Examining alternative fuel options and potential emission reductions from changes in public transport bus fleet in Ireland

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Abstract

Shifting to alternative fuel options, such as bio-CNG, electricity powered buses in public transit play an important role in reducing the environmental impacts of fossil fuels. Ireland's target is to reduce its greenhouse gas (GHG) levels by 30% in 2030, relative to its 2005 levels (European commission, 2017), which are expected to increase by 14% (EPA, 2017). Public transport offers a wider scope to reduce emission levels on a large scale. While alternative fuel options are successfully being used by other countries, public transport bus fleet in Ireland is almost entirely dependent of fossil fuels. Thus, this paper aims to study the current emission levels resulting from the major public transport bus services (Dublin Bus and Bus Éireann) operating in Ireland and the potential of emission reductions from use of alternative fuel and technologies that are available for buses. Three popular alternative fuel options, CNG (compressed natural gas), bio-CNG and electric buses were evaluated in terms of their potential to reduce emission levels. Additionally, possible emissions reductions from bus fleet renewed with euro 6 buses and enhanced environmental vehicles (EEV) were calculated. It has been found that only by renewing the fleet with diesel fuelled euro 6 compliant buses, the CO_2 (carbon dioxide) emissions can be reduced by 5%. Also, if urban bus trips are replaced by electric buses, CO_2 emission levels can be reduced by more than 90%. Total energy consumptions in these scenarios were calculated and land area required for grass silage to fulfil the feedstock demand for bio-CNG were calculated based on diesel energy density. Additionally, cost savings due to reduction in emission levels with the use of these fuel options were also presented. The land area required for grass silage to meet the annual biogas demand for public transport bus operation was estimated to be 21091 hectares (ha).

Keywords: Public service bus; greenhouse gas; alternative fuel; alternative technology; air pollutants; Bio-CNG; emissions reduction; damage cost; energy consumption; feedstock

Introduction

Road transport constitutes a major source of air pollution. This has a huge impact on human health, especially in urban areas where the population and vehicle densities are high. Road transport contributed to 18.5% greenhouse gas emissions in 2015 (EPA, 2017). The greenhouse gas emissions from the transport sector has increased by 130.3% and from road transport alone by 136.7% compared to 1990 emission levels (EPA, 2017). Ireland's target is to draw 10% of all transport energy from renewable sources by 2020. Ireland has an overall target to reduce the GHG by 20% and 30% by 2020 and 2030 respectively relative to 2005 levels. Alternative fuel options such as LPG (liquefied petroleum gas), CNG, bio-CNG are available for buses and they have significant potential in reducing emissions. Public transport bus fleet allows introduction of alternative fuel options and reduction of emissions on a large scale.

The most effective measure to reduce emission levels is fleet renewal with potential to reduce emissions on an average by 16.04% for all major pollutants, CO (Carbon monoxide), CO_2, NOx (Oxides of nitrogen), SO_2 (Sulphur dioxide), $PM_{2.5}$ (Particulate matter less than 2.5 micron), PM_{10} (Particulate matter less than 10 micron), CH_4 (Methane) (Lumbreras et al., 2008). Several researchers have studied the potential of alternative fuels such as natural gas, fuel cell in reducing emission levels (Cohen, 2005; Karlstrom, 2005, Goncalves et al., 2009). Bio-CNG, electric buses are successfully being used by other European countries. Since 2002, there have been 9000 tonnes of CO_2 reduction per year from buses after implementing biogas use produced from organic waste in Sweden (IEA, 2013). It has been estimated that, in 2020, 18% of the total EU buses will be CNG, LPG powered and 30% will be hybrid, electric and fuel cell powered (Mahmoud et al., 2016). CNG has 113% fuel cost savings over gasoline and 57% over diesel buses (Khan et al., 2015). Biomethane is one of the most indigenous nonresidue European transport biofuels and has potential to reduce emissions by 75% (Korres, 2010). Ryan and Caulfield (2010) examined optimal fuel type for urban bus operations in Dublin and concluded that only renewing the fleet with better technology will not be enough measure to reduce the emission levels significantly, therefore, incorporation of alternative fuel options is necessary. Biomethane is renewable and offers reduction of around 80% CO_2 compared to diesel if produced from municipal waste (Baldwin, 2008). Electric buses have zero TTW (tank to wheel) emissions but the well to tank (WTT) emissions need to be considered. If the electricity is produced from renewable sources then the WTT emission for battery electric buses is as low as 20 gCO_2eq/km (Mahmoud et al., 2016).

