



THE USEABLE DRIVETRAINS IN CONTEMPORARY BUS TRANSPORT

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Abstract *This paper focuses on introducing new, environmentally friendly types of drivetrains in the field of bus transport. Main goal is to present approximate costs of purchase and cost of operating (especially fuels or electricity) and connected them with real emissions of carbon dioxide for each different technology of drivetrain, including Well-to-Tank and Tank-to-Wheel emissions. The authors are using the Weighted Sum Approach method to determine currently the most suitable drivetrain for urban busses.*

Keywords *alternative fuels, road transport, bus transport, carbon dioxide, Well-to-Wheel emissions*

1 INTRODUCTION

Passenger road transport is an important part of national economy, especially regarding to availability of transport services in towns or cities, as well as in rural areas. Legal right for available public transport service to job, school, medical services or cultural needs is given by the Law on public services in transportation of passengers for every citizen (Czech Republic, 2010).

Thanks to climatology researches and predictions are environment-protective efforts stronger than ever before and there are tendencies to harm nature as little as possible. One of the ways is to handle natural resources carefully and shift human activities towards climate neutral sphere. Transport industry is one of the most discussed sectors and because public passenger transport services are generally accepted as beneficial for the whole society, it is very likely that subsidies to implement alternative technologies will be widely accepted.

This paper includes characteristics of available drivetrains technologies (in section 3.2) so it may be used as a **source of information for professionals, bus-operating companies and state authorities**.

The **application of multiple-criteria decision making (MCDM) method** to identify the most suitable drivetrain is included. **The paper is focused on segment of urban-buses** because these days it seems to be the most promising sector in terms of possibility to introduce alternative fuels or technologies.

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The aim is not to choose one and only good option, but to offer closer look to available technologies and their pros and cons.

2 METHODOLOGY

2.1 The target of the paper and methods used

The main target of the paper, besides analysing available alternative drivetrains to the “common” diesel, is to apply the MCDM method **WSA** (*Weighted Sum Approach*) for the **selection of the most appropriate drivetrain for urban buses** – see section 5. The theoretical background of the WSA method will not be included in the paper.

2.2 Research question and hypothesis

The paper answers the **research question (RQ)**: “Which of the studied drivetrains is, considering criteria specified in section 2.3, currently the most suitable for public urban busses?”

Hypothesis: based on the research, the authors expect the most suitable fuel to be CNG.

2.3 Determining variants and criteria and their weightings

As mentioned hereinbefore, **the drivetrains that will be considered as variants** in the WSA methods will be:

1. diesel,
2. CNG – Compressed Natural Gas,
3. BEV – Battery Electric Vehicle (pure electric bus),
4. FCEV – Fuel Cell Electric Vehicle (hydrogen bus).

The authors decided to use **following criteria for evaluation of variants** (individual drivetrains):

1. cost of purchase,
2. cost of fuel/electricity for the whole examined period,
3. total emission of CO₂ produced.

The **criterion number 1** has been included as one of the most important in purchasing decision making. **Criterion number 2** represents one of the components of the variable operational costs and is relatively easy to estimate. **Criterion number 3** considers the impact on the environment (emissions of greenhouse gas – CO₂). The data used in this criterion are obtained from the sources specified hereinafter in the paper.

The values in **criterion “cost of purchase”** are self-explaining. The values represents the costs (in Euro, excl. VAT) of particular bus. The values in **criterion “cost of fuel/electricity”** are obtained from outside data and are calculated for 5 year period and total driven mileage of 275,000 km. The values in **criterion “total emission of CO₂ produced”** are based on both main components of road emissions – WTT and TTW (explanation and details can be found in section 4) for the whole period (5 years) and total mileage driven (275,000 km).

All the selected criteria has minimizing character – i.e. before using the WSA method, the criteria have to be converted to maximization. **Weighting of the criteria** was determined equally – i.e. **0.333**. The authors consider every criterion as important as the other ones. The authors don't want to purposefully say that saving CO₂ emissions is worth particular amount of money or not.

