MULTIPLE CRITERIA DECISION MAKING OF ALTERNATIVE FUELS FOR WASTE COLLECTION VEHICLES IN SOUTHEAST REGION OF SERBIA

by

Goran S. PETROVIĆ*, Miloš J. MADIĆ, Danijel S. MARKOVIĆ, Predrag Dj. MILIĆ, and Gordana M. STEFANOVIĆ

Faculty of Mechanical Engineering, University of Nis, Nis, Serbia

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In this paper multiple criteria decision making approach of alternative fuels for waste collection vehicles in southeast region of Serbia was presented. Eight alternative fuels and advanced vehicle technologies were ranked according to thirteen criteria, including financial, socio-technical, and environmental. Assessment of alternatives was performed by using the weighted aggregated sum product assessment method and results were verified using multi-objective optimization on the basis of ratio analysis method. Considered criteria were obtained from previous researches and by assessment of professional experts from manufacturing industries, public utility companies, and academics institutions. The analysis showed that both biodiesel fuels – derived from used cooking oil or from vegetable oils are the best alternative fuels for Serbian waste collection vehicles in this point of time. Compressed natural gas-powered vehicles were also ranked high in this analysis, but due to the lack of financial capability for their purchase (especially in southeast region of Serbia), their gradual introduction into the waste collection fleet was proposed.

Key words: *alternative fuels, vehicle technologies, waste collection vehicles, weighted aggregated sum product assessment method, decision making*

Introduction

Modern cities all over the world face the same problems such as pollution, climate change due to green-house gas (GHG) emissions, *etc.* and these problems are constantly increasing with population growth. The main environmental issues in cities stem from the domination of fossil fuels use in transportation sector combustion of which generates CO_2 and other pollutant emissions. Urban mobility accounts for 40% of all CO_2 emissions of road transport and up to 70% of other pollutants from road transport [1]. The increasing number of vehicles in operation and the increasing rate of global fossil fuel consumption urgently demand the development of more efficient power generation systems for the transportation sector. For the first time ever, the number of vehicles in operation worldwide surpassed the one billion-unit mark in 2010, and a number that is expected to be by 2050 is 2.5 billion [2]. For these reasons development of new, advanced and clean vehicle technologies and the use of al-

* Corresponding author; e-mail: pgoran@masfak.ni.ac.rs

ternative fuels represent an opportunity to face these challenges, *i. e.* to reduce the climate impacts of the transportation sector and reduce consumption of fossil fuels.

Serbia is the fifth polluter of CO_2 (6.2 metric tons of CO_2) per capita in Europe and the main reason is non-environmentally sustainable transportation sector that has one of the biggest green-house gas emissions (15% of total CO_2 emissions). Very important segments of transportation sector in Serbia's cities are utility vehicles. Public utility companies (PUC) have an important role in the economy of every country, because the satisfaction of vital needs of population, such as supplying electricity, water, heating, waste removal and other, depends on their unhindered functioning. Unfortunately, many of PUC in Serbia, especially those in smaller towns, have a problem with the diverse structure of their vehicle fleets, as well as with the vehicles that are at the end of their life cycle [3]. For example, PUC *Mediana Niš* covers approximately 75,000 locations, *i. e.* around 250,000 service users with transportation system which comprises 28 waste collection vehicles (WCV) whose average age is 13.8 years [4]. All WCV use fossil diesel as a fuel with total consumption of over 200,000 liters per year. In terms of environmental protection this amount produces about 20 tons of CO, 500 tons of CO_2, 4 tons of volatile organic compounds, 6 tons of NO_x and many other harmful and toxic products such as compounds of lead and sulfur.

The selection of the most appropriate alternative fuel for WCV as well as vehicle technology is of prime importance for PUC. For a given city such selection is closely related to the efficiency of waste collection and prices of services as well as environmental issues since waste collection vehicles significantly contribute emissions including GHG such as CO_2 and CH_4 and other gases as well as noise. As the price of a WCV is very high, inadequate selection of the most appropriate alternative fuel and vehicle technology has long-term consequences on the business of the entire PUC. However, such selection is a challenging and time consuming task for decision makers which involves consideration of a number of alternatives and conflicting criteria. To handle such types of decision making problems a number of multiple criteria decision making (MCDM) methods have been proposed.

