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THE E-BUS: ECONOMIC OR/AND ECO FRIENDLY ALTERNATIVE?

Key Words

Climate changes; Public transport; Electric buses; Standardization; Energy efficiency

Abstract

Analyzing the values of public transport systems energy indicators and metropolitan air pollution together with the branch specific economic forecasts, the authorities and suppliers can estimate future trends. To reduce the urban usage of personal automobiles it is needed to increase the proportion of electric public transport vehicles (Tramways, Trolleybuses, Electric buses), also it needs to increase the urban mobility satisfaction by increasing attractiveness and accessibility of networks, growing essentially the number of trips by public transport. All together these can ensure more livable cities.

1. INTRODUCTION

A. World climate change

Climate change is a cruel reality, news about the disasters are daily. Although the world's leading heads of state and government agreed to cooperate in the development, application and availability of climate-friendly technologies for developing countries. However, there are blockages. It is enough to refer to the United States 2017's 'turnaround', hopeful the temporary rejection of a treaty accepted by the majority will not trigger an avalanche reaction.

We know there are many environmentally friendly alternatives, this is why urgent action is needed, and climate protection must be one of the foundations for development goals. Regional and urban mobility is a key condition for economic and social development and the reduction in poverty. The transport sector therefore plays a key role in the development and maintenance of the economic and social foundations of both developed and developing countries.

B. Transport's energy consumption and air pollution

The continuous growth in the transport sector has increased concerns about the economic costs of energy supply as well as the impact on the environment. In the EU, the road transport sector is responsible for 26% of final energy consumption and 24% of CO2 emissions (2007). Energy use and emissions from the road sector continue to grow around 1.5 - 2 % per year [1].

The 2016 Report of the International Energy Agency (IEA) [2] found that the share of transport in world oil consumption has increased significantly over the few last decades. Figure 1 and Figure 2 show the transport sector energy needs and evolution comparing 1973 to 2014. If we take the absolute equivalent energy values, the increased use of electricity will help to replace the classic fuels.

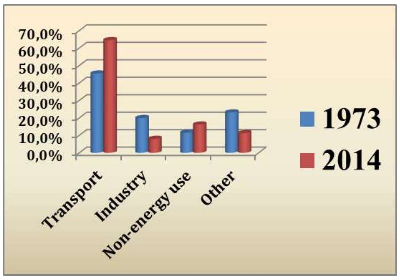

Figure 1. Oil consumption by sector (source: IEA) [1]

The values includes agriculture, commercial and public services, residential and non-specified others. During 1973-2014 oil production increased from 2,252 Mtoe to 3,761 Mtoe (1.67 times), same time the electric energy production increased 3.88 times (from 440 Mtoe to 1,706 Mtoe)!

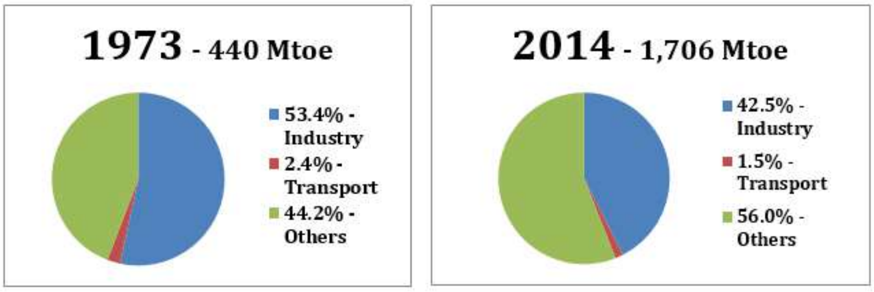

Figure 2. Electric energy consumption by sector (source: IEA)

The comparison marks the first oil crisis as a milestone, according to data from 1973. The share of transport accounted for 45.4% oil consumption in 1973. Nowadays, nearly two-thirds of crude consumption is in the transport sector, in 2014 the rate was 64.5%, value which prove a boom of oil sourced fuel engine transportation.

Although the share of electricity used in transport looks as decreased from 2.8% in 1973 to 1.5% in 2014 but is not exactly a recession of electric cars! If we take the absolute values, it is more than twice the amount of electricity consumed since the 1970's, in figures increase from 10.56 MTOE to 25.59 MTOE. Taking into account the significant advancement of energy efficiency in electric propulsion techniques, it eventually brings about more than two-three times the vehicle ratio. Electricity recommended to be used not only in public transportation (electric locomotives, metro & light rails, trolleybuses, soft freight logistics), in today's traffic are used to have hybrid or total electric private cars. Personal used zero emission cars help to solve the pollution issues in big cities, but about have no any effect on traffic congestion treatment… only one way to reduce travel time in highly crowded area is the public transport, mass transit on segregated lines (tram or metro, bus rapid transit).

2. IMPORTANCE OF THE PUBLIC TRANSPORT

A. Urban mobility

The UITP (International Public Transport Association), based in Brussels, jointly with the EU Commission, strongly recommends that European climate change and energy efficiency policies explicitly address the issue of urban mobility. One of the most important measures proposed is the development of a strategy to promote modal shift and high quality public transport systems [3]. One element of this is the need to develop sustainable urban mobility/transport plans across Europe for cities with more than 100,000 inhabitants (governed by the HG 191/2013 in Romania). Supporting investments in transport, addressing high energy efficiency and low greenhouse gas emissions as priority criteria accentuate the vital role of public transport. Unfortunately, it is often considered to be too costly an endeavor improving energy efficiency and reduced emissions.

