Problems and prospects of sustainable low carbon development of transport in Russia

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Abstract. This article discusses the problems and prospects of sustainable low carbon transport development in Russia. Forecast scenario of Russian transport sector development was elaborated, which includes justification of the set of estimates of GHG emission by separate modes of transport and the transport industry as a whole, quantitative assessment of GHG emission from road, urban electric, rail, air, maritime, inland water transport, road building/maintenance and also justification of possible GHG emissions reduction targets when implementing the most effective measures for the period till 2030. Saving of gross GHG emission in 2030 at 2015 level or its reduction by 1.87–5.5 % is possible in case of implementation of a set of proposed measures. Package of comprehensive measures to improve energy efficiency and reduce GHG emission, first of all from motor transport based on balance of administrative, economic and mixed methods of the State regulation should be focused on introduction of carbon transport tax and norms of specific (per km of mileage) CO₂ emission and fuel consumption of vehicles, as well as the redistribution of the passenger and freight transport work from road and air transport to less energy-intensive transport modes (water, rail, urban electric cycling).

1. Introduction

Ensuring of sustainable low carbon development of transport sector has to be one of the main task of State transport policy. Such a policy has to foresee development of transport sector in direction of greenhouse gases (GHG) emission reduction, improving transport energy efficiency and reducing its negative impact on the environment.

Although the Transport Strategy of the Russian Federation adopted by the Government doesn’t directly use this term it provides for relative reduction of GHG emissions by separate modes of transport to the year 2030 in comparison with 2011. At the same time target values for gross and specific GHG emission from transport (as a whole and from its separate types) in this Document is not installed and is not linked to Russia's obligations in the framework of the implementation of Paris Agreement. This significantly reduces regulatory value of the Strategy as concern goal-setting, development and implementation of measures directed to improvement of energy efficiency and environmental safety both separate vehicles and the industry as a whole.

To solve this problem there was elaborated the transport sector development long-term forecast which includes: reasoning of the set of indices for GHG emission estimation from separate modes of
transport and the transport industry as a whole; quantitative assessment of GHG emission from different modes of transport (road, urban electric, railway, air, maritime, internal water) and also from road building industry; establishment of targets for reducing of GNG emission when implementing the most effective measures.

2. **Indicators of GHG emission by different modes of transport and methods of their evaluation**

On basis of analysis of low carbon transport development indicators which are used for working out of international and national programmers there was defined the nomenclature of the most significant indicators used for assessment of effectiveness of different low carbon transport strategies (Table 1).

**Table 1.** The nomenclature of the most significant indicators of the development of transport industry

| Recommended indicators | Comments |
|------------------------|----------|
| a) general transport indicators (key) | |
| Total gross GHG emission from transport, million tons CO₂ equivalent (CO₂e)/year | Allows to assess the cumulative effect of implementing of the policy directed to reducing of GHG emission in conjunction with overall economic and social processes taking place in society |
| Average specific GHG emission from transport in total per unit of transport work, g CO₂e/ton-km (passenger-km) | Allows to assess the cumulative effect from energy efficiency policy implementation in conjunction with general economic and social processes |
| Carbon intensity of transport in general (the ratio of GHG emission to GDP), ton CO₂e/bln rubles | Widely used in different countries |
| Total gross consumption of fuel and energy resources in transport sector, TJ/year | Allows to assess the cumulative effect of policy directed to reduction of carbon intensity of transport |
| Share of electricity in total energy consumption by transport, % | Allows to assess the cumulative effect of energy efficiency policy implementation |

| (b) indicators by mode of transport | |
|-----------------------------------|----------|
| Motor transport | Allows to assess the effect of policy directed to reduction of GHG emissions, increasing energy efficiency of certain types of stationary and mobile sources of transport |
| Urban electric transport | |
| Rail transport | |
| Air transport | |
| Maritime and inland waterway transport | |
| Road Building/Management | |

| c) prospective indicators | |
|---------------------------|----------|
| Average specific GHG emission during road construction (reconstruction), maintenance, renovation (rebuilding), ton CO₂e/km | Allows to assess the effect from the policy directed to improvement the energy efficiency and reduction of GHG emission from road construction and maintenance |
| Specific emissions of GHG by motor vehicles, g CO₂e/km | Allows to determine perspective normative requirements to specific GHG emission from single vehicles |
| Share of vehicles by mode of transport corresponding with certain classes of energy efficiency, % | Allows to assess the effectiveness of policy directed to renewal of rolling stock. Currently energy efficiency classes of cars in Russia is not installed |