Fazeli *et al.* [5] presented MCDM approach for the selection of the alternative fuel/technology options of light-duty vehicle fleets in a mid-term horizon in Portugal. To identify preferred alternatives, a sequential screening process was applied, starting with a Pareto optimal approach, followed by a data envelopment analysis (DEA) and a trade-off weights procedure. User's acceptance, emissions of pollutants to atmosphere, risk of the technology development, transition costs and availability of fuel supply were considered as the main evaluation criteria.

Tzeng *et al.* [6] applied and compared two MCDM methods, *i. e.* technique for order preference by similarity to ideal solution (TOPSIS) and multi-criteria optimization and compromise solution (VIKOR – due to the original Serbian notation: *visekriterijumska optimizacija i kompromisno resenje*) methods in order to evaluate alternative-fuel buses for public transportation in Taiwan urban areas. Experts from manufacture, academic institutions, research organizations and transportation companies performed the evaluation of alternative vehicles. Analytical hierarchy process (AHP) method was applied to determine the relative significance of the considered criteria.

Tsita and Pilavachi [7] applied the AHP method for evaluation of alternative fuels for the Greek road transportation sector. Seven different alternatives of fuel mode were considered and the evaluation of alternatives was performed according to cost and policy criteria. It has been concluded that internal combustion (IC) engine blended with 1^{st} and 2^{nd} generation biofuels are the most suitable alternative fuels for the Greek road transportation sector.

Vahdani *et al.* [8] applied two novel fuzzy MCDM methods for evaluation of alternative-fuel buses. Several types of fuels were considered as fuel modes, *i. e.*, electricity, fuel cell (hydrogen) and methanol. For the purpose of selecting the most appropriate fuel modes, different criteria were considered such as efficiency, price and capability.

Sakthivel *et al.* [9] described an application of the hybrid MCDM method for the selection of optimum fuel blend in fish oil biodiesel for the IC engine. In the proposed model, analytical network process (ANP) is integrated with TOPSIS and VIKOR methods to evaluate the optimum blend. Evaluation of suitable blend was based on the exploratory analysis of the performance, emission and combustion parameters of the single cylinder, constant speed direct injection Diesel engine at different load conditions.

Safaei Mohamadabadi *et al.* [10] developed an MCDM model to evaluate different road transportation fuel-based vehicles (both renewable and non-renewable) using a preference ranking organization method for enrichment and evaluations (PROMETHEE) method. In the conducted study, vehicles based on gasoline, gasoline–electric (hybrid), E85 ethanol, diesel, B100 biodiesel, and compressed natural gas (CNG) were considered as alternatives. These alternatives were evaluated based on five criteria such as vehicle cost, fuel cost, distance between refueling stations, number of vehicle options available to the consumer and GHG emissions per unit distance traveled.

Recently, Maimoun *et al.* [11] applied the MCDM approach for evaluation of alternative fuels for WCV in the United States. TOPSIS and simple additive weighting (SAW) methods were used to evaluate fuel alternatives with respect to a multi-level environmental and financial decision matrix. The overall analysis showed that conventional diesel is still the best option, followed by hydraulic-hybrid waste collection vehicles, landfill gas, sourced natural gas, fossil natural gas and biodiesel.

The importance of protecting the environment, possible increase of the PUC service quality and eventually reduction of utility prices were key motivating factors for the analysis of alternative fuels and advanced WCV technologies in southeast region of Serbia, particularly in the city of Nis. Having in mind that this is a complex problem that should be considered from different aspects, the MCDM approach was adopted and a relatively new MCDM method, *i. e.* weighted aggregated sum product assessment (WASPAS) was applied. The proposed MCDM model consists of eight alternatives and thirteen criteria. It was developed taking into the account the assessment and opinions of professional experts, previous researches and real data for WCV for the city of Nis.

