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POSSIBILITIES OF BUSES ON ALTERNATIVE FUEL IN PUBLIC URBAN TRANSPORT IN BELGRADE

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Abstract. The accelerated development of transport and transport technology is significantly contributing to air pollution by motor vehicle emissions in large urban environments. The analysis of mass public transport in Belgrade, the transportation supply, the transport services delivered, the number of passengers transported, clearly concludes that by investing in its capacity, significant progress in the preservation of the city environment can be achieved. The paper analyzes the economic and environmental aspects of the modernization and renewal of the public bus subsystem as the major bearer of the transport supply through the use of alternative fuels, natural gas and biodiesel.

Keywords: bus, natural gas, biodiesel, public urban transport, environment.

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1. Introduction

Air pollution by motor vehicle emissions in urban centres is becoming an ever increasing problem with the increase of the number of motor vehicles and population in the cities. Outdated and inadequate urban solutions as well as the configuration of the geography of some of our cities only add to the problem. Long waits at the traffic lights at busy intersections lead to the concentration of vehicles running on idle which is unfavourable from the aspect of polluting components of emissions. All of this contributes to additional percentages of air pollution, which can be ascribed to motor vehicles which along with other sources of pollution,

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leads to a higher incidence of respiratory illness among the urban population. Transport is the cause of almost 90% of emissions of carbon monoxide, nitric oxides and hydrocarbons, thus being a direct contributor to global climate change. Table 1 shows the sectors that are sources of major components that influence air pollution (Gligorijević *et al*. 2004).

Table 1. Emission of air pollution by sector

	CO (%)	NO_X (%)	HC (%)
Motor vehicles	90	52	40
Households	5	3	2
Thermoelectric plants	1	26	1
Industry	4	11	56
Other	–	8	1

The problem of pollution exists since the invention of the motor vehicle gaining in significance with the development of transport and the expansion of motor vehicle use and becoming a major concern of organizations dealing with the environment protection. One of the results of concern with the state of the environment is the standards of permitted detrimental gas emissions produced by motor vehicles. Today's standards (EURO IV – applied since October 2005 and EURO V – to be implemented from October 2008) allow for very low levels of emissions and will certainly contribute to the application of modern technical solutions to meet these standards. Among these are new systems of fuel usage, common rail motors; the use of devices for the treatment of emission gases – three-way catalytic converters, catalytic converters for reduction of nitric oxides, and the use of alternative fuels (CNG, LNG, LPG, methanol, biodiesel, and ethanol).

Within the transport system of Belgrade, mass public transportation is the basic logistic subsystem of the city which with its performance, quality and technology affects the environment to a great extent. It is also an economic activity which employs vast resources invested in vehicles and energy.

Accordingly, the paper analyzes the possibilities of development of mass public transport (MPT) from the angle of modernizing and renewal the bus subsystem through the application of new constructional and conceptional solutions based on alternative fuels. This would also correspond to the general choice of European countries in regard to the development of MPT urban subsystems.

2. Mass public transport of passengers in the transport system of Belgrade

Mass public transport of passengers is a system with a complex structure of numerous technological and organizational entities within the city of Belgrade transporting 1.8 million passengers/day with the vehicles doing 80 million kilometers per year.

The system of MPT in the coming period will develop in harmony with the general goals of the development of the transportation system of the city of Belgrade as defined in the General Plan. These goals are: a mutually synchronized development of all types of transport, an optimal interconnection of all city functions, efficient and rational use of transport capacity, upgrading the level of services and safety, lowering the volume of road and street transport, increasing the appeal of public versus private automobile transport, the decline of detrimental effects of transport on people, the environment and historical cultural heritage and finally, the rational use of material and financial resources (Generalni plan Beograda 2021).

From the adopted goals it is obvious that public transport will not lose its role in the transport system, but that on the contrary it will gain in importance through investment in its development in order to achieve significant progress in the general functioning of the city.