In this study, alternative fuel and technology options that are currently available for bus fleet and their potential in reducing greenhouse gas and exhaust air pollutants are examined. This task has been achieved by designing hypothetical alternative scenarios and calculating emission levels corresponding to each designed scenario. The buses that are currently in use are of Euro 3, 4 and 5 technology classes which have different emission standards. The scenarios are designed by considering replacement of the present bus fleet with different percentages of available technology options (e.g. euro 6, EEV) and fuel alternatives such as, CNG, bio-CNG and battery electric. The emission levels of all the major air pollutants, namely, CO, CO_2, NO_2 (Nitrogen dioxide), NO (Nitric oxide), $PM_{2.5}$, PM_{10}, VOC (Volatile organic compound), N_2O (Nitrous oxide), NMVOC (Non-methane volatile organic compound) emitted by the current public transport bus fleet as well as for the alternative scenarios were estimated using COPERT 5 (Computer Programme to calculate Emissions from Road Transport). COPERT is developed to calculate emissions from road transport in European countries (EMISIA, 2014). Researchers have used COPERT to calculate emissions from buses (Ryan and Caulfield, 2010; Alam et al., 2015) in Ireland.

The findings of this study will report the possible emissions savings from the alternative fuel and technology uptake which will reflect their potential in reducing emissions from public transport bus sector. This study considers Dublin bus and bus Éireann which are the main public service bus operators in Ireland with total 1441 buses in the current fleet (NTA, 2016). The emission levels from CNG, Bio-CNG, electric buses were modelled and the emission savings were compared to the conventional diesel fuelled buses. The final energy consumptions in these scenarios have been reported. With urban public service buses being replaced by electric buses can reduce the CO_2 emissions by 94% followed by bio-CNG which offers 57% savings in emission levels. 21091 hectares of life cycle land area is required to replace the bus fleet studied. It was calculated that the pollutants resulting from the bus fleet examined in this study have caused 10.09 million euros of damage in 2015 and with the incorporation of electric buses this can be reduced to 0.257 million euros.

The next section describes the methodology, followed by results, discussion and conclusion of this research.

Methodology

This section presents the methodology followed to calculate the emission levels from public transport bus fleet and possible reductions with the use of alternative fuel options and technology, also, the resulting damage costs and feed stock required for bio-CNG. This study considers the entire Dublin bus and bus Éireann fleet. The potential of public transport bus fleet in reducing emissions have been assessed by designing four alternative scenarios in addition to the base scenario which uses diesel and older engine technology classes for the entire bus fleet. The emission levels of CO_2, CO, NOx, $PM_{2.5}$, PM_{10}, N_2O, VOC, NMVOC were calculated in tonnes using COPERT which follows top down approach. Emission calculation using COPERT requires detailed input data (Dey et al., 2017) in terms of fuel consumption, trip information (trip length, trip duration), activity (speed, mileage and mileage share), fleet configuration (number of buses of each fuel type and technology class) and environmental information (monthly average relative humidity and monthly average minimum and maximum temperature). COPERT can calculate emissions from diesel, biodiesel and CNG buses for the all euro technology classes. Table 1 presents a summary of the five scenarios that were examined in this study. The scenarios are described as follows,