Electric drives are able to solve the challenges of public transport:

•Reducing local pollution, whether comparing other used engine is gas, liquid or solid,

•The significant reduction of the CO2 emissions,

•Compliance with lower noise emission levels,

•Future reduction of the oil base fuels production and possible inflation of oil prices,

•The possible decreasing of internal combustion engines used in public transport will not affect the development and increasing of urban mobility.

Electric public transport modes are especially defined by used vehicles. A comprehensive view of division of electric driven urban transport vehicle (Figure 3) is based on energy supply mode / energy storage possibility. The development of 'green buses' is an ongoing lengthy process, having started more than a century ago, and overtime has reached different stages of acceptance and appreciation.

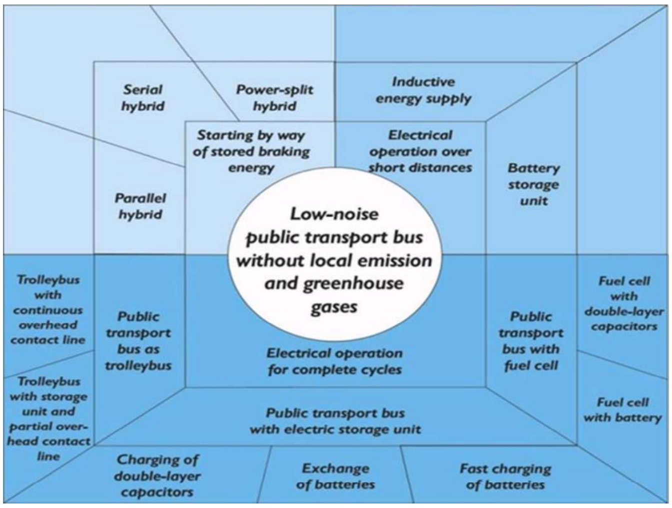

Figure 3. 'Green Bus' vehicles characterizations (source: UITP)

B. About electric drive vehicles

The best solutions for a high passenger flow with more than a few thousand trips per hour are the electric powered systems, whether it is metro or tram, trolley or the electric bus.

Some of the major challenges of the future are:

- what kind of electric energy we can supply to the vehicles;
- from which sources;
- what autonomy it is given by the energy storage;
- how long it takes to recharge it and with what kind of standard.

Energy can also be recharged on a moving or stationary vehicle: so-called **on-go** (generator by internal combustion engine, from outside electric network or as inductive charging), or **on-stop** (battery, supercapacitor). The flywheel mechanical facility helps to conserve energy and achieve efficient torque. The main advantage of electric propulsion is the power-torque characteristics. Energy can also be recharged on a vehicle on-the go (generated by internal combustion engine, from outside electric network as direct connection or as inductive charging), or on-stopped (charge of battery or supercapacitor). Recovery of brake energy is common in today's technology and can be reused immediately by other vehicles or reinjected back into the electric energy network. The flywheel method is a mechanical facility that conserves part of recovered energy. Many concepts have a main scope to achieve the most efficient torque for electric vehicles.

C. Where are the electric buses?

Assessing the present fleet in Europe in 2016 [5], oil-dependent transport systems cannot be replaced in a short time at a low cost, it needs substantial financing and it is an expensive undertaking for any Government. Price of Diesel buses almost remains same last decades, maybe small increased.

Table 1. Different bus supplier list prices along the world in 2017

Bus supplier (Diesel)	Country	Type	Unit price (USD)
King Long	China	XMQ6127	84,500
Mercedes MCV	Egypt	MCV C 120	158,000
Eurobus Diamond	Romania	BMC Urbino	216,500
Marcopolo Daimler	Brazil	Torino O 500-1726/59	274,500
Solaris	Poland	Urbino 12	325,500

Asking standard list prices from the suppliers (Table 1), based on the more used 12 m long urban 'solo' bus type, which depends on features, it start from 75,000 USD to almost over 350,000 USD in Diesel and increasing to several hundred thousand Dollars for the hybrids, not to mention the price of a 'super computerized', ultramodern electric bus which is up to 1,000,000 USD.

As we can see there is a very broad price spectrum. Prices depend on the type, brand, equipment, quality and maintenance services agreements but in the end the authority's budget will determine which manufacturer to sign a contract with.

An inventory made by UITP in 2015 (Figure 4) shows the distribution of buses characterized by engine types in European cities.

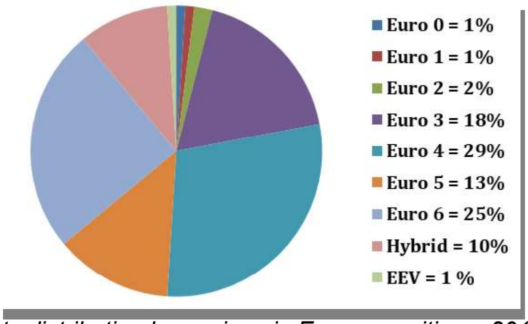

Figure 4. Bus fleets distribution by engines in European cities – 2015 (source: UITP)

As result of a comprehensive survey part of an EU Project [5] about fleets categorized by used energy source, can have the image how 'green' are the buses in Europe… Unfortunately, recently more than ¾ of fleets are diesel based internal combustion engines, the electric buses were only under insignificant value of 1.5 - 2 %. Figure 5 details the main values of used fuel, engine types and shows it has not changed significantly the last decade.

The same survey results show (Figure 6) data about potential intention of what type of bus will be purchased in the near future by operators or authorities.

Today, the electric buses represent less than 2% of the surveyed fleet. Happily, more than 34% of the respondents want to change towards more electric solutions, mainly hybrids and fully electric with batteries. The 'green vehicle' solution are mostly preferred, significant patterns are also evident for more CNG (23%), biodiesel and biogas (12%). The total proportion of other fuels (hydrogen, bioethanol, etc.) is less than 9%.

