International Journal for Traffic and Transport Engineering, 2014, 4(2): 210 - 219

DOI: http://dx.doi.org/10.7708/ijtte.2014.4(2).07 *UDC: 504.054:656(439)*

ENVIRONMENTAL COMPARISM OF ROAD AND RAILWAY TRANSPORT: A CASE STUDY IN HUNGARY

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Received 1 August 2013; accepted 8 May 2014

Abstract: The influence of mankind around the world is unquestionable. Resources are used and pollution is made during the transportation of human capital, raw materials, semi-final and final products. Nowadays pollution is a key factor in the progress towards sustainability in all sectors. Recently only the transport sector has not been able to fulfil the requirements and lower its emission in Europe. Further on there is a global pressure on modal shift from road to rail. But the question is still not answered whether the rail transport pollutions less? This article aims to present a method of analysis and to answer these questions in the case of Hungary.

Keywords: life cycle analysis, comparative analysis, life cycle emission, road transport, rail transport.

1. Introduction

Human activities are now shaping the Earth more than any other geological factor, as human dominance affects almost all biological systems on the Earth (Fig. 1).

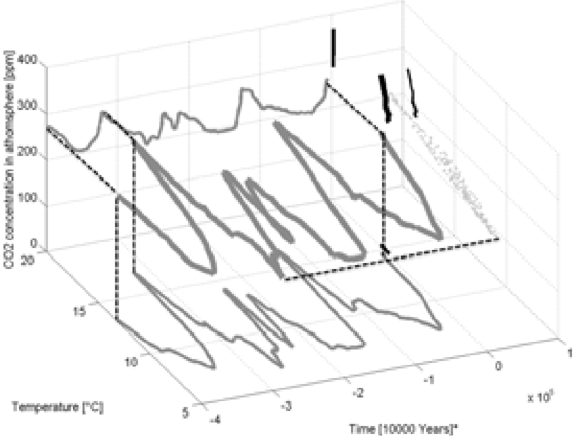

Fig. 1.
Average Atmospheric CO_2 and Average Earth Temperature Complex Time Series
Source: Török and Tánczos (2007)

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The 6°C Scenario (6DS) is largely an extension of current trends. By 2050, energy use almost doubles (compared with 2009) and total greenhouse gas (GHG) emissions rise even more. In this case the transport sector would emit 10 810 million $tCO_{2,eq}$ worldwide (Fig. 2).

Fig. 2.
Forecast of Energy Consumption in the World and in the EU27
Source: International Energy Agency (2012), http://www.iea.org/etp/explore

The 4°C Scenario (4DS) takes into account recent tendencies, emissions made by countries, to limit emissions and step up efforts to improve the energy efficiency. Projecting a long-term temperature rise of 4°C, the 4DS is already an ambitious scenario, which requires significant changes in policy and technologies. Moreover, capping the temperature increase at 4°C requires significant additional cuts in emissions in the period after 2050. The 2°C Scenario (2DS) describes an energy system consistent with an emissions trajectory that recent climate science research indicates. Importantly, the 2DS acknowledges that transforming the energy sector is vital, but not the sole solution: the goal can only be achieved if CO_2 and GHG emissions in non-energy sectors are also reduced. The transport sector contributes to the total CO_2 emission with 24% in the case of the EU27 (International Energy Agency, 2012). Finding out whether road or rail is the most eco-friendly mode of travel is very difficult. In this article the author is only focusing on environmental impact of transport modes - rail and road - based on CO_2 emission (Fig. 3 and Fig. 4).

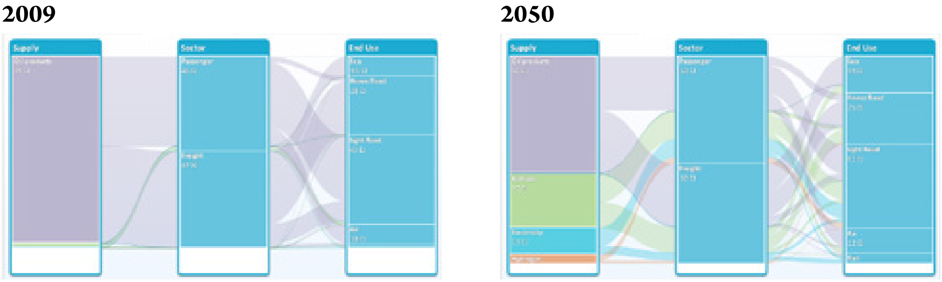


Fig. 3.
Transformation of Energy Flows in Transport Sector in EU27
Source: International Energy Agency (2012), http://www.iea.org/etp/explore

It is almost universally accepted that rail transport is greener than travelling by road. But is it true? This paper tries to answer this question. Firstly the energy flows have been investigated separately for road transport and for rail transport.

