

Comparative Analysis of Bus and Trolleybus Related GHGs Emissions and Costs in Lithuania

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Abstract: The paper is aimed to provide a comparative analysis of costs related to emissions from urban bus and trolleybus. The external costs (Euro per km) of green house gases were analysed for selected bus *Solaris Urbino 12* and trolleybus *Solaris Trollino 12AC*. COPERT 4 software was applied to model green house gases emission factors for the bus, respectively estimation of indirect emissions of green house gases for the trolleybus was based on analysis of primary sources of electric energy production in Lithuania. Monetary values of GHG emissions were derived from the cost factors developed by the HEATCO (Harmonised European Approaches for Transport Costing) project. The study results show that replacement of bus by trolleybus will decrease GHG emissions by 389.69g CO₂/km in 2009 and 287.09g CO₂/km in 2010, at the same time replacement will save 0.042 €/km and 0.039 €/km for each respective year.

Keywords: urban public transport, emissions, green house gases (GHGs), environmental costs.

1 Introduction

The main environmental issues in towns and cities are related to the predominance of oil as a transport fuel, which generates green house gases (GHGs) and air pollutant emissions. Usually, the contribution from the transport sector is estimated from the statistical data on fuel consumption or mobility of citizens living within the local authority area. Increased kilometres travelled reflect increased local contribution to global climate change (Kliucininkas and Macionyte, 2008).

CO₂ emissions from new passenger cars sold in the EU have decreased by 12.4% between 1995 and 2004, following a voluntary agreement between the European Commission and industry. To enable the EU to reach its 120 g objective by 2012, the Commission, in a Communication of February 2007, outlined a comprehensive new strategy. A legislative framework should ensure 130 g CO₂/ km by improvements in vehicle motor technology, and a further reduction of 10 g CO₂/ km by other technological improvements and by an increased use of biofuels. Pollutant emissions from vehicles have also been successfully reduced through a gradual tightening of the EURO emissions standards (Green Paper, 2007).

Most of the National Strategic Reference Frameworks submitted by the Member States include sustainable urban transport as an area for action. Extension, rehabilitation and upgrading of clean urban public transport such as trolley buses, trams, metros and suburban rail as well as other sustainable urban transport projects should continue to be promoted and supported by the EU.

2 Costs related to transport-induced GHGs emissions

Different approaches have been adopted to support estimation of costs related to transport-induced green house gases emissions. One way to combine different environmental impacts of energy is to evaluate the so-called external costs or externalities. These are defined as costs that are not included in the price of energy.

Many impacts of energy production on the environment include such costs to the society. In principle, society can include (internalise) some of the external costs in the price of energy, e.g., by imposing taxes. In practice, however, it may be difficult to assess the costs since the knowledge of many environmental impacts is limited, the impacts may occur only after a long delay or the natural values or resources have no market values. Life cycle assessment has been applied to comparative evaluation of alternative automotive fuels and technologies which are expected to become available in the near future. At present, 99% of the energy consumed in road transportation is based on crude oil. Carbon dioxide emissions result not only from fuel combustion by the vehicle, but also from fuel extraction, transport, production and distribution.

Alternative fuel chains can involve the use of alternative primary energy sources, innovative fuel production technologies, new automotive fuels or innovative vehicle power-trains. Primary energy sources besides crude oil can be natural gas, biomass, hydro, wind or solar energy. Since there are so many combinations of fuel power-trains, it has been customary to perform the life cycle assessment in two stages. The first stage is called “well-to-tank” and comprises fuel extraction, transport, production and distribution. The second stage is called “tank-to-wheel” and comprises conversion of fuel energy into motion of the vehicle. A complete life cycle assessment combines the results of these two stages and is called “well-to-wheel” (World Energy Council, 2004).

The EU has taken an initiative to develop harmonised guidelines for transport costing. The monetary values of transport emissions were estimated by HEATCO (Harmonised European Approaches for Transport Costing and Project Assessment) project (Heatco, 2006). The monetary valuation was based on the principles of welfare economics, contributing in the long run to consistency with transport costing. HEATCO project provides cost factors in Euro per tonne of pollutant emitted for majority of EU countries. Valuation of air pollution effects is based on the damages caused by air pollutant emissions. The types of costs included in the valuation approaches are costs for human health impacts, agricultural and forestry production loss, as well as soiling and corrosion of building materials.