To quantify the values of the above indicators there was developed special methods based on the IPCC Guidelines which are used in the assessment of anthropogenic emissions from emission source and adsorption by GHG absorbers which are not controlled by the Montreal Protocol [1] for rail, air, sea and inland waterway transport as well as for road transport, urban electric transport and road construction/management.
Gross CO₂ emission from the mobile transport sources (in the absence of data on fuel and energy consumption by vehicle classes) is defined as:

\[ E_{CO_2} = \sum_a A_{Da} \cdot E_{Fa} \cdot \frac{Gg}{year} \]  

where: \( a \) – type of fuel (petrol, diesel, natural gas, liquefied petroleum gas, etc.); \( A_{Da} \) – data on fuel type \( a \) consumption, TJ/year; \( E_{Fa} \) – specific CO₂ emission factor for fuel type \( a \), kg/TJ.

Values of the specific CO₂ emission factor per unit of a type fuel burn mass are taken by recommendations of IPCC.

### Table 2. Specific CO₂ emission factor for the level 1 [1, 2]

| Type of fuel | kg/TJ | kg/ton of equivalent fuel | kg/ton, kg/th m³ |
|--------------|-------|--------------------------|-----------------|
| Petrol       | 69 300| 2 031                    | 3 026           |
| Diesel       | 74 100| 2 172                    | 3 149           |
| LPG          | 63 100| 1 849                    | 2 903           |
| CNG          | 54 400| 1 594                    | 1 840           |
| LNG          | 54 400| 1 594                    | 2 710           |
| DMT          | 73 300| 2 115                    | 2 096           |

If data on volumes of transport work for each mode of transport and respective specific emission factors per unit of transport work are available gross GHG emission should be calculated as (1), where: \( a \) – transport mode (road, urban, rail, air, water); \( AD_{Da} \) – the volume of transport work (passenger or freight) for transport mode \( a \), million t-km or passenger-km/year; \( EF_{Fa} \) – specific emission factor for CO₂ emission from transport mode \( a \), kg/t-km or passenger-km.

If data on the fuel consumption by vehicle class are available emission of CO₂, CH₄ and N₂O may be calculated as:

\[ E = \sum_{a,b,c,d} AD_{Da,b,c,d} \cdot E_{Fa,b,c,d} \cdot \frac{Gg}{year} \]  

where: \( E \) – emission of CO₂, CH₄ or N₂O, t/year; \( a \) – type of fuel (diesel, petrol, natural gas or liquefied petroleum gas); \( b \) – type of vehicle; \( c \) – environmental class of vehicle; \( AD \) – energy content of fuel consumed, TJ/year; \( EF \) – specific emission factor for CO₂, CH₄ or N₂O, kg/TJ. Normalization of GHG emission volume to CO₂ equivalent (CO₂e) is carried out in accordance with formula:

\[ E_{CO_2e} = E_{CO_2} \cdot 1 + E_{CH_4} \cdot 25 + E_{N_2O} \cdot 298 \text{, Gg} \]  

Volumes of different fuels (electricity) consumption, for example, by motor fleet in formula (3) can be identified based on the number of passenger cars, light commercial vehicles, buses and trucks with different types of engines and used fuels, their specific fuel consumption (g/km) and the average weighted annual mileage. The formula for estimating emissions of CO₂, CH₄ and N₂O is:

\[ E = (\sum_{a,b,c,d} (AD_{a,b,c,d} \cdot EF_{a,b,c,d})) + \sum_{a,b,c,d} C_{a,b,c,d} / 10^9 \text{, Gg/year} \]  

where: \( E \) – emission of CO₂, CH₄ or N₂O, Gg/year; \( a \) – type of fuel/energy (diesel, gasoline, natural gas, liquefied petroleum gas, electricity); \( b \) – type of vehicle; \( c \) – environmental class; \( d \) – operating conditions (urban or rural roads); \( AD_{a,b,c,d} \) – annual mileage on the road type (d) of type \( b \) vehicles with environmental class \( c \) utilizing type \( a \) fuel/energy, km; \( EF_{a,b,c,d} \) – emission factor for CO₂, CH₄ or N₂O for type \( b \) vehicles with \( c \) environmental class utilizing \( a \) type fuel/energy on road type \( d \), g/km; \( C_{a,b,c,d} \) – emissions during start-up and warming up of engines ("cold start") g/year.

