Energy Consumption and GHG Production in Railway and Road Passenger Regional Transport

Martin Kendra, Tomas Skrucany, Jozef Gnap, Jan Ponicky

***Abstract*—**Paper deals with the modeling and simulation of energy consumption and GHG production of two different modes of regional passenger transport – road and railway. These two transport modes use the same type of fuel – diesel. Modeling and simulation of the energy consumption in transport is often used due to calculation satisfactory accuracy and cost efficiency. Paper deals with the calculation based on EN standards and information collected from technical information from vehicle producers and characteristics of tracks. Calculation included maximal theoretical capacity of bus and train and real passenger's measurement from operation. Final energy consumption and GHG production is calculated by using software simulation. In evaluation of the simulation is used system "well to wheel".

***Keywords*—**Bus, energy consumption, GHG, production, simulation, train.

I. Introduction

MOBILITY is one of the most important human needs in this century. Average number of trips and the average traveled distance per man is constantly rising [1], [3]. Transport is becoming a very important element of human existence which has very negative impact on the environment by noise, vibration, accidents, areas' needs, congestions, and energy intensity.

During the transportation process energy entering transforms in to the movement of vehicles which provide the required transfer of goods and people in the area [2]. Therefore, the transport depends on the supply of energy. Today transportation is largely dependent on oil, as the vast majority of vehicles are driven engines combusting petroleum products - hydrocarbon fuels.

Railway transport is representative mode of transport where most railway vehicles are now powered by electric traction motors, so the rate of dependence on oil is lower than previous modes. But the fact is that in most countries the electricity is produced through petroleum products or coal [5]. All of these are non-renewable natural resources and their stocks have steadily declined.

Proper selection of traction in the railway transport can help implement the objectives of the White Book to minimize the energy consumption of transport and create a sustainable environmentally friendly mobility [4].

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II. Model Situation

In this case study we consider the transport along one chosen valley in Slovakia. There is a railway track without an electrical trolley. Nowadays small trains run at this track regularly several times a day. There are two modes of passenger transport in the valley – train and bus. Tracks of both transport modes are situated along the river Rajcanka. This track connects Zilina (administrative capital city of northern territorial unit of Slovakia) and a small town Rajec situated in the southern part of valley with amenities for people lived in valley villages. Routing of track is North – South with distance of 21.3 km.

Difference of the altitudes between Zilina (340) and Rajec (450) causes the track slope which reaches the highest value 13‰, except a small hill before the railway station in Zilina where is the slope 17‰ but only on a short distance. Average slope between end stations is 5‰.

There are 12 stops (stations) on the track, Zilina is the first one on the beginning and the last one is Rajec at the end of the track. Between them there are 10 other stops. The highest track speed limit is 60 km/h but on some sections there are the speed limits only 50 or 40 km/h [6]. Travelling time between the end stations is 37 minutes.

The average number of transported passengers for the year 2014 is 32 passengers on one train.

III. Vehicle Technical Parameters

Simulation of the energy consumption was done for a real bus and railway vehicles used in this valey. The bus Karosa C 954 was made by Karosa Vysoké Mýto from the year 2001 till 2006 (Fig. 2 (b)). The railway vehicle with series number 813-913 (Fig. 2 (a)) made by ZOS Zvolen as a reconstruction of an old diesel one unit railway vehicle with series number 810 [7]. ŽOS Zvolen has been making this diesel railway vehicle since 2007.

IV. Calculation of Energy Consumption and Emission Production

Software Railway dynamics has been used to calculate the energy consumption of the train. The power consumption of the train has been calculated on the basis of predefined and selected values on the defined route. The software works with imported maps and elevation profile of railway routes. Based on these defaults and selected parameters (locomotive type, train weight, train length, axle load, number and location of stops) power consumption was calculated in kWh. This software can be used to calculate energy consumption and operational or driving time of some arbitrary train on some arbitrary railway track. It is needed to import data of train and track for calculation [8]. It is necessary to use the principle well-to-wheels for relevant comparison of the results for different types of consumed energy.

