Relevance of using electrobuses as public transport in the city of Krasnoyarsk

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Abstract. The article presents the results of the comparative assessment of using autonomous electric transport instead of buses with diesel internal combustion engines that are currently in operation; they are of the same class in terms of environmental and economic characteristics. It is the case study of one of the routes of Krasnoyarsk based on the official data for 2018.

1. Introduction
Krasnoyarsk Krai, as well as the city of Krasnoyarsk, is the largest transport and industrial centre of Siberia; it is one of the most promising regions of the country’s industrial development. On the one hand, industrial enterprises contribute to the economic stability, on the other hand, they cause environmental problems – 29% of the total amount of air pollution (Figure 1).

Figure 1. Main contributors to the atmospheric air pollution in Krasnoyarsk according to the data for 2018

- industrial enterprises, b – motor transport, c – heat power plants, d – secondary pollution of the street network, e – unrecorded sources, f – human and natural sources, g – autonomous heating supplies and stove heating.
Besides, in the air pollution of the city of Krasnoyarsk with the population of more than 1 million people a significant part is played by motor transport which accounts for 27% of the total amount. Other main “contributors” are heat power plants with the indicator of 24% [1].

Unlike the other main sources specificity of line sources of pollution that include motor transport manifests itself in the ground-level air pollution, distribution to unlimited territories often close to residential areas which is the most dangerous factor for humans. The composition of vehicle exhaust gases depends on the type of engine, mode of operation, technical condition of the motor vehicle (MV) and the quality of the fuel used. More than 200 components that make up the exhaust fumes (EF) of vehicles are studied nowadays. The most common atmospheric pollutants related to exhaust fumes of vehicles include: carbon monoxide; nitrogen oxides; benzo(a)pyrene; volatile hydrocarbons, etc. [2].

2. Materials and methods
Alternative types of fuel, such as natural gas, biofuel, hydrogen, electricity, etc., are used to reduce the toxicity of EF of vehicles. Currently, they cannot solve all the problems, not only because of the modern technologies imperfection, but because of the number of specific drawbacks, for example, short expiration date, low technological potential, high cost of production and storage, explosion and fire hazards, and, above all, low efficiency of conversion of potential fuel energy into kinetic in the vehicle ICE [3].

Usage of autonomous electric transport is the most attractive method of reducing environmental pollution. The obvious advantages of autonomous electric transport include:

– environmental friendliness of the vehicle itself – the minimal amount of toxic emissions into the atmosphere and reduced noise level;
– ability to solve the problem of the “energy peak” in the city power grid by recharging accumulator batteries at night;
– reduced operating costs at the expense of relatively low cost of energy carrier production, high efficiency of the onboard energy converter and simplicity of its design.

At the same time, there are also certain disadvantages, the main ones of them are:

– lack of necessary infrastructure which requires significant investments;
– relatively high cost of the MV conditioned by the high price of batteries, however, the price is significantly decreasing with the development of technology;
– limited battery service life and issues of their disposal [4].

China is the world leader in terms of the quantity of electric vehicles (Figure 2). In China, electric transport is put into use by tens of thousands of vehicles annually. Currently, both in Europe and in Russia, there is a good motivation for driving an electric vehicle in the city: free parking, driving along special lanes, free charging in shopping centers, expensive hydrocarbon fuel, tax credits, etc. – these factors make buying an electric vehicle the event that is not only environmentally responsible, but also profitable [5, 6].

Figure 2. Electrobuses and Charge Stations in Shanwei (China).

There are a number of programs promoting the development of electric transport in Russia:
– the instruction of the President of the Russian Federation V.V. Putin of January 18, 2016 № Pr-66: “b) priorities for the scientific and technological development of the Russian automobile manufacturing and
for the development of advanced samples of automotive vehicles, taking into account global trends of the transition to electric vehicles mass production; 
– the regional program *Reducing Negative Impact of Enterprises on the Environment in Krasnoyarsk Krai in 2014-2020*: Reducing emissions of toxic (polluting) substances into the air that are produced by moving sources (motor transport of Krasnoyarsk) by 25% at the expense of implementation of environmental protection measures in Krasnoyarsk aimed at developing public transport system, urban road and street infrastructure and switching public transport to environmentally clean types of fuel; 
– the order of the Ministry of Transport of Krasnoyarsk Krai of January 9, 2018 N 6/2-N *On Approval of the Transport Strategy of Krasnoyarsk Krai up to 2030*.