The volume and structure of fuel consumption, for example for road transport, can be defined by actual (on the base of special investigations) or statistical data from organizations and people who operate motor vehicles.
Collection and analysis of actual and/or average statistical data on fuel consumption may carry out with the use of passport data for each type, subtype and model of vehicle or with the use of determined norms of fuel consumption for each vehicle’s type and subtype and conditions of traffic.

In the latter case norms of specific fuel consumption from the official document "Norms of fuels and lubricants consumption for road transport" [3] may be used.

For electric vehicles (with gross weight less than 3.5 tons) weighted estimation of specific energy consumption per km of mileage accounted for 0.15 kWh/km or 0.54 MJ/km. Specific energy consumption of trams and trolleybuses per kilometer of run should be based on technological standards of energy consumption for electric traction of most common models of trams and trolleybuses and estimation of their nominal weight.

According to MADI estimates specific number of motor transport enterprisers (service stations) in the Russian Federation (depending on the region and the number of vehicle fleet) is 0.6–0.9 per 1000 units of rolling stock, i.e. from 32 to 48 thousand enterprisers/stations [4]. For rough estimation of gross CO2 emission from motor transport stationary objects (road transport enterprises, garages) the next formula may be used:

\[ E_{CO2} = \left[ \frac{1}{h} \sum_{k=1}^{h} (Y_k \cdot Z_k \cdot N_k \cdot L_k) \right] / 10^6 \]  

(5)

where: \( E_{CO2} \) – gross emissions of CO2, t/year; \( h \) – the number of considered types of motor vehicles; \( Y_k \) – per-unit energy consumption during \( k \)-type motor vehicle’s heating, maneuvering, maintenance and repairs on the territory of transport enterprisers, kWh/km; \( N_k \) – total number of \( k \)-type vehicles; \( L_k \) – the total mileage of \( k \)-type motor vehicles, km/year; \( Z_k \) – specific CO2 emission factor values per unit of electricity consumed by motor transport stationary object, g/kWh.

Average weighted specific energy consumption (per km of motor vehicle run) for transport enterprises for different types (categories in accordance with international classification) of passenger and cargo vehicles are (in kWh/km [5]): \( M_1 \), \( N_1 \) – 0.174; \( M_2 \), \( N_2 \) – 0.148; \( M_3 \), \( N_3 \) – 0.110. Specific values of GHG emission per unit of electricity consumed taking into account also losses of electric power in electric networks for stationary emission sources of motor transport as well as for mobile sources of urban electric transport are: CO2 – 435 g/kWh; CH4 – 0.00723 g/kWh; N2O – 0.0033 g/kWh [6].

The calculation of GHG emission from road construction/maintenance is made according to formula:

\[ E_i = \sum_{a} \sum_{k} (FC_{ak} \cdot EF_{aTCE} \cdot EF_{aNCV} \cdot EF_{ia}) \cdot t/year \]  

(6)

where: \( E_{i} \) – greenhouse gas \( i \) emission, t/year; \( FC_{ak} \) – total mass of energy/fuel type \( a \) consumed on the roads of \( k \) technical category, t/year; \( EF_{aTCE} \) – conversion factor in tons of coal equivalent by kind of energy resource \( a \), tce/t; \( EF_{aNCV} \) – conversion factor in energy units by type of energy source \( a \), TJ/tce; \( EF_{ia} \) – greenhouse gas \( i \) emissions coefficient by type of energy resource \( a \), t/TJ.

Gross CO2 emission from road construction/maintenance can also be defined if there are values of specific CO2 emission for different types and categories of roads at all phases of road life cycle (Table 3) and proper roads length (ROSSTAT data) according to the formula:

\[ E_{CO2} = \sum_{y} \sum_{k} (EF_{yCO2} \cdot L_k) \cdot t/year \]  

(7)

where: \( E_{CO2} \) – CO2 emission, tons/year; \( EF_{yCO2} \) – CO2 specific emission on \( k \) technical category roads at \( y \) phase of road life cycle, t/km; \( L_k \) – length of \( k \) technical category road, km.

Indicators of CO2 specific emission on the roads of different categories at different phases of their life cycle shown in table 3 take into account the specific features of road building/management activity.
related to technologies of asphalt cement-concrete mixtures preparation, execution of works on construction, reconstruction, rebuilding, repair and maintenance of different categories of roads [7].

