POSSIBILITIES OF USING LIQUEFIED OIL GAS IN TRANSPORT

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Abstract. The trends of the input of an alternative type of fuel in the transport system of the European Union are analysed. Taking into account the measures of promoting liquefied petroleum gas (LPG) consumption in road transport, a bundle of specific variables was analysed to understand the consumers for making decision to use LPG in cars. It is revealed that the obtained models enable to evaluate the behaviour of consumers and conditioning transition to using an alternative type of fuel in transport industry. The proposed models were assessed conducting statistic and sensitivity analysis. The pay-off of the additional equipment of the car was analysed considering the driven distance with an alternative type of fuel. The pay-off analysis of supplementary equipment depending on the ratio of standard and alternative fuel prices is presented.

Keywords: liquefied petroleum gas, hedonic model, price ratio, statistical analysis.

1. Introduction

A wide use of the alternative types of fuel in transport depends on its production and additional expenditure for its transportation and storage, payment policy and the acceptability of the final user to utilize alternative fuel (Kuglevičius *et al.* 2007; Tanczos and Torok 2007; Butkus *et al.* 2007; Lingaitis and Pukalskas 2008a, b). In any case, the production expenditure of alternative fuel is the price function derived from resources and the level of technology that enables to derive it. The implementation of Directive 2003/30/EC (2003) issued by the European Parliament and the European Council on 8 May 2003 on promoting the use of biofuels and other renewable fuels for transport apply various promoting measures to use the alternative types of fuel in transport. A number of economical experiments have been carried out regarding the impact of car characteristics on the price at the increase of environmental requirements and the change of fuel prices. The research results received by Jonson (2003) and Faiz *et al.* (1996) have revealed that the increasing prices of fuel enable to tackle strict environmental requirements. Hung (2006) notes that the main measure to apply cars to alternative fuel – LPG is to balance taxes giving priority to alternative fuel and paying subsidies to the equipment of alternative fuel. However, a wide use of the alternative types of fuel is stopped by the expenditure of alternative fuel production which usually exceeds the expenditure of producing standard fuel (gasoline, diesel) and an insufficient use of cars consuming different alternative fuel.

2. Trends of LPG Expenditure in the EU

There are a number of different engines using different kinds of alternative fuel. However, LPG, as a type of alternative fuel, is most widely used in the Otto cycle engines of internal combustion. LPG is an ecologic measure to reduce the amount of pollutants in the combustion products of car fuel. Other alternative types of fuel (biodiesel, ethanol or a mixture of methanol and gasoline, hydrogen, compressed or liquefied natural gas) in the engines of internal combustion are used very restrictedly in the EU. Data on using the alternative types of fuel in road transport (prices, consumption amounts) is very limited. Therefore, due to lack of statistical data, only LPG use in the Otto cycle engine of internal combustion in the EU countries will be analysed in the article.

Taking into account the indicated model of LPG use in cars, it is expedient to use statistical data in further analysis justifying relations among variables. For selecting typical values, we use the statistical data of EUROSTAT (2008) and International Energy Agency (IEA) statistic (2008). At this time, LPG is widely used for different needs in the EU (Fig. 1).

One of the exceptional fields is LPG use in road transport. As it can be seen, the final consumption of LPG increases more rapidly in transport. Within the analysed period, it increased by 35%, whereas in other
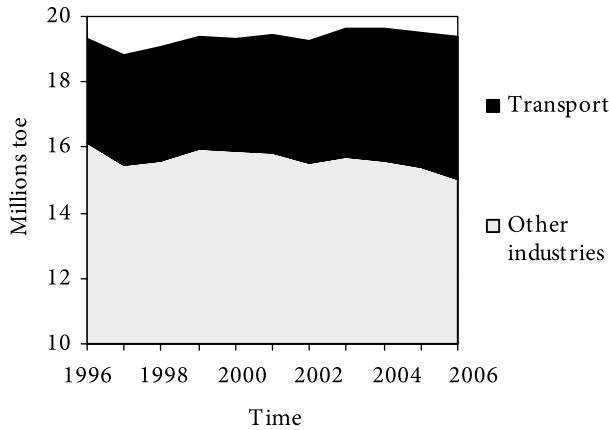
Fig. 1. The trends of final consumption LPG
in the EU countries

