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Sustainable Energy Authority of Ireland

National Energy Research, Development & Demonstration Funding Programme

FINAL REPORT TEMPLATE

SECTION 1: PROJECT DETAILS – FOR PUBLICATION

Project Title	**M**itigation of **A**ir **P**ollution Impacts of Irish **H**eavy **D**uty **V**ehicles (MAP-HDV)
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Report Submission Date	

	Name	Organisation
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Project Summary (max 500 words)

Road freight transportation is a key enabler of economic activity in Ireland, but the industry is mostly dependent on fossil fuels for its energy source, which presents a challenge in realising a low-carbon future. Ireland has adopted a Climate Action Plan and aims to achieve net-zero emission by 2050 (NZE2050), which created the imminent need for addressing the issue of tackling vehicular emission from the Irish Heavy-Duty Vehicles (HDV) fleet.

The main objective of the MAP-HDV project was to investigate emission mitigating measures for reducing the level of emissions from the Irish HDV sector. To achieve the objectives of the MAP-HDV project several approaches, such as detailed literature review, application of simulation tools (COPERT 5 and VECTO), in-person interviews with haulage company owners, and online-survey, were conducted. An extensive overview of various possible mitigation measures applied in Europe and Internationally, tools for estimation and evaluation of emissions and fuel consumption, as well as estimation of the current and future emissions from HDV fleet using COPERT tool has been provided. Further, the Vehicle Energy Consumption Calculation Tool (VECTO) has been utilized for the first time in Ireland for estimation of Greenhouse Gas (GHG) emission and fuel consumption. The influence of loading, alternative fuels, after-treatment technologies, speed, mileage share and road slope on fuel consumption and emissions has been estimated using COPERT 5 model and VECTO tool through scenario analyses.

The emission levels from Irish HDV fleet for average loading of 50% were calculated using COPERT5 emission calculator which showed a total 1367kt of CO2 emission for the year 2018. Approximately, half of this emission was generated from HDV fleet in 2-5t unladen weight category for all EURO classes and showing an increasing proportion for newer emission standards. Alternative fuels, after-treatment technologies, weight optimisation, speed and related strategies have shown to improve fuel efficiency and reduce emissions in HDV fleets. By evaluating the potential environmental and economic impacts and long-term sustainability of multiple measures a suite of the most suitable measures has been recommended for possible implementation. Further, through a detailed survey of stakeholders, the top mitigation measures favoured by the stakeholders were identified.

Keywords (min 3 and max 10)	Heavy Duty Vehicles (HDV), Freight, CO_2 reduction, Pollution Mitigation, Evaluation, COPERT, VECTO, Cost-Benefit Analysis

NB – Both Section 1 and Section 2 of this Final Report will be made publicly available in a Final Technical Report uploaded online to the National Energy Research Database.

In the following Section, please provide a clear overview of your project, including details of the key findings, outcomes and recommendations. The section headings below are provided as a guide, please update or add to these as best suits your project.

By submitting this project report to SEAI, you confirm you are happy for Section 1 and Section 2 of this report to be made publicly available. If you wish to request edits to this section in advance of publication, please contact SEAI at EnergyResearch@seai.ie.

SECTION 2: FINAL TECHNICAL REPORT – FOR PUBLICATION (max 10 pages)