Table 3. Values of the specific CO2 emission on the different types of roads at different phases of their life cycle, t CO2/km (FAU "ROSDORNII", MADI)

| Type of Roads                  | Life Cycle Phase | Road’s Technical Category |
|--------------------------------|------------------|---------------------------|
|                                | (I)              | (II)                      | (III) | (IV) | (V) |
| Federal Roads                  | Maintenance      | 43.73                     | 25.00  | 16.22| 14.09| 11.65|
|                                | Repair           | 533.28                    | 271.70 | 195.84| 190.16| 52.05|
|                                | Rebuilding       | 1556.92                   | 713.82 | 544.34| 526.10| 175.33|
|                                | Construction     | 2958.14                   | 1356.26| 1034.25| 999.6 | 333.13|
| Regional and Inter-municipal   | Maintenance      | 10.93                     | 6.25   | 4.06 | 3.52 | 2.91 |
| Roads                          | Repair           | 133.32                    | 67.93  | 48.96| 47.54| 13.01|
|                                | Rebuilding       | 389.23                    | 178.46 | 136.09| 131.53| 43.83|
|                                | Construction     | 739.54                    | 339.07 | 258.56| 249.9 | 83.28|
| Local (with hard or transitional pavement) | Maintenance | 2.19                      | 1.25   | 0.81 | 0.71 | 0.58 |
|                                 | Repair           | 26.66                     | 13.59  | 9.79 | 9.51 | 2.60 |
|                                 | Rebuilding       | 77.85                     | 35.69  | 27.22| 26.31| 8.77 |
|                                 | Construction     | 147.91                    | 67.81  | 51.71| 49.98| 16.66|

Table 4 shows the results of evaluation of the absolute and specific values of transport GHG emission obtained using the above formulas.

From this Table it may be seen that the gross transport GHG emission in 2015 was 286.01 million tons CO2/year, 73.03% of which were from mobile sources and 26.97% – from stationary (due to the lack of statistical data in this calculation there was not taken into account GHG emission from stationary objects of urban electric transport). It also may be seen that share of road and urban electric transport in total gross GHG emissions is 79.1%, railway – 11.8%, road building/maintenance and air transport (domestic) – 4.4% and 3.9% accordingly.

Table 4. Absolute and specific values of GHG emission by mode of transport, 2015

| Mode of Transport         | Total Gross GHG Emissions by Mode of Transport, Mio t CO2/yr | Specific Total Transport GHG Emission per Unit of Transport Work (distance), g CO2e/modified t km* | Volume of GHG Emission from Mobile Sources by Mode of Transport, Mio t CO2e/yr | Volume of GHG Emission from Stationary Sources by Mode of Transport, Mio t CO2e/yr |
|---------------------------|-------------------------------------------------------------|-------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| Motor transport           | 219.16                                                      | 940.64                                                                                         | 176.16                                                                          | 42.99                                                                            |
| Urban Electric Transport  | 7.20                                                        | No data                                                                                         | 7.20                                                                            | No data                                                                          |
| Rail Transport            | 33.80                                                       | 14.46                                                                                            | 12.70                                                                          | 21.10                                                                           |
| Air Transport             | 11.21                                                       | 2076.14                                                                                         | 10.97                                                                          | 0.24                                                                            |
| Maritime and Inland Water Transport | 1.96                                                  | 18.50                                                                                            | 1.84                                                                            | 0.12                                                                            |
| Road Building/Maintenance| 12.67                                                       | 12.12                                                                                            | 12.67                                                                          |                                                                                   |
| TOTAL                     | 286.01                                                      | 208.89                                                                                         | 77.13                                                                          |                                                                                  |

* – total GHG emission in road building/maintenance is assigned to stationary sources

In the future growth of gross GHG emission is possible due to increase in transport work done by separate modes of transport as well as due to more complete and accurate accounting of direct gross GHG emission from transport infrastructure objects in case of the development of regional and sectoral GHG emission surveys. For the correct formation of transport policy, it is important to monitor not only gross but also specific indicators of GHG emission (in accordance with Task 6 of the Transport Strategy of the Russian Federation to 2030 adopted by the Government).
3. The forecast methods for gross and specific GHG emissions by different modes of transport

Probable scenarios of greenhouse gas emissions by transport of the Russian Federation for the future will be largely determined by the macroeconomic situation in Russia and in the world, rates of GDP growth, policies and measures in the fields of energy sector, industries and transport development, as well as results of implementing policies and measures aimed to reduction and limitation of greenhouse gas emissions and intensification of their outflows.