industrial branches it remained almost constant and re-
duced only by 6%. Detailed LPG consumption accord-
ing to the information provided by the EU countries in
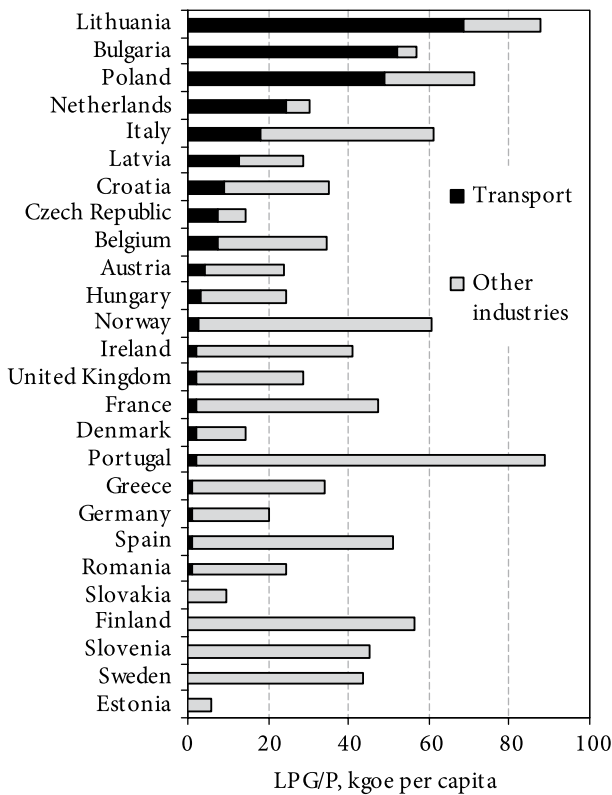2006 is presented in Fig. 2.

Fig. 2. The final consumption of LPG per capita in the
selected EU countries

Due to a number of different reasons, the final con-
sumption of LPG in different EU countries as well as in
road transport changes in wide limits (Fig. 2). The biggest
amount of LPG in transport is consumed in Lithuania, Bul-
garia, Poland, Holland and Italy. In many EU countries, LPG
in transport is not used at all or applied very restrictively
(Slovenia, Slovakia and Finland). Also many countries (e.g.
Estonia, Sweden) though use LPG in transport, no detailed

statistical data is provided. Three EU countries including
Holland, Italy and Poland consume 68% of LPG in road
transport and only due to Poland, LPG consumption in the
EU countries substantialy increase (Fig. 3). Other EU coun-
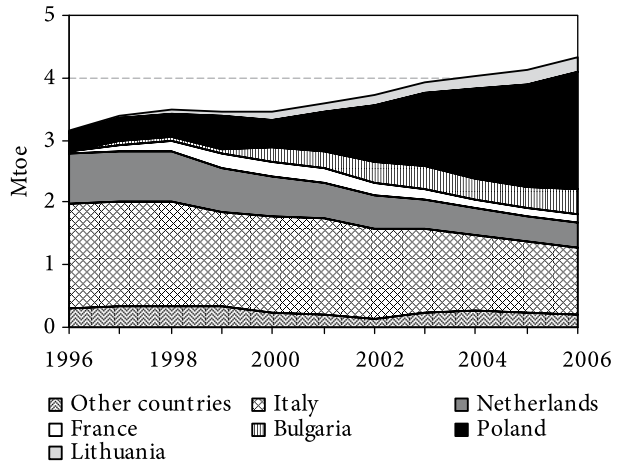tries consume only an insignificant part of LPG.