In the coming period, it is necessary to include the principles related to the environment and aligned with the concept of sustainable development of complex organizational and technological systems (4E – efficiency, economy, effectiveness, ecology) into the strategic vision and goal function of the development of Belgrade. In other words, demands of various interest groups for the volume and quality of transport services are not enough as an input for planning.

3. The bus subsystem in the system of MPT

In Belgrade the network of lines of MPT is very branched out and consists of bus, trolleybus, tram and suburban railways. The bus resources of 331 lines (64 city and 267 in the suburban sector) with 1 200 working vehicles, transport around 80% of all passengers daily and achieve a daily transport workload of 9 million passenger kilometers. The great significance of buses in the system of passenger transportation is also reflected in the transport supply of 27 million place kilometers daily. The cited figures clearly point out that in the long-term planning of MPT problems of the functioning and further development of the bus subsystem which as the primary transportation subsystem must be taken into account.

The strategies of development of public transport and within it of the bus subsystem are numerous and are most frequently aimed at enhancing the efficiency of existing vehicles. These include: the adoption of new technological solutions, the use of alternative fuels, changing and upgrading conventional traffic flows, the application of intelligent transport systems, the education of drivers, etc. (Deakin 2003; Jarašūnienė 2007).

In order to achieve the goal of sustainable MPT, the world trend is to use alternative fuels in city buses due to their favourable economic, energy-efficiency and environmental characteristics. A whole spectrum of demonstration programs with the goal of collecting data on the costs of the functioning of these buses, their performance, reliability and maintenance have been developed: CUTE (Clean Urban Transport for Europe) CFCP (California Fuel Cell Partnership), NRC (National Resources Canada) and STEP (Sustainable Transport Energy for Perth) (Tica *et al.* 2003; Jakimavičius and Burinskienė 2007).

Alternative fuels and therefore the propulsion concepts of buses are numerous (CNG, LNG, LPG, methanol, hydrogen etc). However, the European Commission has, after research come to the conclusion that only 3 options have the prospect of being widely used as a substitute for conventional fuel. At the moment and in the midterm it is natural gas and biodiesel that are alternatives, while hydrogen as a fuel for the classical inner combustion motor and burnable cells could be applicable after the year 2020.

4. Natural gas and biodiesel – alternative propulsion fuel for buses in MPT

Buses with propulsion on natural gas are being produced and developed by major companies and there exists a wide spectrum of vehicles that can satisfy the most sophisticated customers. In 65 countries in the world there are 7 million vehicles that run on natural gas, out of which there are 160.000 buses (NGV Statistics 2007). The advantages of natural gas compared to liquid fuel lie in its easier mixture with air, that it combusts more thoroughly and has a relatively high heating power. It combusts with hardly any remains and has a lower cost than liquid fuel. There are several different ways of using natural gas for the propulsion of buses (Ivković *et al.* 2007):

- Gas propulsion: This conceptual solution requires an industrially produced gas motor or a classic diesel motor which has been adapted for running on natural gas. There are 2 ways of preparing the mixture for combustion: the preparing of a stoichiometric mixture of gas and air ($\lambda = 1$) and the preparing of a weaker mixture of gas and air ($\lambda>1$, $\lambda = 1.4–1.6$).
- Gas diesel propulsion: This conceptual solution requires the use of natural gas with a diesel motor bus without any adaptations on the motor. This can be done in 2 ways of regulating the motor. The first possibility is to have a double combustion motor with the "pilot" injection of diesel fuel (natural gas and air are mixed in an adequate proportion at the entrance to the motor and are brought into the cylinders under the influence of the differences in pressure). The second option is to have a double combustion motor with a variable quantity of injected fuel (progressive injection is used to avoid detonating combustion under maximal utilization).

In a smaller number of cases the application of natural gas in the propulsion of buses is done through gas hybrid turbine propulsion aggregate.

