U.S. DEPARTMENT OF ENERGY

PNNL-25754

Black carbon emissions from diesel sources in Russia

Final inventory report

N Kholod
M Evans

August 2016

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Printed in the United States of America

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Black carbon emissions from diesel sources in Russia

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Prepared by Battelle Memorial Institute
for U.S. Environmental Protection Agency

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Executive Summary

Black carbon (BC) is a significant climate forcer with a particularly pronounced forcing effect in polar regions such as the Russian Arctic. Diesel combustion is a major global source of BC emissions, accounting for 25–30% of all BC emissions.

Russia is the second largest producer of crude oil in the world; likewise, it is a large producer and consumer of diesel fuel. The country increased diesel production from 70 million metric tons in 2010 to 77 million metric tons in 2014. While the demand for diesel is growing in Russia, the country's diesel emissions are poorly understood.

Russia adopted the vehicle emission standards developed by the United Nations Economic Commission for Europe (UNECE) in 2006. Over the last five years, Russia implemented standards that improved the quality of its diesel fuel, reducing sulfur content.

This report presents a detailed inventory of Russian BC emissions from diesel sources. Drawing on a complete Russian vehicle registry with detailed information about vehicle types and emission standards, this report analyzes BC emissions from diesel on-road vehicles. The COPERT emission model with Russia-specific emission factors for all types of on-road vehicles was used for BC emission calculations. This study also factors in superemitters in the Russian diesel fleet. On-road diesel vehicles emitted 21 Gg of BC in 2014: heavy-duty trucks account for 60% of the on-road BC emissions, while cars represent only 5% (light commercial vehicles and buses account for the remainder).

Using Russian activity data and fuel-based emission factors, the report also presents BC emissions from diesel locomotives and ships, off-road engines in industry, construction and agriculture, and generators. All off-road sources emitted 28.5 Gg of BC. The largest emission contributors in the off-road sector are industry, locomotives, and diesel generators.

The study also factors in the role of superemitters in BC emissions from diesel on-road vehicles and off-road sources. The results show that superemitters emitted 8.9 Gg of BC or 43% of all diesel on-road BC emissions. The role of superemitters in emissions by type of vehicles varies from to about 40% for buses and heavy-duty trucks to 44% for cars and 48% for light-duty vehicles. Off-road superemitters are responsible for 21% of BC emissions from off-road sources.

The total emissions from diesel sources in Russia are estimated to be 49 Gg of BC and 16 Gg of organic carbon in 2014. Off-road diesel sources emitted 56 % of all diesel BC in Russia.

This study focuses on BC emissions from diesel sources only per the parameters of the United States Environmental Protection Agency's (US EPA) Reduction of Black Carbon from Diesel Sources in the Russian Arctic project, which is part of the USG Arctic Black Carbon Initiative (EPA, 2016).

Acronyms and Abbreviations

BC	black carbon
CENEf	Russian Center for Energy Efficiency
COPERT	COmputer Programme to calculate Emissions from Road Transport
EC	elemental carbon
ECLIPSE	Evaluating the Climate and Air Quality Impacts of Short-Lived Pollutants
EEA	European Environmental Agency
Fedstat	Federal Statistics Service
Gg	gigagram
GOST	Russian state standards
GWh	gigawatt-hour
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
Kg	kilogram
Kt	thousand metric tons
LCV	light commercial vehicles
MW	megawatts
NIIAT	Russian Scientific Research Institute for Automobile and Transportation
OC	organic carbon
PM	particulate matter
ppm	parts per million
RAINS	Regional Air Pollution INformation and Simulation
RZhD	Russian Railway Company
tkm	tonne-kilometers
UNECE	United Nations Economic Commission for Europe
US EPA	United States Environmental Protection Agency
USG	United States Government
USGS	United States Geological Survey

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1 Introduction

Black carbon (BC), a component of particulate matter (PM), may be the most powerful contributor to climate change after carbon dioxide (Bond and Sun, 2005; Bond et al., 2013). BC emissions cause significant warming effects through direct light absorption, interaction with clouds, and reduced albedo on snow. In polar regions especially, BC plays an important role because BC accumulation on snow and ice facilitates the absorption of solar radiation, increases air temperature, and accelerates snow and ice melting (Bond et al., 2013; Hansen, 2003; Koch and Del Genio, 2010; Quinn, 2008; Quinn et al., 2011; Warren and Wiscombe, 1980).

