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# ANALYSIS OF GLOBAL AND LOCAL ENVIRONMENTAL IMPACTS OF BUS TRANSPORT BY LCA METHODOLOGIES

B. SIMON[1,2✉], L. TAMASKA[2], N. KOVÁTS[1]

[1]Department of Environmental Engineering and Chemical Technologies
University of Pannonia, Egyetem u. 10., HUNGARY
✉E-mail: simonbalint@gmail.com
[2]KMProjekt LTD., Endrődi S. u. 42/C, HUNGARY

The mobility of the globalized world is supported by internal-combustion engines, which generally use fossil fuels. City people have to move daily from place A to B. For that reason cities have public transport systems, including local bus as an important element. As the bulk of the population is concentrated in the city, the atmospherical emissions of local buses have a considerable impact on human health. This study analyses these impacts using the methodology of LCA and the database of the ARTEMIS project. The whole study includes the emissions models of pre-euro and euro 1-5 buses, CNG, biodiesel and hydrogen buses, and the fuel production. Furtermore seven scenarios for modeling traffic situations are included, too. For the impact assessment three CML2001 indicators are used. Global warming potential (GWP) is for assessing the global impacts, carbon footprint; human toxicity potencial (HTP) and photochemical ozone creation potential (POCP) are used for the estimation of impacts in urban environments.

**Keywords:** public transport, local bus, life cycle assessment, global warming potential, human toxicity potential, photochemical ozone creation potential

## Introduction

Transportation of modern ages involves many types of vehicles, from bicycles to trains. The present study analyses the environmental impact of bus types used in Hungarian cities, including the annual impact of the number and type of buses used in Budapest. The number of cars in the year of 2006 was approx. 650 000 on the streets of Budapest [1], simultaneously, the BKV (Budapest Public Transport Co.) had 1400 buses according to data of 2007. Average daily 1.5 million passengers are transported by these buses, amounting to 42.3 % of the total daily passengers [2]. EURO 0 and EURO 1 motors form the biggest part of these buses (see *Table 2*).

60% of the travels are managed by public transport and the rest by cars whose number is about one magnitude higher [3]. The fact that the fleet of buses is rather old, they have high environmental load and environmental emissions make it clear that modernizing of public transport and the bus fleet is a very important work.

Primary aim of this present study is to estimate environmental impacts of air emissions caused by bus transport and to serve as an important basis for a decision-making process being necessary for achieving changes. For such purpose, life cycle assessment (LCA) was selected as the most appropriate methodology. Several studies have been already published for estimating emissions and environmental impact, which results have been incorporated in this present study [4, 5, 6, 7, 8].

## Materials and Methods

The goal, and scope of the study should be determined by assessing the environmental impacts of public transport. In this case this is bus transportation and the production of the fuel. The study was carried out according to the ISO 14044 standard [9]. The analysis provides information about the environmental impact of the different usage of different fuel types.

The analysis takes the values of *Table* 1 and *2* into account, which are derived from the ARTEMIS project database [6, 7].

The databases of fuel production and of the emissions of alternative motor driving have been gathered from international publications and doctoral theses [10-29].

*Table 1:* Emissions and fuel consumption of the bus types

| | E5 | E4 | E3 | |
|---|---|---|---|---|
| HC | 0.078 | 0.076 | 1.356 | g/km |
| Fuel cons. | 641.429 | 622.964 | 637.381 | g/km |
| CO | 0.652 | 0.645 | 6.934 | g/km |
| NOx | 9.459 | 13.717 | 27.644 | g/km |
| PMm | 0.016 | 0.015 | 0.042 | g/km |
| $CO_2$ | 2020.504 | 1962.339 | 2007.748 | g/km |
| Methane | 0.001 | 0.001 | 0.027 | g/km |
| NMHC | 0.076 | 0.075 | 1.328 | g/km |