Fuel alternatives and advanced technologies for WCV

Alternative fuels and advanced vehicle technologies offer WCV fleets the opportunity to decrease their conventional fuels consumption and increase their environmental and social sustainability. There are a number of different fuels and technologies that could be considered for WCV: gasoline (petrol), diesel, natural gas, biodiesel, liquefied petroleum gas, hydraulic-hybrid, hybrid diesel-electric, hydrogen gas, ethanol, dimethyl ether, and electric power [11]. Technologies such as fuel cells (hydrogen gas) and electric power have a significant potential to reduce emissions from the transportation sector but there is also enormous uncertainty and disagreement surrounding the future of these fuels. Unlike conventional vehicles which run on gasoline or diesel, fuel cell cars, and trucks combine hydrogen and oxygen to produce electricity, which runs a motor. The potential benefits of this brilliant alternative fuel are substantial but several challenges must be overcome before these vehicles will be competitive with conventional vehicles [12]. These challenges include the production, distribution and storage of hydrogen, safety of fuel cell technology and overall vehicle cost. Battery electric vehicles use electricity stored in a battery pack. When depleted, the batteries are recharged using grid electricity, either from a wall socket or a dedicated charging unit. Since they do not run on gasoline or diesel battery electric cars and trucks are considered as *all-electric* vehicles. The introduction of large numbers of electric vehicles could be hampered somewhat by infrastructure problems and by reduced performance of vehicles (driving range, recharge time, battery cost...).

In Serbia, especially in its southeastern region, currently only eight fuel and advanced vehicle technologies are commercially available for WCV: gasoline, diesel (fossil), gasoline + CNG, gasoline + liquefied petroleum gas (LPG), biodiesel (agriculture), biodiesel (used cooking oil), hydraulic-hybrid, and hybrid diesel-electric.

A1. Gasoline fuel

Engine petrol fuels are intended to serve as fuels to power up piston petrol engines. Depending on the type of petrol engine and structural characteristics, petrol engines vary significantly in their physical-chemical characteristics and purposes. WCV rarely use petrol engines.

A2. Conventional diesel (fossil) fuels

Diesel fuel is one of the major products of crude oil refining. It is used to power piston Diesel engines with a high compression degree, where the mixture is ignited spontaneously in compressed air. In Serbia public utility vehicles most often use diesel engines with Euro diesel as the fuel of choice. Diesel engine fuels which have the EURO prefix in their name have to comply with all the requirements of the SRPS EN 590 standard. This fuel is introduced in the set of alternatives in order to compare it with the new fuel modes [6].

A3. Compressed natural gas

The CNG is a natural gas which is compressed to the pressure of 220-250 bar. The main ingredient is CH_4, which compared with other products has lower CO_2 emission coefficient per unit of released energy, and as such contributes to air quality. The CNG enables an easier start and better engine performance. The WCV usually install CNG systems in petrol engines.

A4. Liquefied petroleum gas

Local governments and waste collection operators across Europe are increasingly looking at alternatives to traditional petrol and diesel vehicles for their fleets. The LPG – a mixture of butane and propane, is a byproduct of the petrol refinement process. Gaseous fuels do not offer significant CO_2 reductions in comparison to traditional fuels (solid and liquid), however, they can provide major reductions in emissions of PM, NO_X, and noise. The LPG is usually used in cars and light vans. The efficiency of LPG is reflected in its low price, longer life time of engines, as well as lower vehicle maintenance costs. Similar to CNG, WCV also install LPG systems usually in petrol engines.

A5. Biodiesel (agriculture)

Biodiesel is an alternative fuel which is produced completely from renewable source and as such contributes to the reduction of exhaust gases emission responsible for the greenhouse effect. It can be derived from any vegetable oil: sunflower, soy, rapeseed, palm, algae.

It can be used as clean (B100) or as a mixture with fossil diesel in various concentrations (B5, B20). Contrary to fossil diesel, biodiesel is non-toxic and fully degradable.

A6. Biodiesel (used cooking oil)

Apart from obtaining biodiesel by refining vegetable oils, it is becoming increasingly popular to produce it from used cooking oil. A high content of oxygen contributes to the reduction of the amount of particles in exhaust gases and complete combustion which further leads to the reduction of hydrocarbons and CO emission. The WCV can use biodiesel without any modifications in all engines which use fossil diesel as fuel. Furthermore, it has a positive effect on the engine itself, due to better lubrication and less wear, which increases the life time of the engine.