Fig. 3. LPG consumption in transport in various countries

One of the main indicators promoting LPG use in
transport is the ratio of LPG and gasoline prices. The Gov-
ernments of the EU countries differently estimate LPG
application in transport. In most cases, this is related to
the different types of gasoline and LPG prices, i.e. making
discounts to LPG price while reducing taxes. This ratio in
different EU countries fluctuates in the range from 0.49
to 0.85 (Fig. 4). Other impact measures (LPG equipment
installation in cars using subsidies) of LPG installation in
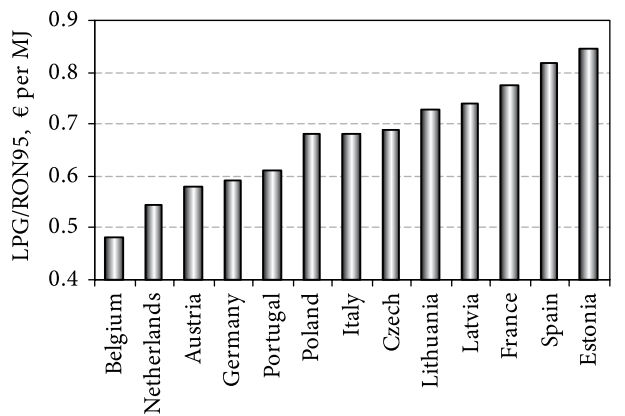transport are more applied to public transport.

Fig. 4. The ratio of LPG and gasoline prices in the EU
countries, 2006

The price of LPG equipment in cars depending on
its complexity and the country of installation may vary in
the range from 700 to 2500 €. In general, it is comprised
of two variables – the price of equipment itself and its
installation to the car. It was not possible to find reliable
sources able to evaluate the prices of LPG equipment and
its installation, and thus in further analysis, only maxi-
mum and minimum prices were taken into account.

When determining the model of LPG application in cars, it is expedient to use statistical data, justifying relations among variables in further analysis. While selecting the typical data, it is considered that the statistical dependence of LPG consumption on road transport is defined by variables. For this purpose, the typical data of various countries is transformed into the form relevant to the model (Table 1). Besides, aiming to use typical values in a regressive model and to reduce the number of variables, the following relative values were used:

- $P(X)$ – LPG consumption in road transport, MJ per capita,
- X_1 – The amount of GDP (at 1995 prices and exchange rates), 1000 € per capita,
- X_2 – Ratio of LPG and gasoline RON95 prices, € per MJ,
- X_3 – Final consumption of LPG, MJ per capita,
- X_4 – Final consumption of all petroleum products, MJ per capita,
- X_5 – Final consumption of all petroleum products in transport, MJ per capita,
- X_6 – Ratio of the amount of individual cars older than ten years to total,
- X_7 – LPG consumption in road transport, average annual increase.

In the row of countries, the data on LPG price and consumption in transport is not presented. The information about the countries not found in the statistical basis of EUROSTAT and International Energy Agency (IEA) statistic will not be included into the future analysis.

Table 1. Data on using LPG in the road transport of the EU countries for regression analysis