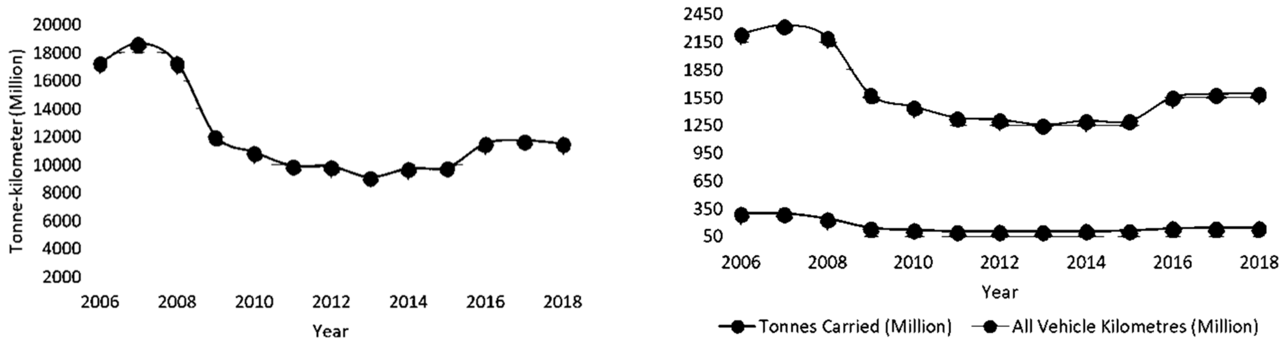
2.1 Executive Summary

In Europe, Heavy-Duty Vehicles (HDVs) are responsible for 27% of CO_2 emissions and almost 5% of EU's GHG emissions while in Ireland the transport sector (40%) accounted for the largest share of energy-related CO2 emissions followed by heat (33%) and electricity generation (27%) in 2018. Irish HDV fleet is approximately responsible for 14% of this transport emission (SEAI, 2020). The main objective of the MAP-HDV project was to investigate emission mitigating measures for reducing the level of emissions from the Irish HDV sector.
As a first step, the current emission levels from exiting HDV fleet was estimated using COPERT5. The emission levels from Irish HDV fleet for average loading of 50% were calculated which showed 1367kt of CO2 emission for the year 2018. Approximately, half of this emission was generated from HDV fleet in 2-5t unladen weight category for all EURO classes and showing an increasing proportion for newer emission standards. The emission levels from HDV are projected for 2030 and 2050. The HDV fleet projection indicated that, the growth of the vehicles in 2-5t unladen weight categories will be much faster than other categories and the emission from this category is expected to be the largest amongst Irish HDV fleet in 2030 and 2050. The Nitrogen Oxide levels will fall sharply with fleet renewal as the emission from older diesel trucks (<EURO5) are the main source of this pollutant. In business-as-usual situation, GHG emission levels will continue to increase for all categories except for vehicles in 7.5-12t unladen weight category. However, this projection calculation did not consider any alternative fuel vehicles as they are not widely available in Ireland yet.
For effective CO_2 certification and monitoring European Commission (EC) has developed the Vehicle Energy Consumption Calculation Tool (VECTO) to evaluate fuel consumption and CO2 emissions from HDVs. In MAPHDV project, the VECTO tool has been effectively used. This is the first application of VECTO in Ireland. Further, VECTO was applied for monitoring the influence of speed, acceleration, loading factor and after-treatment systems on fuel consumption and CO2 emissions. Modelling was carried out for some specific models of trucks as the detailed data necessary for wider application of VECTO was not available. A key recommendation of this project is improved data collection for Irish HDV fleet. For effective decarbonisation in future, it will be necessary to improve data collection, access and archiving in this sector. The analysis indicated CNG to be the most suitable for reduced fuel consumption while in terms of fuel consumption for Rigid Truck for all (long haul, regional and urban) driving cycle mode with low (LL) and reference loading (RL). However, the lowest level of CO_2 from Rigid Truck 4x2 can be achieved with Ethanol PI and CI. Fuel consumption and emissions can be reduced with the improvement of driver efficiency. Average speed, overrevving, idling, hard acceleration, hard deceleration, coasting, number of brakes and stops are parameters that directly influence on driver efficiency.
Further, cost-benefit analysis (COBA) was carried out for evaluating the after-treatment systems as a mitigation measure for the Irish HDV sector. Illustrative COBA was carried out for Selective Catalytic Reduction (SCR) and diesel particulate filter (DPF) technologies considering environmental costs; SCR is only beneficial (1:5) for EURO6 heavier HDV and in all other cases the installation and maintenance of these technologies are not cost effective.

The acceptability of the pollution mitigation measures chosen through modelling and simulation analysis was investigated through a detailed (two-step) survey of policy makers, practitioners and stakeholders. The stakeholders considered, use of alternative fuels, upgrading to the EURO 6 fleet, loading within the permitted limit, driver training programs and use of anti-idling devices as the top five measures to reduce fuel consumption and emissions. Policies supporting these will be favoured by the freight industry.