3 PASSENGER ROAD TRANSPORT

Passenger road transport can be divided into two main sections. Regular public transport and irregular (occasional) passenger transport. Not surprisingly, **each one of them has its own specifics**.

Regular public transport in Czech Republic consists mainly out of urban public transport and inter-urban transport; in 2018, in these two fields were employed about 30,000 people in almost 100 companies (Český statistický úřad, 2020).

Buses are usually operated according to clearly given timetables, which should meet peoples' requests on when to go and where to go. Although buses are usually operated during the day equally, the travelled distance per day is not so high. According to study from Netherlands, about 15% vehicles reach less than 100 km/day, 49% travel 100-300 km/day and 30% of buses can travel 300-500 km/day. Only the remaining 6% travel more than 500 km/day (CROW, 2019).

Regular public transport is also often highly subsidized by local and/or state government, mainly due to possibility to offer transport services for affordable fares. Subsidies can be also justified by the fact, that on average, public transport emits less carbon dioxide per person than individual car transport (European Environment Agency, 2013).

Long distance bus lines also belongs among Regular services, although these lines are usually operated by private companies for profits, hence are not subsidized. Also the distance travelled varies a lot; for example one of the longest bus lines operated in Flixbus network is *Bucharest – Bordeaux*, which means more than 3,000 km in 51 hrs (Zdopravy, 2019). It also means different requests on bus types and its equipment – for example fuel tanks or luggage compartment.

Occasional passenger transport doesn't have any given timetables and is mainly used by tourists and tourist operators. Use of vehicles is highly unpredictable and volatile, so one of the main requests on bus or coach is its versatility. In 2018, occasional passenger transport employed about 9,000 people in about 2,000 companies, which clearly shows, that optimal size of company in this industry is much smaller (Český statistický úřad, 2020).

In Europe, the numbers of newly registered **diesel busses are continuously decreasing**. When comparing years 2019 and 2020, the share of diesel busses dropped from 85.0% to 72.9%. On the other hand, the shares of alternative drivetrains have risen: electric busses from 4.0% to 6.1%, hybrid busses from 4.8% to 9.5% and alternative fuel busses (CNG, LNG, ethanol,...) from 6.2% to 11.4% (ACEA, 2021). According to Sustainable BUS (2021), ca. **150 hydrogen busses** came into the operation during the years 2012-2020. Concerning the Czech Republic as an example of exchanging diesel busses by electric busses, we can mention Hradec Králové, where ca. one third of urban busses is already electric and there are plans to increase the share to one half (Dopravní podnik města Hradce Králové, 2021).

3.1 Ecology of drivetrain technologies

Reducing emissions is an important topic in the whole society and possibility of alternative fuels brings this topic also in the area of buses and passenger transport.

For this paper and also for the whole industry of bus transport, the following document is crucial. It is the **DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL (EU) 2019/1161** of 20 June 2019 **on the promotion of clean and energy-efficient road transport vehicles**. One of the main purposes of this Directive is to increase the share of ecological vehicles in large commercial vehicles, especially trucks of the **N2** (i.e. with maximum weight 3.5-12.0 tons) and the **N3** (i.e. with maximum weight over 12.0 tons) category and buses and coaches of the **M3** (i.e. with capacity higher than 9 people and maximum weight over 5.0 tons) category. It also suggests the possibility of supporting and subsidizing to increase the share of energy-efficient vehicles on the roads.

The newly concluded public contracts, where the main subject is operating heavy vehicles, must now reach certain share of energy-efficient vehicles. These shares varies a little-bit across the EU, for example the Czech Republic should reach **41% in period 2021-2025**, within the years **2026-2030 it should be even 60%** of energy-efficient vehicles of the **M3 category**. Additionally, at least half of these targets should be fulfilled with **zero-emmission buses**. To compare public contracts in bus transport with freight transport, in the Czech Republic the companies (operating N2 and N3 vehicles) are to reach the share of 9% and 11% respectively within hereinbefore specified periods.