Authors of this paper have applied HEATCO monetary values to analyse costs related to GHGs emissions from urban bus and trolleybus.

3 Estimating green house gases emission

The first step in this study was to calculate emission factors of green house gases for bus and estimate indirect emissions related to trolleybus kilometre of travel. Because of its wide acceptance within the European Union and specialization in estimation of pollutant emission COPERT 4 software was selected for this task (Copert 4, 2008).

COPERT 4 is an MS Windows software program aiming at the calculation of air pollutant emissions from road transport. The development of COPERT has been financed by the European Environment Agency (EEA), in the framework of the activities of the European Topic Centre on Air and Climate Change. The COPERT 4 methodology is also part of the EMEP/CORINAIR Emission Inventory Guidebook. It is the most commonly used model in Europe for official national inventories of emissions from road traffic.

3.1 Bus Solaris Urbino 12

This type of bus falls into midi urban bus category, known as HD Euro III – 2000. One hundred percent of driving share of the bus was attached to urban conditions. The average speed of the bus was accepted 30 km/h. Emission factors were estimated for diesel bus with Euro 3 (2000) 98/69/EC emissions standard (Directive 2003/17/EC). To model emission factors the following input data for the city bus Solaris Urbino 12 were used: sulphur quantity in diesel – 10 mg/kg, diesel density – 845 kg/m³, PAHs – 11%v/v, cetane number – 51, 95-percent of distillation temperature (T95) – 360 °C. It's very important to assess slope class of road. The selection of the slope class has influence on emissions and fuel consumption. Emissions and fuel consumption are strongly increasing when the bus climbs road with slope. The emission factors (g/km) of GHGs emitted by the bus are provided in the Table 1.

Table 1. Emissions factors (g/km) of GHGs from the bus Solaris Urbino 12

Emissions factors, g/km	Road slope class (%)			
	0%	2%	4%	6%
CO ₂	723.05	1074.45	1459.69	1857.98
CH ₄	0.0977	0.0977	0.0977	0.0977
N ₂ O	0.0057	0.0057	0.0057	0.0057
CO ₂ equivalent	727.19	1078.59	1463.83	1862.12

* Assessment is based on Global Warming Potential (GWP)

3.2 Trolleybus Solaris Trollino 12AC

Like other electric vehicles, trolleybus doesn't released pollutant emissions directly in its action. However emissions are emitted during generation of electricity at centralized power plants. Emissions from generation of electricity depend on the method of generation, plant characteristics (i.e. type, capacity factor, efficiency, technologies of emission control and lifetime) and source of primary energy. Emissions like SO₂ vary due to content of sulphur in fossil fuel. The biggest emissions are emitted from fossil fuel based power plants. Nuclear power and renewable sources, unlike fossil fuel, does not generate emissions directly. For nuclear power and almost all renewable sources, there are no emissions at the point of generation, but there are releases during the mining and processing of the fuel, construction of the plant, disposal of spent fuel and by products, and waste management and decommissioning. The followings figures present emissions and GHG emissions in g/kWh from electricity production systems (life cycle analysis) (World Energy Council, 2004).

The data of electricity (fuel) consumption (kWh/km) was obtained from Kaunas Trolley Bus Company. The average electricity (fuel) consumption of Solaris Trollino 12AC is 0.9 kWh per kilometre. One should consider that enlargement of electric power consumption during up-hill movement is compensated during downhill movement. Thus, slope class of road has no influence on consumption of electric power.

The GHG emissions depend on the local mix of electric power production system. Currently 70 percent of the Lithuania's electric power is produced at Ignalina Nuclear Power Plant, however the power plant is tentatively scheduled for closure in the end of 2009. Therefore, since 2010 emissions from electric power production sector in Lithuania will increase.

Estimated results of CO₂-equivalent (GHGs) emission factors of trolleybus for the year 2009 and 2010 are given in the Table 2.