Thus, in order to reduce the negative environmental impact on the environment in Krasnoyarsk, putting public autonomous electric transport into use can become an alternative to the old bus fleet. To determine the efficiency of the offer, the quantitative assessment of EF emissions from the vehicle stock following Route 83 was carried out. This route is served by a self-employed entrepreneur. The length of the route is 22 km, the bus fleet consists of 20 LiAZ-5292 buses (diesel ICE capacity is 144 kW, belongs to the 5th category of vehicles), 6 of the busses are on stand-by. The public transport enterprise has a 7-day working week (16-hour workday). The route passes through the center and main urban roads (Figure 3).

![Figure 3. Length of Bus Route 83.](image)

There were three stages of calculations. At the first stage, the quantitative assessment of EF from the vehicle stock in the territory of the motor transport company (MTC) was performed with the reference to the seasonal fluctuations of work. The calculation was carried out according to the methodology of the inventory of pollutants emissions into the atmosphere for MTC [7] with the help of ERA software (version 2.5.373). The final values are presented in Table 1.

| Pollutant Name                  | Emission, g/s | Emission, t/year |
|---------------------------------|--------------|------------------|
| Carbon monoxide                 | 1.882        | 0.408            |
| Kerosene                        | 0.2563       | 0.0477           |
| Nitrogen dioxide                | 0.5755       | 0.08778          |
| Nitrogen (II) dioxide           | 0.0935       | 0.014266         |
| Carbon                          | 0.04801      | 0.004865         |
| Sulfur dioxide                  | 0.0959       | 0.013295         |
| **Total:**                      | **2.95121**  | **0.575906**     |

At the second stage, the calculation was made on the section from the MTC to the starting point of the route. The calculation of vehicle emissions was made by *Magistral-Gorod* software (version 2.3.3.41) according to the methodology of determining vehicle emissions which allows carrying out summary calculations of urban air pollution; the methodology was approved by the order of the State Environment Protection Committee of Russia N 66 of February 16, 1999 [8]. The final values are presented in Table 2.
Table 2. Calculation of Gross and Maximum Single Emissions from Buses on the Route Section from the MTC to the Starting Point

| Section length, m | 9000 |
|-------------------|------|
| Time, s           | 1200 |

Traffic Stream Data

| Vehicle Type, units/hour (Gk) | Right Direction | Left Direction | Speed, km/h | Coefficient of the speed impact (rv) |
|-------------------------------|-----------------|----------------|-------------|---------------------------------------|
| Diesel Busses                | 0               | 20             | 40          | 0.75                                  |

Table of Emissions on the Section

| Pollutant Name                        | Emission, t/year | Emission, g/s |
|---------------------------------------|------------------|---------------|
| Carbon monoxide:                      | 0.1445           | 0.33          |
| Total emissions of nitrogen oxides:   | 0.1752           | 0.4           |
| Nitrogen monoxide:                    | 0.022776         | 0.052         |
| Nitrogen dioxide:                     | 0.14016          | 0.32          |
| Hydrocarbons, kerosene:               | 0.1067625        | 0.24375       |
| Carbon soot:                          | 0.0049275        | 0.01125       |
| Sulfur dioxide:                       | 0.02381625       | 0.054375      |
| Formaldehyde:                         | 0.00509175       | 0.011625      |
| Benzo(a)pyrene:                       | 0.00000001       | 0.00000025    |
| Total:                                | 0.6232341        | 1.423         |

The final stage of the calculation was performed directly on the bus route (from the starting to the terminal point). As well as in the second case the calculation was carried out by Magistral-Gorod software (version 2.3.3.41) according to the corresponding methodology [8]. The results are presented in Table 3.