Two scenarios of changes in greenhouse gas emissions from transport may be considered – inertial (BaU) and basic (innovative). As a base of BaU scenario it was considered the "Basic plus" scenario of long-term socio-economic development project developed by the Russian Ministry of Economy and Development. The assumption was accepted that only measures already adopted in the framework of the State policies will be used to promote low carbon development, including energy efficiency measures, the development of nuclear energy, the use of non-conventional energy sources.

An innovative scenario is characterized by a significant strengthening of requirements to environmental safety and energy efficiency of transport development that in turn assumes changing the structure of used energy resources. This Scenario provides for more sophisticated model of transport management by the State and business and at the same time increase in the expenditure on transport infrastructure development, implementation of high-tech projects and human capacity development.

In both scenarios it is supposed the development and implementation of the State and market regulation mechanisms which foresee implementation of the regulatory, organizational, technical and economic measures grouped into three directions:

1) improving energy efficiency of vehicles and transportation technologies based on the use of traditional types of motor fuel;
2) widening the use of various sources of energy with reduce GHG emission for vehicles of all modes of transport;
3) mobility management – reducing the excessive, irrational, unreasonable movement of passengers and freight, restraint of hypermobility of population by development of transport systems, implementation of ITS and information/telecommunication technologies and so on.

Measures of the first direction include: development and introduction of new energy efficient and environmentally friendly vehicles and transportation technologies; renewal and formation of optimal structure of rolling stock of different modes of transport; implementation of new emission standards (e.g. standardization of specific emissions of CO₂), implementation of non-motorized modes of transport and movement; maintain technical conditions of rolling stock and transport infrastructure objects; encouraging of consumers to choice low carbon vehicles, etc.

Measures of the second directions include: development and implementation of energy-efficient vehicles, alternative fuels and vehicles capable to work on them; electrification of road transport; refueling infrastructure for alternative fuels and energy.

Measures of the third direction include: demand management for transport services; management of priorities in development of various modes of transport; formation of a rational structure of road and public transport networks in cities and agglomerations; low-carbon organization of transportation processes with mutual complementing (but not competition) of different modes of transport (digital transportation and logistics technologies, intelligent transport systems (ITS), etc.); formation of intelligent toll systems (tolls in accordance with distance travelled, vehicles weight, their level of energy efficiency and environmental safety), effective parking policy etc.

The implementation of the above-mentioned measures relates, above all, motor and urban electric transport, the share of greenhouse gas emission from which is almost 80% of emission from all modes of transport.

Gross GHG emission from the mobile sources of motor transport up to 2030 is defined for prognostic number and structure of the fleet of passenger cars, light commercial vehicles, trucks and buses by type of their engine (type of fuel used), the annual runs and specific fuel consumption per km
(CO2 emission). Prognostic number and structure of motor vehicles fleet by type of engine, annual runs were defined in accordance with [8] and are shown in Table 5.

| Years | Cars | Light commercial vehicles | Trucks | Buses | Total |
|-------|------|---------------------------|--------|-------|-------|
| 2015* | 44253 | 3054                      | 3176   | 873   | 51355 |
| 2016* | 44699 | 3033                      | 3179   | 896   | 51807 |
| 2017* | 46887 | 3188                      | 3246   | 896   | 54216 |
| 2020  | 48960/54720 | 3325.4**                  | 3840** | 890** | 56250/62010 |
| 2025  | 54900/60690 | 3509.5**                  | 3953** | 910** | 62510/68300 |
| 2030  | 58400/65700 | 3818.0**                  | 4130** | 930** | 66330/73630 |

* – GIBDD (Traffic Police) data;  ** – for both scenarios: numerator/denominator – BaU/innovative scenario

From this Table it’s possible to see that the Russian motor fleet to 2030 will increased by 29.0–43.4 % as compared to 2015 reaching a size of 66.33–73.63 million units respectively (by BaU and innovative scenarios). The number of cars may amount to 58.4–65.7 million units (88 %), light commercial vehicles – 3.8 million units (5.2–5.8 %), trucks – 4.13 million units (5.6–6.2 %) and buses – 0.9 million units (1.3–1.4 %).