BC, as a major component of diesel PM, also has adverse health impacts (WHO, 2012). Chronic exposure to PM is associated with a range of diseases and can cause premature death from cardiopulmonary disease and lung cancer (Pope III et al., 2011). Exposure to PM emissions is the ninth leading factor of premature death globally (Lim and et.al., 2012); the World Health Organization estimates that PM pollution accounted for 3.1 million deaths in 2010 (WHO, 2013). According to the Global Burden of Disease study, ambient PM pollution caused more than 100,000 premature deaths in Russia in 2013 (GBD, 2016). BC is a product of incomplete combustion of fossil fuels, biofuels and biomass. In 2000, diesel BC emissions accounted for 25-30% of all energy-related BC emissions worldwide (Bond et al., 2013). In Europe, North America, and Latin America, diesel transport, both on- and off-road, accounts for about 70% of all energy-related BC emissions.

Over the decade, diesel production in Russia has risen by 10% (Minenergo, 2015). Diesel is important to BC for two additional reasons. First, diesel combustion results in a high share of BC in PM emissions compared with other emissions sources. Second, there are well-established control technologies and policies to reduce emissions from diesel combustion. In fact, this study finds that Russian emissions are lower than many previous studies specifically because we are able to account for the impact of the emission standards in reducing emissions. Russia is the second largest producer of crude oil in the world (IEA, 2015b); likewise, it is a large producer and consumer of diesel fuel. Despite the large diesel consumption of Russia, the country has historically represented a significant gap in our global understanding of BC emissions. Russia is important for global BC inventories because the country is the largest in terms of territory and emissions in the country have impact on the rest for the world. Appendix Table A1shows data on Russia’s population and territory by region.

Inventories are important in developing mitigation policies and improving our understanding of global climate in models. Global or regional emission inventories, however, tend to rely on simple assumptions for emission calculations because country-level data might not be available. The aim of this report is to present a detailed BC emission inventory from diesel sources in the Russian Federation for the base year 2014. Previous studies reporting BC emissions from Russian diesel sources were estimated primarily by combining fuel consumption with fuel-based emission factors. This report instead draws on detailed data about the Russian vehicle fleet, annual mileage by vehicle category, the usage of emission controls on off-road vehicles, and other factors such as the existence of super-emitters in the on-road diesel fleet.

2 Methodology

2.1 Emission standards for diesel engines

Russia has adopted the vehicle emission standards developed by the United Nations Economic Commission for Europe (UNECE). Specifically, Russia introduced Euro 2 standards in 2006 (Appendix Table A2). Emission standards in Russia apply to both domestically produced and imported vehicles. The minimum emission standard in 2014 was Euro 4 for cars and Euro IV for trucks and buses. As of January 2016, the minimum standard is Euro 5/Euro V. Russia has no official plans to move to the Euro 6 standard.

Russia has also adopted the European standard for PM emissions for off-road vehicles used for agriculture and forestry (these off-road standards are broken into “Stages” in the European system). According to Technical Regulation 031/2012, agricultural and forestry off-road vehicles should meet the UNECE standard (Stage III) (Eurasian Commission, 2012). However, in the baseline year for this inventory (2014), there was no PM emission standard for agricultural vehicles in Russia. Additionally, the implementation of this new standard appears to be weak. Apart from agriculture and forestry, equipment in other sectors in Russia is not obliged to comply with any PM emission standards (Eurasian Commission, 2011a).

2.2 Methodology for emission calculations from on-road vehicles

The European COPERT model (COmputer Programme to calculate Emissions from Road Transport) calculates emissions from on-road vehicles. The European Environmental Agency (EEA) supported the development of COPERT. EEA member countries use this free software for official road transport emission inventory preparation (Emisia, 2015). Twenty-two countries of the European Union use the model to calculate road transport emissions (Ntziachristos et al., 2009). In this study, we use the COPERT 4 model (version 11.3).

Diesel vehicles in the COPERT model are classified into four large groups: passenger cars, light commercial vehicles (LCVs), heavy-duty trucks, and buses. In the model, exhaust BC emissions from vehicles depend primarily on the following: 1) the number of vehicles on the roads, 2) emission factors, and 3) average number of kilometers traveled.