Energy optimization and environmental friendliness does not characterize today's inventory of bus types, although the automotive industry offers more and more technical solutions. The following areas have a special priority [6]:

- Energy recovery by regenerative breaking, heat recovery from exhaust system and energy or heat recovery from heating or cooling of the hybrid batteries
- Weight reduction using lighter more durable composite materials and redeveloping the structure of the vehicles using these new technologies
- Optimizing the traction by eliminating friction energy losses, adding more start-stop functions and using more efficient drive chains.

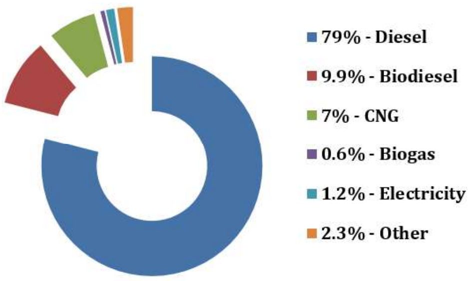

Figure 5. Bus engines in Europe – 2016 (source: EBSF 2)

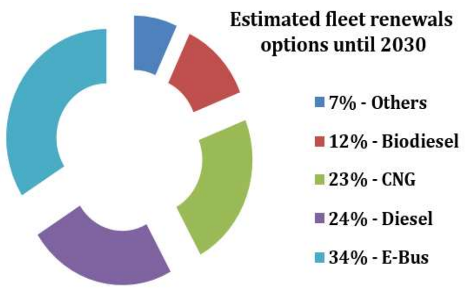

Figure 6. Respondents distribution according to future plans to change propulsion system ratio (source: EBSF 2)

3. THE ELECTRIC BUS (E-BUS)

A. Electric and Hybrid over Diesel

Fully electric powered buses are widespread and operate in large daily traffic areas in several large cities. Their polluting gas emissions are zero and the noise emission is lower than diesel buses. However, greenhouse gas emissions continue to depend largely on the production method of the electricity used, and the manufacturing process of the batteries.

In the long term, for the achievement of the EU's 2050 targets [3], electric buses show the best prospects, which might be supplemented by hydrogen fuel cell buses on longer routes. This is due to the high energy efficiency of the entire electric drive, which together with the potential of using renewable energy production methods can result in low greenhouse gas emissions and energy consumptions altogether.

B. European Union's recommendations

The basic legislation regarding the four major transport sectors (air, rail, road and water) is the – "White Paper on Transport/Roadmap to a Single European Transport Area" (COM 2011/0144). The European Commission has issued a mandate "M-533" calling on CEN/CENELEC (the EU Commission for Standardization) to propose a standard for the classification of electric vehicles by end of 2019 [3].

"Key Performance Indicator" – KPI's are utilized for a multitude of features that make the different characteristics comparable. According to the UITP recommendation, within the framework of the ZeEUS project, number of 187 different performance attributes have been selected and mapped.

After the analysis of these attributes, researchers from ZeEUS have reduced the number of KPI's indicators through different categories, so the comparison will be easier and transparent [7].

C. Infrastructure of chargers

When switching to electric buses, conflicts between parallel or competing technical solutions must be avoided. From an efficiency point of view, it should be possible to connect as many vehicles as possible to the same charging apparatus or charging station. Existing tram or trolleybus network can be an excellent basis for the electric charging system [6].

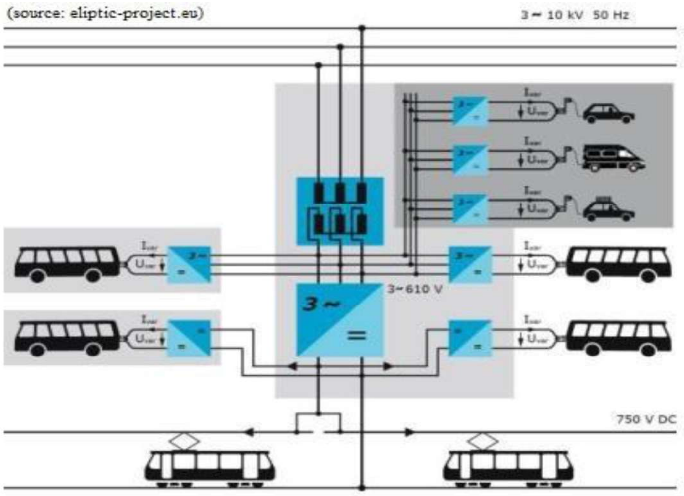

Figure 7. Power stations as optimal charger points

Figure 7 explains how a classic electric power supply network (the overhead line system work in parallel), can be easily converted to charging units of the electric bus fleet and other electric cars.

The possibility to link the usage of a bus battery on the route with the cell tests is given by comparing the number of routes performed or summing up the energy throughput of cycles, in order to divide it into a number of to equivalent full cycles. In Figure 8 the C-rate is set as voltage and current limits during the charging procedure, defining the timing. For the recharge process the available time of charging decide the power needs, number of recharging cycles will depend also of battery capacity to store the energy. The end of life criteria is the value of remaining capacity (less than 80% of initial).

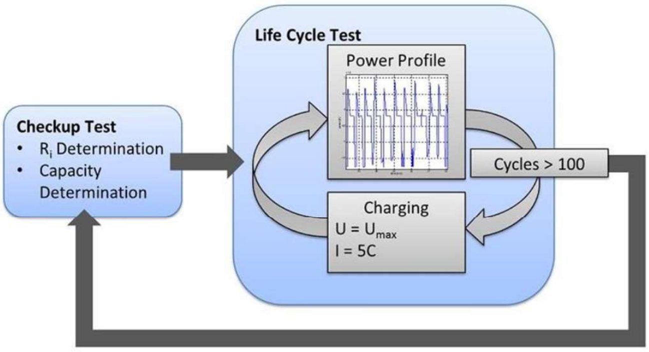

Figure 8. Battery recharging process (Life Cycle Test) (source: ZeEUS)

D. Survey for energy requirement

The capacity of the 600 V batteries and the charging cycle of the electric bus can be determined [4] by taking into account the available charging time and the amount of charging power required.

