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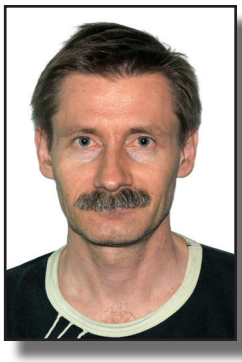
Environmental Impact of ICE Vehicles and Battery Electric Vehicles: Comparison and Assessment of Impact Factors



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ABSTRACT

In 2017 the number of motor vehicles, being in operation in the world, exceeded 1,5 billion units. Motorization has caused serious problems for safety of the environment, life and health of humans.

This article discusses various factors of impact of motorisation and automobilisation on the environment.

Until recently, harmful emissions from vehicles have been considered as the main significant factor in environmental pollution. Due to implementation of the technical policy for implementation of EURO environmental standards, the «center of gravity» in the problems of improving the environmental safety of vehicles is moving towards minimising the heat entering the environment after being emitted by motor vehicles engines. The greatest practical interest is associated with the recovery of energy spent on traction, as the recovery increases the energy efficiency of road transport while reducing the negative impact on the environment.

A comparative assessment of cars with internal combustion engines and battery electric vehicles showed that the overall negative impact of comparable vehicles on the environment currently differs slightly.

It is necessary to continue research and development in the field of energy recovery problems.

Keywords: *hybrid cars, electric cars, battery electric cars, energy recovery, ecology, car efficiency, recycling, efficiency, environment, lithium-ion batteries.*

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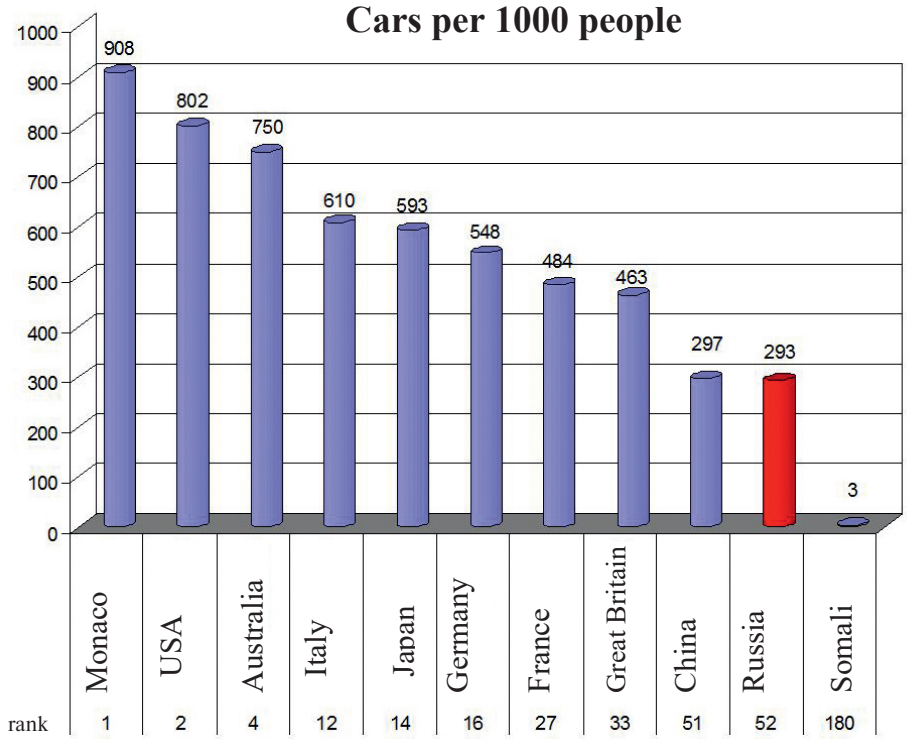


Pic. 1. The number of cars per 1000 people in selected countries [https://knoema.ru/atlas/topics].

Introduction. During recent years, there has been a dramatic jump in the number of motor vehicles on Earth. The number of cars exceeded 1 billion units back in 2010. Over the next 4 years, the growth of cars amounted to another 330 million units. Now in the world there are about 1,5 billion units of vehicles, and the same number of motor vehicles.

If we consider the number of cars per 1000 inhabitants in countries most susceptible to motorization (Monaco, USA, Australia), then they have 1 car per almost every resident (Pic. 1). In Russia, occupying 52nd place in the world by the number of cars per 1000 inhabitants, there is a car on average per 3,5 people*.

Motorization has become a significant phenomenon affecting various aspects of global sustainable development: social, economic, environmental ones etc. It has both positive and negative consequences. At the same time, technological changes and creation of innovative means of road transport, including electric vehicles, vehicles with hybrid engines, having important positive qualities, require, as the experience of their operation is being understood, a comprehensive and balanced reassessment of the environmental impacts, especially compared to traditional cars with internal combustion engines.