The COPERT model uses European-specific emission factors and allows users to input country-specific emissions factors. The Russian Scientific Research Institute for Automobile and Transportation (NIIAT) developed two methodologies for calculating emissions from on-road transport (NIIAT, 2006, 2012). They are based on the simplified EMEP/CORINAIR approach (now called EMEP/EEA Air Pollutant Emission Inventory Guidebook).

NIIAT has developed PM emission factors for Russian vehicles based on vehicle emission test data for both Russian and foreign vehicles. Appendix Table S3 provides the emission factors for the following categories of diesel vehicles: cars, light trucks and buses (LCVs), heavy-duty trucks, and buses on three types of roads (urban, rural, and highways).

We derive BC/PM ratios from the EEA emission guidebook (EEA, 2013). The COPERT model can also directly calculate emissions of elemental carbon (EC) and organic carbon (OC). In European emission studies, EC is assumed to be equal to BC for transport due to the nature of the combustion processes.

Diesel engines emit BC emissions in two distinct stages of operations – cold start and hot operation. The COPERT and the NIIAT models use different approaches to calculate cold start emissions. However, in their study of BC emissions from diesel vehicles in the Murmansk Region, Evans et al. showed that both methodologies yield very similar total emissions (Evans et al., 2015). As a result, in this study we do not analyze hot and cold emissions separately and present only the total emissions.

2.3 Methodology for emission calculations from off-road engines

BC emission calculations from off-road diesel engines can be expressed by Eq. 1:

$$BC\ emissions = fuel(kg) * PM\ emission\ factor\ (g\ kg^{-1}) * BC/PM\ \ ratio \quad (1)$$

We used Formula 1 to calculate emissions from off-road sources listed in Section 5. Table 1 presents PM emission factors and BC/PM speciation ratios used in this study.

Table 1. $PM_{2.5}$ emission factors and BC/PM ratios for off-road diesel sources.

Sector	Emission controls	$PM_{2.5}$, g kg^{-1}	Source	$BC/PM_{2.5}$ ratio	Source
Diesel generators	No control	6.0	Bond et al. (2004)	0.66	Bond et al. (2004)
Heat plants	No control	0.25	Bond et al. (2004)	0.29	Bond et al. (2004)
Industry (stationary engines)	No control	4.308	EEA (2013), 1.A.4.,Table 3-2	0.55	EEA (2013), 1.A.4.,Table D3
	1991-Stage I	3.551	EEA (2013), 1.A.4.,Table 3-2	0.55	EEA (2013), 1.A.4.,Table D3
	Stage II	1.031	EEA (2013), 1.A.4.,Table 3-2	0.80	EEA (2013), 1.A.4.,Table D3
Construction	No control	4.308	EEA (2013), 1.A.4.,Table 3-2	0.55	EEA (2013), 1.A.4.,Table D3
	1991-Stage I	3.551	EEA (2013), 1.A.4.,Table 3-2	0.55	EEA (2013), 1.A.4.,Table D3
Rail	No control	4.62	Yan et al. (2014)	0.65	EEA (2013), 1.A.3.c.,Table A.1
Ships	No control	1.4	EEA (2013), 1.A.3.d.,Table 3-2	0.31	EEA (2013) 1.A.3.d., Table 3-2
Agriculture	No control	3.755	EEA (2013), 1.A.4.c.ii, Table 3-2	0.55	EEA (2013), 1.A.4.c ii, Table D3

1991-Stage I	1.644	EEA (2013), 1.A.4.c ii, Table 3-2	0.54	EEA (2013), 1.A.4.c ii, Table D3
Stage I	0.832	EEA (2013), 1.A.4.c ii, Table 3-2	0.79	EEA (2013), 1.A.4.c ii, Table D3
Stage II	0.627	EEA (2013), 1.A.4.c ii, Table 3-2	0.77	EEA (2013), 1.A.4.c ii, Table D3

Though emission factors reported in the literature could be different from those in the emission guidebook, we use the EEA emission factors for consistency. The advantage of using this approach is that the guidebook reports emission factors for equipment without emission controls. Since the majority of diesel off-road vehicles and equipment is old and Russia does not regulate particulates from off-road diesel sources, we assumed that there are no emission controls on most of the off-road diesel sources. Some small percentage of imported engines might have emission controls.

