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Methods and results of forecasting number and structure of motor fleet in the Russian Federation by types of engine and fuel used for calculation of greenhouse gases emission till 2050

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ABSTRACT

It`s proposed a methodological approach for assessing and forecast the level of motorization, structure of the vehicle fleet by engine's type, environmental class and other parameters for predicting gross greenhouse gas emissions by Russian motor fleet for the long term (until 2050). A reliable time dependence of the motorization level index of was obtained what made it possible to find expected time frame for achievement of the maximum of this index. It is justified the possibility for further decline of motorization level due to the refusal of the population to buy cars as a result of technological, social, political changes (innovative scenario) or retains of motorization growth by inertial scenario. Developed scenario of motorization changes were used for calculation of greenhouse gases emission till 2050 with the use of two IPCC methods –level 1 and level 3.

Key words : Engine type, fleet size, forecast, motorization level, greenhouse gases.

1. INTRODUCTION

1.1 Review of literature

The estimated number of vehicle fleets in the State or region can be determined using different approaches. In the absence of reliable information about the dynamics of supplies and removing of vehicles from the car fleet, it is advisable to assess the number (growth dynamics) of car fleet (M1 category) by analyzing the dynamics of the level of motorization (units per 1000 inhabitants) in retrospect by selecting reliable dependencies that describe the change in the level of motorization over time initially in retrospect, which are then used for predictive estimates of the level of motorization for a given perspective.

Many papers use S-curves to describe the level of motorization (see Figure 1), characteristic for describing the saturation of the commodity market, which can be described by various functions – logistic, Gompertz, quasi-logical, power growth, regression, etc.

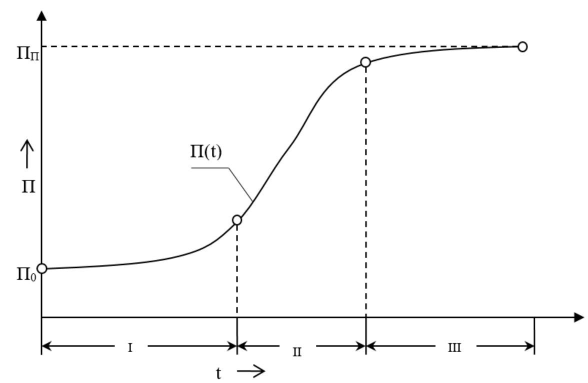

Figure 1: The type of motorization curve and the stages of motorization in different countries [1]

The S-shaped curve shown in Figure 1 is described by an expression of the form:

$$\Pi(t) = \frac{\Pi_{\Pi}}{1+ze^{-kt}},(1)$$

where $\Pi(t)$is the current value of the level of motorization; Π_{Π} – the limit value of the indicator corresponding to the moment of saturation; z, k are the coefficients that determine the nature of the flow of the logistic function for a particular park at a certain stage of development; e – the basis of natural logarithms; t is time.

The values of z and k can be determined based on the analysis of a retrospective statistical series of values of the level of motorization using standard software packages. To obtain the initial series, it is necessary to have statistical data on the dynamics of the fleet and the dynamics of the population.

Curve, the form of which is shown in Figure 1, is based on the analysis of statistical data on the retrospective dynamics of the level of motorization and reflects the pattern of development of the transport system (in the absence of “revolutionary changes” in it). The curve can be divided into three sections that characterize different stages of motorization:

- at the first stage of development the scale and pace of motorization is relatively low;
- on the second – they are replaced by intensive growth;

- in the third stage, the rate of growth of the motorization level slows down significantly, there is a "saturation" of vehicles fleet growth and stabilization of the level of motorization.

1.2 Prediction technique the number and structure of motor fleet by types of engine and fuel

Meanwhile, in recent years, in some developed countries and major European cities (e.g. Vienna, Zurich, etc.) it have begun to form a tendency to decrease the level of motorization after reaching its maximum (see Figure 2) under the influence of "revolutionary changes" at the 3rd stage of development of transport systems (driverless driving, electric mobility, multimodality, car-sharing, car-pooling, etc.). At this stage, the type of motorization curve is defined by the influence of factors which lead in the end to refusal of people from buying cars as a result of technological, social, political and other changes that "revolutionize transport" [2].