A7. Hydraulic-hybrid

A hydraulic hybrid can store large amounts of energy during braking, therefore stop-and-go WCV are particularly well suited to utilize hydraulic hybrid drive. The use of hydraulic-hybrid diesel WCV has a potential fuel savings of up to 14%. The tail-pipe emissions from hydraulic-hybrid WCV were assumed to be also 14% less than conventional diesel-fueled WCV [13]. Oliveira *et al.* [14] also reported 15 to 25% improvement in fuel economy of heavy-duty hydraulic hybrid WCV compared to conventional diesel-fueled WCV.

A8. Hybrid diesel-electric

A hybrid vehicle is defined as a vehicle that is powered by more than one source of power. The options for hybridization that have been explored for WCV are electric hybrid drives and hydraulic hybrid drives. The strengths of the hybrid diesel-electric WSV are collection areas with high population density and a high number of waste bins on a short collection stretch. The use of hybrid diesel-electric WCV has a potential fuel savings of up to 33% [13].

Criteria for assessment of fuel alternatives for Serbian WCV

The selection of an appropriate waste treatment scenario is a complex problem in which a set of environmental, economic, and social criteria must be taken into account [15]. The criteria used in the evaluation of the best alternative fuel or advanced vehicle technology for WCV fleets are based on a mixture of objective and subjective assessment. Financial, socio-technical and environmental criteria can be generally divided into two groups:

– criteria obtained from previous researches and collected from literature [4, 6, 8, 11], and
– criteria obtained by assessment of professional experts.

In the second case, the expert group members are from WCV manufacturing industries, PUC that use and maintain these vehicles and academics and research institutions. For this reason, the experts from the PUC *Mediana Niš*, Center for engines and motor vehicles, Department of Material Handling Equipment and Logistics Systems and Department of Energy and Process Engineering (Faculty of Mechanical Engineering of the University of Nis) were involved in this research. Within the evaluation process twenty four valid questionnaires were retrieved from professional experts. Firstly, the experts rated relative importance of the criteria and in second round they gave performance value between 0 and 1 to the each alternative according to the set of pre-specified criteria. The criteria, used to evaluate the best alternative fuel or advanced vehicle technology for Serbian waste collection industry, were selected from a combination of those from previous studies and from discussions with a number of professional experts. Thirteen evaluation criteria were established:

C1. Costs of implementation

The costs of implementation represent vehicle costs obtained as WCV market prices in Serbia. These costs [€] were obtained from PUC *Mediana Niš* internal sources as shown in tab. 3.

C2. Fuel price

The second financial criterion considers current fuel prices in Serbia. In order to estimate the fuel prices in Euro per WCV kilometer of travel, the average diesel fuel mileage from PUC *Mediana Niš* (0.5411 l/km or 4.27 l/active moto-hour) was adopted [4] and, based on that data, the average mileages for alternative fuels were recalculated according to recommendations given in the literature [6, 13, 16]. Next, the current national fuel prices (unit price) according to The Association of Oil Companies of Serbia (UNKS) [17] as well as journals, magazines, and newspapers published in Serbia were determined. Due to the fact that biodiesel cannot be purchased at the time in Serbia because of the current market and regulatory conditions (procurement is only possible by importing from neighboring countries – Bulgaria, FYRM, Greece, B&H), a similar price for biodiesel as for regular diesel was assumed. Then, the average travel costs [€ per km] were calculated as shown in tab. 1.

Table 1. Fuel prices data

Fuel costs	Mileage [kml_{de}^{-1}]*	Unit price [$€l^{-1}$]	Travel cost [$€km^{-1}$]
Gasoline BMB 95 (EN228)	1.340	1.013	0.756
Diesel (fossil) (EN590)	1.848	1.028	0.556
CNG	1.540 km/kg	0.76 €/kg	0.493
LPG (EN589)	1.032	0.532	0.516
Biodiesel (agriculture)	1.848	1.028	0.556
Biodiesel (used cooking oil)	1.848	1.028	0.556
Hydraulic-hybrid	2.107	1.028	0.488
Hybrid diesel-electric	2.458	1.028	0.418

* l_{de} – liter diesel equivalent

C3. Fuel price stability

The fuel price stability was measured by the standard deviation of the Serbian national fuel prices during 2015-2016 years. The data were collected using information from government institutions, regulatory agencies, major media sources and oil companies. Two of the main sources were dominant, UNKS [17] and websites Global Petrol Prices and Autotraveler [18, 19]. The cost of biodiesel was assumed to be stable during the analyzed period. The values of standard deviation are given in tab. 3.