2.2 Introduction to Project

In the European Union (EU), road vehicles account for one-fifth of Europe's total GHG emissions. HDVs are responsible for 27% of CO_2 emissions from road transport and almost 5% of the EU's GHG emissions[1].
In Ireland, the transport sector accounted for the largest share of energy-related CO_2 emissions, 40% in 2018. The Irish HDV fleet contributes approximately 14% of all road-transport related GHG emissions[2]. The transport sector is dependent on fossil fuels, and CO_2 emissions from the transport sector are expected to increase in the absence of a fuel mix. According to the 'Transport Trends 2019' report by the Department of Transport, Tourism and Sport (DTTaS) (Department of Transport, 2019), road freight activities have significantly increased indicating an upward future trend (Figure 1).



(a) Road Freight activity over the years (Source: CSO)

(b) Road Freight activity in years in terms of tonnes carried and vehicle kilometres (Source: CSO,2018)

Figure 1 Road Freight activity over the years (Source: CSO,2018)

Figure 2 Quantity of goods hauled by types of work (Source: CSO, 2018)

However, due to COVID-19 and Brexit, the expected improvement in the economy and resultant freight activities may not materialise. In the year 2018, a total of ~150 million tonnes of goods were transported by road covering 1,595 million kilometres distance[3]. Overall, the total tonnes of goods transported in 2018 was 1.9% higher than in 2017 (Figure 1 (b)). It was estimated that in 2018, 118,032 Irish registered good vehicles (trucks > 2 tonnes) operated in Ireland and abroad, which was 8.8% higher than in 2017. Based on the types of goods, in 2018, over 50 million tonnes of goods were transported for road work and building sites followed by retail outlets deliveries, (~17 million tonnes) as presented in Figure 2.

To mitigate emissions from HDVs, several European policies, initiatives, and actions have been launched to address the disadvantages of the HDV sector (Grigoratos, Fontaras, Giechaskiel, & Zacharof, 2019). The EC has listed three main strategies to reduce emissions from the transport sector (EU commission MEMO-16-2497), which are as follow: 1) Increase in efficiency by the use of digital technologies, 2) Use of alternative fuels 3) Encouraging low/zero-emission vehicles.

As indicated in the '**European Strategy for Low-Emission Mobility** '(COM/2016/0501) it is necessary to focus on the HDV fleet which represents less than 5% of road vehicles in the EU but produces about 25% of CO2 emissions from road transport in the EU28. The commission introduced **Regulation (EU) 2019/1242** setting CO2 emission standards for HDVs in August, 2019. Irish HDV fleet is anticipated to account for about 3Mt of CO2 emissions by 2030. The Irish Government has recently published a **Climate Action and Low Carbon Development (Amendment) Bill 2021** which seeks to halve Ireland's greenhouse gas (GHG) emissions to 31 Mt CO2eq by 2030. In the Irish Sustainable Mobility Policy Review these EU regulations have been identified for the Irish HDV sector: CO2 emissions for HDVs must be lower than those taken from a reference period of July 2019 - June 2020 by 15% by 2025 and by 30% by 2030. From 2019, HDV manufacturers must also calculate the CO2 emissions and fuel consumption of all new vehicles (above 7.5 tonnes) produced for the EU market, using the new Vehicle Energy Consumption Calculation Tool (VECTO).

2.3 Project Objectives

The key objectives of the project are as follows:

- Reporting on state-of-the-art on demand and fleet management methods that has been employed in Europe and globally to reduce vehicular emissions including CO2 emissions and other harmful pollutants.
- Estimation of air pollutant and Greenhouse Gas (GHG) emission levels from the existing HDV fleet utilising European standard emission estimation software tool COPERT5. The levels will be projected for Business-as-Usual (BaU) case to year 2050.
- Illustrative examples of estimation of fuel consumption and CO2 emission from HDV vehicles
- Cost calculation for fleet management policies which are utilised to reduce emissions
- Perception and identification of policies (fleet management, demand management, alternative options) and methodologies to mitigate pollution from HDG fleet amongst policy makers, practitioners and stakeholders

2.4 Summary of Key Findings/Outcomes

Based on available literature and research reports, alternative engine and vehicle technologies, combustion techniques and alternative fuels have been found as helpful fleet management measures for reducing fuel consumption and emissions in Europe and internationally. Amongst various demand management measures low emissions zones, optimization of weight and vehicle rerouting can mitigate emissions and fuel consumption. To evaluate the effectiveness of any mitigation measures in Ireland, it is necessary to estimate the existing conditions. Current emission levels from exiting HDV fleet was estimated using COPERT5.