The Directive is not focused on coaches (i.e. the *class 3*) of the **M3 category**, usually used for long-distance lines and occasional passenger transport. There are two main reasons. First, this business is only marginal in public contracts; and second, market supply of these vehicles in energy-efficient versions is very limited, especially because of current technologies that are not so advanced yet to be used for long-distance vehicles – i.e. the problem is the range.

It is important to mention, that the emissions reduction efforts are not only the topic of last several years. Continuous reductions of emission of diesel-powered vehicles (as well as petrol-powered) is very well known for last three decades as **EURO norms** – since the early 1990s. Currently, the **EURO VI** norm is in charge.

Introduction of a new EURO norm definitely doesn't mean that older vehicles are banned from operating, but they can be somehow disadvantaged. Typical example can be higher taxes, toll or **implementing LEZ (Low Emission Zones)** – i.e. the areas where the entrance is allowed only for vehicles with certain EURO norm or higher. But it is necessary to mention, that expected benefits were much higher than they are in reality (Hooftman et al., 2018).

In the **Tab. 1**, the emission limits of EURO norms for categories of trucks (N2 and N3) and busses (M2 and M3) are presented. From the table, significant decrease of emissions' limits is obvious. (Dieselnet.com, 2019).

Tab. 1 The EURO norms; source: Dieselnet.com, adjusted.

Norm	Date	Approval	CO	HC	NOx	PM	PN	Smoke
				g/kWh			1/kWh	1/m
Euro I	1992, ≤ 85 kW	ECE R-49	4.50	1.10	8.00	0.61	-	-
	1992, > 85 kW		4.50	1.10	8.00	0.36	-	-
Euro II	1996.10	ECE R-49	4.00	1.10	7.00	0.25	-	-
	1998.10		4.00	1.10	7.00	0.15	-	-
	1999.10 (EEV)		1.50	0.25	2.00	0.02	-	0.15
Euro III	2000.10	ESC & ELR	2.10	0.66	5.00	0.10	-	0.8
Euro IV	2005.10	ESC & ELR	1.50	0.46	3.50	0.02	-	0.5
Euro V	2008.10	ESC & ELR	1.50	0.46	2.00	0.02	-	0.5
Euro VI	2013.01	WHSC	1.50	0.13	0.40	0.01	8.0×10 ¹¹	-

For example *carbon-monoxide* was lowered on one third and the *nitrogen oxides* are twenty-times lower in comparison with the year 1992.

3.2 Available technologies

In this section, we will present the main current technologies that can be used as drivetrain in buses. **We will focus on urban buses**, because nowadays only this category can offer multiple choices of alternative fuels, which are not yet available for longer-distance vehicles.

3.2.1 Diesel fuel

This category can be considered as the oldest one, but it does not mean that it does not use state of art technologies. So far, it is the most common type of the drivetrain.

Internal combustion engine uses diesel as fuel and of course, it emits various emissions from burning the fuel. More on this topic is discussed in section 4.1. The engine is connected via gearbox directly to the driven wheels.

Among the advantages of this type belongs: **low acquisition costs; historically known and predictable maintenance costs; developed infrastructure** for this type of fuel. Among the most important disadvantages – from the perspective of this paper – the locally produced exhaust emissions or higher level of noise belong.

3.2.2 CNG – compressed natural gas

The CNG engine is very similar to diesel engines, it is also the ICE (Internal Combustion Engine), but instead of diesel, it burns highly compressed natural gas (methane). Generally, this type of fuel has lower distance travelled per one refuelling – but mostly, it is still enough for daily operation.