Figure 2 shows the following factors that affect the level of motorization, taking into account the above trend: 1) dynamics of population income; 2) the development of secondary car market; 3) the development of motor-car industry and 4) the financial sector; 5) the formation of developed international car markets; 6) spatial and 7) environmental restrictions; 8) the decline in the prestige of car ownership; 9) the evolution of settlement; 10) extension the use of the Internet and mobile (android) application to assist users of public transport [3]; 11) development of car-sharing, parking management and vehicle inventory system [4]; 12) the introduction of driverless cars; 13) formation of a new sector of individualized public transport with the use unmanned technologies, intelligent traffic and car networking technology [5], [6].

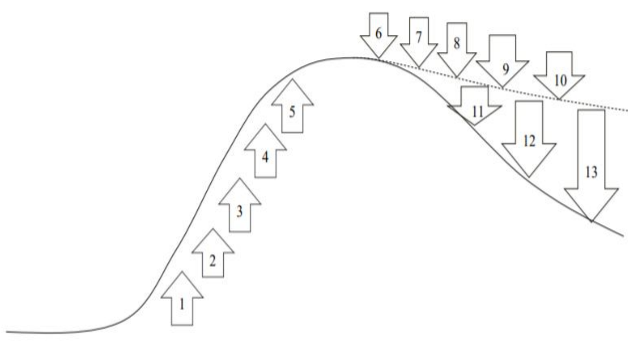

Figure 2: View of the change in the curve describing the level of motorization in conditions of "revolutionary changes" in the transport system [2]

Such where a trend can be taken into account by introducing into the equation of motorization dynamics change from a certain point in time $t`>(t_0)$, where $t_0$ is the year of achieving sufficient potential for changes in transport policy and transport behavior of the population, a certain function – $F(t`)$, which characterizes the decrease in demand for the purchase of new vehicles. According to our data, for Russia the year t_0, in which the level of motorization will reach its maximum approximately occur after 2036. Based on the given methodological approach, a forecast assessment of the level of motorization and the number of car fleet in the Russian Federation for the period up to 2050 has been made for conditions of implementation of two scenarios – inertial and innovative.

The country's population forecast is based on data from the official statistics service (Rosstat) on population dynamics in 1990-2018, as well as corresponding forecast estimates for the period up to 2036. The forecast estimates of the population for the period 2037-2050 are obtained by interpolating the corresponding population change trends for the considered scenarios in the period from 2019 to 2037. For further calculations, the dynamics of the population of the Russian Federation was used under the option which provides a reduction in the population by 2050 compared to 2019 from 146.9 million up to 138.2 million people, i.e. by 6.3%.

The second indicator which is needed to assess the level of motorization is the number of cars in the fleet (M1 category). Analysis of Traffic Police data for the period from 1990 to 2018 showed that the dynamics of the number of passenger cars with a high level of reliability is described by the dependence of the type:

$$y = 0.0047x^3 + 13.52x^2 + 1145.3x + 11131 \text{ (thousand units)}, \quad R^2=0.9879 \qquad (2)$$

where$x$ is the year.

Using the (1) and data on population dynamics in 1990-2018 changes in the level of motorization in the Russian Federation in considered time interval was estimated with a high degree of reliability by the dependence of the type (cars/1000 people):

$$y = -0.005159x^3 + 31.13113x^2 - 62606.55x + 419611171, \quad R^2=0.9987 \qquad (3)$$

where$x$ is the year (1990...2018).

The obtained dependence was used to search for a specific year in the forecast period, in which the dynamics of the level of motorization will begin to change and divide it into two branches (trajectories), one of which will continue the asymptotic growth of the motorization level until 2050, approaching the saturation level beyond the considered forecast period (inertial scenario) (see Figure 1), on the other-reaching a maximum in 2036-2040. motorization will begin to decline in accordance with equation (innovative scenario) (see Figure 2).