3 Diesel consumption

3.1 Production of diesel fuel

The Russian Federation is the second largest producer of crude oil in the world, producing 13% of total world oil in 2014 (IEA, 2015b). It is also a large producer of diesel fuel as well. The country increased diesel production from 70 million metric tons in 2010 to 77 million metric tons in 2014. Importantly, over the same time frame, Russia implemented standards that improved the quality of its diesel fuel, reducing sulfur content (Figure 1). Sulfur content of diesel fuel is an important factor in emission reductions. Diesel with high sulfur content (measured in parts per million or ppm) can destroy emission control devices, such as particulate filters. Availability of low sulfur diesel is an important prerequisite for the introduction of more stringent vehicle emission standards.

The share of Euro 5 diesel (with sulfur content of 10 ppm, otherwise known as ultralow sulfur fuel) increased from 6% in 2011 to 50% in 2014 (Fedstat, 2015h). By the end of 2015, according to an estimate of the Russian Ministry of Energy, Euro 5 diesel accounted for 82% of the total diesel production (Government of Russian Federation, 2015). Russia exports more than half of diesel produced; the quality of exported diesel is lower than that of the diesel used domestically.

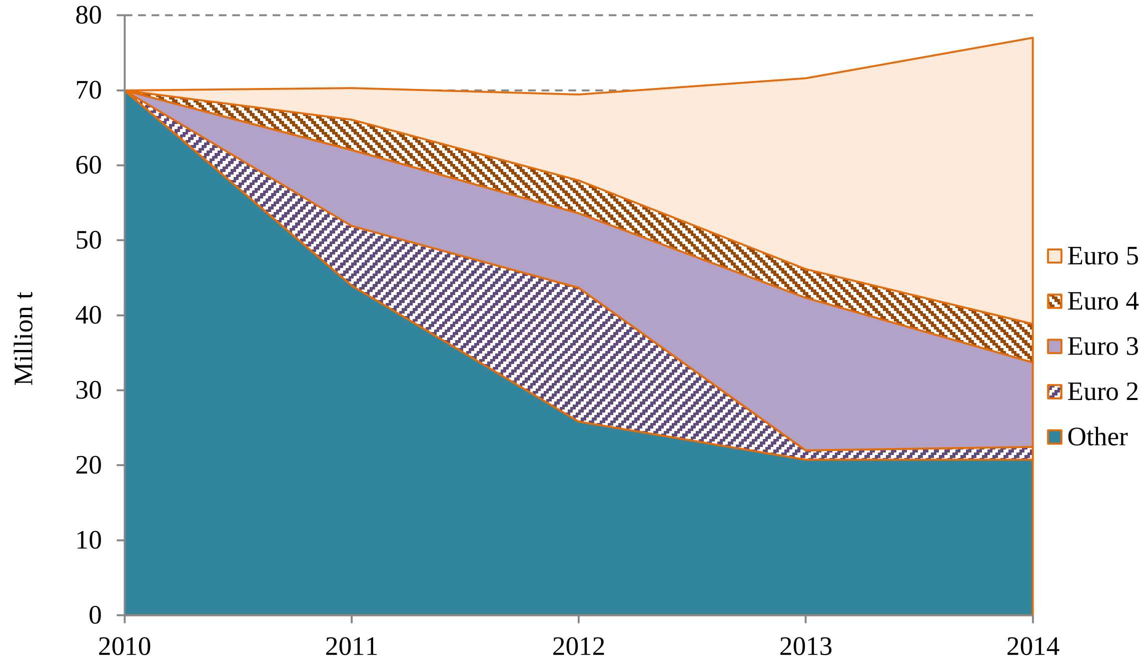

Figure 1. Production of diesel fuel by Euro class in Russia, 2010-2014, million metric tons.

Source: (Fedstat, 2015e).

Russia banned the domestic sale of lower grade diesel in 2013. In 2014, only Euro 4 (50 ppm) and Euro 5 (10 ppm) fuels were legal to sell for on-road transport (Eurasian Commission, 2011b). However, compliance with this standard is not universal. Rosstandard, a government agency responsible for fuel quality control, found that the sulfur content exceeded the maximum allowable content in 21% of the fueling stations checked in 2014 (Rosstandard, 2015). Though Russia banned high-sulfur diesel, the demand for cheap diesel remains because older engines, especially off-road vehicles, can save money by using high-sulfur diesel.

3.2 Diesel consumption

According to the Russian Ministry of Energy, Russia's domestic diesel supply was 32 million metric tons in 2014 (Minenergo, 2015). Euro 4 and Euro 5 diesel accounted for 88% (28 million metric tons) of the domestic diesel supply in 2014, which is more than enough to fuel all the Euro 4 and Euro 5 vehicles. In other words, fuel quality alone likely does not impact emissions.