- Scenario 1 (S1): In this scenario emissions were calculated for the base year fleet. 2015 was taken as the base year. Public transport bus fleet in Ireland is diesel powered and of older euro technology classes which have higher emission factors. Dublin bus and bus Éireann being the dominant public service bus operators in Ireland, have been considered in this study. The fleet data were obtained from Dublin Bus (2016) and National Transport Authority (NTA, 2016). The present fleet composition corresponding to euro class has been shown in table 1. For Dublin bus, the mileage share was taken as 100%, whereas, the mileage shares were taken as 15% rural and 85% urban (NTA, 2016). COPERT 5 provides the scope of specifying the peak and off-peak driving percentages and corresponding speeds separately. The urban share was further split into 50% for peak and 50% for off-peak hours with average peak hour speed taken as 13 kmph (kilometre per hour) and average off-peak hour speed as 26.5 kmph (CSO, 2014; Ryan and Caulfield, 2010; Alam et al., 2015; RSA, 2015). For Bus Éireann, average rural speed was assumed to be 40 kmph. Annual average mileages were taken as 57288 km and 71074 km for Dublin bus and bus Éireann respectively (NTA, 2016).

Table 1: Scenario descriptions

Scenario	Technology class	Fuel type	Number of Buses
1	Euro 3	Diesel	666
	Euro 4	Diesel	218
	Euro 5	Diesel	557
2	Euro 6	Diesel	1441
3	Euro 6/EEV	CNG	1441
4	Euro 6/EEV	Bio-CNG	1441
5	Euro 6	Diesel	72
	Electric		1369

- Scenario 2 (S2): This scenario presents the emission levels considering if all the buses are replaced by Euro 6 diesel buses. Euro 6 has improved technology, especially in terms of lower emission factors for NOx, PM and VOCs. Emissions in this scenario were calculated using COPERT 5 with the entire fleet to be euro 6, whereas, the rest of the input parameters were taken as described in scenario 1.
- Scenario 3 (S3): This scenario presents the emission levels resulted from the public transport bus fleet if all the buses are replaced by EEV/Euro 6 CNG. It was found that EEV and euro 6 have the same emission factors. This scenario tests the emissions reduction by replacing both fuel and technology. Emissions levels in this scenario were

also calculated using COPERT 5 with other input parameters than fuel and technology considered to be same as scenario 1.

- Scenario 4 (S4): In this scenario emissions were calculated assuming if all public transport buses are replaced by Bio-CNG euro 6/EEV buses. Therefore, this scenario also assume replacement of both fuel and engine as considered in S3. Grass silage was chosen to be the optimum feedstock to produce bio-CNG in Ireland and carbon neutrality of bio-CNG was taken as 60% (Ryan and Caulfield, 2010).
- Scenario 5 (S5): This scenario evaluates the possible emission savings by replacing urban bus fleets by electric buses. In this scenario, the WTT emissions i.e. the emission due to electricity generation was calculated for two cases. The first case assumes the energy source to be electricity generated from renewable sources which has WTW (well to wheel) emissions of 20 gCO_2eq/km and the second case assumes that the required electricity comes from EU-mix with GHG emission rate 720 gCO_2eq/km (Mahmoud, 2016).

The cost of health and other (biodiversity, crop, buildings) damages caused by the pollutants discharged by the bus fleet were calculated by multiplying the quantity of pollutants (tonne) with unit damage cost per tonnes of the pollutant as obtained from Handbook on External Costs of Transport (2014) and DTTaS (2016). Damage costs per tonne of pollutant were taken as €13.22, €5,851, €19,143, €1,438, €1,398, €200,239, €48,779, €16,985 for CO_2, NOx, PM_{10}, VOC, NMVOC, $PM_{2.5}$ (Urban), $PM_{2.5}$ (Suburban), $PM_{2.5}$ (Rural) respectively.
The land area required for grass silage to meet the bio-CNG demand for entire Dublin bus and bus Éireann fleet was estimated based on diesel energy density. Total diesel fuel consumption by the 2015 fleet was 5,567,000 litres which was converted to energy taking diesel energy density as 33.7 MJ/litre. Grass yield from 1 ha of land area was taken as 60 t and biogas yield from 1 tonne of glass was taken as 123 m^3 (Murphy & Power, 2009).

Results and discussion

This section presents the emission levels resulted from the existing public transport bus fleet in Ireland and potential emissions savings from changing to alternative fuel and technology. Table 2 presents the emissions from the status quo and percentage change in the designed scenarios with respect to the base scenario.

