

MAKING PUBLIC TRANSPORTATION MORE SUSTAINABLE – A SOPHISTICATED LCA & LCC MODEL FOR ASSESSING BUS BASED PUBLIC TRANSPORT

Michael Faltenbacher, PE INTERNATIONAL AG;*

Markus Wiedemann, Stuttgarter Straßenbahnen AG.

** Hauptstr. 111-113, 70771 Leinfelden-Echterdingen, Germany;
m.faltenbacher@pe-international.com.*

Keywords: decision support, LCA, LCC, bus, public transport.

ABSTRACT

As integral part of its sustainability strategy Stuttgarter Strassenbahnen AG (SSB AG) has decided to implement a holistic life cycle based evaluation approach for its bus fleet back in 2006 which was developed by PE International. Since then a combined modular LCA & LCC model is used and constantly refined. Covering a 15 year time horizon the environmental and economic life cycle profiles of different fleet scenarios are quantified via a transparent comparison of resources consumed, emissions released and costs incurred for different combinations of fuels and propulsion technologies. The developed model proves to be an effective tool to support the strategic decision making of a bus operator to enhance the competitiveness and attractiveness of the public transport service offered.

INTRODUCTION

The provision of an attractive, sustainable public transport system is a key goal of SSB AG. Public transport is seen as one of the key solution options for addressing mobility demands as well as air pollution in growing urban areas. As such public transport operators are under constant pressure for innovation with regard to resource efficiency and the limitation of harmful emissions. For the bus based public transport recent developments show a variety of options for fuels & propulsion technologies. As decisions made on fuel & propulsion technologies not only define direct emissions and costs for the regular operational lifetime of a bus which is 10 to 14 years but also have an influence on the up- and downstream processes, it is essential to transparently quantify and evaluate all life cycle stages of the bus system including the production and End-of-Life of the considered vehicle technology as well as the production of the consumed fuel and the operation of the bus.

METHODS

The goal is to determine the most beneficial fuel/ propulsion technology for the community and the bus operator from a sustainability perspective. In this context it is of key importance to consider the specific local boundary conditions such as availability of fuel resources, major pollution issues which need to be addressed, operational conditions (topography & speed profiles etc.), energy supply vector (e.g. fuel) etc. As integral part of its sustainability strategy SSB AG has decided to implement such a holistic life cycle based evaluation approach for its bus fleet in 2006 which was developed by PE (Faltenbacher, 2006). Since then a combined modular LCA & LCC model is used and constantly extended (Wiedemann, 2007).

Scope of the model:

Covering a 15 year time horizon the environmental and economic life cycle profiles of the current bus fleet as well as different fleet development scenarios are quantified via a transparent comparison of resources consumed, emissions released and costs incurred for different combinations of fuels and propulsion technologies. With a worldwide market share of >90 %, diesel ICE is the current reference drivetrain technology in public transport buses. By now a range of different fuels incl. fossil diesel, 1st & 2nd gen. biofuels (blends & pure), gas-to-liquid, natural gas, hydrogen (from various sources) and a equal number of propulsions systems incl. diesel combustion (with various exhaust gas treatment systems) combined with parallel & serial hybrid drive trains, natural gas and fuel cell technology have been analysed using the developed model (Faltenbacher, 2010). The scope of this publication is given below.

Table 1. Considered fuels and drivetrain technologies

Propulsion	Diesel	Diesel-Hybrid	Fuel Cell-Hybrid	Battery
Type of fuel	Diesel conventional (B7) (Bio)Diesel B30		Hydrogen from electrolysis of wind power	Wind power
Exhaust gas treatment	Depending on Euro-class: DeNOx (from Euro IV; AGR/SCR) Particle filter (optional until Euro V)		N/A	N/A
Energy storage	N/A	26 kWh Li-Ion battery	26 kWh Li-Ion battery	200 kWh Li-Ion 2-3x recharg. during daytime + recharg. during nighttime

RESULTS

Analysis of fuel/drivetrain combinations

The model allows the comparison of individual fuel/drivetrain combinations on specific routes, i.e. for the bus operation the topography and speed profile of a given route is considered incl. the route specific fuel consumption and emission values (Hausberger, 2009). Figure 2 gives an example for the break even analysis of 18m conv. Diesel and a Dieselhybrid bus with a parallel hybrid drivetrain, both Euro V, on Stuttgart’s Line 44 (Rau, 2011).