In order to select an electric vehicle, it is necessary to specify exactly what the customer desires. It must be decided whether environmental issues and other people-centered considerations are solid enough and acceptable for investing in a high-priced electric bus.

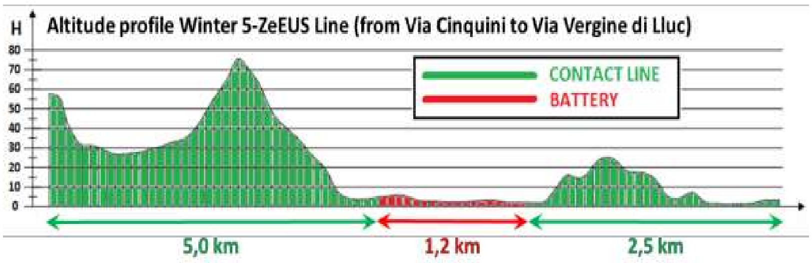

Figure 9. Elevation on Route 5 - Winter (source: ZeEUS)

Figure 9 and Figure 10 shows a bus route, namely Line 5 of the ZeEUS partner, Cagliari in Italy. Three main sections can be distinguished, two green areas (2.5 and 4.0 km) on a hilly district and a red section on a flat-lane. On the green sides overhead contact lines are needed for trolleybus operation. On the red area where city authorities do not allow overhead lines, it is possible and mandatory to run on battery mode.

Knowing the terrain condition makes it possible to determine the vehicles configuration, such as energy storage and energy sources.

Charging can be done in four separate ways. 4 modes of charge are used:

• battery cables;

• pantograph;

• armed connector;

• inductive charge.

Figure 10. Cagliari – Route 5 – Winter on map (source: ZeEUS)

The energy structure of vehicles can be analyzed with a SANKEY diagram. Figure 11 and Figure 12 show the SANKEY diagram for diesel and electric buses. The reduction of losses is one of the main priorities for increasing the efficiency of used energy, but the reversible energies are also important elements of operation [8], [9].

The thickness of the arrows indicates the ratio of the energy. The green arrow means the energy recycling of the internal combustion engine: heat recovery and reduced heat loss, proportionally greater drive force.

In order to optimize the efficiency of electric-powered vehicles, it is of utmost importance to recycle the recovered energy directly and efficiently in the electrical grid (green return arrow thickness is the amount of recovered energy to the system).

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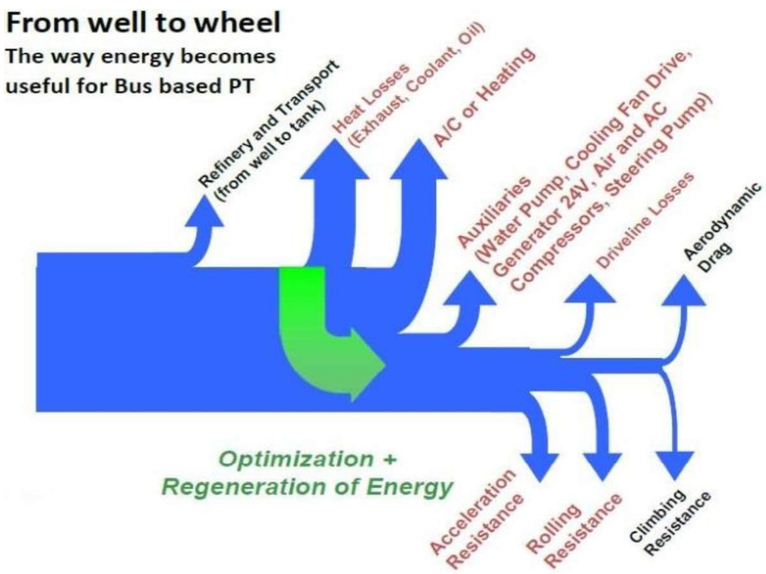

Figure 11. Sankey diagram for diesel buses (source: ELIPTIC)

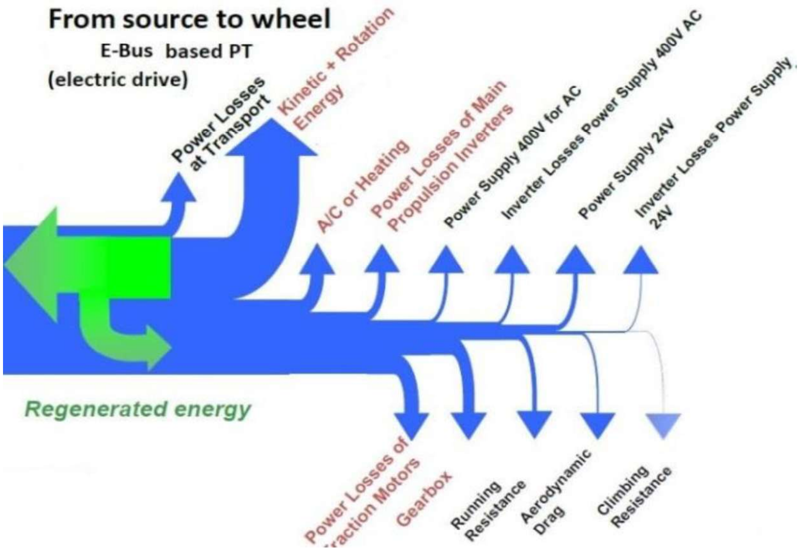

Figure 12. Sankey diagram for Electric buses (source: ELIPTIC)