In COPERT, HDV fleet configuration classified by EURO standards, fuel types, average kilometres travelled, energy consumed, loading, driving conditions, average speed and metereological information were provided as inputs. The results are presented in Table 1.

Table 1: Pollutant Emission Levels from Irish HDV fleet in 2018

Pollutant	Unladen Weight	Emissions (tonnes)					
		Euro2	Euro3	Euro4	Euro5	Euro6	Total
CO_2	<=7.5t (without 2-5t)	1569.64	6428.62	9045.91	5818.89	19988.76	42851.82
	<=7.5t	7833.71	59133.52	157693.41	73217.17	462400.56	1366727.16
	7.5 - 12t	5382.70	30429.14	63602.05	26430.90	148113.42	
	12 - 14t	1933.77	22099.31	62008.70	28829.34	217619.47	
CO	<=7.5t (without 2-5t)	2.24	8.62	6.85	9.84	1.92	29.47
	<=7.5t	11.17	79.26	119.45	123.87	44.48	761.89
	7.5 - 12t	9.04	50.84	53.36	46.54	19.61	
	12 - 14t	3.49	40.27	56.13	58.82	45.57	
NOx	<=7.5t (without 2-5t)	16.75	47.89	47.81	11.53	1.62	125.61
	<=7.5t	83.59	440.50	833.52	145.10	37.52	1541.41
	7.5 - 12t	59.33	237.89	355.91	58.13	29.46	
	12 - 14t	21.27	177.79	354.53	72.70	48.80	
$PM_{2.5}$	<=7.5t (without 2-5t)	0.47	1.46	1.31	0.86	2.18	6.29
	<=7.5t	2.36	13.47	22.85	10.87	50.45	168.59
	7.5 - 12t	1.64	6.84	7.91	3.36	12.24	
	12 - 14t	0.61	5.17	7.54	4.07	19.21	
PM_{10}	<=7.5t (without 2-5t)	0.62	2.04	2.11	1.40	3.99	10.16
	<=7.5t	3.10	18.79	36.87	17.57	92.26	279.35
	7.5 - 12t	2.03	8.93	12.31	5.17	22.19	
	12 - 14t	0.74	6.63	11.68	6.19	34.88	
N_2O	<=7.5t (without 2-5t)	0.02	0.04	0.16	0.29	0.93	1.43
	<=7.5t	0.08	0.38	2.75	3.67	21.41	55.10
	7.5 - 12t	0.04	0.15	0.86	0.99	5.10	
	12 - 14t	0.03	0.20	1.50	2.32	15.61	
NMVOC	<=7.5t (without 2-5t)	0.31	1.05	0.41	0.11	0.41	2.29
	<=7.5t	1.54	9.70	7.12	1.37	9.37	60.99
	7.5 - 12t	1.46	6.87	2.96	0.51	3.66	
	12 - 14t	0.56	5.44	3.11	0.68	6.65	
VOC	<=7.5t (without 2-5t)	0.42	1.48	0.45	0.13	0.49	2.97
	<=7.5t	2.11	13.58	7.77	1.67	11.29	73.04
	7.5 - 12t	1.75	8.40	3.16	0.59	4.12	
	12 - 14t	0.66	6.50	3.30	0.77	7.36	

Irish HDV fleet data recorded vehicle registration years and not emission standards. So, emission standards were assumed based on vehicle registration years; All vehicles introduced since 2015 were identified as EURO6 and further classification within this emission standard was not possible in COPERT. In Table 1, the emission levels from Irish HDV fleet for average loading of 50% were calculated which showed 1367kt of CO2 emission for the year 2018. Approximately, half of this emission was generated from HDV fleet in 2-5t unladen weight category for all EURO classes and showing an increasing proportion for newer emission standards.

Using COPERT5, the emission reduction potential of after-treatment systems, reduced loading, speed, mileage share and road slope were analysed. The results obtained from all designed scenarios illustrated that reduction of loading reduced emission levels of major pollutants. CO emission were reduced when after-treatment systems were used especially for EURO5 vehicles.