Country	$P(X)$	X_1	X_2	X_3	X_4	X_5	X_6	X_7
				2004				
Belgium	8.46	25.4	0.46	21.8	1606	973	0.29	−0.08
Czech	7.34	5.0	0.69	18.7	666	545	0.55	0.03
Germany	1.02	26.4	0.60	19.4	1106	737	0.31	0.07
Spain	1.87	14.9	0.72	60.0	1237	894	0.39	0.00
France	2.67	23.6	0.72	52.9	1195	786	0.32	−0.10
Italy	20.99	16.9	0.65	67.3	1024	738	0.39	−0.07
Latvia	10.78	2.9	0.70	25.4	562	432	0.85	0.06
Lithuania	60.94	2.4	0.62	81.5	438	383	0.92	0.19
Netherlands	25.53	25.1	0.50	32.1	1076	919	0.31	−0.10
Poland	37.63	4.1	0.62	63.7	456	287	0.56	0.29
Portugal	2.10	10.4	0.66	99.0	1166	693	0.74	0.00
				2005				
Belgium	8.04	25.6	0.44	20.0	1582	936	0.29	−0.06
Czech	7.53	5.3	0.66	16.7	679	584	0.53	0.03
Germany	1.07	26.7	0.59	19.7	1075	713	0.32	0.06
Spain	1.14	15.2	0.77	57.2	1233	904	0.39	−0.13
France	2.44	23.7	0.75	51.5	1171	773	0.32	−0.10
Italy	19.35	16.7	0.63	66.2	1000	726	0.39	−0.08
Latvia	11.27	3.2	0.72	26.9	578	456	0.83	0.07
Lithuania	65.98	2.6	0.69	87.0	470	409	0.91	0.14
Netherlands	24.10	25.4	0.51	28.7	1067	918	0.31	−0.10
Poland	43.14	4.2	0.63	68.1	468	307	0.55	0.21
Portugal	2.28	10.4	0.66	92.1	1003	665	0.73	0.05
				2006				
Belgium	7.61	25.7	0.48	34.6	1479	902	0.29	−0.04
Czech	7.71	5.6	0.69	14.3	673	595	0.51	0.04
Germany	1.07	26.9	0.59	20.4	1089	709	0.33	0.02
Spain	1.03	15.5	0.82	51.7	1213	918	0.39	−0.16
France	2.27	23.8	0.78	47.4	1147	779	0.32	−0.08
Italy	18.45	16.6	0.68	61.7	978	728	0.39	−0.07
Latvia	12.64	3.5	0.74	28.3	642	507	0.82	0.08
Lithuania	68.17	2.8	0.73	87.3	490	435	0.91	0.10
Netherlands	24.49	25.7	0.54	30.1	1062	945	0.31	−0.06
Austria	4.48	28.1	0.58	23.8	1377	883	0.34	0.06
Poland	48.96	4.4	0.68	71.1	483	343	0.55	0.16
Portugal	2.18	10.4	0.61	89.1	957	664	0.73	0.01

3. Hedonic Model of LPG use in Cars

In general, manufacturers find important to evaluate the impact of product price on the consumer which is determined by the price of the sold item. The method analyzing the behaviour of customers in regard to the price of a good is called hedonic analysis. The main presumption of the method is that the customer buying different amounts and goods of different properties strives to maximize their use. The objective of the analysis is to join the variety of different factors and evaluate the price of a good as a unit.

Formalizing the priority of the customer to individual facility, the benefit function may be applied by Biderman *et al.* (2005):

$$u = u(X, Z, \delta), \qquad (1)$$

where: X – a supplementary equipment vector in volume car; Z – the consumption of other material resources, δ – a vector defining customer's priority to equipment. From the benefit function, it is possible to indirectly get customer's need regarding car modernization (including the use of supplementary equipment).

$$D = D(X, Y, u, \delta), \qquad (2)$$

where: Y – the income of consumer.

The consumer will try to maximize benefit and will choose such X and Z values so that the function (2) would have maximum values.

$$P(X) \le \max\{X, Z, \delta\}, \qquad (3)$$

where: $P(X)$ – a price vector attributed to equipment X, called 'hedonic price function'.

In general, this function is found as a multiple regression equation of many variables, McCormack (2003). The regression model may be determined modelling the relation of variables and determining their significance. The elimination of insignificant variables and the determination of the number of minimum variables was the objective of data regression analysis.

The performed regression analysis has revealed that the significance of various values such as GDP per capita, ratio of LPG and gasoline RON95 prices, LPG final consumption etc. (Table 1) depends on the expression of the function. The regression equations of the following form defining LPG use in transport were obtained:

$$P_1(X) = b_0 + b_1 \cdot X_4 + b_2 \cdot X_2 + b_3 \cdot X_3, \qquad (4)$$

$$P_2(X) = b_0 + X_2 \cdot \left(b_1 \cdot X_2 \cdot X_3 + b_2 \cdot X_4^2 + b_4\right) + b_3 \cdot X_3^2 \cdot X_4, \qquad (5)$$

or

$$P_3(X) = b_0 + b_1 \cdot X_2 \cdot X_3 + b_2 \cdot X_2 \cdot X_4 + b_3 \cdot X_2. \qquad (6)$$