Biodiesel is a liquid bio-fuel, produced from renewable agricultural resources which can completely substitute fossil fuels in bus motors. It is derived from soy, sunflower, and other vegetables and through recycling of oils and fats through a process of trans-etherification with a catalyst. It can be used independently or in a mixture with conventional diesel derived from crude oil in any proportion. Depending on the proportion of bio-fuel in the mixture, biodiesel are called B100 (pure, 100% biodiesel), B5 (5% biodiesel and 95% fossil diesel), B20 (20% biodiesel and 80% fossil diesel) etc.

Biodiesel as an alternative fuel has been known since 1900 when Rudolf Diesel and Henry Ford introduced it as the fuel of the future at the Paris Exhibition. In spite of early interest, it did not reach wide application in the transport sector primarily because of poor thermal stability and changing viscosity. So far the major interest for the use of biodiesel in vehicles has been a result of the recommendation from the European Union in regards to the proportion of diesel from renewable resources (5.75% by the year 2010) in the total consumption of diesel fuels (Directive 2003/30/EC).

The major advantages of biodiesel as a propulsion fuel for buses are (Gligorijević *et al.* 2004):

- no danger in applying to motors with catalytic converters because of a lack of sulphur;

- it has around 11% of oxygen which leads to smaller emissions of carbon-monoxide (CO), hydrocarbon (HC), particles (PM) and carbon-dioxide (CO_2);
- it is a good lubricant for the injection system;
- cetin number is close to or greater than in mineral diesel;
- it is bio-down breakable.

5. The emission of harmful waste in the use of natural gas and biodiesel

With the combustion of the mixture of fuel and air in the motor aside of complete combustion, products and matter of incomplete combustion arise with the breakdown of fuel. These are extremely important as they have a harmful effect on human health being toxic in nature. Their influence on humans manifests itself through skin inflammation, intoxication, breathing problems, as a cause of cancer etc. The most damaging effects are those from carbon- monoxide CO, nitrogen-oxides NO_x, sulfur-oxides SO_x, hydrocarbons HC and particles that is soot. Also, aside of toxic gases the effects of pollution by the combustion of various types of fuels is measured through the emission of greenhouse gases of which proportionally the most represented are carbon dioxide CO_2 as well as volatile organic compounds (VOCs).

In order to analyze the effects of buses using alternative fuels on the environment one must keep in mind the following (Ivković and Žeželj 2005; Kapski *et al.* 2008):

- The emission of harmful waste depends on the system of feeding fuel to the motor, that is, on the way in which the mixture for combustion is produced.
- The emission of harmful waste depends on the conditions of exploitation. That is the type of required emission tests that vehicles have been subject to: ESC (European steady-state Cycle), ETC (European Transient Cycle), ELR (European Load Response), CBDC (Central Business District Cycle), NYBC (New York Bus Cycle), DUDBC (Dutch Urban Bus Drive Cycle), DE LIJN, RS54/92, RS30/39, On Board measurement.
- The emission of harmful waste depends on the composition of natural gas and quantity of biodiesel in the mixture with mineral diesel (B100, B20, and B5).

Table 2 and Fig. 1 show data compiled by the International Energy Agency on the emission of pollutants corresponding to various buses under various conditions of exploitation.

The bus subsystem is the major pillar of MPT in Belgrade with a gross output of 225.500 vehicle km per day. On the basis of this figure, as well as the numbers from Table 2, it is possible to deduct the emission of pollutants produced by the bus subsystem of Belgrade. In accordance with this, we made an estimate (Table 3) of the total emission of pollution within a year taking into account the conditions of exploitation which most closely correspond to the ones in Belgrade in accordance with the types of the propulsion aggregate (Žeželj *et al.* 2007).