*Table 2:* Emissions and fuel consumption of the bus types

| | E2 | E1 | 80ties | |
|---|---|---|---|---|
| HC | 1.571 | 2.403 | 7.047 | g/km |
| Fuel cons. | 605.975 | 664.391 | 843.085 | g/km |
| CO | 6.939 | 7.092 | 16.703 | g/km |
| NOx | 22.898 | 21.031 | 31.743 | g/km |
| PMm | 0.044 | 0.115 | 0.278 | g/km |
| $CO_2$ | 1908.823 | 2092.833 | 2655.721 | g/km |
| Methane | 0.031 | 0.048 | 0.141 | g/km |
| NMHC | 1.539 | 2.355 | 6.906 | g/km |

A scenario analysis is included in the study. These scenarios are modelling a yearly traffic situation (in km) according to *Table 3*, first using the old buses and than they are displaced by the emission models of the seven buses of the alternative drives.

*Table 3:* The "present" scenario in vehicle kilometer (vkm) per year and number of pieces of buses

| | vkm/y | pieces |
|---|---|---|
| E0 | 27 998 055 | 460 |
| E1 | 34 826 840 | 577 |
| E2 | 13 189 275 | 248 |
| E3 | 11 120 090 | 151 |
| total | 87 134 260 | 1436 |

*The indicators*

The results of emission models are investigated by the global warming potential (GWP), human toxicity potential (HTP), and photochemical ozone creation potential (POCP) of CML 2001. These are impact oriented indicators, that is, the impact of emissions is given with a mass equivalent value of a reference compound.

GWP puts the emphasis on the role played in the climate change, and represents the environmental impact in kg $CO_2$ equivalent. This indicator can be used during the estimation of the carbon foot print. Its value equals to the impact posed by the same amount of $CO_2$. As its name indicates, it makes a global impact, and caused by emission to the air, which have life-time from some decades to several thousands of years.

HTP characterizes materials with human toxic potential. The impacts of such materials are normalized to dichloro-biphenyl equivalent (kg DCB equiv). It will be used as a local impact, caused by heavy metals, $PM_{10}$, halide, dioxins emissions. As such, recipients are mainly those who live nearby to emitting facilities. For example, HTP of a waste incinerator has negligible impact on those who live app. 100–200 kms from the facility.

POPC helps to determine the impact of materials, which have a big role in the formation of tropospheric ozone, wherewith help in the development of summer smog. The unit is the kg ethane equivalent. The head materials with POCP impact are the hydrocarbons (gas) and NOx. [30]

Accordingly, due to the magnitude of the impact, in case of public transport mainly HTP and POCP are emphasized, whilst considering the total emission, the GWP is a good component to characterizing of the whole system.

## Results

We show first the impacts of 1 vehicle kilometer, so differences between the bus types and fuel types addressed can be made clear.

*Fig. 1* shows that by all bus types, except the hydrogen fuelled buses, the emissions of urban traffic cause the biggest global warming potential. The GWPs of the use of diesel motors are on the same level, the highest $CO_2$ equivalent emission is posed by the buses from the 80'es. However, the average impact is around app. 2 kg $CO_2$-equivalent. The GWP of fuel production changes in proportion to the fuel consumption.

In case of biodiesel an app. 3 kg $CO_2$ equivalent minus appears, because the system boundaries cover the $CO_2$ assimilation of plants, too. Naturally, this does not mean that biodiesel is the best choice, because the GWP does not provide information about the other environmental impacts, such as land use or eutrophication.

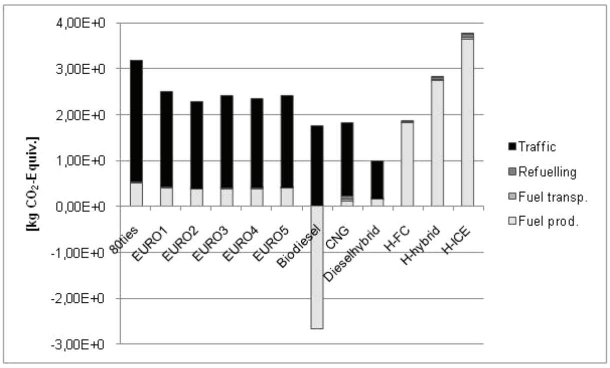


*Figure 1:* GWP of 1 vehicle kilometer

The value of HTP is mainly derived from fuel production, which is especially remarkable in case of the hydrogen. The high electricity demand of the hydrogen production makes these values so high. Because the production of the electricity is the impact holder, the HTP is not formed like a point source of pollution, but is dispersed between the power plants of Hungary, similarly to the other environmental impacts.