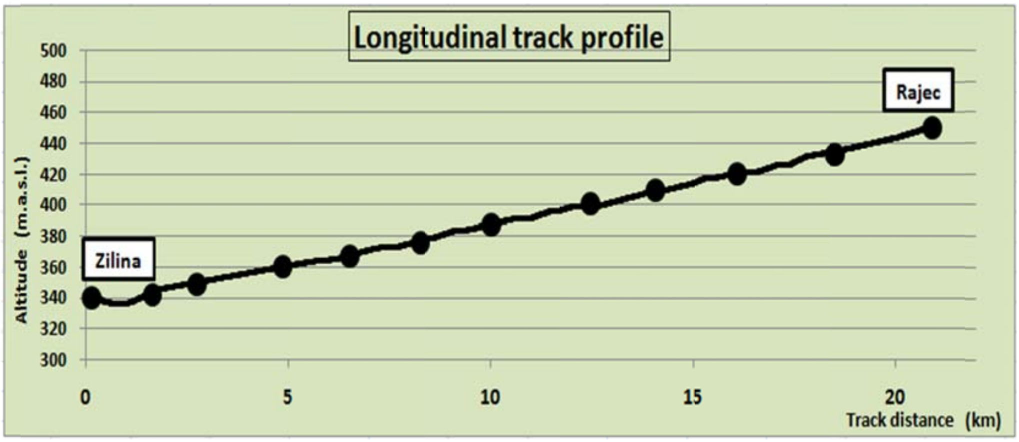

Fig. 1 Elevation track profile with stations

TABLE I
BASIC TECHNICAL PARAMETERS OF THE VEHICLES

Vehicle	Train unit 813-913	Bus Karosa C 954
drive arrangement	1´A´ + 1'1'	-
power system	diesel	diesel
power transmission	hydromechanical	mechanical
maximum speed	90 km/h	105 km/h
combustion engine	MAN D 2876 LUE 21	Iveco Cursor F2 B
design rate	257 kW	228 kW
tare weight	39 t	10,8 t
gross weight	53 t	18 t
vehicle length	28 820 mm	11 990 mm
number of seats	78 + 5	49
maximum number of standing passengers	120	39

(a) (b)

Fig. 2 (a) Railway vehicle 813-913, (b) Bus Karosa C 954

V. STANDARD EN 16258: 2012 AND ITS USING IN CALCULATIONS

This European Standard [1] specifies general methodology for calculation and declaration of energy consumption and greenhouse gas emissions (GHG) in connection with any services (cargo, passengers or both). It specifies general principles, definitions, system boundaries, methods of calculation, allocation rules (allocation, assignment) and recommendations on information to support standardized, accurate, reliable and verifiable declarations regarding energy consumption and greenhouse gas emissions associated with any freight services [9]. It also contains examples of these principles use.

The calculation for one given transport service must be performed using the following three main steps:

- Step 1: Identification of the various sections of the service;
- Step 2: Calculation of energy consumption and greenhouse gas emissions for each section;
- Step 3: Sum the results for each section.

The standard does not consider only the production of the secondary emissions and energy consumed during the combustion of the fuel (energy conversion from fuel to mechanical energy) but as well as primary, incurred in the extraction, production and distribution:

- ew well-to-wheels energetic factor for defined fuel,
- gw well-to-wheels emissions factor for defined fuel,
- et tank-to-wheels energetic factor for defined fuel,
- gt tank-to-wheels emissions factor for defined fuel.

Well-to-wheels is "well on wheels" and also covered primary and secondary emissions and consumption. This factor is somewhere also called as LCA (life-cycle-analysis).

Tank-to-Wheels factor is thinking only of secondary emission and consumption.

Standard [1] specifies general methodology for calculation and declared value for the energetic factor and factor in greenhouse gas emissions must be selected in accordance with Annex A.

Emission gases are composed of several individual components (gas). Each of them has different chemical and physical properties; so, they, otherwise, participate in environmental degradation. In order to compare emissions from different activities, fuels, vehicles where emissions have different impact, one representative unit used in the comparison must be designated. This is the CO_2 equivalent which is a measure of the impact of specific emissions and likens it to the impact of CO_2. The label is CO_2e (equivalent).

$$E_{TF} = FC_V . e_w = \left[(E_{ME} . BSFC).\frac{1}{\rho_F}\right].e_w \; [MJ] \tag{1}$$

where; E_{TF} is total energy consumed by diesel vehicles [MJ]; FC_V consumed fuel of vehicle [l , dm^3]; E_{ME} is mechanical energy consumed by the movement of the train (train dynamics software result) [kWh]; BSFC is break specific fuel consumption of the vehicle engine [g/kWh]; ρ_F is fuel (diesel) specific weight (density) [g/dm^3]; e_W is energetic factor "wtw" for defined fuel [MJ/dm^3].

The calculation of consumed energy by the bus was easier. The fuel consumption data were provided to us from the bus carrier. He does fuel consumption measurements regularly, so the number of average fuel consumption is known. This value is exactly for one type buses operating in the valley with the corresponding capacity usage.

$$E_{TB} = FC_V . e_w = \left[(FC_A . L).\frac{1}{100}\right].e_w \; [MJ] \tag{2}$$

where; E_{TB} is total energy consumed by bus [MJ]; FC_V is fuel consumption of vehicle [l, dm^3]; FC_A is average fuel consumption [l/100km]; L is driven distance [km]; e_W is energetic factor "wtw" for defined fuel [MJ/dm^3].