The data on LPG consumption in road transport in the EU countries was fitted with Steppan *et al.* (1998) software package. The summary of regression equations is presented in Table 2. It should be emphasized that due to a small number of data, the disperse of standard error

is significant. The coefficient of determination R^2 shows the total variability of the over fitted models. In our case, $P_2(X)$ is a high prediction quality model. The lowest suitable model to predict $P(X)$ is $P_1(X)$. Durbin–Watson statistics is designed for assessing the autocorrelation of differences in regression analysis. These differences are always between 0 and 4. In our case, $1.5 < d < 2.5$ and the test for the autocorrelations of residuals is inconclusive. The parameter collinearity outlines dependency among the variables. 0 points to linear dependency among the variables, whereas 1 means that there is no collinearity.

The values of the coefficients of regression equations and their evaluations of statistical hypotheses are given in Table 3. The obtained *p*-values close to zero reveal that zero hypotheses are rejected and differences among the variables are obvious. The variance inflation factor of values reveals that the variables are not identical (VIF<10). Thus, it may be stated that the obtained regression equation is adequately described.

Table 2. Parameters for the model adequacy of regression equations

Function	$P_1(X)$	$P_2(X)$	$P_3(X)$
$\|R\|$	0.811	0.967	0.941
R^2	0.658	0.935	0.885
R^2 adjusted	0.624	0.926	0.873
Standard Error	12.09	5.360	7.025
# Points	34	34	34
PRESS	5877	1478	1889
R^2 for Prediction	0.542	0.885	0.853
Durbin-Watson d	1.878	2.050	1.815
First Order Autocorrelation	–0.048	–0.107	–0.003
Collinearity	0.740	0.161	0.339

Table 3. The coefficients of regression equations and ±50% confidence interval

Function	Coefficient	P value	–50%	50%	VIF
$P_1(X)$ b_0	100.74	1.43E-05	87.45	114.04	
b_1	–0.04152	1.04E-06	–0.0462	–0.0369	1.216
b_2	–91.25	0.00113	–108.56	–73.94	1.256
b_3	0.298	0.00159	0.239	0.357	1.141
$P_2(X)$ b_0	107.09	4.21E-14	101.70	112.47	
b_1	–164.27	1.93E-12	–173.92	–154.63	1.984
b_2	2.375	1.05E-14	2.262	2.488	5.525
b_3	–2.40E-05	1.57E-09	–2.59E-05	–2.21E-05	1.206
b_4	–7.70E-06	1.35E-11	–8.19E-06	–7.21E-06	3.976
$P_3(X)$ b_0	74.98	5.543E-09	68.62	81.34	
b_1	–108.98	7.284E-08	–119.50	–98.46	1.374
b_2	1.658	2.262E-15	1.582	1.734	2.830
b_3	–9.35E-04	7.67E-14	–9.84E-04	–8.86E-04	2.282

The obtained regression equations reveal that there is a close connection between LPG consumption in road transport and the ratio of LPG and gasoline RON95 prices, the final consumption of LPG and the final consumption of all oil products. The significance of the predicted

values $P_1(X)$ differs from $P(X)$ data (Fig. 5). Equation (5) evaluates LPG consumption more precisely, and thus forecasting LPG consumption in transport, we suggested using equations (5) or (6) which is simpler. In this case, equation 6 is the best option.
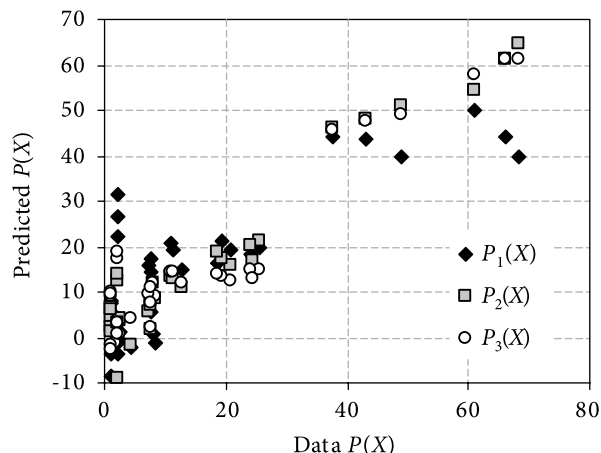