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4. CHARGERS FOR E-BUSES

A. Galvanic connection

Within the framework of the ZeEUS project [7], for the bus tested at the Bonn SWBV, Fraunhofer recommends the following measuring equipment: voltage converters LEM LV 100/SP47, current converters LEM ITN 600-S, GPS receiver, Compact-Rio data logger. This equipment has the possibility to monitor and register instantaneous power at a given GPS position. Territorial mapping of energy consumption can be used to calculate the route energy gain. Recharging durations are particularly important where charging is used at intermediate stops. At such a bus-stop there is a limited amount of time which can be spent on recharging. Within the test, direct energy consumption (EC_{Bus}) measurements are performed on a bus, calculated by (1), which can be compared to the consumption values measured at the charging stations.

$$\mathbf{EC_{Bus}} = \int_0^t (U_t \; x \; I_t) \qquad [1]$$

Measuring at the same time the charge energy and knowing the initial charging ratio, after running the replenished electric energy to the same point, EC charge energy value can be obtained (as used full to full option). By allocating the charge energy to the energy consumed on the bus (effective), CEC energy efficiency coefficient can be calculated by (2):

$$\mathbf{C_{EC}} = \frac{\boldsymbol{EC_{Bus}}}{\boldsymbol{EC_{charge}}} x100 \qquad [2]$$

B. Equipment, connector standards

The world-wide standard **IEC62196/2011** recommends the connectors.

- For American systems - **CCS 1** (but also accepted for CCS 2) for electric buses in North America
- For European systems - **CCS 2** (Combined Charging System) as a charging interface for Europe's electric bus manufacturers

Synergies between car and bus solutions are possible. Industry standards for chargers and inlets both in the United States and Europe are similars as recommended solutions.

Positioning the charging connector is essential to eliminate unwanted heat loss due to the high charging current. Figure 13 shows recommended charger positions for electric buses for a better space efficiency.

Today with the environmental condition obliging municipalities to think about solutions, the big challenge is how they can reduce the pollution in cities and how can ensure a livable and healthier environment for inhabitants increasing the urban mobility.

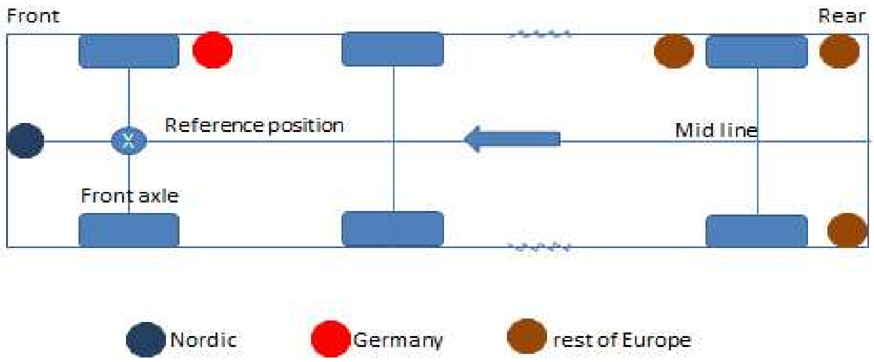

Figure 13. Recommended positions for chargers (source: ELIPTIC)

The 600 V battery and charging cycle of the electric bus can be estimated from Figure 14 and Figure 15 histograms [4], depending on available charging time and amount of charging power required.

There are several methods to calculate and approximate technical parameters of charging equipment. One of them is a graphical approach [4] as a histogram show dependency of the batteries capacity, weight and volume, power needs for bus, charging methods and the available time for that.

In order to select an electric vehicle, it is necessary to specify exactly what the customer can meet. The main issue, environmental and other people-centered considerations are solid enough for the argumentation of choice, is it recommended and acceptable for an electric bus?

First step is to decide the optimum selection on technical side next histograms can help on that.

Using the histograms operators can estimate the amounts of necessities knowing the input data given by needs interpretation and translation in technical values. It depends from routes difficulty and length, passenger flows, trip frequency (fast or slow charging), other parameters, which technical solution can be an optimum for the real application.

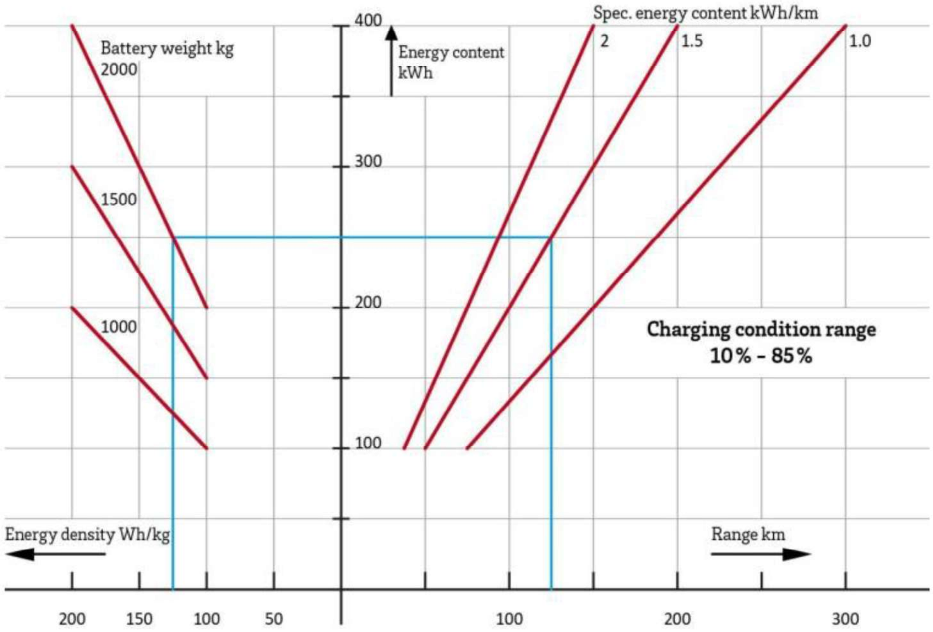

Figure 14. Recommended Rough estimation of the range for an E-Bus (source: Müller-Hellmann)