When developing a forecast of the level of motorization for the considered scenarios, a number of the following assumptions were made, based both on the analysis of existing trends in the field of road transport and on foreign experience:

- motorization in Russia, starting in 2016, is likely to enter the phase of sustainable growth completion and beginning its slowdown in accordance with the shape of the curve presented at Figure 1 (its second stage);

- stabilization or minimal further growth of the level of motorization in Russia can be expected at the level of 475-540 cars per 1000 people, which corresponds to the average level reached in the most of European countries;
- the level of motorization close to saturation under the inertial scenario can be reached after 2036,

Using (3) to interpolate data for the period 2019-2036 (in the part of the left increasing branch of the resulting curve according to this equation), it is possible to describe the predicted dynamics of the growth of motorization until its actual saturation in accordance with the above assumptions (the third stage in accordance with the curve in Figure 1), both for the inertial scenario and for the initial stages of the innovation scenario (for the period up to 2030-2035), i.e. for a period when changes in the transport system and transport policy on average in the country will not be fundamental, large-scale and significant in terms of changing the transport behavior of the population. Meanwhile, in the largest cities of Russia, an active change in the stereotypes of transport behavior of the population is already taking place, which is associated with the introduction of paid parking facilities, the advanced development of public transport, the development of car-sharing, etc.

In accordance with the inertial scenario (see Figure 3), the growth of motorization may continue after 2036.

Based on the calculations and the assumptions made, it can be expected that the level of motorization for the period up to 2030 will not change significantly in both scenarios.

In the period after 2036, the level of motorization under the inertial scenario will grow slightly with a growth rate of 0.5-1.5% per year. In 2050, according to this scenario, the level of motorization will be approximately 520 cars/1000 people. According to the innovative scenario, it will decrease by 2050 and may reach 398 units of cars/1000 people.

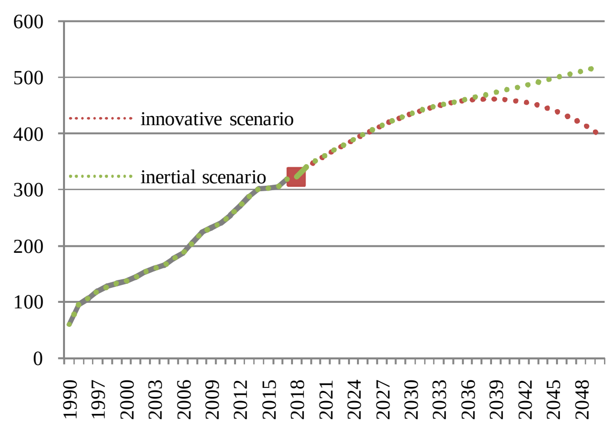

Figure 3: Forecast of the level of motorization in the Russian Federation for the period up to 2050, cars/1000 people

Using the data shown in Figure 3, as well as the projected population, there was estimated the number of car fleet in the Russian Federation for the period up to 2050.

It is expected that under the inertial scenario, the number of cars will grow throughout the forecast period. In 2050, its number may reach 71.8 million units. According to the innovative scenario, until 2036, the number of car fleet will grow (from 50 million units up to 66.5 million units), and then will decrease under the influence of factors above to the value of 55.0 million units in 2050.

According to predictive estimates up to 2034, the total number of Russian motor fleet (including cars, freight vehicles and buses) will grow in both scenarios approximately identical – from 57.58 to 73.75 million units. In subsequent years by implementation of the inertial scenario, the total number of car fleet will continue to grow to 80.66 million units; by innovative scenario it will peak in 2037 (74,03 million units) and then reduced to 61,34 million units in 2050.

For reliable forecast of gross greenhouse gas emission with the use of the level 3 method for road transport of the IPCC methodology and the COPERT software [7], [8] except for the number of Russian motor fleet it`s required to define the fleet structure by: working volume of engines for cars, the total mass of freight motor vehicles and passenger capacity of buses; environmental class of motor vehicles; the type of power plants used.

Forecasting the structure of the motor vehicle`s fleet by type of engine and fuel used is the most difficult task due to the instability of energy prices, the uneven development of renewable energy sources for transport in different countries and regions and the implementation of energy saving measures. The main directions of motor transport development which will affect the structure of the vehicle fleet by type of engine and fuel should include:

a) the tightening of regulatory requirements for greenhouse gases emission and consumption of petroleum fuels;

b) introduction of restrictions or prohibitions on the use and production of vehicles with certain types of engines (e.g. cars with diesel engine);

c) introduction of mechanisms to encourage the purchase and use of electric vehicles, as well as the expansion of the use of natural gas as a motor fuel;

d) switching to renewable power sources in order to avoid the mass burning of fossil fuels for power generation[9].