The *objectives* of the study are to assess the overall positive and negative consequences of global motorization, to suggest a comparative analysis of the environmental impact factors of cars with ICEs and electric vehicles, as well as to identify engineering solutions that help to minimize the negative environmental impacts of cars in terms of energy efficiency and environmental protection.

The study used physical and mathematical *methods*, statistical analysis tools, scientific tools of engineering sciences, in particular, of electrical engineering, comparative analysis and study of the existing experience.

1. The positive consequences of motorization

A personal car in the modern world is most attractive to humans as a means of everyday travel, firstly, for its technical capabilities, and secondly, because of the ability to satisfy the individual needs of each

* http://stat.gibdd.ru/

Table 1

The content of environmentally hazardous materials and liquids in a passenger car (the characteristics of lithium batteries are highlighted in bold)

Material	Weight (kg)	Share by weight in total mass (%)
Ferrous metals	626	55,9
Aluminum Al	52	4,6
Chrome Cr	1	0,07
Copper Cu	10	0,9
Zinc Zn	0,2	0,02
Lead Pb	12	1
Lithium Li	**300–700**	**20–50**
Oils	10	0,9
Petroleum	5	0,4
Ethylene glycol	3	0,3
Rubber	66	5,9
Glass	32	2,9
Plastics and other waste	303,6	27,1
Total	1120,8	100

owner to the greatest extent. In warm climate, the motorcycle is an alternative to the car. As the result, cars and motorcycles have become the most sought-after vehicles in the world. Motorization continues, which allows us to consider it a development trend of the anthroposphere for the foreseeable future.

Mass motorization has resulted in significant positive social consequences, such as:

• increase in mobility mobility, that is, the ability to travel and transport goods quickly, comfortably and efficiently;

• accessibility and convenience of travel for passengers and cargo transportation;

• reduction of time spent on passenger trips and acceleration of cargo transportation;

• providing employment for a significant part of the population.

The specified factors contribute to economic growth, specialization and cooperation of labour, stimulation of scientific and technological progress, and development of industrial technologies, which in turn ensures expansion of the tax base [1].

But, at the same time, motorization has significant negative consequences.

2. The negative consequences of motorization

One of the most negative consequences of motorization is associated with road traffic accidents (RTA). At the international level, data on road traffic accidents and their negative consequences for human life and health are compiled by the World Health Organization (*WHO*), that publishes reports on road safety in the world with a frequency of 3–5 years (*Global Status Report on Road Safety*), as well as the World Bank, that publishes *Mortality reports caused by road traffic injury (per 100,000 people)*. According to the WHO report of 2018, more than 1,35 million people die every year in the world as a result of RTA. According to the level of citizens' risk to be involved in RTA, Russia ranks 72nd (out of 175 compared countries). This risk is estimated by the number of fatalities in RTA per 100 thousand population (Russia – 18 people/100 thousand inhabitants). The leaders of the road safety rating are Western European states (primarily the Scandinavian countries). Absolute leadership belongs to San Marino: zero people died in RTA. High mortality due to RTA correlates with the level of poverty, social underdevelopment, low-quality roads, and the lack of proper medical support [2].

According to the Scientific Center for Road Traffic Safety of the Ministry of Internal Affairs of the Russian Federation, in 2018, 168 thousand road traffic accidents (RTA) occurred within the country's road network, in which 18,2 thousand people died and another 214,9 thousand people received injuries of different severity. Every ninth RTA was fatal.

Unfortunately, data on deaths from carbon monoxide and on the increased number of cancer patients due to the increased level of carcinogens released into the atmosphere by moving vehicles do not fall into the statistics of the victims of motorization.

The automotive industry, which is developing rapidly in the interests of motorization, requires the use of a significant amount of natural resources. Motorization, moving ahead of development of transport infrastructure (primarily road transport network and parking in cities), is a cause of traffic jams. Speed decrease due to traffic congestion requires an increase in the number of vehicles in use to provide transportation. The increase in the

number of cars leads to increased emissions of various nature, including greenhouse gases, heat, tire wear and brake mechanisms products. Currently, the problems of utilization and recycling of waste from motor transport activities and transport mechanical engineering manufacturing have become much more acute.

Reducing the environmental load from motorization is associated with the use of electric vehicles and vehicles equipped with hybrid power plants. Such expectations are based solely on an estimate of reduction of emissions of harmful substances into the atmosphere.