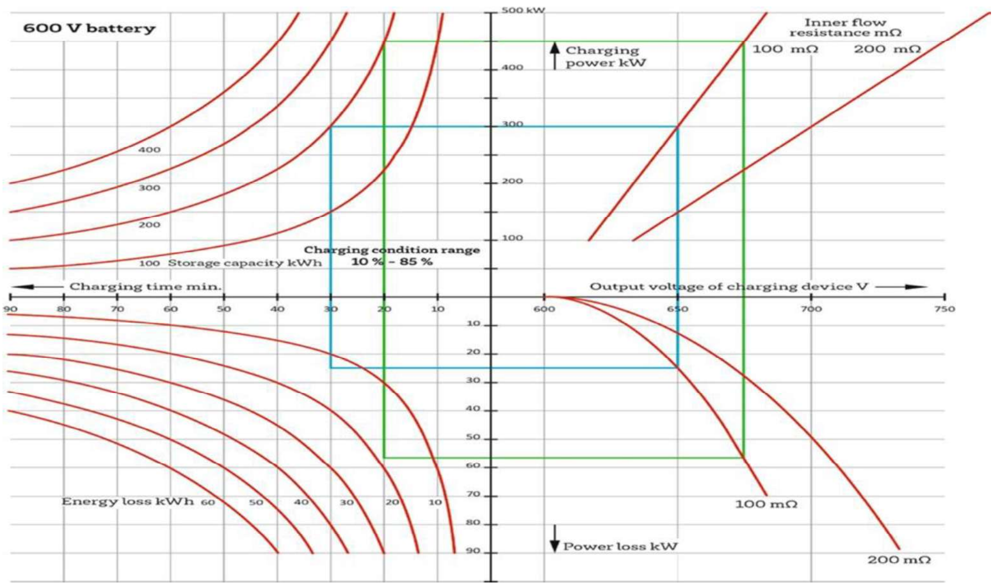

Figure 15. Rough calculation of the charging power needed in dependence of the charging time of a 600 V battery for a fully E-Bus (source: Müller-Hellmann)

5. CASE STUDIES

A. BELGRADE (Serbia): Eko 1 E-Bus Route

The new route EKO 1 [10] links the old and new Belgrade that crosses the crowded City Center using HIGER A6L E-Buses as in Figure 16.

Figure 16. Electric Bus Higer A6L charging in Belgrade (source: Chariot Ltd)

Analysis of the charge indicators by graphical representation of the measurement statistics defines the energy consumption range between 0.85 and 1.23 kWh / km, which varies according to field and operational impacts. The terrain features and outdoor weather (air conditioning or heating) determine the highest energy consumption, but also the traffic factors (crowded downtown, traffic jams, etc.). The volume of passenger flow has a strong influence itself as an important factor on energy usage. The daily average consumption is noted in Table 2 - the HIGER type Chinese buses have been running on the Route EKO 1 since the fall of 2016 (today similar buses runs also in other places: Sofia/Bulgaria, Graz/Austria and Tel Aviv/Israel).

Table 2. Daily statistics in Belgrade: average consumptions

E-bus No	(30°C) AC-on	(24°C) AC-off	(20°C) AC-off
2101	1.26	0	1.04
2102	1.14	1.01	0.89
2103	1.13	1.06	0.97
2104	1.14	0.97	0
2105	0.97	0.88	1.00
Average <kWh >	**1.128**	**0.98**	**0.975**

The energy consumptions were recorded in second part of September 2016. Important to observe, that consumption values show the AC – on the bus use more (10-12% up) electric energy, comfort condition will influence the total consumption.

B. ORADEA (Romania): Measurements and test results

In Romania the Chinese-made BYD electric bus was presented to the press and trialed by specialists from the public transport company OTL SA (Oradea Transport Local SA - www.otl.ro). Same, the Czech - made SOR E-bus was tested for a period of two weeks on different routes, namely Route 14, an urban cross city and another cross-border route to Biharkeresztes in Hungary, with a longer range of more than 80 km per one trip traveled distance.

Figure 17. The Czech Electric Bus model SOR in Bus Depot of OTL (source: OTL SA)

The 2015's November test runs and the measurements were designed to prepare for the acquisition of one or more electric buses. The measured values with FLUKE 345 were analyzed in a statistic Table 3, energy efficiency and power factors provided satisfactory results.

The values are very similar to the Belgrade example, around 1 kWh/km, with the average energy consumption 0.8728 kWh/km with the mention of operation without AC or heating. As a smaller capacity bus (10 m instead of 12 m) shows very good results for energy efficiency. Knowing the comparison of different OTL's networks (buses & trams), energy consumption (in TOE - Tone of Oil Equivalent) and the number of passengers carried, the tram systems energy-efficiency is very obvious [11]. The differences are essential; approximately one-third of energy consumption of the diesel engine-based bus system. Per ten thousand of passenger in 2014 the tram system used 0.34 TOE of electricity, while the fuel combustion bus system is 0.99 TOE, in 2015 energy consumption is similar 0.37 TOE to 1.00 TOE (a light increase by changed rules on heating and HVAC time extension). In 2016 the values are better thank to energy efficiency optimizations (fuel savings, brake energy recovering on trams).