Compared to diesel engines, the CNG engine has a little bit **lower emissions of CO₂, which are about 15% lower compared to EURO VI diesel engine** (Scania, 2020). Second big advantage is that excise duty on CNG is lower than on diesel, hence fuel is cheaper. On the other hand, acquisition costs are higher and CNG is less versatile than diesel and, naturally, it still produces exhaust emissions.

3.2.3 EV – electric vehicles

This category definitely is the fastest growing of all. Thanks to the development in batteries, this technology may be used in real-life service, but still with some constraints. Electricity is stored in batteries and electric motor is connected to driven wheels.

Generally, there are three main subgroups:

1. **BEV – Battery Electric Vehicle**, which runs only on electricity and needs to be recharged regularly. Distance travelled depends on capacity of the batteries.
2. **HEV – Hybrid Electric Vehicle** runs mainly on combustion engine and smaller electric motor is used as an additional assistance for fuel consumption reduction.
3. **PHEV – Plug-In Hybrid Electric Vehicle** can use both types of drivetrains, depends on current needs. Batteries need to be recharged from electric network.

Nowadays, the biggest disadvantage is **low distance travelled per one recharging and it is very dependent on outside temperatures** (need of heating) – according to Sustainable Bus (2020), the range can fall of more than 50% in cold conditions (for 300 kWh battery – decrease from 300 km to 130 km). Batteries are also quite heavy part of electric buses – the lithium batteries have energy density of ca. 100 Wh/kg – i.e. in the case of 300 kWh battery pack, the weight will be 3 tons (AVID Technology, 2016). But we can expect, that with progress and development, the batteries become lighter and with higher capacity. Theoretically, with advanced manufacturing process and chemical composition, capacity can be even tripled (Nitta et al., 2015).

Second big disadvantage is frequent recharging need. It depends on operating schedule, but it can be said that electric bus needs couple hours of recharging every single day. This has to be considered when purchasing this type of vehicle.

Last, but not least disadvantage are the acquisition costs – see section 5 for the details.

On the other hand, this type of vehicle doesn't produce any local exhaust emissions (Tank-to-Wheel; for explanation see section 4) and has lower level of noise. But **the real total emissions** (Well-to-Wheel) **has to be calculated** with respect to certain technology of electricity production (and distribution) – they definitely *will not* be zero.

3.2.4 FCEV – Fuel Cell Electric Vehicles

This technology is the most advanced and least common, mainly because it is still more or less in research and development stage; pure commercial products are very rare.

Drivetrain is very similar to electric vehicle, electric motor is connected to driven wheels. The crucial difference is in storing energy. Fuel cells directly produce electricity using electrochemical reaction of hydrogen and oxygen, heat and water are still by-products. As the fuel, pure hydrogen is used. It goes through anode and aerial oxygen goes through cathode, between them the membrane is placed (The Fuel Cell and Hydrogen Energy Association, 2020).

According to US Office of Energy Efficiency & Renewable Energy, **fuel cells can be 2.4 times more energetically effective than combustion engine** (Office of Energy Efficiency & Renewable Energy, 2020).

Fuel cells could become irreplaceable part of future mobility, mainly because they are environmentally friendly. There is no combustion process, so no exhaust gases are produced during operation of a vehicle. The only emission product is pure water, which even fulfils US requirements on drinkable water. For completeness, we can state that **1 kg of pure hydrogen produces with aerial oxygen up to 9 kg of water** (Tibaquirá et al., 2011). The water produced may partly vaporize into the air, and partly is held in a special tank, so it is not flowing out during driving – which may be unsafe, especially in freezing weather. This water is usually drained away on site of refuelling (Baldini and Day, 2015).

The biggest disadvantage of this technology are costs of purchase. It is the most expensive possibility so far. Also, the price of hydrogen as a fuel is still quite high. These prices are expected to decrease in future. This type can be also considered as local zero-emission drivetrain (Tank-to-Wheel), but it is important to consider ways of hydrogen production (Well-to-tank) when calculating whole emission footprint (Well-to-Wheel). Compared to BEV, the FCEV can offer wider operating range of distance travelled per one refuelling.