2. RESULTS AND DISCUSSION

2.1 Numerical simulation results

Based on the above information and summarization of the results of similar forecasts made in other countries and also results of expert assessments made by specialists from MADI, NIIAT and other Russian organizations [7], [10] in the table 1 there are presented the results of the forecast of the structure of the car, freight motor vehicles and buses fleets in the Russian Federation for the period up to 2050 by the type of engine (type of fuel) according to the inertial and innovative scenario.

Table 1: Forecast of the fleet structure by type of engine (fragment), %

Type of engine/fuel	2015	2030		2050	
		Inertial	Innovative	Inertial	Innovative
Cars					
Petrol	92,98	75,3	76,2	55,3	17,2
Diesel	4,89	5,0	15,0	15,0	15,0

Gas engine	2,1	7,4	6,2	16,5	40,0
Hybrid	0,03	2,0	1,6	11,7	7,8
Fuel cells and electric	0,0003	0,3	1,0	1,5	20,0
Total	100,0	100,0	100,0	100,0	100,0
Freight motor vehicles					
Petrol	31,5	21,1	22,8	16,4	12,1
Diesel	62,3	67,0	65,0	50,0	46,0
Gas engine	6,2	9,8	9,2	20,3	25,0
Hybrid	0	1,8	2,0	11,7	7,8
Electric	0	0,3	1,0	1,6	9,1
Total	100,0	100,0	100,0	100,0	100,0
Buses					
Petrol	34,6	22,2	24,7	11,3	5,0
Diesel	57,5	64,0	50,0	50,0	15,0
Gas engine	7,9	13,5	25,0	31,2	50,0
Hybrid and electric	0	0,3	0,3	7,5	30,0
Total	100,0	100,0	100,0	100,0	100,0

2.2 Discussion

Thus, if the inertial scenario will be implemented, the share of electric vehicles and hybrids in the car fleet may increase from almost zero (thousandths of a percent) in 2015 to 2.3% of the car fleet (M1 category) by 2030. By 2050 their share may reach 13.2%. The share of gas-fueled cars will increase from 2.1% to 7.4% by 2030, compared to 2015, and to 16.5% by 2050. At the same time, the share of petrol cars in the period under review will constantly decrease – from 93% in 2015 to 75.3% in 2030 and 55.3% in 2050. A different picture can be seen for cars with diesel engine. Their share in the car fleet will initially grow from 4.9% in 2015 to 15% in 2030, reaching a maximum of 25% in 2035, but then will begin to decline to 15% in 2050.

Insufficient development of the refueling network and service infrastructure is one from the key factors that will constrain the expansion of the use of gas fuel by motor transport for the period up to 2030. This is especially noticeable for the HDV fleet. Thus, in comparison with 2015, by 2030 their share in truck fleet will increase from 6.2% to only 9.8% by 2030. However, after 2030, the gasification level of truck fleet will grow more rapidly, reaching 20.3% of truck fleet by 2050. It is expected that by 2030 the share of electric vehicles and hybrids in truck fleet will be 2.1%, and by 2050 it will increase to 13.3%. The expected dynamics of changes in the share of petrol and diesel truck in the inertial scenario is expected to be as follows: the share of petrol trucks will constantly decrease from 31.2% in 2015 to 21.2% in 2030 and to 16.4% in 2050. The share of trucks with diesel engine will first grow from 62.3% in 2015 to 67.0% in 2030, but then it will start to steadily decrease to 50% in 2050 (primarily-due to vehicles with a total mass of up to 12 tons).

The change in the structure of the bus fleet by type of engine is expected to be as follows. The share of electric buses and hybrids from zero in 2015 will increase to 0.3% by 2030, and to 7.5% by 2050. The growth in the share of gas-powered buses is expected to be more significant-from 7.9% in 2015 to 13.5% in 2030 and to 31.2% in 2050. The share of petrol buses will decrease from 34.6% in 2015 to 22.2% in 2030 and 11.3% in 2050. The share of motor vehicles with diesel engines will increase to 64% by 2030, and then it is expected to decrease to 50% in 2050.