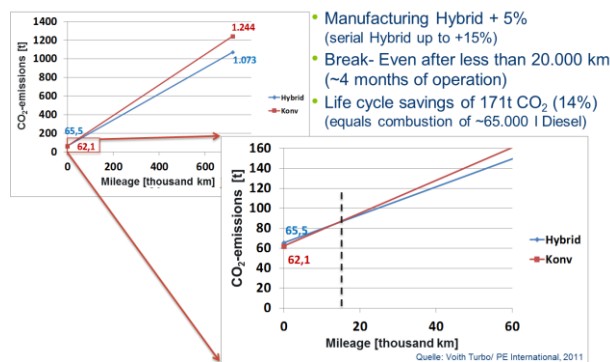


Figure 2. Break-even analysis 18 m Diesel vs. Diesel-Hybrid (parallel) bus

While the vehicle manufacturing of the Hybridbus is associated with ~5% higher CO₂ emissions compared to the conventional Diesel bus the 15% reduction of fuel consumption for the hybrid bus leads to a break even already after 4 months of operation and to a total life cycle saving of 14% or 171 t of CO₂ emissions.

Complete fleet analysis

Based on the analysis of individual fuel & drivetrain combinations the environmental as well as the cost profile of the bus operator’s fleet can be compiled. Baseline is the fleet composition for a given year. In the case of SSB this is the fleet composition as of Dec. 31

2012 featuring 89 12 m & 177 18m buses. Starting from this baseline fleet composition ‘what-if scenarios’ for the future structure of the bus fleet can be developed. Usually any new drivetrain technology is gradually introduced i.e. it is important to consider the operator specific vehicle renewal cycles for the development of the scenarios. For this publication three scenarios considered by SSB are investigated. The 1st scenario is the business-as-usual scenario, i.e. any decommissioned bus will be replaced by a new conventional Diesel bus which, as of beginning of 2014, has to comply with the Euro VI emission standard. Scenario 2 assumes that from 2017 onwards all decommissioned Diesel 18 m buses are replaced by Euro VI Diesel hybrid 18m buses and that all 12 m Diesel buses are replaced with Fuel Cell hybrid 12 m buses. Scenario 3 follows scenario 2 for the 18 m buses (replacement with 18 m Euro VI Dieselhybrid buses from 2017). The 12 m buses are replaced by 50% Euro VI Dieselhybrid and 50% Battery buses. Fig. 3 depicts the development of SSB’s bus fleet from 2013 to 2025 for scenarios 1 & 3. SCR & CRT stand for DeNO_x and particle exhaust gas cleaning systems.

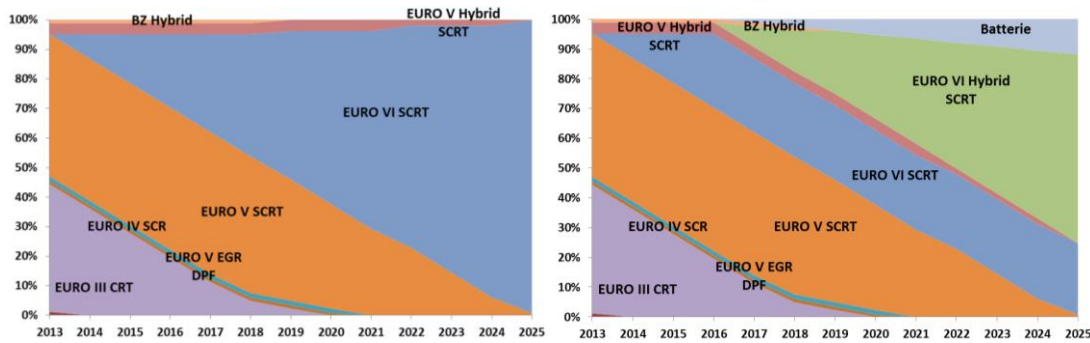


Figure 3. SSB’s bus fleet composition Scenario 1 (BAU) and 3 (Diesel Hybrid/ Batterie)

Considered results from the environmental (LCA) part of the model include CO₂, NO_x, PM₁₀, HC, CO as well as the impact categories Primary energy demand, Global warming potential (GWP100), “Summer smog“ potential (POCP) and human toxicity potential. The economic (LCC) part of the model considers the following cost categories: investment cost for buses and filling station, maintenance, fuels and operating materials (e.g. Ad Blue, oils etc.) costs as well as external costs for the above mentioned emissions to air. Bus driver costs are not included. Figure 4 gives the expected as an example the yearly GWP emissions of the SSB fleet for the three scenarios and the cumulated LCC costs from 2013 to 2025.