Natural gas and diesel are energy sources with different emission characteristics. Conventional diesel bus motors produce a lower level of total hydrocarbon in relation to CNG $\lambda>1$ bus motor. This occurs independently of the use or non-use of the gas oxidation catalyst (GOC) because the influence of the latter mostly amounts to the reduction of non-methane toxic hydrocarbons. Preparing the stoichiometric mixture of fuel and air ($\lambda = 1$) while treating emissions gases with the aid of a three-way catalyst (TWC), the emission of THC can

Table 2. The emission of harmful gases of different buses under different conditions of exploitation (Pelkmans *et al.* 2001)

	CO_2 [gr/km]			CO [gr/km]			THC [gr/km]			NO_x [gr/km]			PM [mgr/km]		
	Diesel	CNG λ = 1	CNG λ>1	diesel	CNG λ = 1	CNG λ>1	diesel	CNG λ = 1	CNG λ>1	diesel	CNG λ = 1	CNG λ>1	diesel	CNG λ = 1	CNG λ>1
On board (city exploitation)	1633	1475	1634	3.5	0.7	0.8	1.7	0.15	7.5	15.2	1.8	25.1	241	9	25
CBDC	1301	1386	1580	4.5	0.9	0.8	1.4	0.04	7.1	12.5	0.5	21.7	220	7	21
DUDBC	1435	1527	1602	3.1	0.7	0.8	1.2	0.07	12.7	12.8	2.5	25.5	237	7	23
DE LIJN	1252	1322	1445	5.1	0.4	0.6	1.9	0.12	8.0	11.5	1.9	18.8	208	6	18
On board (suburban. and intercity transport services)	937	1102	1332	2.1	1.0	0.6	1.0	0.09	5.4	8.9	1.3	23.7	197	4	15

Table 3. The estimate of emissions using different concepts of buses (Žeželj *et al.* 2007)

	CO_2 [t/year]			CO [t/year]			THC [t/year]			NO_x [t/year]			PM [kg/year]		
	diesel	CNG λ = 1	CNG λ>1	Diesel	CNG λ = 1	CNG λ>1	diesel	CNG λ = 1	CNG λ>1	diesel	CNG λ = 1	CNG λ>1	diesel	CNG λ = 1	CNG λ>1
On board (city transport)	134408.15	1214.04	1344.90	288.08	57.62	65.85	139.92	12.35	617.31	1251.07	148.15	2065.92	19836.11	740.77	2057..69
CBDC	107082.06	1140.78	1300.46	370.38	74.08	65.85	115.23	3.29	584.38	1028.84	41.15	1786.07	18107.65	576.15	1728.46
DUDBC	118111.26	1256.84	1318.57	255.15	57.62	65.85	98.77	5.76	1045.31	1053.54	205.77	2098.84	19506.88	576.15	1893.07
DE LIJN	103048.99	1088.11	1189.34	419.77	32.92	49.38	156.38	9.88	658.46	946.54	156.38	1547.38	17119.96	493.85	1481.54
On board (suburban and intercity transport)	77122.13	907.03	1096.34	172.85	82.31	49.38	82.31	7.41	444.46	732.54	107.00	1950.69	16461.50	329.23	1234.61

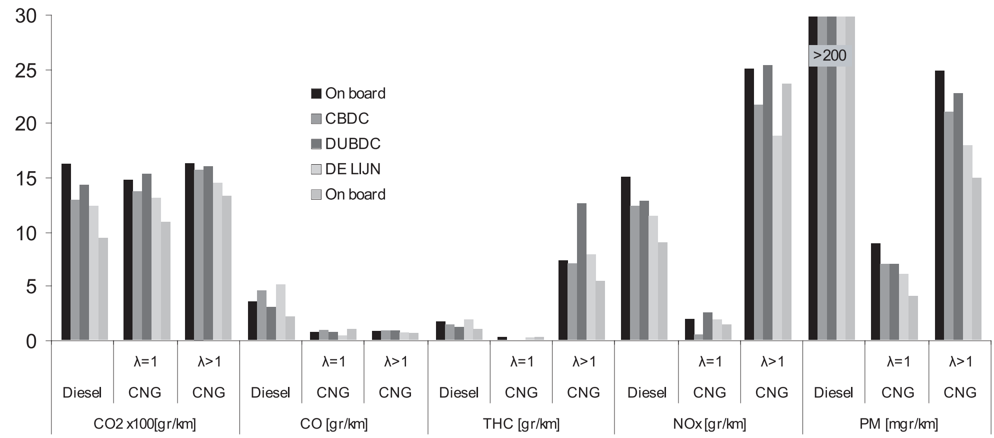

Fig. 1. The emission of harmful gases of different buses under different conditions of exploitation (Pelkmans *et al.* 2001)