Table 3. Daily statistics in Oradea: consumption data (source: OTL)

Date	Distance km/day	Charging [h]	Average kWh/km
1-Nov	80	4:10	1.0625
2-Nov	139	8:30	0.8705
3-Nov	123	7:20	0.8618
4-Nov	47	3:30	0.6835
5-Nov	82	2:10	0.9014
6-Nov	123	9:00	0.9024
7-Nov	47	4:20	0.7660
8-Nov	150	3:20	0.9467
9-Nov	113	3:00	1.0177
10-Nov	59	4:40	0.8644
11-Nov	128	3:50	0.8516
12-Nov	144	8:30	0.7639
13-Nov	93	6:10	0.9032
14-Nov	90	5:90	0.8922
15-Nov	79	6:00	0.7835

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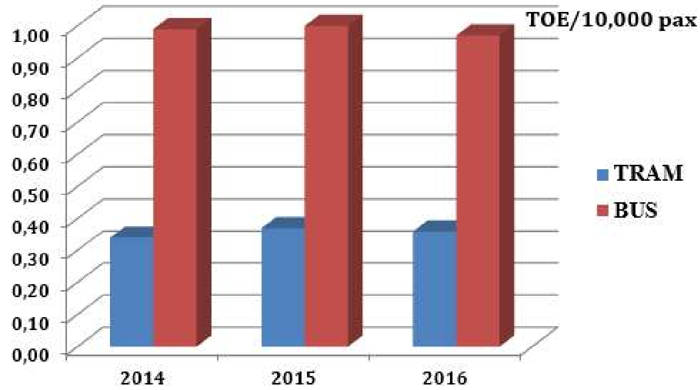

Figure 18. Average energy consumption per 10,000 pax during 3 years (source: OTL)

C. *CLUJ (Romania): First E-Bus fleet in operation in Romania*

In middle of June 2018 arrived in city of Cluj-Napoca the first 11 E-Buses from the future 30 pieces fleet of CTP SA's electric buses, purchased by Swiss Government loan (6,456,938 CHF) and Municipality local contribution (1,139,460 CHF) with condition of 5 years full warranty. The electric bus "Solaris EV Urbino 12" is fully equipped: low floor and 3 double slide doors, disability person access, AC & heating, ABS, EBS, ESR and full ITS equipment (GPS, APC, AVL, AFC, Wi-Fi, CCTV, passenger info displays). Maximum capacity is 27 seats and 51 standing passenger (total 78 pax), electric engine of 160 kW and batteries given an autonomy of 105 km in urban condition.

The electric buses will operate in the CTP's public transport network on the next routes:

- Route 27: Piața Gării – Cartierul Grigorescu (length 9,7 km)
- Route 28: Piața Mihai Viteazu – Cartierul Grigorescu (length 8,5 km)
- Route 30: Aurel Vlaicu – Cartierul Grigorescu (length 17,2 km)
- Route 32: Brâncuși – Piața Mihai Viteazu (length 6,6 km)

The buses autonomy of 105 km likely ensure the possibility to work one duty of 6-8 trips on mentioned routes. The charger disposals help to have the necessary availability of recharged energy.

The charger stations are disposed mixed 5 slow chargers (5-6 hours during the night) and 1 fast charger (5-10 minutes), two locations, Bus Depot "Grigorescu" and "Mărăști-IRA", completed by one-one fast and slow charger in the Bus Depot "Gheorghieni".

The tests were made by Technical Department of CTP SA Cluj-Napoca [13], using 7 of buses from the fleet of 11 electric buses during 5 days operating in public transport network in the real condition, using the AC, with passenger (from 02nd June till 08th July 2018). The measurement was made using the inbuilt energy counter of bus charger unit for recharged electric energy and the braking recovering energy counter built-in the bus. The registered values are in Table 4:

Figure 19. Fleet of electric buses of CTP SA – the "Solaris EV Urbino 12"

Figure 20. Charger stations: by cable (left) and by pantograf (right)

Table 4. Electric bus average consumptions in Cluj's operation

No	**E-Bus inv.nr**	**Total [km/period]**	**Energy consumptions Total [kWh]**		**Averages consumption [kWh/km]**
			Recharged	**Recovered**	
1	202	2264	2813	935	1.24
2	203	2280	2574	866	1.13
3	205	1845	2389	636	1.29
4	207	3536	4038	1437	1.14
5	208	3494	4186	1630	1.19
6	209	3971	4409	1579	1.11
7	210	3305	4007	1415	1.21
				AVERAGE	**1.188**

Taking into account the price of electric powered bus (E1) 625,500 USD (in the local currency exactly: 2,374,725 RON/E-Bus + VAT) need to mention that the purchase cost include the charger equipment and infrastructure for the 11 buses fleet. The operating, maintenance and energy costs must be calculated for the whole life cycle cost. To this end, it is worth adding ~ 185,000 USD for the battery replacement (A1), type Solaris High Energy (lithium–iron-phosphate – LiFePO4) for 200 kWh. Manufacturers openly admit that besides today's technologies there is a guarantee only of five years for today's electric vehicles batteries. A same size (12 m length) almost similar equipped Euro VI bus (D1), made by same bus supplier (Solaris) is available around 320,500 USD (Table I). Annual energy consumption (for fuel or electric) values are included in TABLE V, which help analyze difference between the Diesel and E-Bus. As presumption we assume the maintenance cost will approximate that is same value for both buses' life cycles.