The black column shows the important HTP impacts (inside the city). This decreases with the increase of EURO norm, but is rather high in the case of biodiesel, as opposed to GWP, The HTP of CNG and diesel hybrid are similar. Such impact of public transport is the lowest when hydrogen is used.

Hydrogen-shovel buses provide the highest environmental performance in this category, with the immission of max. 0.003 kg ethylene equivalent.

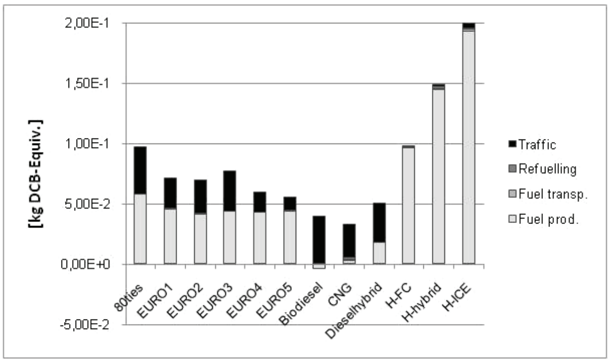


*Figure 2:* HTP of 1 vehicle kilometer

Favouring smog formation is a capacity being characteristic of old buses; the biodiesel and CNG have better performance than the newer EURO norm buses. Though the POCP of diesel's whole lice cycle is worse than that of the biodiesel and CNG, the emissions of use are lower (for of urban traffic).The possibility of smog formation is the lowest in case of the hydrogen buses (see *Fig. 3*).

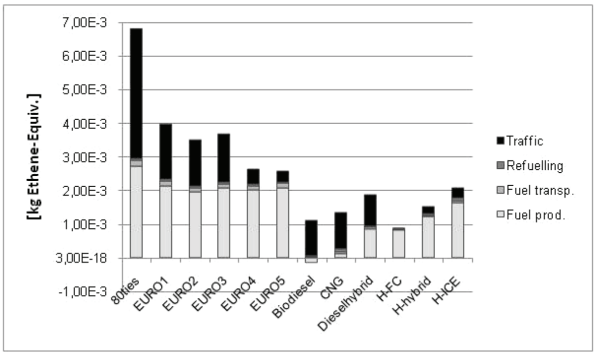


*Figure 3:* POCP of 1 vehicle kilometer

*The scenarios*

Different bus types and different fuel types have given different impact values, and it is not possible to determine the best bus or fuel type from environmental aspect.

The next scenarios will simulate a real situation, where the composition of the bus fleet and the value of travelled kilometres are given in Table 3. This is the "present" scenario. By the other scenarios the bus fleet of the "present" scenario will be displaced with the alternative bus types, like biodiesel, hybrid diesel, CNG, or hydrogen bus (taking travelled kilometres as reference).

The emission of GHG in case of fossil fuel buses comes mostly from the combustion of fuel. This is 20 000 ton $CO_2$-equivalent emission in the "present" scenario. This is decreased in case of the EURO 5 and in case of the CNG and hybrid is less than 20 000 and 10 000 tons, respectively. In the case of hydrogen buses the GHG emission amounts to almost 100% due to the hydrogen production, that causes, except the "fuel cell hydrogen" (H-FC), higher impact as the "present" scenario. The $CO_2$ assimilation ability of plants has a "negative impact" on the biodiesel production, whereby the overall GHG emission of biodiesel is negative, as such, this process rather captures than emits $CO_2$.