be reduced in comparison with the conventional diesel motor. The percentage of reduction varies from 90 to 97. It is necessary to emphasize that hydrocarbons produced by gas motors contain a large quantity of methane (98% in comparison to toxic hydrocarbons produced by conventional diesel motors) which is much less toxic than non-methane hydrocarbons. The fact of the low direct toxicity of methane is supported by certain US regulations which do not limit the quantity of CH_4, that is not the case with EURO standards.

The emission of carbon dioxide is approximately the same (in relation to the total quantity) for all conceptual diesel solutions and CNG propulsion aggregates, controlling for all relevant factors which influence the estimate of environmental desirability of the fuels in question. One of the causes of this result is the higher percentage of CO_2 in natural gas.

The emission of carbon monoxide is at a much lesser level in both buses running on natural gas than is the case of the diesel bus. The drop in emissions varies from 4 to 5 times to between 8.5 and 12.75 times depending on the conditions of exploitation.

The emission of nitric oxides is far lower for the CNG concept with the stoichiometric mixture of fuel preparation in comparison to the diesel motor. In the case of the CNG $\lambda>1$ bus without a gas oxidation catalyst due to a higher degree of compression in the combustion chamber, the temperature is raised which leads to a higher level of NOx. With the use of the catalyst, the level of emissions can go down by over 20 times.

The environmental advantage of the CNG bus for ($\lambda>1$ and $\lambda = 1$) in comparison with the conventional diesel motor is mostly pronounced, regardless of the conditions of exploitation when observing the emission of particles both in terms of quantity and quality. The quantity aspect manifests itself in the lowering of emissions by 90%. In terms of quality, the composition of pollutants is such as to exclude particles that contain cancerous compounds given the lack of sulfur in natural gas (as viewed from the aspect of a fuel for the internal combustion motor).

In Table 4 and Fig. 2 the results of testing emission gases of buses that run on biodiesel and buses that run on euro-diesel are shown. (Projekat BIO-PEX 2006). These measurements are in accordance with Regulation 30/97-QMS ME 13.01.

The bus with biodiesel propulsion produces a significantly lower level of toxic gases in all 3 operating regimes as compared with a bus with identical propulsion aggregate that uses euro diesel. The percent of reduction is significant in terms of carbon monoxide and soot while working on idle (72.03% CO and 75.70% soot and around 90% for SO_2, Table 5) which is important for vehicles of MPT keeping in mind that they often stop for picking up and unloading passengers, waiting in terminals, intersections and keeping an interval of following the vehicles on route. Furthermore, it is evident that the emission of unregulated pollutants by the EURO standard – benzene, toluene and xylene – is several times lower for buses which use biodiesel for fuel.

Table 4. The emission of toxic gases of buses running on mineral diesel and biodiesel (Projekat BIO-PEX)