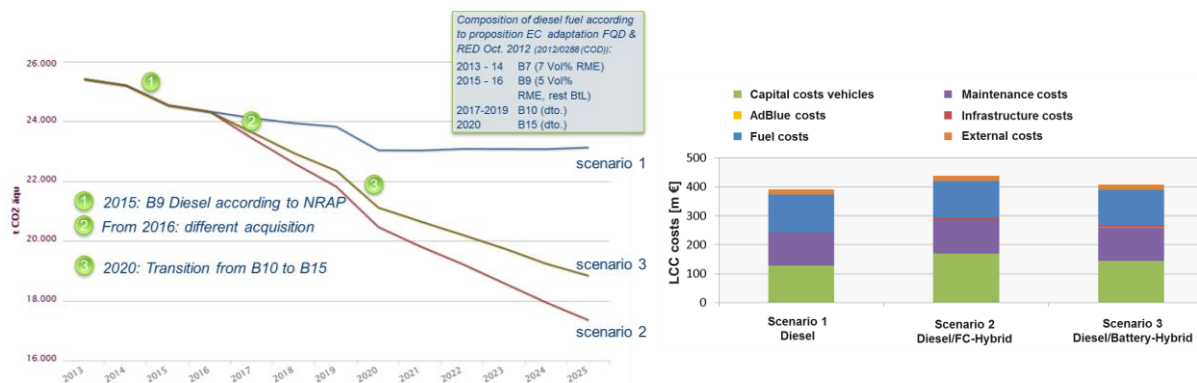


Figure 4. Yearly GWP emissions and aggregated life cycle costs for the 3 scenarios

GWP emissions of the SSB bus fleet are dependent on different factors. One factor changing over time is the share of the biodiesel according to European/national regulations European Parliament (2012). E.g. for Germany an increase from today 7% to 9% Biodiesel in 2015 and to 15% in 2020 is planned leading to GWP reductions accordingly Fed. Republic of Germany (2010).

From 2017 on the different drive train technologies are gradually (8% of all vehicle p.a.) introduced in each scenario leading to the depicted differences in GWP. While Scenario 1 features a 9% reduction in 2025 vs. 2013, scenario 2 leads over time to a 32% reduction in yearly GWP. In 2025 Scenario 2 leads to 5.800t lower emissions compared to the Business-as-usual scenario. If a Diesel with a share of 30 % biodiesel (B30) is used the analysis showed that roughly additional 10 % GWP can be saved in all three scenarios. However it needs to be noted that most bus manufacturers currently do not allow a Biodiesel share beyond 7% (B7).

Looking at the LCC of the scenarios it becomes clear that improved environm. performance of a bus fleet comes with a price tag, both scenarios 2 and 3 feature higher costs. Scenario 2 has 12% higher cost, i.e. a markup of ~47 Mio € over 13 years. This results in CO₂ abatement costs of ~1,600 €/t CO₂e. The distribution between the cost categories is relatively homogeneous. The external cost account for ~ 5% of the total LCC, i.e. are not a big enough factor to offset by themselves the increased costs for altern. fuels & drivetrain technologies.

CONCLUSIONS

The developed analysis model based on LCA and LCC allows a transparent evaluation with regard to GWP and other environm. impact categories (e.g. smog, human toxicity), energy efficiency and resource consumption as well as costs including emission abatement costs. It enables the quantification of the current and potential environmental as well as cost profile of the entire fleet including upstream processes and external effects. This holistic life cycle based approach allows the identification of potential tradeoffs between environmental impact categories and/or costs as well as life cycle phases (e.g. bus operation vs. fuel supply). The results from the model serve as a comprehensive, updateable quantitative information basis for questions regarding the environm. performance & relevance of bus based public transport (e.g. clean air action plans). Last but not least its results are well suited for communication with stakeholders (e.g. employees, customers, local administration and politics).

In summary the developed model proves to be an effective tool to support the strategic decision making of a bus operator to enhance the competitiveness and attractiveness of the public transport service offered.

REFERENCES

- European Parliament (2012). Proposal for a directive of the European parliament and of the council amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources. COM(2012) 595 final, Brussels, 17.10.2012.
- Faltenbacher, M. (2006). Modell zur ökologisch-technischen Lebenszyklusanalyse von Nahverkehrsbusssystemen. Dissertation, University of Stuttgart, 2006.
- Faltenbacher, M. (2010). Propulsion Scenarios for strategically and environmentally optimized bus fleet development (diesel, EEV, CNG, BTL, hybrid, electric). UITP, 6th Intern. Bus Conference, Lyon, June 2010.
- Federal Republic of Germany (2010). National Renewable Energy Action Plan in accordance with Directive 2009/28/EC on the promotion of the use of energy from renewable sources. BMU, Berlin, 2010.
- Hausberger, S. et al (2009). Emission Factors from the Model PHEM for the HBEFA Version 3. Report Nr. I-20/2009 Haus-Em 33/08/679, Universtiy of Graz, 07.12.2009.
- Rau, W. (2011). DIWAhybrid – Entwicklung eines Parallelhybrid-Antriebssystems für Stadtbusse. BMVBS, Final Conference "Elektromobilität in Modellregionen", Berlin, November 2011.
- Wiedemann, M.; Faltenbacher, M. (2007). Quo vadis Omnibus?. Der Nahverkehr 7-8/2007. Alba Verlag, 2007.