Table 2: Emissions (tonnes) from the designed scenarios and percentage differences over base scenario

Pollutants	**Emissions (t)**	**Difference with base (%) in each scenario**			
	S1	S2	S3	S4	S5
CO	244.86	-88	-61	-61	-97
CO_2	99185.35	-5	8	-57	-94* (-35**)
NO	786.31	-94	-53	-53	-97
NO_2	114.26	-96	-87	-87	-97
N_2O	1.47	137	-100	-100	-100
VOC	29.71	-85	216	216	-97
NMVOC	25.46	-84	-42	-42	-97
$PM_{2.5}$	16.07	-77	-74	-74	-99
PM_{10}	19.44	-64	-61	-61	-98

*Percentage decrease in CO_2 levels when renewable source of electricity is used; ** Percentage decrease in CO_2 emissions when electricity from EU-mix is used as source of electricity

Emission standards have become stricter with every progressive emission standard directive, therefore, significant reductions in CO, NOx, $PM_{2.5}$, PM_{10}, VOCs can be noticed from renewal of the fleet with euro 6 buses. However, reduction in CO_2 emissions is not significant as other pollutants which is because CO_2 emission is mainly dependent on fuel consumption and fuel type. Whereas, if the fleet is replaced by euro 6 CNG buses, CO_2 levels are expected to increase by 8%. The results show that scenario 5, i.e. if the urban share of Dublin bus and bus Éireann fleet is replaced by battery electric buses, has maximum potential in reducing CO_2 followed by scenario 4 which considers the entire fleet to be Bio-CNG powered buses. However, scenario 2 provides highest savings in NOx (NO_2+NO), CO and PM after scenario 4.

The damage costs caused by the emissions (table 2) have been shown in table 3 along with the possible savings if alternative fuel and technology options are implemented.

Table 3: Damage costs from the pollutants in the base scenario and possible savings in alternative scenarios

Pollutants	Cost of emissions (€)	Potential cost savings relative to damage costs in S1 (€)			
	S1	S2	S3	S4	S5
CO_2	1311230	63687.58	+105172	744669.2	1259118
NOx	5269213	4968777	3017719	3017719	5108574
VOC	42719.81	36101.48	+92288.5	+92288.5	41479.65
NMVOC	35593	29789	15084	15084	34388
$PM_{2.5}$	3055587	2354735	2272714	2272714	3020654
PM_{10}	372206.2	236862.4	228595.8	228595.8	365193.5
Total (Mil€)	10.09	7.69	5.34	6.19	9.83

It can be observed that the pollutants from the public transport bus fleet alone have caused a damage worth 10.09 million euros in 2015. Scenario 5 offers highest annual saving in damage costs and scenario 3 offers the lowest possible savings. Table 4 presents the energy consumption in the scenarios under this study. Electricity requirements for buses in scenario 5 were calculated taking the WTW energy consumptions as 18.66 MJ/km and 10.33 MJ/km for the energy sources being electricity from EU-mix and renewables respectively.

Table 4: Energy consumption

Scenarios	S1	S2	S3	S5	
Fuel consumption (TJ)	1875.03	1809.49	2601.69	74.52	
Electricity consumption (TJ)	-	-	-	EU-mix	Renewable
				1568.1	868.1

It can be seen that CNG buses have highest energy requirement, whereas, substantial reduction in energy consumption is possible in S5 for renewable based electricity. Scenario 4, which considers the alternative fuel option as bio-CNG and technology class as euro 6/EEV for public transport bus services, is a very suitable option for Ireland by utilising the agricultural grass silage as feedstock in producing biomethane (Smyth et al., 2009). This study calculates the land area requirement if grass silage is considered to generate bio-gas to be used as a fuel option for public transport buses. Table 5 presents the land area calculation based on diesel energy density and reports the final land area requirement for grass sileage to satisfy the annual energy demand. The parasitic energy demand was taken as 42% of the total demand (Smyth et al., 2009) and based on this, final Life Cycle Analysis (LCA) land area requirement was determined (table 5). The energy value of methane was taken as 37.78 MJ/m^3 (Smyth et al., 2009).