C4. Maintenance costs

The maintenance costs include costs of all materials, spare parts and labour for planned and unplanned maintenance activities. Vehicle maintainability has significant impact on maintenance costs. This term includes all vehicle features regarding the possibilities of implementing the necessary maintenance procedures (preventive or corrective). Maintenance costs as a criterion are quite difficult to express. In this research, we use the assessment of professional experts from the WCV manufacturing and operations sector as well as academic and research institutions.

C5. Energy efficiency

In this study, a method of alternative fuel energy efficiency assessment given in [16] was adopted. In order to assess various fuel technologies it was assumed that for a WCV to move one kilometer, the same amount of energy is required regardless of the fuel type. All alternative fuel WCV were assumed to have the same weight further indicating that they will have the same resistance while traveling at the same speed on similar roads. Consequently, a WCV using any fuel requires the same amount of energy for one kilometer traveled. Diesel-fueled WCV are the baseline for this model and they travel an average of 1.848 kilometer per liter of diesel (tab. 1). According to the available data [18, 20], one liter of diesel contains 35,940 kJ. Therefore, in order to move a diesel vehicle a distance of one kilometer, it requires:

$$\text{Energy required per km of travel} = 35{,}940\frac{1}{1.848} = 19{,}448 \text{ kJ/km} \tag{1}$$

Based on the model, the same amount of energy must be provided by any fuel type to move a WCV. Following the same methodology and available data [20] the values of energy required per kilometer of travel [kJkm^{-1}] were obtained, tab. 3.

C6. Security issues

Any fuel, including those used in motor WCV, can be dangerous if handled improperly because fuels contain energy, which is released when the fuel is ignited. The relative safety of alternative fuels must take into consideration the particular circumstances of its accidental release and its reactive nature. In this research, quantification of the fire and explosion hazards of alternative fuels is based on the autoignition temperature of the fuel. The autoignition temperature represents the minimum temperature at which gas, vapour or liquid fuel spontaneously self-ignites in the air without external source of ignition (spark or flame). Higher autoignition temperature typically indicates a safer substance. According to literature, *e. g.* [20], the values of autoignition temperatures, for analyzed alternatives, are given in tab. 3.

C7. Fueling station availability

This criterion considers availability of fuel infrastructure in Serbia. Unfortunately, the current status of alternative refueling infrastructure is not satisfactory as compared to the conventional fuel stations. This confirms the fact that only nine CNG refueling stations were commercially available in Serbia by the end of 2014 with only one in Southeast region of Serbia. Also as previously mentioned, biodiesel cannot be purchased at the time in Serbia. In that sense, a clear strategy concerning further development of alternative fuels infrastructure in Serbia is needed.

C8. Vehicle capability

This criterion considers the cruising range and gradeability (slope climbing) of WCV according to different types of fuels. The cruising range, in the case of Serbian WCV, does not have great importance due to the relatively short vehicles routes. On the other hand, gradeability of the vehicle is one of the most important factors for vehicle capability. All WCV were assumed to have the capability to take gradients even on full loads. The gradeability of a WCV depends primarily on the type of road surface in southeast region of Serbia.

C9, C10, C11. Air pollution: CO_2, CO, and NO_x

Different alternative fuels have different effects on environment, which is expressed through a variety of environmental indicators. To assess the environmental impact of a certain fuel, it is necessary to carry out an adequate analysis of all influential environmental criteria. In this paper, three indicators were analyzed as different MCDM criteria: CO_2, CO, and NO_x. In order to evaluate the alternatives A1-A8 according to environmental criteria CO_2, CO, and NO_x, COPERT IV model [21] was used. COPERT IV is a world-wide used tool for calculation of air pollutant and green-house gas emissions from road transport. By using the model, accompanying literature [22] and data (WCV type, the average speed of the working cycle) from PUC *Mediana Niš* [4], quantities of CO_2, CO, and NO_x [gkm^{-1}], that are produced for distance of one kilometer of WCV movement, were determined for gasoline, diesel and LPG fuel. Then, on the basis of the available literature [6, 11, 16, 23, 24] the values of CO_2, CO, and NO_x produced per kilometer of travel, were recalculated for other alternative fuels and advanced vehicle technologies, tab. 3.