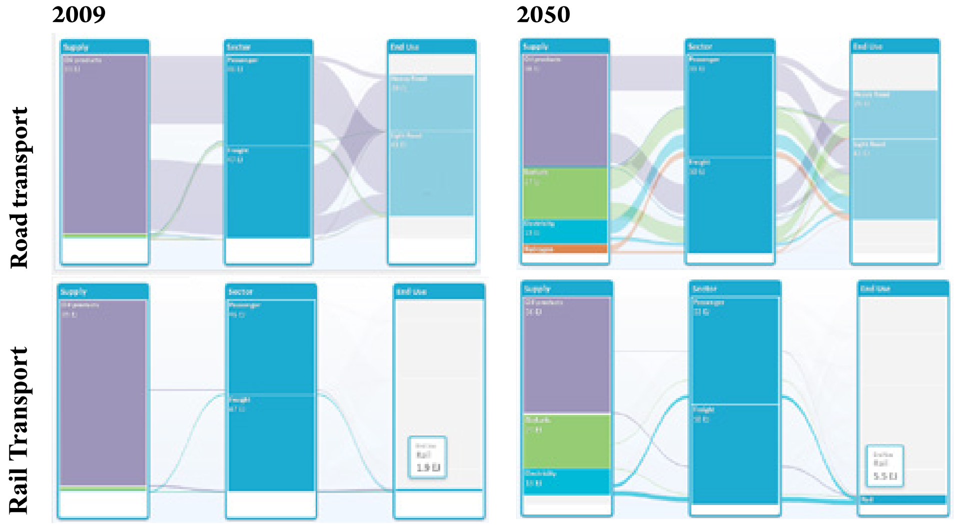


Fig. 4.
Transformation of Energy Flows in Transport Sector in EU27
Source: International Energy Agency (2012), http://www.iea.org/etp/explore

According to the study of the International Energy Agency (2012) in 2009 the road transport subsector used 71 EJ worldwide, and the rail transport subsector used 1.9 EJ from fossil fuel.

Based on the forecast until 2050 the road transport will lower its fossil fuel consumption and will use 46 EJ biofuels. Compare to this, rail transport will use 5.5 EJ biofuel.

2. Methodology

The basic assumption was that passenger cars should be compared to rail transport in case of passenger transport, and heavy goods road vehicles should be compared to rail transport in case of goods transport in terms of environmental pollution. In the case of the passenger cars and electric railway, the emission should be on the basis of distance and in the case of the goods transportation, the comparison between electrified railway and heavy goods road vehicles should be on the basis of energy unit.

Estimating the CO_2 emission of fossil fuel burning is a very complex task, because fossil fuel is a chemically complex blend of more than 400 hydrocarbon components. The described CO_2 estimation processes are based on the following studies by Zöldy (2011), Bereczky (2012) and Barabas and Todorut (2011), as a description of ideal burning (Eqs. (1-4)).

$$2\,C_8H_{18} + 25\,O_2 \rightarrow 16\,CO_2 + 18\,H_2O \quad (1)$$

$$2\,C_{14,5}H_{30} + 44\,O_2 \rightarrow 29\,CO_2 + 30\,H_2O \quad (2)$$

$$C_2H_5OH + 3\,O_2 \rightarrow 2\,CO_2 + 3\,H_2O \quad (3)$$

$$2\,C_{19}H_{38}O_2 + 53\,O_2 \rightarrow 38\,CO_2 + 19\,H_2O \quad (4)$$

It is an upper estimation for CO_2 emission, in real condition there is no such perfect burning. So firstly the fuel consumption was needed to be defined for distance based emission (Eq. (5)) and for energy based emission (Eq. (6)):

$$\tau_{kl} \cdot \rho_{kl} = \varphi'_{kl} \quad (5)$$

where:

τ – fuel consumption $[litre\ fuel\ \cdot 0{,}01\ km^{-1}]$,

ρ – density of fuel $[g \cdot\ l^{-1}]$,

k – type of fuel (1 – gasoline, 2 – diesel oil),

l – type of road vehicle (1 – passenger car, 2 – light goods vehicle, 3 – heavy goods vehicle, 4 – trucks, 5 – bus),

