consumption and environmental impact caused by the transport system. One of the significant contributors to energy consumption and endangerment of the environment in the world has been the overall transport sector. Among all modes of transport, especially heavy-duty vehicles, was recognized as the significant energy consumer and contributor to air pollution. Many of the research articles have evaluated potential mitigation measures for the reduction of emissions and fuel consumption. A potential possible solution that can be implemented to reduce emissions from HDVs were summarized in this paper. Also, possible techniques for evaluation and monitoring of emissions and fuel consumption of HDVs were presented.

Based on the literature review, we found that several potential solutions that can be implemented for HDVs. Some of the potential solutions could be alternative fuels, alternative/ advanced engine technologies, the introduction of combustion and aftertreatment strategies, the implementation of emission standards. Vehicle routing and weight optimization of the vehicle were also suggested in past research. Furthermore, the introduction of higher user charge and low emission zones, as well as modal shift to an environmentally friendly mode of transport (railway) were proposed as potential measures to reduce emissions. Among all of those measures, as the most appropriate and efficient for implementation in HDV fleet can be the introduction of alternative fuels. Some of these measures, such as advanced engine technologies and combustion and after-treatment strategies, cannot be easily implemented as they required a long time and require significant capital investment for implementation. Therefore, in terms of the cost and the time consumption, vehicle rerouting, low emission zones, eco-driving and shift to an alternative mode of transport (railway) could be better options in comparison with others for implementation in Irish HDV fleet. SAFED is one of the successful projects to reduce emissions from HDVs. The findings from the SAFED program could help policymakers and practitioners to develop a policy to reduce emissions from HDVs.

To create the right solution for the reduction of HDVs emissions, different techniques for testing and simulation of HDVs under different conditions should be evaluated before implementation. Also, before implementing any strategy or policy, a pilot study should be conducted within a city/country to assess the possible outcomes from the implementation.

For future work, the focus should be on testing these solutions for implementation in the Irish HDV market. Based on that, alternatives fuels, eco-driving and control strategies will be further investigated as a potential solution to reduce emissions from Irish HDV fleet. Then, measures such as the optimization of loading and vehicle routing will be explored for implementation.

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