4 THE EMISSION COMPONENTS

According to the EU Science Hub (2016) there are two main components of total fuel emissions called **Well-to-Tank (WTT)** and **Tank-to-Wheel (TTW)**. Explanation of the components is as follows:

- **Well-to-Tank (WTT)** are the emissions produce by mining raw materials, processing, producing and transporting of fuel, before it finally reaches a vehicle which will consume it.
- **Tank-to-Wheel (TTW)** are the emissions, which are produced during vehicle's operation.
- The sum of these two components is then called: **WTW – Well-to-Wheel**.

4.1 Internal combustion engines

Regarding the WTT: El-Houjeiri and Brandt (2012), the Stanford University study, shows that amount of CO₂ emitted is around 3.3 to 6.7 pounds per gallon of diesel, which means emissions production of ca.

400-800 grams per 1 liter of diesel even before it is burned in a vehicle's engine. For the purpose of this paper, the average of these two values will be used.

Regarding the TTW: Ecoscore.be (2020) database states that **1 liter of combusted diesel** produces **2,640 grams of CO₂** and **1 kg of CNG** produces **2,252 grams CO₂**.

According to EUCAR (European Council for Automotive R&D) research association the ecological footprint when producing CNG is ca. 5.5 grams of CO₂ per 1 MJ of energy. When converted, it means emissions of **270 grams of CO₂ per producing 1 kg of CNG** (European Commission Joint Research Centre, 2011).

4.2 Zero-emission engines

Even though these vehicles do not emit anything directly from exhaust pipes, **it is very important to consider emissions from producing electricity or hydrogen.**

According to the ČEZ group, the Czech Republic leading energetic company, average CO₂ emissions from non-renewable resources are 650–700 grams/kWh of electricity. Newly built, state of art non-renewable resources power-stations emit ca. 350 grams/kWh (ČEZ, 2019). Together, renewable and non-renewable resources power-stations makes an EU-average about 300 grams/kWh; **average for the Czech Republic is 512 grams/kWh** (European Environment Agency, 2018).

Fuel cell buses do not directly emit any CO₂ either, but is very important to solve how the pure hydrogen is produced. Using electrolysis from renewable resources is the way how to reduce CO₂ emissions down to zero. Hydrogen produced this way is called "**Green Hydrogen**". But this method is yet more theoretical than reality.

These days, 95 % of hydrogen is produced by the SMR technology (Steam Methane Reforming), this method uses water steam and methane gas and it produces hydrogen and carbon dioxide (Holladay et al., 2009). As the methane is a fossil fuel (and from its nature a greenhouse gas!), this method can't be described as renewable (and ecological) at all.

Indian study shows, that **per 1 kg of hydrogen, the 7.33 kg of CO₂** is produced when using SMR. If coal burning process is used, it is even **30 kg of CO₂ per 1 kg of hydrogen** is produced (Kothari et. al., 2008).

To use hydrogen as a fuel, it is necessary to compress it to very high pressure. Passenger cars reach pressure of 70 MPa, **for busses the pressure of 35 MPa** is sufficient. To compress 1 kg of hydrogen to pressure of 70 MPa, up to 6 kWh of electricity is needed (Sheffield et al., 2014). In this paper, the authors assume that to compress 1 kg of hydrogen to 35 MPa, 3 kWh of electricity is necessary. Using general electrical mix of the Czech Republic, it means additional 1,500 grams of CO₂ per 1 kg of hydrogen. Using hereinbefore explained values, the **WTW emissions of hydrogen** are $7.33 + 1.5 = 8.83$ **kg of CO₂** per 1 kg of compressed hydrogen.