φ' – fuel consumption of 100 km $[g\ fuel\ \cdot 0{,}01\ km^{-1}]$.

$$\gamma_k \cdot \delta_k = \varepsilon_k \quad (6)$$

where:

γ – emitted CO_2 by litre of fuel $[\mathrm{g\ CO_2\ \cdot l\ fuel^{-1}}]$,

δ – fuel needed to produce 1 MWh energy $[\mathrm{l\ fuel\ \cdot MWh^{-1}}]$,

ε – energy production related emission $[\mathrm{g\ CO_2\ \cdot MWh^{-1}}]$.

Looking at the entire "greening" of the transportation, significant results were achieved in the last couple of decades (Domanovszky, 2014; Olli-Pekka, 2014). Firstly, from 1999 the petrol is unleaded, and the compulsory blending of bio component was a great step towards a sustainable future (Wilde, 2011; Bereczky and Török, 2011). In Hungary now (in 2013) 4.4V/V% of bio component is added to fossil fuel. These conditions were taken into account for distance based emission (Eq. (7)) and for energy based emission as well (Eq. (8)):

$$\Gamma \cdot \tau_{pl} \cdot \rho_{pl} = \varphi_{pl} \qquad (7)$$

where:

Γ – constant, can be $\begin{cases} 0{,}95 \text{ if } p = 1{,}2 \\ 0{,}05 \text{ if } p = 3{,}4 \end{cases}$

$$\Gamma \cdot \rho_{pl} \cdot \omega_{pl} = \sigma_{pl} \qquad (8)$$

where:

ω – burning related CO_2 production

$[\text{g } CO_2 \cdot \text{g fuel}^{-1}]$,

σ – emitted CO_2 $[\text{g } CO_2]$.

Firstly, the system limits have been widened. In the case of the road transport not only the fuel consumption were taken into account (tank to wheel consumption), but production, transportation (well to tank consumption) were also included separately for distance (Eqs. (9) and (10)) and for energy based comparison (Eqs. (11) and (12)).

$$\left[\frac{\varphi_{pl}}{100} = \frac{\sum_{l=1}^{5} 0{,}95 \cdot \tau_{1l} \cdot \rho_{1l} + 0{,}05 \cdot \tau_{3l} \cdot \rho_{3l}}{100}\right] \cdot \vartheta = \phi_{1;gasoline} \qquad (9)$$

$$\left[\frac{\varphi_{pl}}{100} = \frac{\sum_{l=1}^{5} 0{,}95 \cdot \tau_{2l} \cdot \rho_{2l} + 0{,}05 \cdot \tau_{4l} \cdot \rho_{4l}}{100}\right] \cdot \vartheta = \phi_{1;diesel\ oil} \qquad (10)$$

$$\left[\varepsilon_p = \gamma_1 \cdot \delta_1 + \gamma_3 \cdot \delta_3\right] \cdot \vartheta = \phi_{2benzin} \qquad (11)$$

$$\left[\varepsilon_p = \gamma_2 \cdot \delta_2 + \gamma_4 \cdot \delta_4\right] \cdot \vartheta = \phi_{2gázolaj} \qquad (12)$$

where:

ϑ – constant, burning related emission compared to total life cycle emission [-],

ϕ_1 – Total CO_2 emission (well-to-wheel) on

1 km $[\text{g } CO_2 \cdot \text{km}^{-1}]$,

ϕ_2 – Total CO_2 emission (well-to-wheel) on

1 MWh g $CO_2 \cdot \text{MWh}^{-1}$.

So far the model setup can be concluded as (Fig. 5):

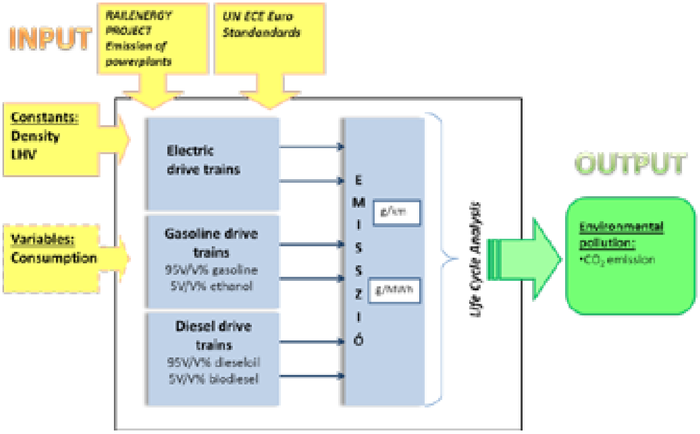


Fig. 5.
Methodological Overview of the Comparative Analysis

The above mentioned model is capable for investigation the further extension of bio component, for instance in the case of 10V/V% or the significant penetration of electric road vehicles (European Automobile Manufacturers Association, 2010a).