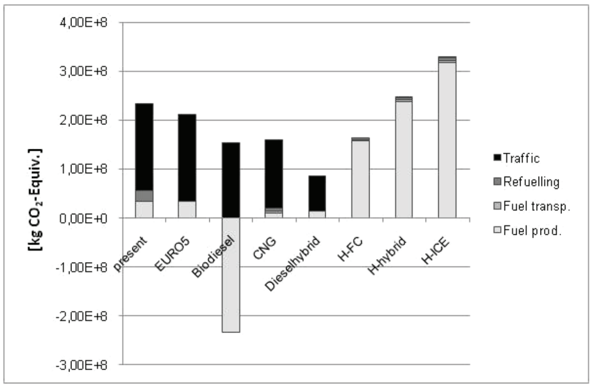


*Figure 4:* GWP of the scenarios

The advantage of biodiesel considering GWP disappears when HTP is discussed. CNG has the best overall performance although this impact of the previous two bus types comes almost exclusively from the urban area. On the other hand, the hydrogen buses have higher impact, but this arises from the fuel production and accordingly these bus types have the smaller impact on the citizens. The EURO 5 has the smaller impact in urban are, following the hydrogen buses.

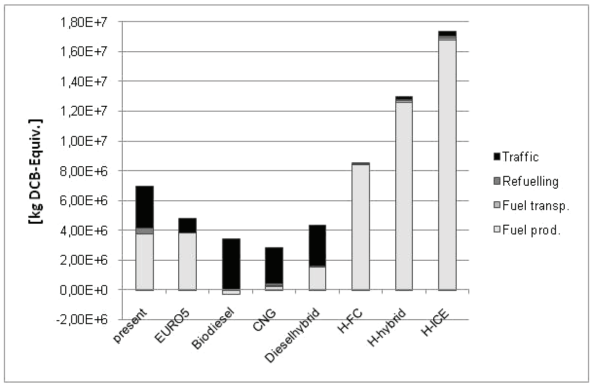


*Figure 5:* HTP of the scenarios

All of the alternative buses perform better than the "present" scenario considering smog development. The EURO 5 and H-FC have the smaller POCP in the urban area; these are followed by hydrogen ICE and the other fossil fuel user bus types.

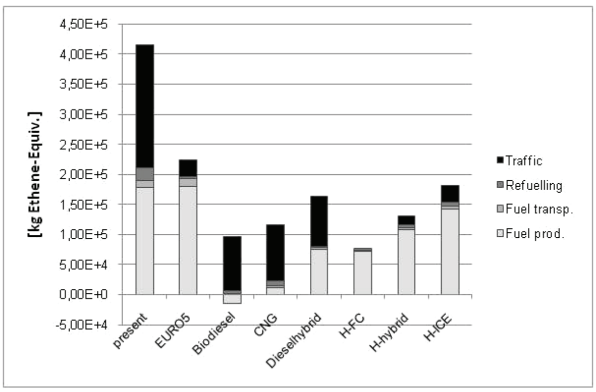


*Figure 6:* POCP of the scenarios

## Conclusion

The environmental impacts of older buses are higher than those of the alternatives. However, this tendency does not apply to hydrogen buses, because hydrogen production poses significant environmental impact, and/or high energy consumption.

The GWP of old buses is between 2–3 kg $CO_2$ equivalent per vehicle kilometres, the same impact of alternatives is less than 2 kg $CO_2$ equvalent. Considering those impacts which are important in urban environments, the EURO 4-5 have better environmental performance than the alternatives.

It can be concluded, that in the traffic situation (scenarios) the biodiesel, diesel hybrid, the CNG and the H-FC have the best GWP values. Considering local impacts (important impacts in urban area, like HTP and POCP) the EURO 5 has better performance, but if the fuel production is also taken into account, the EURO 5 occupies only the 4th and 6th positions out of the seven scenarios. As such, the EURO 5 norm buses are highly capable for the urban public transport. With the improving of the environmental profile of the hydrogen production (e.g. use of renewable energy, find the high performance hydrogen storage), it can be the best adaptable bus type for the mass transport in densely populated areas, due to their almost negligible emission and environmental impact.