C12. Life-cycle emissions

This criterion is intended to assess the overall environmental impact of alternative fuel technologies. The life cycle analysis of alternative fuels encompasses emissions from the complete fuel cycle: production, refining, transportation, distribution of the fuel to the WCV tank, and finally, the combustion of the fuel. There are a number of studies designed to examine life-cycle emissions of alternative fuels. Mindful of the fact that a life-cycle estimate of alternative fuel emissions is applicable only within the country in which it is generated, in this research we considered this criterion through assessment of professional experts.

C13. Noise pollution

This criterion refers to the noise produced during the operation of the vehicle. The WCV is used to operate the waste-collection procedure at collection points, which requires the use of engines with higher power and running at higher speeds. This fact often leads to harmful effect on the environment in the form of higher levels of noise emission. This criterion is also considered through assessment of professional experts.

The WASPAS – the basic structure of the chosen MCDM methods

For solving previously described MCDM problem the WASPAS method was used. This method was proposed by Zavadskas *et al.* [25] in 2012 and till date, the WASPAS method had a number of successful applications from different fields in engineering. The popularity of the method has resulted in the development of advanced methods such as WASPAS-G [26], WASPAS-F [27], and WASPAS-IVIF [28] that are intended to work with grey numbers and interval-valued intuitionistic fuzzy numbers, respectively. In essence the WASPAS method represents a unique combination of two well-known MCDM methods, *i. e.* weighted sum method (WSM) and weighted product method (WPM). The main procedure of the WASPAS method solving MCDM problems includes several steps [25, 29].

Step 1. Set the initial decision matrix:

$$\mathrm{X} = [x_{ij}]_{m\times n} = \begin{bmatrix} x_{11} & x_{12} & \ldots & x_{1n} \\ x_{21} & x_{22} & \ldots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \ldots & x_{mn} \end{bmatrix} \tag{2}$$

where x_{ij} is the assessment value of the i^{th} alternative with respect to the j^{th} criterion, m – the number of alternatives, and n –the number of criteria.

Step 2. Normalization of assessment values of alternatives given in decision matrix with respect to considered criteria by using following equations with respect to maximization criteria, where $\max_i x_{ij}$ is the most preferable value:

$$\overline{x}_{ij} = \frac{x_{ij}}{\max_i x_{ij}} \tag{3a}$$

with respect to minimization criteria, where $\min_i x_{ij}$ is the most preferable value:

$$\overline{x}_{ij} = \frac{\min_i x_{ij}}{x_{ij}} \tag{3b}$$

Step 3. In the WASPAS method the summary criterion of optimality is determined on the basis of two criteria of optimality. The first criterion of optimality is the criterion of optimality of the WSM. Based on the WSM, the total relative importance of i^{th} alternative, denoted as $Q_i^{(1)}$, is calculated as [30]:

$$Q_i^{(1)} = \sum_{j=1}^{n} \overline{x}_{ij} w_j \tag{4}$$

where w_j is the weight coefficient which represents the relative significance of the j^{th} criterion.

Step 4. The second criterion of optimality is the criterion of optimality of the WPM. According to the WPM, the total relative importance of i^{th} alternative, denoted as $Q_i^{(2)}$, is calculated as [31]:

$$Q_i^{(2)} = \prod_{j=1}^{n} \overline{x}_{ij}^{\,w_j} \tag{5}$$

Step 5. In order to have increased ranking accuracy and effectiveness of the decision making process, in the WASPAS method, a more generalized equation for determining the total relative importance of alternatives is given as [32, 25]:

$$Q_i = \lambda Q_i^{(1)} + (1-\lambda) Q_i^{(2)} = \lambda \sum_{j=1}^{n} \overline{x}_{ij} w_j + (1-\lambda) \prod_{j=1}^{n} \overline{x}_{ij}^{\,w_j}, \quad \lambda = 0,\ 0.1,\ \ldots ,1 \tag{6}$$

where λ is the coefficient of linear combination and can take values between 0 and 1. When the value of λ is 0, WASPAS method is transformed to WPM, and when λ is 1, it becomes WSM [30].

Finally, the competitive alternatives are ranked based on the Q values, *i. e.* the best alternative would be that one having the highest Q value. By varying the values of the coefficient of linear combination one can analyze the stability of the obtained complete ranking of the alternatives.