5 THE APPLICATION OF THE MCDM TO IDENTIFY THE MOST SUITABLE BUS DRIVETRAIN

In this section, the authors provide suitability analysis of different types of drivetrains for urban buses. Part of input data is taken from foreign sources, like professional magazines or specialized websites; the rest is based on previous sections of this paper.

For the demonstration, the authors have taken urban bus **Mercedes-Benz Citaro** with different types of drivetrain (diesel, CNG and BEV). As an FCEV vehicle, the hydrogen bus **Solaris** has been used. All prices are calculated excluding VAT, the exchange rate is taken 26 CZK/EUR.

The main inputs for the MCDM and their sources are:

- price of an electric version of Citaro is adopted from realized purchases from Germany (The DriveEN, 2019);
- price of diesel and CNG version is taken from German magazine BusFahrt (busfahrt.com, 2017);
- price of the FCEV bus is taken from Sustainable Bus (2019);
- price of diesel fuel is considered to be 24.38 CZK/liter (Erneks Invest, 2020);
- price of CNG gas is adopted from CNGplus (2020) and is 22.76 CZK/kg;
- price of electricity is taken from E.ON (2020) and is based on tariff specified for recharging electric vehicles – the price is set to 4.60 CZK/kWh excl. VAT;
- price of hydrogen is adopted from German market (h2-map.eu, 2020), because there is no available public hydrogen refuelling station in the Czech Republic – the price is 9.26 EUR/kilogram.

The values of consumption of fuels or electricity were taken from specialized magazines, where similar buses were tested under real conditions (busfahrt.com, 2020), (Busmagazin.de, 2020). The emissions values were taken from the previous section of this paper. In Tab. 2 below, the values of individual characteristics are summarized.

Tab. 2 The main characteristics of drivetrains considered; source: Authors, using cited documents/sources.

Drivetrain type	Cost of Purchase (EUR)	Consumption per 100 kms (liters/kg/kWh)	Price per 1 unit of fuel/ electricity (EUR)	CO ₂ emissions (grams per 1 unit of fuel/electricity)
Diesel	250,000	34.2	0.937	3,240
CNG	309,000	38.25	0.875	2,522
BEV	570,000	102	0.177	512
FCEV	1,070,000	8.5	9.26	8,830

The authors assume **5 year period of operating**, which is equal to the length of accounting depreciation. Yearly mileage is assumed to be 55,000 km, which means roughly 150 km/day. This daily travelled distance is considered to be reasonable.

5.1 The WSA method

In this section, the application of the WSA method is shown – i.e. individual WSA matrixes are presented. See Tab. 3 to Tab. 8.

Tab. 3 The criteria matrix; source: Authors.

Drivetrain type	Cost of Purchase (EUR)	Cost of fuel 5 year operation (EUR)	Total CO ₂ emission for 5 year operation (tons)
Diesel	250,000	88,125	304.7
CNG	309,000	92,039	265.2
BEV	570,000	49,649	143.6
FCEV	1,070,000	216,453	206.4
criterion type	MIN	MIN	MIN

Tab. 4 The matrix of conversion of minimization values to maximization values; source: Authors.

Drivetrain type	Cost of Purchase (EUR)	Cost of fuel 5 year operation (EUR)	Total CO₂ emission for 5 year operation (tons)
Diesel	820,000	128,328	0
CNG	761,000	124,414	39.5
BEV	500,000	166,804	161.1
FCEV	0	0	98.3
criterion type	MAX	MAX	MAX

Tab. 5 The matrix of ideal and basal variants; source: Authors.

	Cost of Purchase (EUR)	Cost of fuel 5 year operation (EUR)	Total CO₂ emission for 5 year operation (tons)
ideal variant	820,000	166,804	161.1
basal variant	0	0	0

Tab. 6 The normalized criterion matrix; source: Authors.

Drivetrain type	Cost of Purchase (EUR)	Cost of fuel 5 year operation (EUR)	Total CO₂ emission for 5 year operation (tons)
Diesel	1.000	0.769	0.000
CNG	0.928	0.746	0.245
BEV	0.610	1.000	1.000
FCEV	0.000	0.000	0.610

Tab. 7 The matrix of criteria weightings; source: Authors.