Table 5. "Solaris" buses: diesel and electric comparison

Bus types "SOLARIS" / **Averages**	**E-bus EV Urbino 12**	**Euro VI / Diesel Urbino 12**
L- yearly average operation milage (km)	80,000	
E_u- average energy consumption (kWh/km)	1.1855	-
ENERGY consumption - total (kWh/year)	94,840	-
Ce_u - electric energy unit price (USD/kWh)	0.11	-
F_u- average fuel cons-umption (liter/100 km)	-	45
FUEL consumption - total (liter/year)	-	36,000
Cf_u- average fuel unit price (USD/liter)	-	1.51
C_{Atc} - Annual Energy Total Cost (USD/year)	10,433	54,360
CE_{diff} – annual energy cost difference (USD/year)	**43,927**	

Equation (3) calculates the annual cost differences (**CE_{diff}**) between the two buses:

$$\mathbf{CE}_{\text{diff}} = [\left(\frac{L \times F_u}{100}\right) \times Cf_u] - (L \times E_u \times Ce_u) \quad [3]$$

Applying average values contained in Table V the yearly difference is in the amount of 43,927 USD.

$$\mathbf{T}_{inv} = \frac{(E1+A1)-D1}{CE_{diff}} \quad [4]$$

The Return of Investment (**ROI**) time (**T_{inv}**) is calculated by (4) taking into account the price difference between the E-Bus and diesel (E-Bus/625,500 USD +

Battery/185,000 USD = 810,500 USD and for Diesel Bus/320,500 USD) total difference 490,000 USD divided by 43,927 USD per year. The calculated amortization period is: **T_{inv} = 11.15 years**. As result and first conclusion, when the electric bus has an average life expectancy not more than 10 years as such it is not a desired investment for the only one economic reason!

6. CONCLUSION

"Everyone was laughing at BYD for making a toy…" recalled Isbrand HO, the Chinese Shenzhen-based company's managing director in Europe. "And look now. Everyone has one…" [14].

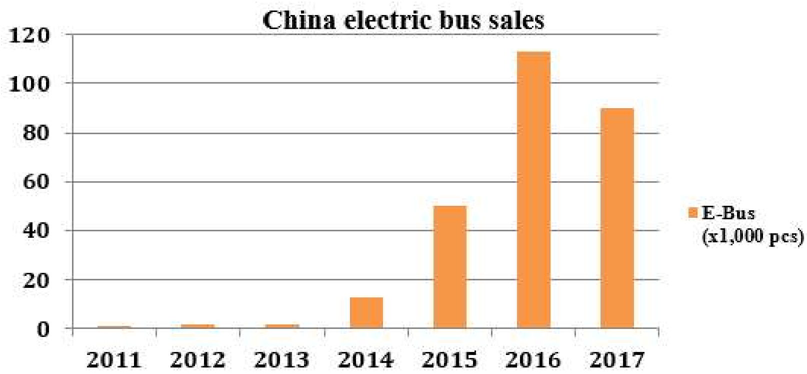

Figure 21. China electric bus sales last years (source: Bloomberg New Energy Finance)

Suddenly, buses with battery-powered motors are a serious matter with the potential to revolutionize city transport and add to the forces reshaping the energy industry. With China leading the way, making the traditional smog-belching diesel behemoth run on electricity is starting to eat away at fossil fuel demand. The numbers are staggering. China had about 99% of the 385,000 E-buses on the roads worldwide in 2017. For every 1,000 battery-powered buses on the road, about 500 barrels a day of diesel fuel will be displaced from the market according to Bloomberg New Energy Finance – BNEF calculations [14].

Although this paper is drafted as a technical study, it had to be completed with economic content in order to better understand the usage of E-Buses. There is a lot of money in the field of environmental protection, and governments more or less support the issues. An IMF (International Monetary Fund) study states that support schemes have a serious fiscal, welfare and environmental impact. According to calculations and simulations, with the withdrawal of major post-tax subsidies, globally the governments' revenues would have risen by 3,6% of GDP in 2015. Furthermore, and this is very important too, the mortality rates caused by air pollution would have been halved [15]. This decision is not made by engineers, but by politicians. Social backlashes, inflation and unemployment must be taken into account when shifting to eco-friendly industries. People need to be trained for new job markets.

The European Commission looks into a cost-effective way to make the European economy more environmentally friendly and energy-efficient. The – "Roadmap for a Low Carbon Economy", CE112 (2011), suggests that by 2050 the EU should reduce emissions by at least 80% below 1990 levels, with milestones being 40% by 2030 and 60% by 2040 [16].

Debate is open and engineers can argue whether the electric bus is environmentally friendly or not! This study had to take into account the whole process of manufacturing such a vehicle, which includes using rare earth materials. End of life costs are also higher for electric buses, given the higher hazardous material content. This is the main difference between Life Cycle Cost Management and Total Cost of Ownership, given that the owner should not only take on the costs and profits of the operation, but the vehicle's (or other products) owners are also responsible for the end operation, after-removal treatment costs.

As in Figure 21 in 2017 China E-bus sales has a small decrease. Many explanations we can have: other competitors, other suppliers conquered part of market with similar rate of price/quality. Maybe the operators/authorities are not full convinced that E-Bus will be the optimal solution? City governments all over the world are being taken to task over poor urban air quality. This pressure isn't going away, and electric bus sales must positioned to benefit.

Without energy, our society does not work. Our viable future lies in a much more balanced energy mix, and this will continue to play a role in fossil fuels in the long term, just as in the case of the rapidly growing proportion of renewable energy sources or the otherwise zero-carbon nuclear power.

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