	Eurodiesel bus			Biodiesel bus		
	Idle	**50% load**	**100% load**	**Idle**	**50% load**	**100% load**
Temperature of emission gases	90.1	149.3	179.7	134.2	153.6	164.9
Total concentration CO [ppm]	118	165	179	33	65	92
Total concentration NO [ppm]	178	168	129	171	114	113
Total concentration NO_2 [ppm]	22.0	29.4	23.4	23.9	26.3	26.5
Total concentration NO_X [ppm]	200	198	153	195	141	139
Total concentration SO_2 [ppm]	83	92	102	8	5	5
Total concentration H_2 [ppm]	3	14	19	4	5	11
Percent O_2 [vol%]	18.88	17.90	17.50	18.9	18.5	17.7
Percent CO_2 [vol%]	1.83	2.55	2.84	1.81	2.11	2.7
Total concentration PM [mg/m^3]	74.9	85.2	95.3	18.2	24.5	31.2
Total concentration benzene [μg/m^3]	335	621	825	<10	<10	<10
Total concentration toluene [μg/m^3]	168	211	398	<10	<10	<10
Total concentration xylene [μg/m^3]	<10	23	40	<10	<10	<10

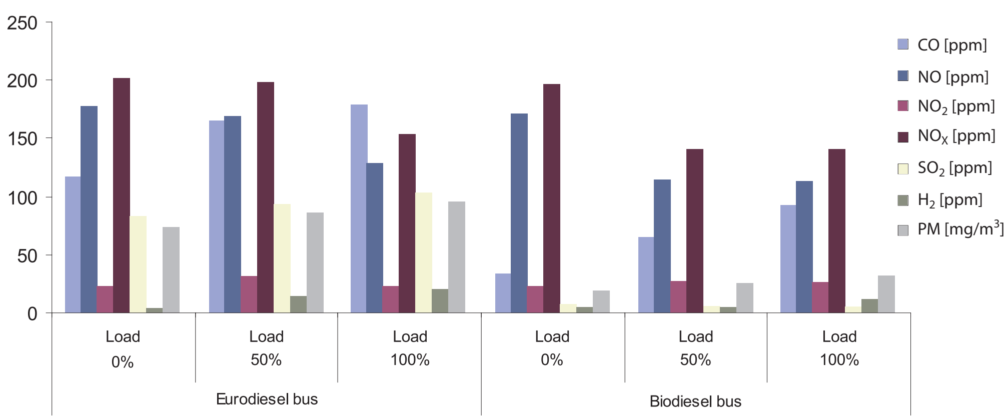

Fig. 2. The emission of toxic gases of buses running on mineral diesel and biodiesel (Projekat BIO-PEX 2006)

Table 5. Percent of reduction of pollutants using buses with biodiesel propulsion at various load levels (Žeželj *et al.* 2007)

	Reduction % CO	**Reduction % NO**	**Reduction % NO_2**	**Reduction % NO_x**	**Reduction % SO_2**	**Reduction % H_2**	**Reduction % soot**
0%	72.03	3.93	–8.64	2.50	90.36	–33.33	75.70
50%	60.61	32.14	10.54	28.79	94.57	64.29	71.24
100%	48.60	12.40	–13.25	9.15	95.10	42.11	67.26

6. Expected economic effects

From the point of view of the owners of bus fleets, the costs of operation of vehicles in comparison to total cost over a bus life cycle, are key in evaluating economic characteristics.

Economic analysis shows that controlling the conditions of operation, the bus with compressed natural gas is more profitable than the diesel bus. The greatest impact on cost comes from the difference in the price of fuel which can best be illustrated by the fuel equivalent. In the use of natural gas as energy for buses, the average consumption of 1.3 cubic meters of natural gas is equivalent to the consumption of 1 liter of diesel fuel under identical conditions of exploitation (Stevanović 2004). With a price of 80 dinar (1 Euro)/lit of diesel fuel (C_D) and 22 dinar (0.27 Euro)/m^3 of natural gas (C_{NG}), the economic efficiency (G_E) is equal to:

$$G_E = \frac{C_D}{E\ C_{NG}} = \frac{80}{1.3 \cdot 2.2} = 2.79 \ .$$

The economic efficiency of gas can be illustrated by the example of a bus fleet of 15 buses on gas and on diesel using the data on exploitation.