If the innovative scenario will be implemented, the share of electric vehicles and hybrids in the car fleet may reach 2.3% of the fleet by 2030, but their share may increase to 27.8% by 2050. The share of gas-powered cars will increase from 2.1% to 40.0% by 2050 compared to 2015. The share of petrol cars in the period under review will decrease more intensively than under the inertial scenario – from 93% in 2015 to 17.2% in 2050. As for the inertial scenario, the share of diesel vehicles in the car fleet will initially grow from 4.9% in 2015 to 25% in 2035, but will then begin to decline to 15% in 2050.

The share of hybrids and electric vehicles in the truck fleet under this scenario will increase approximately by 2030, as in the inertial scenario, to 2.9%, but by 2050 it may reach 16.9%. The share of gas-powered vehicles in the truck fleet will increase to 9.2% by 2030, and to 25.0% by 2050. At the same time, the share of gasoline trucks will increase to 22.8% by 2030, and then decrease to 9.1% by 2050. The share of diesel trucks in the fleet will increase to 65.0% in 2030, but then it will begin to decline and may reach 15.0% by 2050.

The share of electric buses and hybrids in the bus fleet by 2030 according to the innovative scenario may be 0.3%, and by 2050 – 30%. The share of gas-powered buses will increase even more, reaching 25% in 2030 and 50% in 2050. The share of buses with diesel engine will increase slightly at first (up to 62% in 2025), but then it will begin to decrease in 2030 – up to 50%, in 2050 – up to 15%.

Forecast values of direct gross CO_2 emission from motor transport (mobile sources with internal combustion engines) for the scenarios under consideration were estimated taking into account updated forecasts of the number and structure of fleets by type of engine and using two IPCC methods-level 1 and level 3, which differ in the completeness of the set of indicators taken as input data [10]. The values of gross CO_2 emission from vehicles with internal combustion engines calculated with the use of the level 3 method are slightly higher than with the use of level 1 method, both in the base year (by 7.3%) and throughout the forecast period. For further calculations and generalizations, it is assumed that the forecast values of direct (when burning motor fuel in the internal combustion engines of motor vehicles` fleet) CO_2 emissions are determined as a weighted average value obtained using the methods of levels 1 and 3 for a specific forecast year (table 2).

Table 2: Forecast estimates of greenhouse gas emissions by the Russian motor fleet up to 2050, million tons of CO_2

Scenario	2015	2020	2030	2040	2050
Inertial	172.92	181.30	192.97	190.21	184.85
Innovative	172.92	181.58	196.97	169.28	127.72

If the inertial scenario is implemented, the maximum direct emissions of greenhouse gases by motor transport in 2030 will be about 192.97 million tons, and then they will be slightly reduced by 2050 (up to 185 million tons). When implementing the innovation scenario, the maximum CO_2 emissions are also expected in 2030 (197 million tons), and then they will decrease more significantly by 2050 than when implementing the inertial forecast (up to 127.72 million tons).

3. CONCLUSION

A methodological approach has been developed to assess the level of motorization, the number and structure of the car fleet by the types of engine and fuel, by environmental class and other parameters. It was obtained a reliable time dependence of the motorization level which gave the possibility to find expected time frame for achievement of the maximum of this indicator. There were defined factors and conditions which will then lead to decline in motorization level due to the refusal of the population to purchase cars as a result of technological, social, and political changes (innovative scenario) or will save the continuation of motorization growth approaching the asymptote (inertial scenario).

Using the updated forecast data on the number and structure of the cars, trucks and buses fleets by the types of engine and fuel, by environmental classes there were refined previously obtained values of gross greenhouse gas emissions from the motor transport of the Russian Federation for the period up to 2030, and also for the first time there were received the forecast estimations of greenhouse gas emissions by 2050, in the light of the transition of motor transport towards low-carbon development model after 2030. It is expected that despite the dramatic increase in the number of gas-powered vehicles in the fleet, as well as hybrids and electric vehicles, when implementing the innovative scenario, a cardinal reduction in greenhouse gas emissions in the forecast period compared to 2015 will not occur – by 2030 there will be an increase of emission on 12.2% and then - its decrease on 26.1% by 2050.

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