3. Results

Due to the more and more stricter regulations, technological advances have dramatically reduced the footprint of road vehicles in the past 20 years. In 1998, most new cars in the UK emitted an average of 186 grams of CO_2 per passenger kilometre. By 2020, cars will be required by the European Union to emit almost half of the previous amount: no more than 95 grams. For CO_2 emission it is worth observing on the basis of the data of *European Automobile Manufacturers Association* (Fig. 6). The CO_2 emission of traditional internal combustion engines are significantly decreasing, more and more energy-efficient vehicles are being sold with lower CO_2 emissions than 120 g/km (European Automobile Manufacturers Association, 2010b).

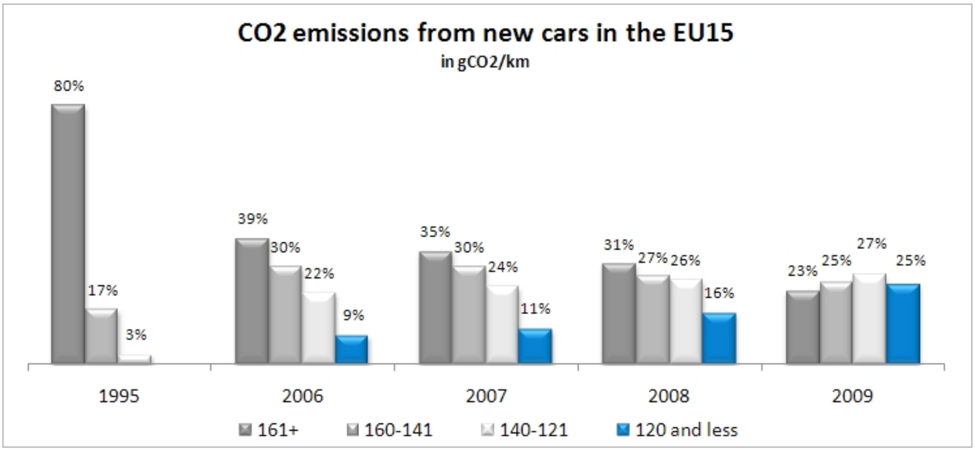
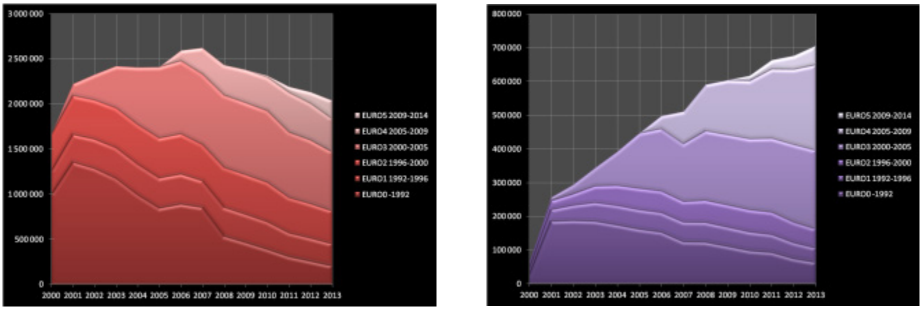


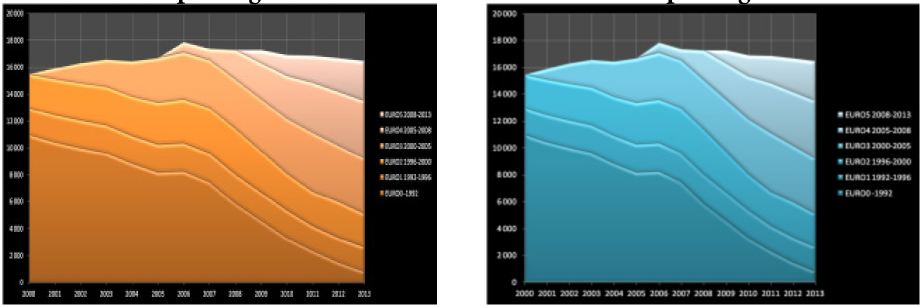
Fig. 6.
Distance Based Emission of New Cars in EU27
Source: European Automobile Manufacturers Association (2010b)