From 1 January 2019, the Vehicle Energy Consumption calculation Tool (VECTO) should be used for determining CO2 emissions and Fuel Consumption from HDV. For monitoring and reporting used VECTO, detailed information regarding engine, gearbox, vehicle specifications required to be used. Due to lack of availability of information from all or a large section of Irish HDV fleet, illustrative examples using two generic trucks, Rigid Truck 4x2 and Tractor 4x2 were calculated. The results indicated that Tractor 4x2 consumes 34,78 l/100km while Rigid Truck consumes 20,91 l/100km. However, regarding the fuel consumption per 100tkm, Rigid Truck 4x2 requires more fuel (-i.e., 6,92l/100tkm) than Tractor 4x2 which uses 1,80 l/100tkm. Regarding the CO_2 Tractor 4x2 produces 910,2 g/km and Rigid Truck 4x2 produces 547,1g/km, while Rigid Tuck produces 181,2 g/tkm and Tractor 4x2 47,2 g/tkm of CO_2.

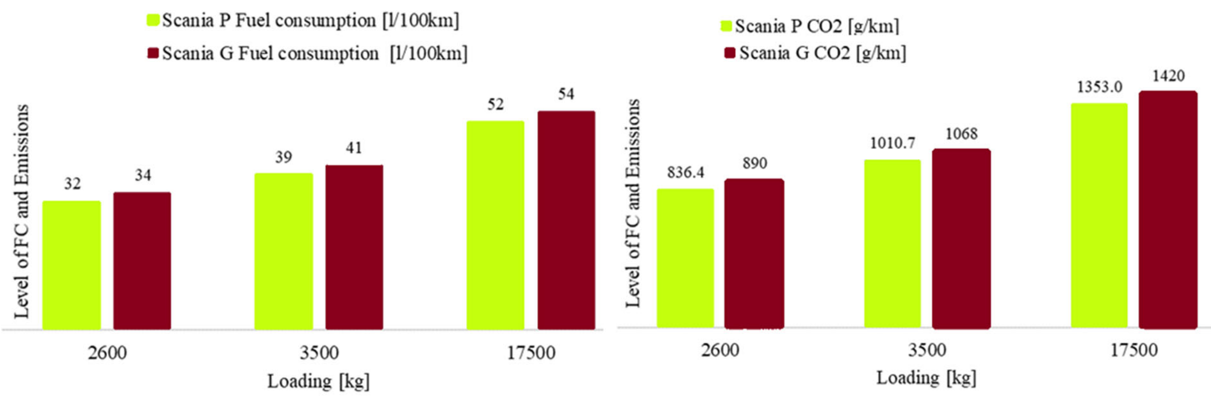


Figure 3 Excerpts of VECTO calculations

Then, using VECTO tool fuel consumption and CO2 emission have been simulated for two Scania trucks under different amount of loading. Results have shown that Scania G use more fuel and produce more CO2 emission in comparison with Scania P. Also, results indicated that the highest amount of fuel and level of CO2 is related to the high amount of loading (Figure 3).