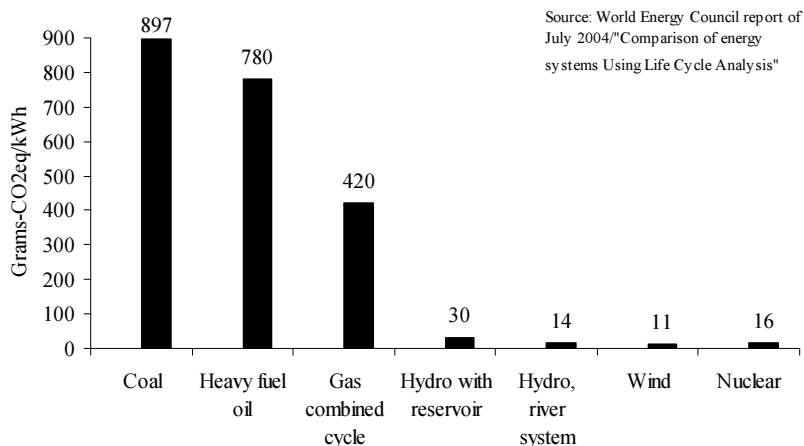


Figure 1. GHGs emissions in g-CO₂/kWh from electricity production systems (life cycle analysis)

Table 2. CO₂-equivalent (GHGs) emission factors of trolleybus

Emissions factors, g/km	CO ₂ -equivalent
Year 2009	337.5
Year 2010	440.1

4 Calculating monetary values of GHGs emissions

The method of calculating costs due to the emission of greenhouse gases (GHG) (usually expressed as CO₂ equivalents) basically consists of multiplying the amount of CO₂ equivalents emitted by a cost factor. The CO₂ equivalent of a greenhouse gas is derived by multiplying the amount of the gas by the associated Global Warming Potential (GWP). The GWP for methane is 25, for nitrous suboxide –298, and for CO₂ it is 1. Carbon dioxide, methane and nitrous suboxide are also called direct GHGs. Some of the local pollutants CO, NMVOC, NO_x, and SO₂ contribute to global warming by forming other species such as ozone and sulfate aerosol particles and for this reason they are also called indirect GHGs. Monetary values of indirect GHGs are not estimated in this study.

Due to the global scale of the damage caused, there is no difference how and where in Europe the emissions of greenhouse gases take place. The value of 22 € per tonne of CO₂ equivalent emitted of 2000–2009 years is recommended for all countries. Costs factors of CO₂ equivalent emissions for 2010–2019 are estimated to be 26 €/t.

Values of emissions are calculated using HEATCO factor prices (Bickel and Droste-Franke, 2006). Monetary values of emission from bus and trolleybus for the year 2009 and 2010 are given in the Tables 3 and 4.

Table 3. Monetary value of bus related GHGs emissions

Road slope class		0%	2%	4%	6%
Cost, €/km	2009	0.016	0.024	0.032	0.041
	2010	0.019	0.028	0.038	0.048

Table 4. Monetary values of trolleybus related GHGs emissions

Emissions	CO ₂ -equivalent
Cost for 2009, €/km	0.007
Cost for 2010., €/km	0.011

5 Conclusions

The study responds to the target of the European Council to reduce EU greenhouse gas emissions with 20% by 2020 and provides environmental financial estimates of clean urban public transport.

A comparative study gives an example of alternative strategies for public urban transport development. The results of the study demonstrate that environmental costs, structured for monetary values of CO₂-equivalent emissions (GHGs) per one kilometre of travel, are much higher for bus than for trolleybus. The comparative analysis shows that replacement of bus by trolleybus will decrease GHG emissions by 389.69g CO₂/km in 2009 and 287.09g CO₂/km in 2010, at the same time replacement will save 0.042 €/km and 0.039 €/km for each respective year.

Analysis of emission factors and respective monetary values show that bus transport in cities with hilly relief make more significant contribution to the climate change if compare with those plain relief urban areas. Bus related CO₂-equivalent emissions for the road slope class 0% make up 727.19g CO₂/km, while for the road slope class 4% – 1463.83g CO₂/km.

The substantial difference between monetary values of the trolleybus related emissions for the year 2009 and 2010 are determined by the following factors: i) from 2010 the electric power production system in Lithuania will face radical changes; ii) according to the HEATCO methodology 2010 is the threshold year for the higher monetary cost factors.

The study applies to development of urban public transport system. The proposed scheme could be adjusted to the local conditions of the individual city and serve as a methodology for sustainable decision support in urban transport planning.

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