Within the EU27 there is large market segregation between Core Countries and Newly Associated States (Panasiuk and Lebedevas, 2014). For instance the market penetration of greener vehicles is slower in Hungary (Szendrő et al., 2012) (Fig. 7) that can be influenced by soft measures of transport policy related tools (Szendrő, 2011):



Gasoline driven passenger cars

Diesel oil driven passenger cars



Buses

Heavy goods vehicles

Fig. 7.
Hungarian Road Vehicle Fleet

Therefore in the process of analysing Hungary, the EURO 3 categories were used to follow the lower rate of green cars.

Table 1 indicates the converted (distance based) emission of electricity, compared to EURO-5 standard if their energy originates from different power plants.

Table 1
Distance Based Comparison of Emissions in the Case of the Power Plants and Passenger Cars

	SO_2	NO_x	PM	CO_2	CO
	g/km	g/km	g/km	g/km	g/km
Nuclear	0,001	0,001	0,000	0,394	NA
Coal	0,007	0,011	0,004	16,300	NA
Gas	0,000	0,007	0,000	8,518	NA
Oil	0,000	0,023	0,002	22,000	NA
Wind	0,000	0,000	0,000	0,129	NA
EURO 3 Diesel	-	0,176	0,000	208,640	
EURO 3 Gasoline	0,059	0,588	0,000	286,713	

Table 2 indicates the converted (energy based) emission of electricity, compared to EURO-3 standard, if their energy originates from different power plants.

Table 2

Distance Based Comparison of Emissions in Case of Power Plants and Goods Vehicles

	PM [g/MWh]	NO_X [g/MWh]	SO_2 [g/MWh]	CO_2 [g/MWh]
Nuclear	7	70	32	19700
Coal	182	560	326	815000
Gas	21	326	4	425882
Oil	79	1159	2	1100000
Wind	5	20	15	6460
EURO 3 Diesel	0	5882	118	501437

4. Analysis and Discussion

So in terms of "greening" the transportation, considering EURO 3 standard, the environmental impact of road transport in Hungary will only decrease with the wide spread of rail transport if electricity is produced in a nuclear, gas or wind power plant (Table 3).

Table 3

Comparison of Road and Rail Transport from Environmental Point of View

Passenger transport [g/km] (well-to-wheel emission)						**Goods transport [g/MWh] (well-to-wheel emission)**				
	PM	NO_X	SO_2	CO_2			PM	NO_x	SO_2	CO_2
Nuclear	0,000	0,001	0,001	0,394		Nuclear	7	70	32	19700
Coal	0,004	0,011	0,007	16,300		Coal	182	560	326	815000
Gas	0,000	0,007	0,000	8,518		Gas	21	326	4	425882
Oil	0,002	0,023	0,000	22,000		Oil	79	1159	2	1100000
Wind	0,000	0,000	0,000	0,129		Wind	5	20	15	6460
EURO 3 Gasoline	0,000	0,176	-	208,640		EURO 3 Diesel	0	5882	118	501437
EURO 3 Diesel oil	0,000	0,588	0,059	286,713						

Unfortunately in Hungary the penetration of wind turbines are low. Only nuclear power plant exists. Mostly old and environmentally unfriendly power plants are producing electricity. Further on the electrified railway penetration in Hungary is very low. So taking into account all these the modal shift – only from environmental point of view – can be questionable. Finally a sensitivity analysis has been done, to investigate the influence of the reliability of inputs and parameters (Table 4).

Table 4
Result of Sensitivity Analysis

			CO$_2$ emission [g/km]		CO$_2$ emission [g/kWh]
			Passenger Transport		**Goods Transport**
			Gasoline	**Diesel oil**	
Ratio of bio component			0,34%	0,39%	0,38%
Fuel consumption	**Passenger car**	**Gasoline**	1,00%	0,00%	0,00%
		Diesel oil	0,00%	1,00%	0,00%
	Heavy Goods Vehicle		0,00%	0,00%	0,00%
Technological efficiency of fuel production and distribution			1,16%	1,16%	1,16%

The sensitivity analysis showed that the model most sensitive to technological efficiency of fuel production and distribution. This means that if the efficiency of fossil fuel production refine or distribution can be increased then the maximal CO$_2$ emission reduction can be achieved.