On-road transport is the largest consumer of diesel, but estimates vary. There are several data sources on diesel consumption by on-road transport, including official statistics, officially commissioned fuel balances, data from international organizations, and bottom-up estimates.

The Russian fuel consumption statistics are based to a large extent on reports from enterprises. Only medium and large enterprises must report their fuel use to the Federal Statistics Service (Fedstat). Large companies must complete the so-called TER 4 form on fuel consumption “Fuels and energy inventory, inflow, consumption, and balance at the end of the reporting period.” The aggregated data are publicly available (Fedstat, 2015c, e). Another data source is the TER 11 form on fuel consumption by unit of production; however, this information is not available for all sectors. Small businesses are not required to submit this information, yet they employ 11 million people (Fedstat, 2015a, b, f, g) and produce more than 20% of goods and services (GKS, 2015b). Neither is there official information on diesel consumption by vehicles owned by individuals (for example, on diesel sold at fueling stations). As a result, the official data on diesel consumption by on-road vehicles are incomplete. However, large enterprises do not need to conduct surveys to analyze their sales, so the diesel data likely underreport diesel consumption by individuals and small enterprises.

According to Fedstat, vehicles owned by medium and large enterprises consumed 12.7 million metric tons of diesel in 2013 and 12.2 million tons in 2014 (Fedstat, 2015c). The International Energy Agency (IEA) reports that Russia’s on-road transport consumed 11.2 million tons of diesel in 2013 (IEA, 2015a). Both assessments likely underestimate the diesel consumption by on-road vehicles in the country.

There are several independent bottom-up estimates of diesel consumption by on-road transport. The Russian research company Petromarket estimated that on-road vehicles consumed 23.5 million tons of diesel in 2013 and 24.5 million tons in 2014. Analytical agency Avtostat calculated that on-road vehicles consumed 25.8 million tons of diesel in 2014 (Avtostat, 2015a). Avtostat also estimated that vehicles in the European part of the Russian Federation consumed 70% of fuel used by on-road transport. However, their assessments both have their limitations because they do not use a fuel balance approach; in other words they do not match diesel consumption by on-road vehicles and off-road engines with the production of diesel fuel in the country.

In this report, we use data from the Russian Center for Energy Efficiency (CENEf), which uses a balance approach for assessing the fuel consumption. CENEf is a leading Russian energy research organization commissioned by the Ministry of Energy to develop fuel balances. It has access to multiple types of fuel statistics and uses a sophisticated transport model to calculate fuel consumption by on-road vehicles. CENEf prepares the Russian energy balances by integrating the reporting forms from medium and large enterprises and bottom up calculations to cross-check allocations across sectors. CENEf also ensures that supply of crude oil and oil products balances demand. Table 2 shows the diesel consumption in 2014 (in thousand metric tons (kt).

Table 2. Diesel consumption by sector in 2014 (thousand metric tons).

Diesel consumption	2013	2014
Domestic supply	**30,350**	**31,991**
Transformation processes	1,211	1,349
Electricity plants	945	1,034
Heat plants	266	315
Energy industry own use (coal, oil, gas)	173	236

Final consumption	**28,966**	**30,406**
Industry	2,785	3,279
Mining	1,281	1,509
Other industry	1,504	1,771
Construction	438	414
Transport	23,993	24,970
Rail	2337	2,261
Road	21,066	22,189
Domestic navigation	423	372
Other transport	167	148
Agriculture and fishing	1,749	1,711
Agriculture	1,592	1,557
Fishing	157	154
Other	31	32

Source: (CENEf, 2016)

CENEf estimated that the total diesel consumption in the country was about 32 million metric tons in 2014. On-road vehicles used 22.2 million metric tons of the final diesel consumption. Other significant consumers of diesel are rail, diesel generators and boilers, industry, and agriculture.

We did not attempt to estimate the military fuel consumption. Military might be a large consumer of diesel in the country; however, none of the Russian experts were able to provide fuel estimates. We might assume that military consumption is spread throughout all sectors, but we cannot verify this assumption. We should note that the military uses diesel with high sulfur content. Most of the military equipment is designed for high-sulfur fuel; Russia prohibits low-sulfur diesel for military goals. From 1 January 2015, the intergovernmental standard GOST 305-2013 requires the 2000 ppm sulfur content for the defense orders (Rosstandard, 2013).