Fig. 5. A comparison of factual and predicted LPG consumption in transport

Due to relatively small amount of data function (6), the limits of confidence interval ±50% significantly change the values of the function. The presented diagram (Fig. 6) describes the sensitivity coefficients of equation (6).
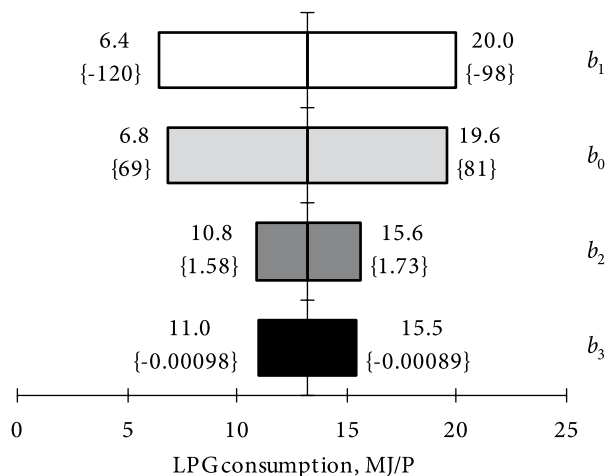

Fig. 6. The sensitivity of equation (6) with confidence interval ±50% (Tornado diagram)

Tornado diagrams graphically display the results of the analyzed single-factor sensitivity values b_i presented in Table 3. Figure 6 represents the effect of four parameters b_i on the result $P_3(X)$. Minimum and maximum b_i values correspond to confidence interval ±50% (in parenthesis), whereas the values of function $P_3(X)$ lay in the X-axis at average X_2, $X_2 \times X_3$ and $X_3 \times X_4$ values. Coefficients b_1 and b_0 have the biggest impact on the solution, whereas the sensitivity of coefficients b_2 or b_3 is less significant. According to equation (6), the main influence on consumers to make a decision on using LPG in transport are the final

consumption of all petroleum products, the ratio of LPG and gasoline RON95 prices and the final consumption of LPG. The interpretation of equation (6) is as follows. Keeping the level of other characteristics constant:

- one percent increase in the final consumption of all petroleum products gives a 3.23% increase in LPG consumption in transport,
- one percent increase in the ratio of LPG and gasoline RON95 prices gives a 1.43% increase in LPG consumption in transport,
- one percent increase in the final consumption of LPG gives a 0.65% decrease in LPG consumption in transport.

4. Pay-off of LPG Equipment in the Car

When installing LPG equipment in a car, a customer needs to know its pay-off time. Since LPG is installed in the car, pay-off time is more convenient to change with the driven distance:

$$L = \frac{K}{B_G \cdot \left(B_k - S \cdot D_k\right)}, \text{ km}, \qquad (7)$$

where: K – expenditure for installing LPG fuel supply system in the car; in €, B_G – gasoline consumption, MJ per km; B_k – gasoline price, € per MJ; D_k – LPG price, € per MJ; S – the ratio of the amounts of gasoline and LPG fuel of the car using dual fuel. Ratio S is derived from the ratio of the amounts of gasoline and LPG heat which is a constant size for gasoline internal combustion engines:

$$S = \frac{Q_G}{Q_D} \cdot \frac{\eta_G}{\eta_D}, \qquad (8)$$

where: Q_G – gasoline and Q_D – LPG calorific capacity, MJ/litre.

We have obtained these figures from International Energy Agency (IEA) statistic. Simpson (2005) estimate powertrain efficiency % with gasoline is $\eta_G = 10.6$ and efficiency with LPG is $\eta_G = 11.2$.

Analysing the pay-off of LPG equipment, the expenditure of car fuel makes 8.5–11.5 litre per 100 km. LPG equipment and the price of installation in the car varies in a wide range. In general, installation price depends on the complexity of equipment and its implementation price that may vary in different EU countries. The minimum and maximum prices of gasoline RON95 and LPG prices were taken from International Energy Agency (IEA) statistic, whereas retail prices were obtained taking into account the ratios of gasoline and LPG prices presented in Fig. 7. Using the values presented in Table 4, the impact of different variables on the installation of LPG equipment in the car may be evaluated (Fig. 7).