Table 5: Land area calculation using quantity and energy density of diesel

Parameter	Unit	Value
Diesel	litre	55670000
Diesel energy by volume	MJ/litre	33.7
Diesel	GJ	1876079
Energy density of methane	MJ/m^3	37.78
Methane	m^3	49657994
Biogas	55% of CH_4	90287261
Biogas yield	m^3/t of silage	123
Mass of silage	t	734043
Sileage yield	t/ha of land	60
land area	ha	12234
LCA land area	ha	21091

Thus, 21091 ha land area is needed to fulfil the energy demand of bio-CNG for public transport bus fleet in Ireland. Ireland has $1.2x10^6$ ha of sileage area (Smyth et al., 2009). Therefore, bio-CNG suggests to be considered as a suitable alternative fuel option.

Conclusion

This paper aims to evaluate the potential of alternative fuel options available for public transport bus fleet in reducing emissions. The results showed that all the scenarios offer significant reduction in emission levels. Euro 6, being the clearer technology shows considerable reduction in CO, PM, NO, NO_2, VOCs emissions but does not significantly reduce the CO_2 emissions. This indicates that alternative fuels must be incorporated in order to move towards meeting Ireland's GHG target for 2020 and 2030. From this view, CNG is also not a suitable option as the results show that use of CNG as bus fuel will increase the CO_2 emissions by 8%. But when the emission levels resulting from use of Bio-CNG are compared, 57% CO_2 emissions reduction was observed with CO, NO_2, $PM_{2.5}$ reductions being 61%, 87% and 74% respectively. Looking at the availability of grass land in Ireland, Bio-CNG offers a convenient and feasible option as an alternative fuel for public transport buses. Scenario 5, which examined the emission reductions from only replacing the urban bus fleets by battery electric buses, shows the highest potential in reducing both GHG and other harmful pollutants. Emission levels of all the pollutants can possibly be reduced by more than 90% which, in addition, reduces the financial damage worth 9.83 million euros. With the electricity source being renewable energy based which has high energy efficiency, the energy demand can be reduced by 49% relative to base scenario.

It can be concluded that electric buses offer the most attractive option. The public transport bus services studied in this paper mainly operates in cities like Dublin, Cork and Galway where the population density is higher. Renewal of the fleet will not only reduce the emission levels but also will improve public health. Thus, replacing the urban public service bus fleets with electric buses is highly recommended, given the electricity is produced from renewable energy sources.

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References

[1] ACEA (European Automobile Manufacturers association). Differences Between Diesel and Petrol. 2016. http://www.acea.be/news/article/differences-between-diesel-and-petrol

[2] M. S. Alam, P. Duffy, B. Hyde and A. McNabola. Estimation and back extrapolation of CO_2 emissions from the road transport sector: emissions in Ireland, 1990 to 2013. Air Pollution XXII, Vol. 198, pp. 63-75, 2015. doi:10.2495/AIR150061

[3] Baldwin, J. The renewable CNG option for carbon neutral transport. cng services ltd., 2008. http://awbriefing.com/presentations/20080129_john_Baldwin.pdf. Accessed 15/04/2017

[4] J.T. Cohen. Diesel vs. compressed natural gas for school buses: a cost effectiveness evaluation of alternative fuels. Energy Policy, Vol. 33, pp. 1709–1722, 2005. http://dx.doi.org/10.1016/j.enpol.2004.02.010

[5] CSO (Central Statistics Office). National Travel Survey: key findings, 2014. Available at: http://www.cso.ie/en/releasesandpublications/ep/p-nts/nationaltravelsurvey2014/keyfindings/ [Accessed 05.06.2017]

[6] CSO (Central Statistics Office). Transport Omnibus 2015: Public transport. 2015. Available at: http://www.cso.ie/en/releasesandpublications/ep/p-tranom/to2015/pt/ [Accessed 05.06.2017]

[7] S. Dey, B. Caulfield and B. Ghosh. The potential health, financial & environmental impacts of *dieselgate* in Ireland. Journal of Transportation Planning and Technology, 2017. (Accepted)

[8] DTTaS (Department of Transport, Tourism and Sport). Common Appraisal Framework for Transport Projects and Programmes. 2016.