The cost of maintenance are similar for both buses and do not significantly influence the result presented in Table 6. The results show that the savings stemming from the difference in cost of fuel would allow for the renewal of the bus fleet by 3 buses, provided that the vehicles run on natural gas. In case that the owner of the fleet also owns the fuel station, the station would require an initial investment of around 250.000 Euro in order to adjust it to natural gas. However, this investment would be recovered over a period of 205 working days, as Table 6 shows. As opposed to natural gas, the production of biodiesel is relatively high at the moment (750 EUR/ton). However, it is realistic to expect a falling price trend. The adoption relevant to EU laws in Serbia would trigger a fall in price, since biodiesel would be exempt form value added taxes in retail. This would make a liter of biodiesel 0.15 EURO cheaper than a liter of diesel. Since the MPT in Belgrade, uses 1.200 vehicles daily in its subsystem, using around 150.000 liters of diesel fuel (or around 45 million liters yearly), the use of biodiesel could provide for substantial economic benefits.

The substitution of 10% of mineral diesel by biodiesel on a monthly basis would yield 56 000 Euro in savings (or 675.000 EURO yearly). As in the case of using buses that run on natural gas, this solution faces some constraints. It should be mentioned that the percent of potential share of biodiesel (B5, B10, B50, and B100) and corresponding increase in profitability would depend on the capacity of production and distribution as well as the strategy of use in the bus subsystem.

7. Conclusions

Conventional diesel buses are used not only in Belgrade, but also in Serbia at large. They are used in 99% of cases. They are large sources of pollution, primarily soot (PM), nitrogen oxide (NOx) and carbon monoxide (CO).

Having this in mind, it is necessary to find new solutions in order to alleviate the problem of environmental pollution while taking into account other criteria relating to the advantages of alternative fuel use: economic efficiency, availability, security, energy efficiency, etc. Using buses on natural gas propulsion and biodiesel would significantly reduce the emission of pollutants which would improve quality of life in the urban centres. From the economic standpoint, the application of natural gas is a solution that would pay for itself in a very short time period. At the moment, the major constraint for more massive use of these buses lies in the fact that Belgrade does not have a network of stations for this fuel type. On the other hand, the application of biodiesel for bus propulsion is constrained only by the possibilities of local producers. It should be kept in mind that this fuel has the highest potential to lower dependence on the import of oil.

Finally, in order to implement alternative solutions of urban transport as quickly as possible, it would be necessary to provide regulations and fiscal stimuli.

The research results, given in tables 3, 5, and 6, show that the environmental and economic effects of natural gas and biodiesel buses in public urban transport in Belgrade would be significantly positive. These results are part of the scientific evaluation of the viability of the production of a new generation of domestic buses by the Serbian manufacturer IKARBUS.

Table 6. Economic efficiency of gas propulsion on the basis of price difference over one year (Žeželj *et al.* 2007)

	CNG bus	Diesel bus
Number of vehicles	15	15
Price of vehicle (EUR)	100 000.00	80 000.00
Value of investment (EUR)	1 500 000.00	1 200 000.00
Number of working days per year	300	300
Consumption of fuel (m^3/100 km; lit./100 km), (Stevanović 2004)	45	40
Price of fuel (EUR/m^3; EUR/lit.)	0.278	0.987
Average daily run (km)	300	300
Cost of fuel over one year (EUR)	168 885.00	532 980.00
Cost difference [gas-diesel (EUR)]	364 095.00	

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VIEŠOJO TRANSPORTO ALTERNATYVAUS KURO TAIKYMO GALIMYBĖS BELGRADE

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Santrauka

Didėjantys transporto ir transporto technologijų vystymosi tempai gerokai padidina oro užterštumą urbanizuotose teritorijose. Analizuojama viešojo transporto (autobusų) modernizacijos bei atkūrimo, naudojant alternatyvų kurą (natūralias dujas ir biodyzeliną), galimybė ekonominiais ir aplinkosaugos aspektais.

Reikšminiai žodžiai: autobusas, natūralios dujos, biodyzelis, viešasis transportas, aplinkosauga.

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