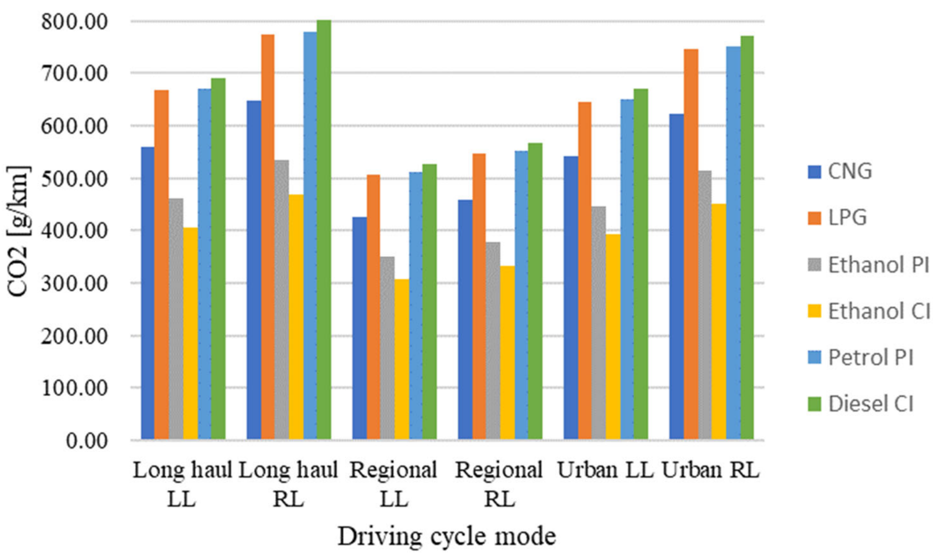


Figure 4 CO2 emissions from Rigid Truck for variation in fuel type

Influence of speed and acceleration, alternative fuels and loading on fuel consumption and emissions from individual trucks were estimated using VECTO. Results related to the dependence of fuel consumption and speed and acceleration indicated that lower fuel consumption was achieved with reduced acceleration/deceleration, while increased fuel consumption was presented with increasing speed and acceleration. In terms of fuel consumption for Rigid Truck the best alternative fuel was CNG for all (long haul, regional and urban) driving cycle mode with low (LL) and reference loading (RL). However, the lowest level of CO_2 from Rigid Truck 4x2 can be achieved with Ethanol PI and CI. Then, the least consumption of fuel and CO_2 production were obtained under regional low loading mode.

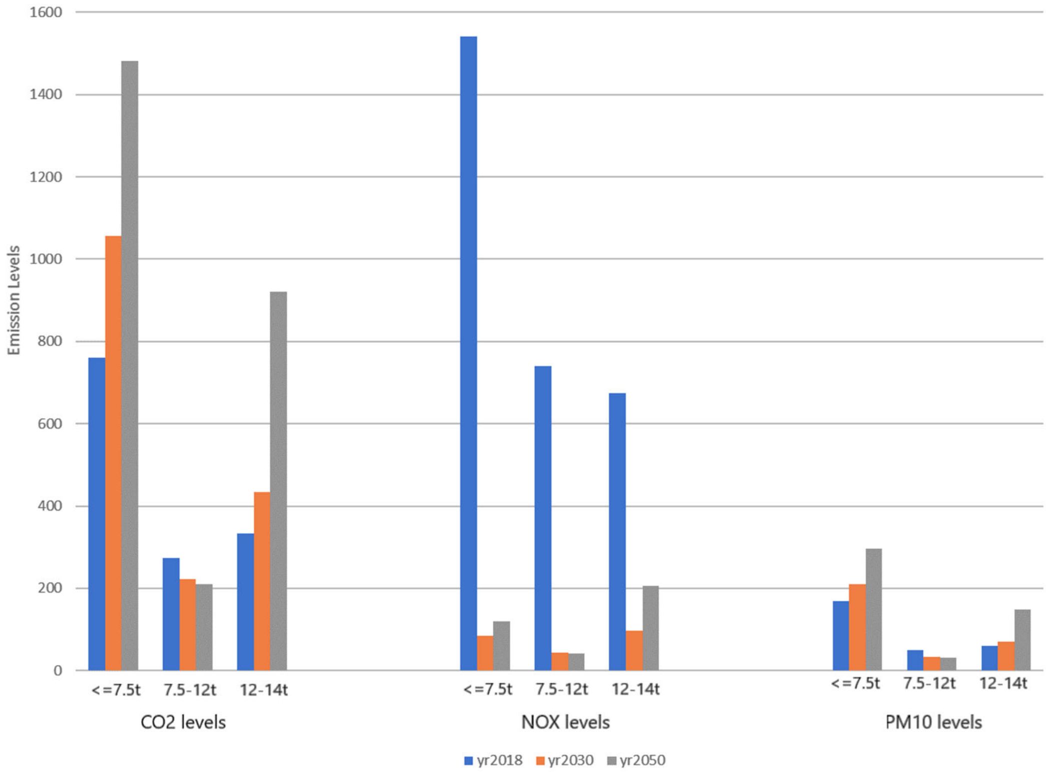


Figure 5 CO2 emissions from Irish HDV fleet in 2030 and 2050

The emission levels for the year 2030 and 2050 are shown in Figure 5. In 2018, the main contribution of NOX levels are from older EURO engines, while in 2030 and 2050 the emission levels are highest in lower unladen weight categories especially from 2-5t. The increase in emission levels in 2050 show that while continuing with diesel HDV trucks (EURO6), it will not be possible to meet the emission reduction targets of EU.