Results and discussions

The first step in assessment of alternative fuels and advanced vehicle technologies for WCV with respect to considered criteria was evaluation of criteria weights by the relevant decision making experts. In this research, twenty four experts and managers were invited to survey thirteen ranking criteria. They assessed the relative importance (subjectively) for each of the criteria and the average values of weights are presented in tab. 2. The weights are shown for three categories of professional experts: academics and research institutions, manufacturing industries, and PUC and all professional experts. These data show that maintenance costs (C4), energy efficiency (C5), fueling station availability (C7) and emissions of carbon monoxide (C10) are four the most importance criteria for decision making.

Table 2. Criteria weights

Criteria		Academics and research institutions	Manufacturing industries and PUC	All professional experts
1	Costs of implementation	0.0537	0.0642	0.0584
2	Fuel price	0.0896	0.0780	0.0858
3	Fuel price stability	0.0806	0.0872	0.0839
4	Maintenance costs	0.0955	0.0872	0.0931
5	Energy efficiency	0.0896	0.0917	0.0912
6	Security issues	0.0627	0.0550	0.0511
7	Fueling station availability	0.0985	0.0780	0.0912
8	Vehicle capability	0.0597	0.0734	0.0657
9	Emissions CO_2	0.0806	0.0780	0.0803
10	Emissions CO	0.0985	0.0780	0.0912
11	Emissions NO_x	0.0925	0.0780	0.0876
12	Life-cycle emissions	0.0597	0.0780	0.0675
13	Noise pollution	0.0388	0.0734	0.0529

After the evaluation of criteria weights, the next step is the evaluation of alternatives with respect to each criterion. The described MCDM problem can be easily expressed in matrix format. A decision matrix is an (m×n) matrix in which element x_{ij} indicates the performance of alternative A_i when it is evaluated in terms of decision criterion C_j , (for i = 1, 2, 3,..., 8, and j = 1, 2, 3,..., 13). The final step is determination of alternative rank based on the

Q values as described in the section *WASPAS – the basic structure of the chosen MCDM methods*. The results of the WASPAS method are presented in fig. 1 and tab. 4.

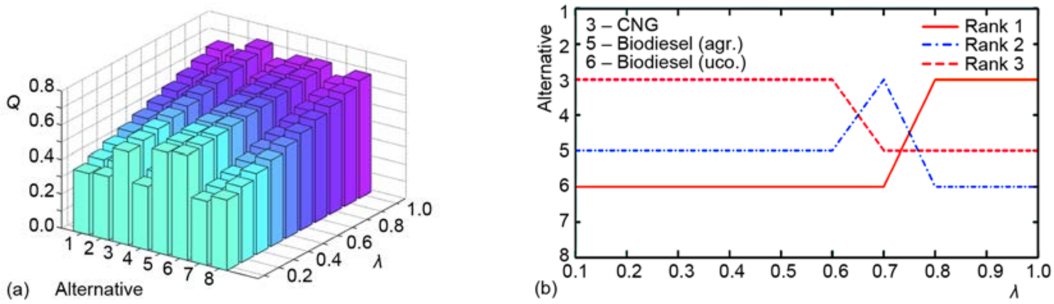

Figure 1. The results of proposed MCDM methodology; (a) the total relative importance of alternatives, (b) rankings of three most preferable alternative fuels for WCV with respect to λ

As could be seen from fig. 1(a) there exists a significant difference between relative importance of alternatives obtained on the basis of two criteria of optimality (WSM and WPM). According to the WPM (lower values of λ), only three alternatives A6, A5, and A3 have total relative importance values higher than 0.55, whereas the majority have total relative importance values between 0.35 and 0.41. On the opposite, according to the WSM criteria of optimality (higher values of λ) all alternatives have total relative importance values approximately equal (between 0.64 and 0.72) and due to this there is some rank reversal of alternatives, fig. 1(b).