When forecast the structure and size of motor fleet by type of engine as the key condition there was defined the need to achieve the targets set out in the Transport Strategy of the Russian Federation to 2030: "the share of the vehicle fleet with hybrid, electric engines and engines used alternative fuels in the total number of vehicles in 2020 will reach 26 % for BaU scenario and 29 % for innovative scenario, and in 2030 – respectively 49 % and 54 %. Table 6 shows the results of the prediction of vehicle fleet structure by type of engine and fuel type which based on projections made abroad and in Russia (MADI and other organizations).

The proportion of electric vehicles and hybrids in car fleet for period concerned is characterized by the following values: 2015 – 0.026 %; 2020 – 7.7–8.5 %; 2025 – 10.8–24.0 %; 2030 – 23.0–48.0 % respectively for considered scenarios. The share of electric vehicles and hybrids in LDV fleet in 2030 could be 12.0–25.0 %, in trucks fleet – 3.0–10.0 % and in bus fleet – 3.0–4.0 %.

| Type of Vehicle | Type Engine | 2015 | 2020 | 2025 | 2030 |
|----------------|-------------|------|------|------|------|
| **Cars**       |             |      |      |      |      |
| Petrol         | 92.959      | 64.2/61.0 | 53.1/49.0 | 41.0/34.0 |
| Diesel         | 4.893       | 9.8/10.0  | 9.9/9.5 | 10.0/12.0 |
| Gas-engine     | 2.122       | 18.3/20.5 | 26.2/17.5 | 26.0/6.0 |
| Hybrids        | 0.026       | 6.7/7.0   | 8.8/20.0 | 20.0/40.0 |
| Electric, FC*, hydrogen | 0.000284 | 1.0/1.5 | 2.0/4.0 | 3.0/8.0 |
| TOTAL          | 100.0       | 100.0     | 100.0 | 100.0 |
| **Light Commercial Vehicles** | | | | |
| Petrol         | 61.166      | 40.0/37.6 | 31.0/26.6 | 21.0/17.4 |
| Diesel         | 32.935      | 34.0/33.4 | 32.0/31.9 | 30.0/28.6 |
| Gas-engine     | 0.5899      | 21.0/22.2 | 29.6/29.0 | 37.0/29.0 |
| Hybrids        | 0.0         | 4.7/6.0   | 6.4/10.0 | 8.0/20.0 |
| Electric, FC*, hydrogen | 0.0 | 0.3/0.8 | 1.0/2.5 | 4.0/5.0 |
| TOTAL          | 100.0       | 100.0     | 100.0 | 100.0 |
| **Trucks**     |             |      |      |      |      |
| Petrol         | 8.463       | 8.6/9.0  | 7.6/7.0 | 1.0/2.0 |
| Diesel         | 85.4572     | 82.0/82.4 | 81.0/60.5 | 60.0/44.0 |
| Gas-engine     | 5.965       | 8.4/8.4  | 10.0/28.5 | 36.0/44.0 |
With taking into account target values fixed in the Transport Strategy to 2030 the share of trucks used natural gas as a fuel could reach 36–44 % of trucks fleet and buses – 46–50 %. Insufficient development of gas filling station network and gas-fueled vehicles service infrastructure is one from the key factors restrained the expansion of natural gas use as motor fuel for transport. This has been taken into account in the BaU scenario.

Analysis of data presented in Tables 5 and 6 showed that the total number of Russian vehicle fleet for the period up to 2030 in accordance with the type of engine may undergo significant changes as compared to 2015: the number of petrol vehicles in the Russian Federation in 2030 may be reduced almost in 2 times and will constitute about 23.1–24.7 million units; the number of vehicles with diesel engine on the contrary will increase by one third and can reach 9.47–10.8 million units; the number of vehicles with gas-driven engine, hybrids in 2030 may rise dozens of times and the number of electric vehicles – thousand times. This dynamics of the Russian motor fleet change by type of engine and fuel type can only be achieved in case of urgent adoption of a complex of regulatory, organizational, engineering and technical measures directed to reducing GHG emission.

Gross GHG emission from motor fleet for forecasted period was estimated by multiplying the volumes of consumption of different fuels (electricity) on specific CO₂ emission indices (kg CO₂/tce) (Table 7).