Illustrative cost-benefit analysis (COBA) was carried out for Selective Catalytic Reduction (SCR) and diesel particulate filter (DPF) technologies considering environmental costs; SCR is only beneficial (1:5) for EURO6 heavier HDV and in all other cases the installation and maintenance of these technologies are not cost effective.

The acceptability of the pollution mitigation measures chosen through modelling and simulation analysis was investigated through a detailed (two-step) survey of policy makers, practitioners and stakeholders. The first step in-person interviews were carried out as a pilot survey. In second step, a series of questions about potential mitigation measures for reducing fuel consumption and emissions were asked to haulage company owners, policy makers and other stakeholders by an online survey. Respondents stated that biodiesel (91% of respondents), hydrogen-powered (80% of respondents), CNG (78% of respondents), LPG (75% of respondents), and electric (55% of respondents) trucks are extremely likely or very likely to be seen in near future as shown in Figure 6. However, 57% of respondents stated that autonomous trucks are very unlikely to be seen in the near future.

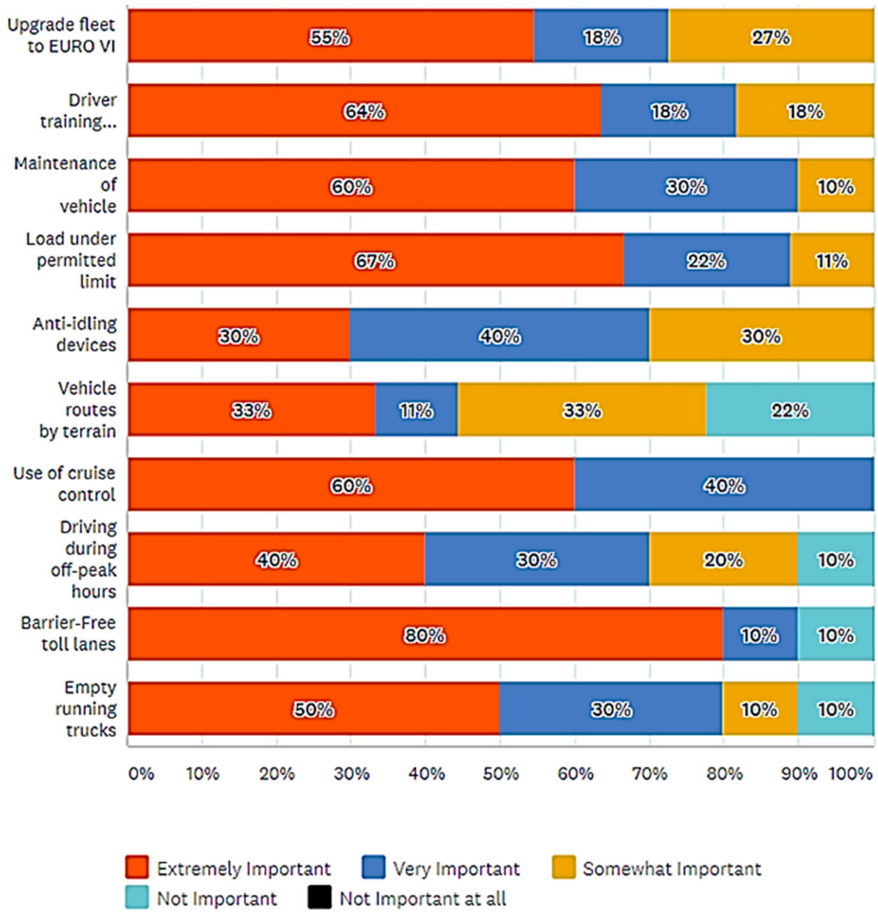


Figure 6 Perception of haulage company owners on several measures to reduce fuel consumption.

Based on all the abovementioned analysis a set of policy measures are proposed.