However, pointing to the use of electric traction, people usually forget that the electric energy consumed by electric vehicles is generated somewhere. So, the environment is still under the influence of a harmful effect, which is a pointed one, though the generators of power plants cause less environmental damage per unit of energy produced than internal combustion engines, since power plants work not under transient, but under constant modes, and they themselves have high efficiency.

As a result, if we consider two fundamentally different types of vehicles: an electric car and a car with an internal combustion engine in terms of a combination of factors, it turns out that the negative impact from them is about the same.

On the one hand, ICE cars produce harmful greenhouse gas emissions in the atmosphere, but according to modern EURO 6 standards, these emissions are minimized. On the other hand, electric cars, seemingly environmentally friendly, have Li batteries in their composition, which are very dangerous and harmful to the environment and are difficult to be recycled. If we consider electric cars as mass transport, then in a few years there will be serious problems with disposal of a huge amount of rechargeable Li batteries (Table 1) [2, 4–7].

However, all cars, regardless of design of their engines, generate common problems with disposal of used tires; plastics; oils and other operating fluids, as well as problems caused by the dispersion in the environment of the heat generated during operation.

3. Energy saving: questioning and fundamental approaches to solving

For all vehicles, there are still common problems of energy loss during braking: **each braking is a transfer of energy of vehicle motion into heat.**

Let's perform an approximate calculation of the heat emission coming daily from all cars into the planet's atmosphere due to braking and dissipated in it. For calculations we will use the following initial data:

- the number of cars in operation – 1 billion units (A = 1000000000 units);
- average estimated speed of a car –57 km/h (V = 16 M/s);
- the number of braking operations at full speed per 1 hour of operation – n = 18 units;
- average estimated duration of a car's stay on the move per working day – T = 3 hours;
- average estimated weight of one car (obtained by the authors through expert estimates, taking into account the share of various types of vehicles and of different total mass in the car fleet) – 3 t (M = 3000 kg).

With each braking from the estimated speed until completely stopping, the braking mechanisms of each car will accumulate and then dissipate in the atmosphere the thermal energy Q, equal to the transformed kinetic energy of the car in motion, and determined by the formula known from physics:

$Q = (M \cdot V^2): 2 = 3000 \cdot 16^{2:} 2 = 384\,000$ J = 284 kJ.

Per day, one car will produce thermal emission Q_{day} in the amount of

$Q_{day} = Q \cdot T \cdot n = 284 \cdot 3 \cdot 18 = 15\,336$ kJ.

Total thermal emission $Q_{tot.}$ from all cars per day of their operation will be

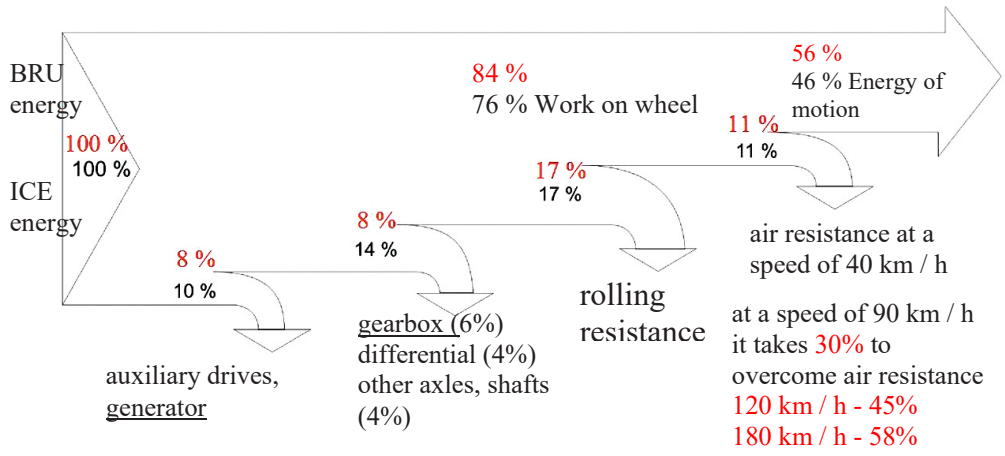
$Q_{tot.} = Q_{day.} \cdot A = 15\,336\,000\,000\,000$ kJ = 15 336 TJ.

For comparison, all nuclear power plants of Russia in 2018, according to Rosatom, generated 204,3 billion kWh of electricity, or about 11 % of all electricity generated in the country*. Taking, for simplicity of comparison, constant power generation on different days of the year, 204,3 W: 365 = 0,6 billion kW/h of electricity was produced daily at Russian nuclear power plants, or 2160 TJ.