**Table 7. Specific GHG emission by mode of transport in 2015, t CO₂/tce**

| Mode of Transport | Specific emission |
|-------------------|-------------------|
| Motor and Urban Electric Transport | 1.62 |
| Rail Transport | 1.53 |
| Maritime and Inland Water Transport | 2.01 |
| Air Transport | 2.02 |

Consumption of different types of fuels (electricity) by motor transport for a given forecast period was defined by simplified method based on the number of cars, light commercial vehicles, trucks and buses with different types of engines (Tables 5 and 6), their specific fuel consumption (g/km) and the average weighted annual runs of cars, light commercial vehicles, trucks and buses, which were established for basic year taking into account fuel consumption balance and results of calculations with the use of COPERT programme [9] or [10] (NIIAT) and for forecast period – taking into account trends of increasing of vehicle’s fuel efficiency (2 % per year). Average values of fuel consumption per km of mileage by different types of vehicles in 2015 were accepted by EMEP/EEA data [11]. For the next period values of specific fuel consumption were received on the basis of analysis and synthesizing of transport development trends and expert judgements.

4. The results of transport greenhouse gas emissions forecast for the period until 2030
As the main parameters for forecast of gross GHG emission by separate modes of transport and road construction/maintenance there have been used:
1) transport work for passenger and freight transportation by all modes of transport which depends on transport services market development, volumes of freight and passenger transportation;
2) development of transport infrastructure (projected length of public roads set by the State programs); 3) development of vehicle fleet (forecasted fleet number by the type of engine and fuel used is estimated taking into account fleet renewal and introduction of major production capacities, balance of supply and disposal of vehicles); 4) GHG emission factors (forecasted values of specific GHG emission (per unit of transport work, per unit of mileage, per unit of road length, per unit of consumed fuel/energy) for all modes of transport are established on the basis of the target values of the Transport Strategy, analysis of trends of transport technics and technology development, tightening of normative values of specific emissions, as well as expert judgements).

Figure 1 shows the forecasted values of gross GHG emission from transport as a whole and from separate transport modes for the period up to 2030 in conditions of two scenarios realization.

In comparison with 2015 gross transport GHG emission for the period up to 2030 will decline in both scenarios under consideration. At that if for BaU scenario gross GHG emission reduction will be relatively small (about 1.4 percent or 4.0 million tons of CO₂e) and sufficiently smooth (from 286.01 to 281.98 million tons of CO₂e), then in innovative scenario in 2030 transport gross GHG emission reduction will be substantial – in 6.1 times more than for the BaU scenario (24.77 million tons of CO₂e). The most significant reduction in gross GHG emission in this scenario (from 277.81 to 261.25 million tons of CO₂e i.e. 16.6 million tons of CO₂e) is expected in the period after 2025 mainly on account of intensive replacement of benzene and diesel car by electric cars and hybrids as envisaged in the updated version of the Transport Strategy of the Russian Federation.

Maximum contribution to total gross GHG emission from transport in 2030 will make motor transport – 74.8–72.5 % from all emission what is in line with assessments by other authors and confirms the earlier findings on the importance of priority introduction of measures to reduce GHG emissions just by motor transport.
The railways share in total emissions from transport can constitute 8.6–10.7 %, road building/maintenance – 4.8–5.2 %, air transport – 7.8–8.4 %, urban electric transport – 2.64–2.48 %, maritime and inland water transport – 1.12–0.95 %.

Table 8 shows the forecasted values of major multimodal indicators of GHG emission and energy consumption of transport in the Russian Federation for the period until 2030 obtained on the basis of the fulfilled projections of GHG emission and energy consumption, population projections, changes in GDP and other indicators of socio-economic development.

Table 8. Prognostic values of the main multimodal indicators of GHG emission and energy consumption of transport in the Russian Federation for the period until 2030