2.5 Project Impact

The analysis and results of MAP-HDV project are essential to inform policy in this sector. The MAP-HDV project investigated a suite of pollution mitigation measures to reduce vehicular emission and improve energy efficiency including increased use of renewable energy in the Irish HDV fleet. The project aims and objectives were linked with and relevant to the Irish energy sector, SEAI and Irish transport sector and EPA Ireland.

From a national policy perspective as well as from the legislative obligation of member states it was essential to carry out research in this area at this time to improve the energy efficiency of the HDV fleet in Ireland in conjunction with the reduction of GHG emission levels. The project is aligned with multiple important national policies and planning frameworks as well as the newest European directives: **Climate Action Plan, Climate Action and Low Carbon Development (Amendment) Bill 2021, 2030 Climate & Energy Framework, European Strategy for Low-Emission Mobility (COM/2016/0501), Regulation (EU) 2019/1242, National Emissions reduction Commitments (NEC) Directive (2016/2284/EU), National Policy Framework on Alternative Fuels Infrastructure for Transport, CNG Vehicle Grant Scheme, 'Eurovignette' Directive 1999/62/EC.**

It was critical to carry out research to inform policy makers and practitioners in relation to achieving sustainability in road transport sector in this country. In MAPHDV project emission levels, the impacts of different mitigation measures and the effect of them in the Irish context were provided which provide the necessary evidence base for policy makers.

2.6 Recommendations

Potential measures that can be implemented to reduce emissions from Irish HDV fleet are summarized in this section.

- The results of MAP-HDV project indicated that, the growth of the vehicles in 2-5t unladen weight categories will be much faster than other categories and the emission from this category is expected to be the largest amongst Irish HDV fleet in 2030 and 2050. Accordingly, specific policies to control the growth should be considered for decarbonisation of the sector.
- Older diesel vehicles are the biggest contributors to NOX emissions in Ireland and fleet renewal to EURO VI engine is essential to control this. In relation to GHG emissions, Ethanol CI seems to be the most promising alternative fuel type for the Irish HDV fleet while CNG seems to be most appropriate for reduction in fuel consumption. These results were illustrated through analysis using VECTO tool.
- Through COPERT based scenarios analyses, it was established that optimisation of loading can be a key factor in reducing fuel consumption and emission from HDV fleet. Consequently, policies to reduce empty loading should be adopted along with introducing physical internet based supply chains.
- The COPERT software which is traditionally used for estimating transport emission cannot consider alternative fuels for HDV fleet. Consequently, VECTO tool should be adopted immediately for evaluating the effect of alternative fuels on HDV fleet.
- It is widely accepted that the easiest, immediate method for reduction of emission from Irish HDV fleet can be using after-treatment technologies. Implementation of these systems contribute to emissions reduction, but both entail significant costs. The effectiveness of them were tested through cost calculation. The implementation of SCR in trucks except EURO6 have significantly higher costs in comparison to benefits, so this technology should be only used for EURO6 vehciles.
- Fuel consumption and emissions can be reduced with the improvement of driver efficiency. Average speed, overrevving, idling, hard acceleration, hard deceleration, coasting, number of brakes and stops are parameters that directly influence on driver efficiency.
- The stakeholders considered, use of alternative fuels, upgrading to the EURO 6 fleet, loading within the permitted limit, driver training programs and use of anti-idling devices as the top five measures to reduce fuel consumption and emissions. Policies supporting these will be favoured by the freight industry.
- 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.
- One of the key challenges of MAP-HDV project was lack of availability of detailed data on Irish HDV fleet. For effective decarbonisation in future, it will be necessary to improve data collection, access and archving in this sector.

2.7 Conclusions and Next Steps

Over the last decade, the primary and intensive topic of research 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 has evaluated potential mitigation measures for the reduction of emissions and fuel consumption. In this project potential of loading, after-treatment technologies, alternative fuels, speed and acceleration, and road conditions for reducing emissions and fuel consumption from HDVs were analysed using VECTO and COPERT simulation tools. The promising measures in mitigation pollution from HDVs can be usage of alternative fuels, optimization of loading and implementation of after-treatment technologies. Although the after-treatment technology can be useful for reducing emission the main issue about it are costs. Therefore, in the project a cost-benefit analysis of SCR and DPF has been conducted. Based on the results, signifact benefits are expected for SCR for Euro VI HDVs.

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

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