	Cost of Purchase (EUR)	Cost of fuel 5 year operation (EUR)	Total CO₂ emission for 5 year operation (tons)
criteria weightings	0.333	0.333	0.333

Tab. 8 The aggregate utility and ranking of variants; source: Authors.

Drivetrain type	the utility of individual variants	the rank of variants
Diesel	0.59	3
CNG	0.64	2
BEV	0.87	1
FCEV	0.20	4

The result: the WSA method has shown the **best drivetrain is BEV**. The resulting *aggregate utility* of this variant is **0.87**.

6 FINDINGS AND DISCUSSION

In this paper, the authors have been primarily oriented on **suitability of available drivetrains in urban buses** and their main pros and cons. If the authors would have chosen different criteria and/or counted different weightings of the same criteria, the results would be different.

It is very **difficult to make trade-off between environmental protection and costs**, especially from the political point of view. In cases, where for example costs of purchase are not so important (e.g. cost of a bus itself is mainly or fully covered out of public subsidy), then higher weightings will be at operating costs and environmental impact criterion.

Additionally, on the other hand, **if external circumstances unexceptionally requires zero-emission vehicles without any local exhaust emissions (the TTW emissions)**, then any internal combustion vehicles should be dismissed from decision-making process.

Into more precise analysis, criteria like maintenance costs or costs of necessary infrastructure should be added, but it would be for much wider research. Especially for alternative drivetrain vehicles, maintenance costs and costs of unexpected repairs are very difficult to estimate. These types of vehicles are relatively new in service and not old enough to precisely estimate total operational costs over its real lifetime. Plus other aspects can affect this – for example: is Prague with cobblestone roads as suitable as Paris with wide boulevards?

Decision to purchase alternative type of buses to fleet, which nowadays means mainly electric buses, should be also considered from additional criteria that were not important in past, for instance:

1. **additional needs** – for recharging infrastructure and costs to build it,
2. **recharging schedule** – precisely planed with respect to time of the day or total number of vehicles needed, so buses that are being recharged right now may be substituted by other ones,
3. **qualification of personnel** – electricians instead of car mechanics or even sufficient number of bus drivers that can operate required number of busses.

By implementing above mentioned criteria into the MCDM methods we will **increase the objectivity of choice** of the best suitable urban-bus drivetrain technology. The choice of criteria is one problem, the other is the count of their relative importance (weightings).

7 CONCLUSIONS

The aim of this research paper was to introduce available/useable drivetrains for urban-buses in public passenger transport. After a brief description of passenger transport industry and main types of available drivetrains, their environmental consequences and the **application of the WSA method** took place. The authors have analysed each of these drivetrains, mainly concerning:

1. **acquisition costs:** calculated for 5-year time-period, with respect to accounting principles;
2. **variable costs of fuel/energy:** simplified estimation of costs to cover fuel/electricity consumption over the 5 years;
3. **their impact on the environment:** from the global point of view of CO₂ greenhouse gas emission.

The paper provides **the answer on the research question** defined in section 2.3: the most suitable drivetrain is BEV. The WSA method gave result of 0.87.

The hypothesis specified in section 2.3 was **not supported** – the most suitable alternative system is not the CNG.

Corresponding with the discussion in section 6, **further research** should include especially long-term costs of ownership of alternative drivetrains/fuels and how operating alternative buses changes accessibility of public transport for the general public. The discussion over **criteria, their values and their importance** should take place, as well.

Furthermore, the capacity of energy distribution infrastructure will be (and in some states – like Norway – already was/is) **the significant problem.**

When more advanced technologies of producing electricity will be commonly available (for recharging batteries or green hydrogen electrolysis), the alternative (non-ICE) types of drivetrains will become much more attractive.

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