VI. GHG Production

For the GHG production calculation, the consumed amount of diesel fuel should be multiplied by an emission factor for that fuel from Appendix A of the EN standard.

$$G_{TF} = FC_V . g_w = \left[(E_{ME} . m_{Pe}).\frac{1}{\rho_F}\right].g_w \; [gCO_2e] \tag{3}$$

where; G_{TF} the total amount of emissions produced by diesel train [gCO_2e]; gW emission factor for defined fuel [tCO_2e/MWh], for the buses the same principle.

$$G_{TFB} = FC_V . g_w = \left[(FC_A . L).\frac{1}{100}\right].g_w \; [gCO_2e] \tag{4}$$

where; GTFB is the total amount of emissions produced by bus [gCO_2e]; gW is emission factor for defined fuel [tCO_2e/MWh].

The basic units of MJ and gCO_2 were chosen for the calculation because they are declared units in the standard [10]. However, for better comparison and expression, it is possible to expressed individual amounts in other units, for example GJ, KJ, tCO2, $kgCO_2e$ or a combination of them, in the case of proportional expressing of quantities (see the evaluation).

VII. Evaluation

The calculation for this model study was done on the track in bidirectional ways, so one way down the hill and the other way up the hill. This elevation is seen in the energy consumption which is higher for uphill track, from Zilina to Rajec. Only the numbers as the results from transport in both directions are in the evaluation Table II.

Table of the final evaluation shows the advantage of the road transport vehicle – bus. There are very similar engines (performance and consumption) in both of the vehicles. However the railway track is not so difficult in slopes like the road, thus the railway vehicle does not reach the fuel consumption lower than bus. It is caused by its tare weight – 39 t what is about 28 t more than cca 11 t of bus tare weight.

TABLE II
Final Evaluation

State	Vehicle	Fuel consumption (L)	Total energy consumption (MJ)	State	Vehicle	Passenger number	Energy per capita (MJ/person)	Emissions per capita ($kgCO_2e$/person)
Full loaded	train	22,98	981,2	Full loaded	train	83	11,82	0,90
	bus	12,48	532,9		bus	49	10,88	0,83
Real passenger number	train	17,72	756,6	Real passenger number	train	32	23,65	1,79
	bus	11,76	502,2		bus	26	19,31	1,47

The simulated fuel consumption of the diesel train was compared to the real consumption of this train operated on this track. This simulated result was validated because the simulation error was only -8%. So every consumption results were increased of the value 8% to be closer to the reality. However, the diesel train reaches higher value of the real passenger number, thus it does not reach higher efficiency than the bus. As mentioned above, this fact is caused by the tare weight of the train. The total energy consumption of the bus represents only 54 - 66 % of the train consumption, according to the actual capacity usage. In the unit expression (MJ/prs) the difference is lower on account of higher capacity and passenger nr. values regardless of the effectiveness reached by the road vehicles. Similar case as the energy consumption is the GHG production [11]. The share between GHG production of vehicles is the same as the energy consumption because it was calculated according to the EN 16 258:2012 where the GHG production is a multiply of the fuel consumption and emission factor ((3), (4)).

The results of this simulation do not determine which transport mode is better, greener or friendlier to the environment. It is not possible to do it, because the energy efficiency and GHG production is not dependent only on the fuel or energy consumption but also on the capacity usage. It is necessary to load the vehicles with the adequate number of passengers (suitable choice of the vehicle according to the transport flow). The transport efficiency is decreasing with the decreasing of actual capacity usage. So the coordination of the transport flow and vehicle operation is the step to greener transport.

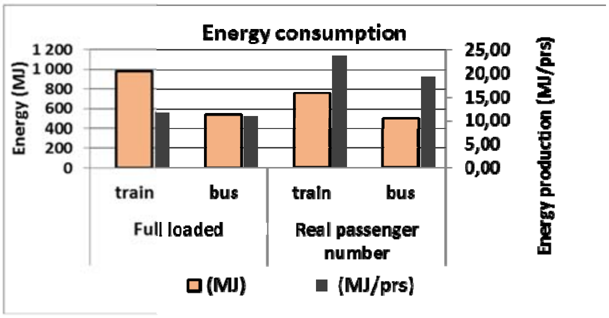

Fig. 4 Evaluation of the energy consumption

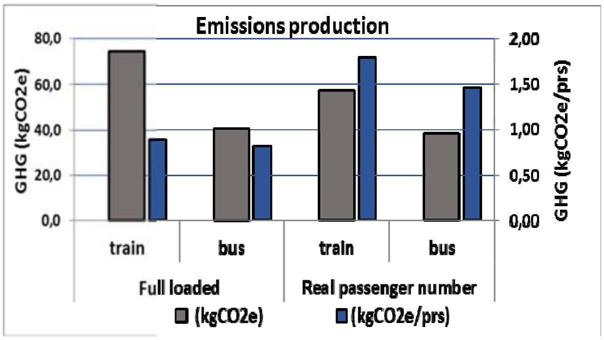

Fig. 5 Evaluation of the GHG production

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