[9] Dublin Bus. Dublin Bus Fleet. 2016. Accessed November 23, 2016. https://www.dublinbus.ie/About-Us/Dublin-Bus-Fleet/

[10] EMISIA. The popular, straightforward and simple to use emissions calculator. EMISIA: mission for environment, 2014. Available at: http://emisia.com/products/copert [Accessed 10.03.2017]

[11] EPA (Environmental Protection Agency). Ireland's Greenhouse Gas Emissions in 2015, 2017.

[12] EPA (Environmental Protection Agency). Ireland's Greenhouse Gas Emission Projections: 2016-2035, 2017.

[13] European Commission. Ireland's EU 2030 emissions targets published. http://ec.europa.eu/ireland/news/ireland-s-eu-2030-emissions-targets-published_en Accessed 28 July, 2017.

[14] M. Gonçalves, P. Jiménez-Guerrero, and J. M. Baldasano. High resolution modeling of the effects of alternative fuels use on urban air quality: Introduction of natural gas vehicles in Barcelona and Madrid Greater Areas (Spain). Science of the Total Environment, Vol. 407, pp. 776 – 790, 2009.

[15] IEA (International Energy Agency). 100% Biogas for Urban Transport in Linköping, Sweden. IEA Bioenergy Task 37. 2013 Available at: http://www.seai.ie/Renewables/Bioenergy/100_biogas_for_urban_transport_in_Linkoeping_IEA_Bio_Task_37.pdf Accessed 16/04/2017

[16] J. D. Murphy and N. M. Power. An argument for using biomethane generated from grass as a biofuel in Ireland. biomass and bioenergy, Vol. 33, pp. 504 – 512, 2009. doi:10.1016/j.biombioe.2008.08.018

[17] M. Karlström. Local environmental benefits of fuel cell buses – a case study. Journal of Cleaner Production, Vol. 13, pp. 679 – 685, 2005.

[18] M. I. Khan, T. Yasmin and A. Shakoor. Technical overview of compressed natural gas (CNG) as a transportation fuel. Renewable and Sustainable Energy Reviews, Vol. 51, pp. 785–797, 2015. http://dx.doi.org/10.1016/j.rser.2015.06.053

[19] N. E. Korres, Singh, A., Nizami, A., S., and Murphy, J., D. Is grass biomethane a sustainable transport biofuel? Society of Chemical Industry and John Wiley & Sons, Ltd, 2010.

[20] J. Lumbreras, M. Valdés, R. Borge, and M. E. Rodríguez. Assessment of vehicle emissions projections in Madrid (Spain) from 2004 to 2012 considering several control strategies. Transportation Research Part A, Vol. 42, pp. 646–658, 2008.

[21] NTA (National Transport Authority). Bus Statistics for Ireland. Statistical Bulletin Number:03/2016, 2016.

[22] M. R. Mahmoud, Garnett, M. Ferguson and P. Kanaroglou. Electric buses: A review of alternative powertrains. Renewable and Sustainable Energy Reviews, Vol. 62, pp. 673–684, 2016. http://dx.doi.org/10.1016/j.rser.2016.05.019

[23] Ricardo- AEA. 2014. Update of the Handbook on External Costs of Transport, Report for the European Commission: DG MOVE, United Kingdom, January 8.
[24] RSA (Road Safety Authority). Free Speed Study: Survey Report 2015, 2015.
[25] F. Ryan and B. Caulfield. Examining the benefits of using bio-CNG in urban bus operations. Transportation Research Part D, Vol. 15, pp. 362–365, 2010. doi:10.1016/j.trd.2010.04.002
[26] Smyth, B., M., J., D. Murphy and C., M. O'Brien. What is the energy balance of grass biomethane in Ireland and other temperate northern European climates?. Renewable and Sustainable Energy Reviews, Vol. 13, pp. 2349–2360, 2009. doi:10.1016/j.rser.2009.04.003