At average values (Table 4), equipment pay-off is 19048 km (X-axis). This scheme distributed according to the downtrend order of variables the impact of which reveals that LPG and gasoline prices have the biggest influence on consumer's decision regarding the installation of LPG equipment in the car. LPG equipment is frequently installed in the cars running for more than 10–15 years.
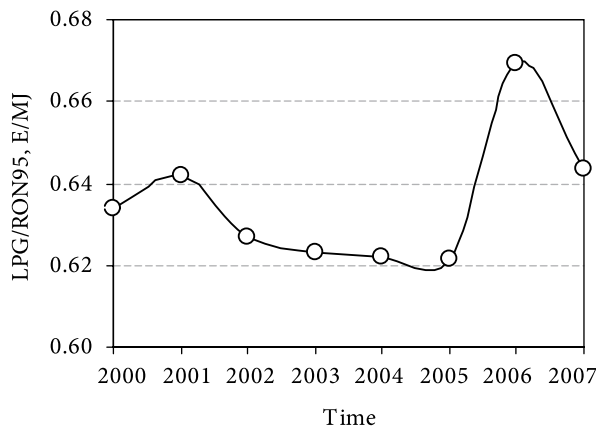
Fig. 7. Tendencies toward the prices of
LPG and gasoline RON95 ratio

Table 4. The pay-off of LPG equipment

Variable	Notation	Dimension	Average	Min.	Max.
Gasoline consumption	B_G	Liter/km	0.1	0.085	0.12
LPG installation price	K	€	1500	750	2500
Gasoline price	B_k	€/liter	2.0	1.5	2.5

In such cases, the pay-off of the equipment may be longer than the exploitation of the cars.

It is easy to notice that the ratio of LPG and gasoline RON95 prices (X_2) may be expressed as the variables of equation (7):

$$X_2 = \frac{D_k}{B_k} = \frac{1 - \dfrac{K}{L \cdot B_G \cdot B_k}}{S}. \tag{9}$$

For a number of years, the ratio of EU fuel prices has had a tendency to fluctuate (Fig. 8). This means that the distance driven by the car has a tendency to fluctuate alike and the use of LPG equipment in the car is getting less attractive.
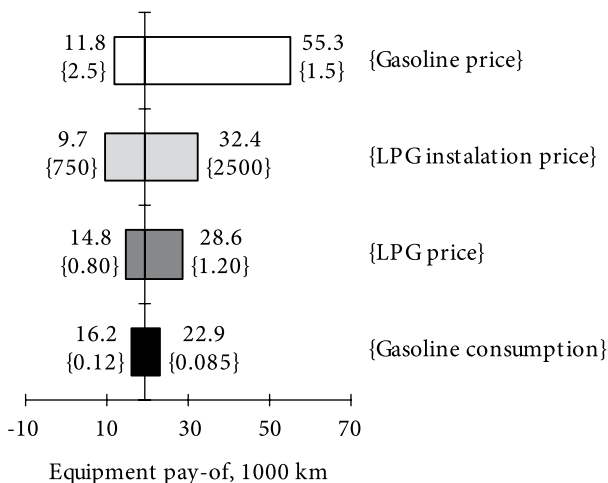

Fig. 8. Driven distance pay-off of LPG equipment

5. Conclusions

1. Though it is obvious that LPG in cars enables to reduce the amount of hazardous pollutants, particularly relevant in towns, however, LPG in cars is used only in some countries of the EU.
2. Under the close scrutiny of hedonic model diagnosis, LPG use in cars can be derived from a bundle of specific variables. The model can be used for predicting and understanding the relationship between response and the response and predictors.
3. The ratio of LPG and petrol prices is a promoting measure for making decision to use LPG in cars; however in order to widely use LPG in transport, LPG prices should be reduced.

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