## REFERENCES


1. K. MOGYORÓSI et al.: A közép-magyarországi régió társadalmi atlasza, 2006, 40–41.
2. ZS. BALOGH: Budapesti Közlekedési Zártkörűen Működő Részvénytársaság 2007 éves jelentés. (2007)
3. E. BELICZAY, A. LUKÁCS: Ajánlások Budapestért. (2006)
4. M. CHESTER, A. HORVATH: Environmental Life-cycle Assessment of Passenger Transportation: A Detailed Methodology for Energy, Greenhouse Gas and Criteria Pollutant Inventories of Automobiles, Buses, Light Rail, Heavy Rail and Air v.2. (2008)
5. M. KELLER, M. LEBKÜCHNER et al.: Diesel, gas-, oder trolleybus? (2006)
6. M. REXEIS, S. HAUSBERGER et al.: Assessment and Reliability of Transport Emission Models and Inventory Systems, Heavy duty vehicle emissions; Final Report. (2005)
7. M. REXEIS, S. HAUSBERGER et al.: Heavy duty vehicle emissions (ARTEMIS). (2005)
8. M. WANG: GREET Life-Cycle Analysis Model Development. (2008)
9. Int. Stand. Org.: ISO 14040:2006 Environmental management – Life cycle assessment – Requirements and guidelines. (2006)
10. R. AHLUWALIA, X. WANG et al.: Fuel economy of hydrogen fuel cell vehicles, Journal of Power Sources, 130, 2004, 192–201.
11. J. A. BARCLAY: Advances in Cryogenic Engineering/ Cryofuels now and in the future, P. Kittel (Ed.), Plenum Press, 1995.
12. E. BOOTH, J. BOOTH et al.: Economic Evaluation of Biodiesel Production from Oilseed Rape grown in North and East Scotland. (2005)
13. CompAir: CNG refuelling solutions. (2009)
14. http://www.e-traction.com/fuel_cell.htm (2009, September).
15. FIBA Canning Inc: Gas transportation vehicles (broshure). (2005)
16. FIBA Canning Inc.: Gas transportation vehicles (broshure). (2005)
17. Hennlich Ipartech.: Professzionális elektromos Diesel üzemanyag-szivattyúk (www.hennlich.hu). (2009)
18. IKP Stuttgart & PE-Europe: GaBi software, manual. (2003)
19. JP Sauer & Sohn: Sauer Compressors for Gas Compression. (2009)
20. http://www.global-hydrogen-bus-platform.com/# (2009, September)
21. MAN Nutzfahrzeuge AG.: Ecology and economy – the hybrid city bus. (2009)
22. http://www.nrel.gov/lci/ (2009, September)
23. M. PEHNT: Ganzheitliche Bilanzierung von Brennstoffzellen in der Energie- und Verkehrstechnik. Institut für Technische Thermodynamik Deutsches Zentrum für Luft- und Raumfahrt; Institut für Energiewirtschaft und Rationelle Energieverwendung. (2002)
24. W. PESCHKA: Advances in Cryogenic Engineering/ Hydrogen Cryofuel in Internal Combustion Engines, P. Kittel (Ed.), Plenum Press, 1993.
25. E. REBHAN: Energie Handbuch, Gewinnung, Wandlung und Nutzung von Energie, Springer Berlin-Heidelberg, 2002.
26. J. SHEEHAN, V. CAMOBRECO et al.: Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus. (1998)
27. http://www.agraroldal.hu/repce-5_cikk.html (2009, September)
28. P. L. SPATH, M. K. MANN: Life Cycle Assessment of Hydrogen Production via Natural Gas Steam Reforming. (2001)
29. Umweltbundesamt & Ökoinstitut: Processorientierte Basisdaten für Umweltmanagement-Isntrumente. (2009)
30. M. GOEDKOOP, A. M. SIEBEL: LCA methodology and practice. (2005)
31. B. J. GUINÉE, M. GORRÉE et al.: Life Cycle Assessment, An operational guide to the ISO standards. (2001)