According to the data for 2017, Central Heating and Power Plants of SGC that generate electricity for the needs of population and industrial enterprises of Krasnoyarsk except for the Krasnoyarsk Aluminum Plant emitted 21 200 tons of pollutants into the atmosphere; during this period they generated about 3.5 billion kW*h of electricity [9]. Thus, it turns out that the generation of 1 kW*h of electricity comprises 0.006 kg of pollutants. A modern LiAZ-6274 electrobus of the 2nd generation with the capacity of 85 people at the conventional speed of 23 km/h consumes 0.25 kW*h/km of electricity [10, 11].

Table 3. Calculation of Gross and Maximum Single Emissions from Buses on the Route (from the Starting to the Terminal Point)

| Section length, m | 22000 |
|-------------------|------|
| Time, s           | 57600 |

Traffic Stream Data

| Vehicle Type, units/hour (Gk) | Right Direction | Left Direction | Speed, km/h | Coefficient of the speed impact (rv) |
|-------------------------------|-----------------|----------------|-------------|---------------------------------------|
| Diesel Busses                | 7               | 7              | 35          | 0.88                                  |

Table of Emissions on the Section

| Pollutant Name                        | Emission, t/year | Emission, g/s |
|---------------------------------------|------------------|---------------|
| Carbon monoxide:                      | 13.92928763      | 0.66254222    |
| Total emissions of nitrogen oxides:   | 14.38975991      | 0.68444444    |
| Nitrogen monoxide:                    | 1.870668847      | 0.08897778    |
| Nitrogen dioxide:                     | 11.51180809      | 0.54755556    |
| Hydrocarbons, kerosene:               | 10.28867845      | 0.48937778    |
| Carbon soot:                          | 0.47486215       | 0.02258667    |
| Sulfur dioxide:                       | 2.295166743      | 0.10916889    |
| Formaldehyde:                         | 0.490690909      | 0.02333956    |
| Benzo(a)pyrene:                       | 0.000010512      | 0.0000005     |
| Total:                                | 55.25093324      | 2.62799334    |
3. Results and discussion
In case when 14 electrobuses (6 are on stand-by) are used on a daily basis all year round Route 83 consumes about 365000 kW*h of electricity. Thus, for generating the additional electricity required for Route 83, the CHP plants of SGC will emit about 2.19 tons of pollutants more into the atmosphere, which is almost 27 times less than the gross emission of toxic elements from the exhaust gases of Route 83 buses.

Table 4 presents comparative economic indicators calculated via use of the following data: electricity cost for industrial enterprises is 1.9 rubles per 1 kW*h; the cost of diesel fuel liter is 40 rubles. The cost of consumable materials for maintenance operation (MOT) of ICE of a LiAZ-5292 bus (engine oil (volume of 23 l) is 4988 rubles, oil filter – 1650 rubles, air filter – 1232 rubles, fuel filter – 554 rubles); MOT interval – 10000 km) [12, 13].

| Seq No. | Indicator | ICE Bus (LiAZ-5292) | Electrobus (LiAZ-6274) |
|---------|-----------|---------------------|------------------------|
| 1       | Capacity, people | 85                  | 85                     |
| 2       | Price of the bus, rubles | 9 600 000          | 25 000 000             |
| 3       | Price of the engine/battery, rubles | 707 000            | 5 000 000              |
| 4       | Price of consumable materials required for MOT of ICE, rubles/km | 0.84                | -                      |
| 5       | Mileage of engine/battery, km | 1 000 000          | 1 000 000              |
| 6       | Price of diesel fuel/electricity per kilometer, rubles | **12.44**           | **0.475**              |

4. Conclusion
Thus, the study allows drawing the following conclusions. Replacement of traditional vehicle stock of the public transport with autonomous electric transport will make a significant contribution to improving the environmental situation in the city of Krasnoyarsk. It should be noted that the current world experience proves the possibility of using electric vehicles as well as their power equipment at low temperatures [14]. The cost of “fuel” for electrobuses is significantly lower (26 times) than that for buses of the same class with diesel ICEs. However, the cost of electrobuses themselves is currently quite high, though with the developing technology it will decrease, which as a whole will give the prerequisites to reduce the price cost of transportation. It is understood that the operation of electrobuses requires significant financial investments in infrastructure projects which is practically impossible without a private-public partnership.

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