Table 3. Decision matrix for MCDM of WCV alternative fuels

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
unit	$\times 10^3$ [€]	[€km^{-1}]	[–]	[–]	[kJkm^{-1}]	[°C]	[–]	[–]	[gkm^{-1}]	[gkm^{-1}]	[gkm^{-1}]	[–]	[–]
A1	100	0.76	0.097	0.81	24.40	257	0.95	0.80	1781.7	20.70	1.44	0.50	0.73
A2	110	0.56	0.088	0.75	19.45	315	0.95	0.85	1409.2	10.26	4.33	0.58	0.61
A3	135	0.49	0.013	0.65	22.87	540	0.45	0.71	1160.5	0.73	1.73	0.63	0.68
A4	110	0.52	0.078	0.67	23.91	482	0.78	0.73	1573.9	17.13	1.92	0.58	0.67
A5	110	0.56	0.000	0.68	18.40	149	0.33	0.77	784.7	5.13	4.76	0.77	0.60
A6	110	0.56	0.000	0.68	19.52	149	0.39	0.77	784.7	5.13	3.89	0.78	0.60
A7	170	0.49	0.088	0.51	17.06	315	0.95	0.83	1211.9	8.82	3.72	0.65	0.69
A8	170	0.42	0.088	0.52	14.62	315	0.95	0.83	944.2	6.87	2.89	0.69	0.69
Type	min	min	min	max	min	max	max	max	min	min	min	max	max

In tab. 4 rankings of all considered alternative fuels for WCV with respect to λ were presented. It can be observed that alternative six (biodiesel – used cooking oil) is determined as the best. It is revealed that alternative five (biodiesel – agriculture) is the second best choice, and that alternative three (CNG) is the third choice. Alternative one (gasoline) is the least preferred fuel.

Table 4. Rankings of all considered alternative fuels for WCV with respect to λ

Alternative λ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
A1 Gasoline	8	8	8	8	6	5	5	5	5	5
A2 Diesel (fossil)	7	7	7	7	8	7	7	7	7	7
A3 CNG	3	3	3	3	3	3	2	1	1	1
A4 LPG	6	6	5	5	5	6	6	6	6	6
A5 Biodiesel agr.	2	2	2	2	2	2	3	3	3	3
A6 Biodiesel uco.	1	1	1	1	1	1	1	2	2	2
A7 Hydraulic-hybrid	5	5	6	6	7	8	8	8	8	8
A8 Hybrid dies.-elec.	4	4	4	4	4	4	4	4	4	4

In any MCDM analysis it is beneficial to check the stability of the obtained complete ranking of alternatives. In this study the stability of obtained complete ranking of alternatives was checked by the application of the multi-objective optimization on the basis of ratio analysis (MOORA) method [33]. The complete ranking of alternatives was obtained as: A1 (rank 8) – A2(6) – A3(1) – A4(7) – A5(4) – A6(2) – A7(5) – A8(3). It is revealed that CNG, biodiesel (used cooking oil) and hybrid diesel-electric were identified as the best WCV for this case study.

Taking into account the small difference in values of total relative importance Q_i for alternatives 6, 5, and 3 (1.87% between 6-5 and 2.53% between 5-3, $\lambda = 0.5$) as well as the fact that CNG systems are usually installed in gasoline engines that are rarely used in the Serbian fleets of WCV and fact that biodiesel can be used in existing diesel vehicles (without or with very slight modifications), biodiesel is proposed as the best alternative. The CNG vehicles have excellent performance, but due to the high prices and lack of money for their purchase (especially in southeast region of Serbia), their gradual introduction into the waste collection fleet is proposed.

Conclusions

This paper aims to evaluate different alternative fuels and advanced vehicle technologies for Serbian WCV fleets. The selection of alternative fuels is a typical MCDM problem considered for different vehicles categories (passenger cars and light duty vehicles, heavy duty vehicles, buses, motorcycles ...). In this study eight alternative fuels and advanced vehicle technologies for WCV were ranked according to thirteen financial, socio-technical and environmental criteria. The well known WASPAS method was used due to its property that combines two well known MCDM methods WSM and WPM.

Based on the analysis of the results obtained using the WASPAS method and verified using MOORA method, biodiesel derived from used cooking oil was proposed as the best alternative fuel for Serbian WCV. At this point of time, this is fully justified taking into account existing WCV fleets, but also imposes the need for its imports from neighboring countries. In the future period, it is necessary to think about gradual introduction of CNG and hybrid vehicles, what will be significantly accelerated by implementation of new environmental regulations in Serbia.

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