Acknowledgements

This work is connected to the scientific program of the "Development of quality-oriented and harmonized R+D+I strategy and functional model at BME" project. This project is supported by the New Szechenyi Development Plan (Project ID: TÁMOP-4.2.1/B-09/1/KMR-2010-0002). The author is grateful to the support of Bólyai János Research fellowship of HAS (Hungarian Academy of Science). The author is grateful for the support of Prof. Dr. Florian Heinitz, Director of Transport, and Spatial Planning Institute in Erfurt, Germany. Further on the author is grateful for the support of Judit Wirth and Boglarka Dunar MSc students for their valuable work.

References

Barabas, I.; Todorut, I.A. 2011. Predicting the temperature dependent viscosity of biodiesel-diesel-bioethanol blends, *Energy & Fuels*. DOI: http://dx.doi.org/10.1021/ef2007936, 15(12): 5767-5774.

Bereczky, Á. 2012. Parameter analysis of NO emission of spark ignition engines, *Transport (Vilnius)*. DOI: http://dx.doi.org/10.3846/16484142.2012.664563, 27(1): 34-39.

Bereczky, Á.; Török, Á. 2011. International literature review on the possibilities of biodiesel production, *Periodica Polytechnica-Transportation Engineering*. DOI: http://dx.doi.org/ 10.3311/pp.tr.2011-1.06, 39(1): 31-37.

Domanovszky, H. 2014. Gas propulsion or e-mobility is the solution on the way of clean and carbon free road transportation?, *Periodica Polytechnica-Transportation Engineering*. DOI: http://dx.doi.org/ 10.3311/PPtr.7254, 32(1): 63-72.

European Automobile Manufacturers Association. 2010a. *ACEA Communication – vehicles and biofuels towards 2020*, European Automobile Manufacturers Association. Available from Internet: http://www.acea.be/images/uploads/files/20100512_ACEA_communication_biofuels_2020.pdf. 4 p.

European Automobile Manufacturers Association. 2010b. *ACEA Economic Report - full year 2009*, European Automobile Manufacturers Association. Available from Internet: http://www.acea.be/images/uploads/files/20100311_ER_1003_2010_I_Q1-4.pdf. 212 p.

International Energy Agency. 2012. *Energy Technology Perspectives 2012 - Pathways to a Clean Energy System.* Executive Summary, International Energy Agency. Available from Internet: http://www.iea.org/publications/freepublications/publication/ETP2012SUM.pdf. 10 p.

Szendrő, G. 2011. Congestion charging in Budapest – a comparison with existing systems, *Periodica Polytechnica-Transportation Engineering*. DOI: http://dx.doi.org/10.3311/pp.tr.2011-2.09, 39(2): 99-103.

Szendrő, G.; Csete, M.; Török, Á. 2012. Unbridgeable gap between transport policy and practice in Hungary, *Journal of Environmental Engineering and Landscape Management*. DOI: http://dx.doi.org/10.3846/16486897.2012.660881, 20(2): 104-109.

Panasiuk, I.; Lebedevas, S. 2014. The assessment of the possibilities for the Lithuanian fleet to comply with new environmental requirements, *Transport*. DOI: http://dx.doi.org/10.3846/16484142.2014.896828, 29(1): 50-58.

Olli-Pekka, H. 2013. From Bubble to Sustainable Economy in the Baltic States, *Transport and Telecommunication*. DOI: http://dx.doi.org/ 10.2478/ttj-2013-0021, 14(3): 237-249.

Török, Á.; Tánczos, K. 2007. The linkage between climate change and energy consumption of Hungary in the road transportation sector, *Transport (Vilnius)*. DOI: http://dx.doi.org/10.1080/16484142.2007.9638112, 22(2): 134-138.

Wilde, Gy. 2011. *Yearly Report*, Hungarian Petroleum Association. 13 p.

Zöldy, M. 2011. Ethanol-Biodiesel-Diesel Blends as a Diesel Extender Option for Internal Combustion Engines, *Transport (Vilnius)*. DOI: http://dx.doi.org/10.3846/16484142.2011.623824, 26(3): 303-309.