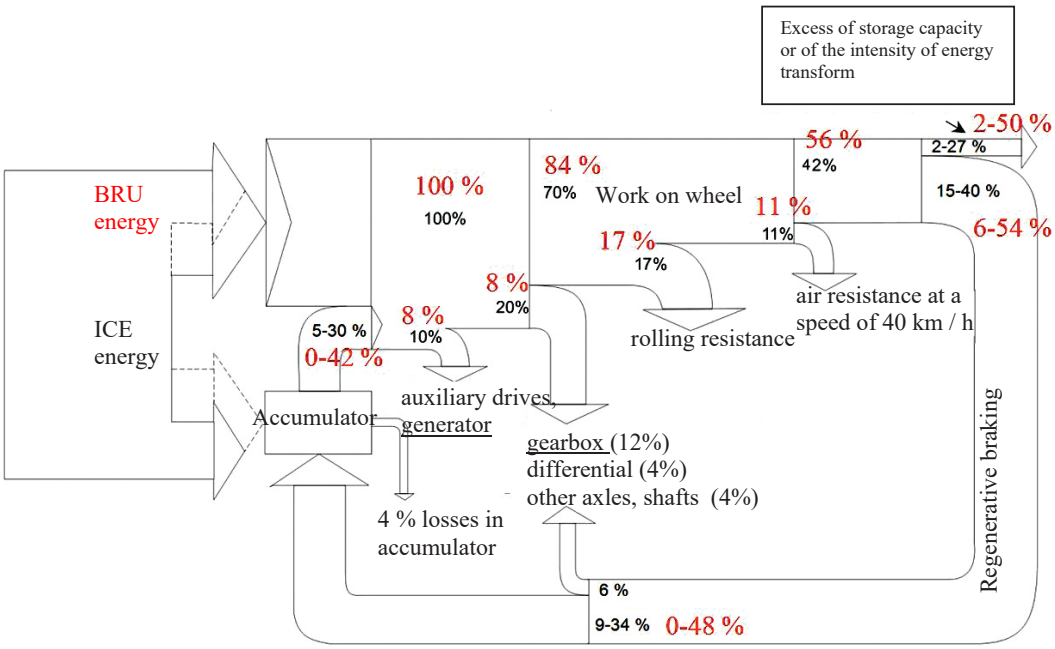
The data presented indicate significant thermal emission entering the atmosphere from vehicles.

Based on the foregoing, in our opinion, the problem of beneficial use of kinetic energy, which is lost with every braking, comes to the

* Rosatom State Corporation: nuclear technologies, nuclear power, nuclear power plants, nuclear medicine. www.rosatom.ru. Last accessed February 24, 2019.



Pic. 2. The energy balance of a conventional car and an electric car without recovery of energy of motion; units that are absent in an electric car are underlined [8].



Pic. 3. The energy balance of a conventional car and electric vehicle with recovery of energy of motion; units that are absent in an electric car are underlined.

fore today. The fact that 10 years ago people did not pay attention to, due to other serious problems, is now becoming important cause of harmful effects on the environment.

If humanity learns to recover energy of car movement, that is, accumulate it during braking and reuse it during acceleration, then this measure alone will solve many problems, starting from reducing the need for fuel for traction to reducing the greenhouse effect.

In the example shown above energy balance of a car with an internal combustion engine and of an electric vehicle is considered in two versions – without energy recovery (Pic. 2) and with recovery (Pic. 3) [8].

From Pics. 2 and 3 it is seen that with each braking, up to half of energy generated by the engine is lost, and this is the part of the generated energy that can be reused [9–15]. However, do not forget that the percentage estimates of possible recovery are correct only

at speeds up to 40 km/h. With increasing speed, more and more useful energy is irrevocably spent on overcoming air resistance.

Conclusions. Motorization is associated with the need to solve a number of problems it generates. The most significant problem remaining is associated with the reduction of environmental damage caused by operation of cars. Modern models of ICE cars have significantly lower greenhouse gas emissions thanks to the use of innovative technologies in their design and production. Among various factors determining environmental pollution by cars, emission of heat dissipated by the braking mechanisms of vehicles is taking the leading position.

The most promising direction for reducing thermal emission from cars is recovery of kinetic energy, which is converted by brake mechanisms into heat dissipated in the atmosphere.

Known technical solutions come down to either replacing cars with internal combustion engines with electric vehicles, or to using braking energy recovery systems. Within the latter option cars with hybrid power plants are being implemented.

The use of a hybrid power plant (more than one source of energy for driving) in a car together with energy recovery is the most promising development of its design and, if the concept is successfully implemented, will lead to fuel economy, reduction in air emissions, minimization of the greenhouse effect while maintaining and even increasing the autonomy of the run, which is vehicle mileage per one refueling with an energy carrier placed on its board.

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