| Indicators                                      | 2015      | 2020      | 2025      | 2030      |
|------------------------------------------------|-----------|-----------|-----------|-----------|
| Total gross GHG emission from transport, Mio t CO$_2$e/yr | 286.01    | 288.28    | 279.93    | 277.81    | 282.41    | 261.25    | 281.98    |
| Average specific transport GHG emission in total per unit of transport work, g CO$_2$e/t-km (pass-km) | 106.66    | 89.68     | 89.75     | 77.34     | 87.97     | 64.85     | 84.38     |
| Carbon intensity of transport in general (ratio of GHG emission from transport to GDP), t CO$_2$e/billion rub. | 3429.9    | 3457.1    | 3357.0    | 3248.6    | 3386.7    | 3050.3    | 3381.6    |
| Transport GHG emission per capita, t CO$_2$e per capita | 1.95      | 1.97      | 1.91      | 1.85      | 1.93      | 1.74      | 1.93      |
| Total gross consumption of fuel/energy in transport sector, TJ/year·10$^3$ | 4846.03   | 4869.17   | 4709.73   | 4105.9    | 4764.57   | 3836.55   | 4730.66   |
| Average specific power-intensity of freight transportation in general, MJ/t-km | 1.81      | 1.51      | 1.51      | 1.17      | 1.49      | 0.98      | 1.42      |
| Average specific power-intensity of passenger transportation in general, MJ/p-km | 9.14      | 8.06      | 7.95      | 6.00      | 7.55      | 4.59      | 6.70      |
| Share of electricity in total energy consumption by transport, % | 29.58     | N.d.      | N.d.      | N.d.      | N.d.      | N.d.      | N.d.      |
| Volume of final consumption of different types of fuels and energy by transport in general, Mio tce/year | 165.39    | 166.18    | 160.74    | 140.13    | 162.75    | 130.94    | 161.46    |

From projections given in the Table 8 it follows that realization of both scenarios in the transport sector will lead to decline in gross (from 286.01 million tons CO$_2$e to 281.98–261.25 million tons CO$_2$e), specific GHG emissions and energy use. Besides in case of realization of innovation (target) scenario expected reduction of GHG emission and energy consumption by 2030 will be approximately 10–20 % greater than when implementing BaU (conservative) scenario. And in terms of specific GHG emission in total per unit of freight transport work the reduction could reach 33 % as compared with BaU scenario, for specific energy intensity of passenger transportation – 37.4 %, for specific energy intensity of freight transport – 48.2 %.

If for transport sector it will also be set a target level for reduction of gross GHG emission in 2030 to 25–30 % compared to 1990 in accordance with the declared aim of Russia, to which we should strive within the framework of the Paris Agreement, then received forecasted values of gross GHG
emission by 2030 must be reduced even at 126.08–136.47 million tons CO$_2$e when implementing the BaU scenario and to 115.7–105.34 million tons CO$_2$e when implementing innovative scenario. To reach the target level of gross GHG emission in 2030 is possible only in case if all Russian motor fleet (66–73.6 million units) will consist from hybrids and electric vehicles (50:50). In this case total GHG emission of transport in general can amount in 140.17 million tons CO$_2$e, i.e. at 5.34–15.74 million tons CO$_2$e less than possible target level.

A full replacement of petrol and diesel vehicles in Russian motor fleet by electric vehicles and hybrids even to 2050 is unrealistic particularly for political and socio-economic considerations associated with dominating today and in the future in the economy raw materials sectors. In this regard, it is not acceptable for the transport sector setting the target level of gross reduction of GHG emission to 2030 as 70–75% from the level of 1990.

Thus, the persistence of gross GHG emission in 2030 at 2015 level or it reduction at 1.87–5.5% is possible in case of implementation of a set of proposed measures and fits into the targets and indicators contained in the updated edition of the Transport Strategy of the Russian Federation for rail, air and water transportation, as well as in case of realization of predictive values of gross and specific GHG emission for motor, urban electric transport and road building/maintenance.

Package of comprehensive measures to improve energy efficiency and reduce GHG emission, primarily for motor transport, based on balance of administrative, economic and mixed methods of the State regulation should be focused on introduction of carbon transport tax and norms of specific (per km of mileage) CO$_2$ emission and fuel consumption of the vehicle, as well as redistribution of passenger and freight transportation from motor and air transport to less energy-intensive transport modes (water, rail, urban electric, cycling) by reorganization of transportation process through implementation of multimodal transport links, development of digitalization of logistic processes and so on.

A new trend on electrification of motor transport must be backed up by actions in the energy sector to create additional generating capacity (estimated from 2.76 to 7.95 billion kWh (electric vehicle fleet from 1.879 to 5.415 million units) and from 48.69 to 54.05 billion kWh – with full substitution of petrol and diesel vehicles by electric vehicles and hybrids (common fleet from 33.2 to 36.8 million units) required for the implementation of this trend preferably with the use of renewable energy sources.

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