4 On-road transportation

4.1 Activity data

Registered fleet

We use the complete vehicle registry containing information from about 49 million records to analyze on-road transport in Russia. The Russian analytical agency Avtostat provided the official registry with detailed vehicle information on fuel type and emissions standard (Avtostat, 2015b). We also provide information from official vehicles registry (Table A9, A10).

According to Avtostat data, 40.83 million passenger cars were registered in Russia as of January 2015 (Table A11). The share of diesel passenger cars was 4.2% (Avtostat, 2015b). The popularity of diesel cars is growing in Russia, representing 7-8% of new sales. As Russia does not have large-scale production of diesel passenger cars, only 2% out of the 1.7 million diesel cars registered in Russia in 2014 were Russian models. All other diesel cars were imported or produced in Russia by foreign companies. Overall, foreign-make cars, both gasoline and diesel, constitute about 50% of the passenger fleet.

Among the 3.96 million light commercial vehicles (LCVs) registered in 2014, 28% used diesel. The share of diesel LCVs in new sales is also growing, and every other LCV sold in Russia is equipped with a diesel engine.

The heavy-duty truck fleet consists of 3.73 million vehicles. There were 2.32 million registered diesel trucks (62% of the truck fleet) registered in 2014. The fact that not all heavy-duty trucks use diesel plays an important role in emission calculations. Studies that assume that all heavy-duty trucks use diesel tend to overestimate their emissions.

In recent years, 98% of new trucks run on diesel. Russian-make heavy-duty trucks constitute about two thirds of the diesel truck fleet. We grouped all diesel trucks into four groups depending on their weight: <7.5 t (35% of the truck fleet), 7.5-12 t (19%), 12-14 t (9%) and above 14 t (37%) (RAMR, 2012). This classification is consistent with the COPERT and NIIAT models.

There were 0.39 million buses registered in Russia in 2014. Forty-five percent of buses run on diesel. Russian brands made up about two thirds of the diesel bus fleet. We group all diesel buses into three groups depending on their size: small buses (75% of the bus fleet), medium (12 %), and large and extra-large (13%).

Active vehicles

Russian experts point out that the official vehicle registry does not correctly reflect the number of vehicles on the roads (Avtostat, 2015c, 2016; Donchenko, 2013, 2016). A significant share of the fleet is very old: 28% of cars and 49 % of LCVs are older than 10 years; and 36% of trucks and 23% of buses are older than 20 years (Avtostat, 2015b). The fact that these vehicles are still registered does not mean that they are in working condition. Figures A1-A4 provide additional information about the age distribution of diesel vehicles. For emission calculations we assess the “active fleet,” that is, the vehicles that are used regularly.

To estimate the share of active vehicles, Avtostat used annual data from the Russian Union of Insurers about the number of insurance policies (stickers) issued. The total number of stickers issued is a good proxy for the active fleet because it is illegal to use vehicles without insurance stickers. According to Avtostat estimates, the share of active passenger cars is 76 % of the number of registered cars; for LCVs, buses, and trucks these shares are 80%, 49%, and 64%, respectively. Using the age distribution of diesel and gasoline vehicles, we calculated the share of active vehicles in the diesel and gasoline fleets. Table 3 shows the summary of our calculations. Table A12 shows the number of active diesel vehicles by type and emission standard in Russia in 2014.

Table 3. Percentage of active diesel and gasoline vehicles.

	Share of all active vehicles (Avtostat)	Share of active diesel vehicles (calculated)	Share of active gasoline vehicles (calculated)
Cars	76%	86%	75%
LCVs	80%	84%	67%
Trucks	49%	57%	41%
Buses	64%	70%	63%

Distribution by emission standard

Emission standards and fleet upgrades play an important role in emission reductions. For example, NIIAT estimated that from 2006, when Russia first had introduced emission standards, to 2011, PM emissions from on-road vehicles in the country dropped by 30% (Donchenko, 2007, 2013). This occurred even as the number of registered trucks and cars increased by 12% and 36%, respectively (GKS, 2014a).

Figure 2 shows the distribution of diesel vehicles by emission standard. Because gasoline vehicles emit practically no BC, gasoline vehicles were differentiated from diesel vehicles in the on-road fleet and not analyzed in this study (Table A13 provides additional information about gasoline vehicles).

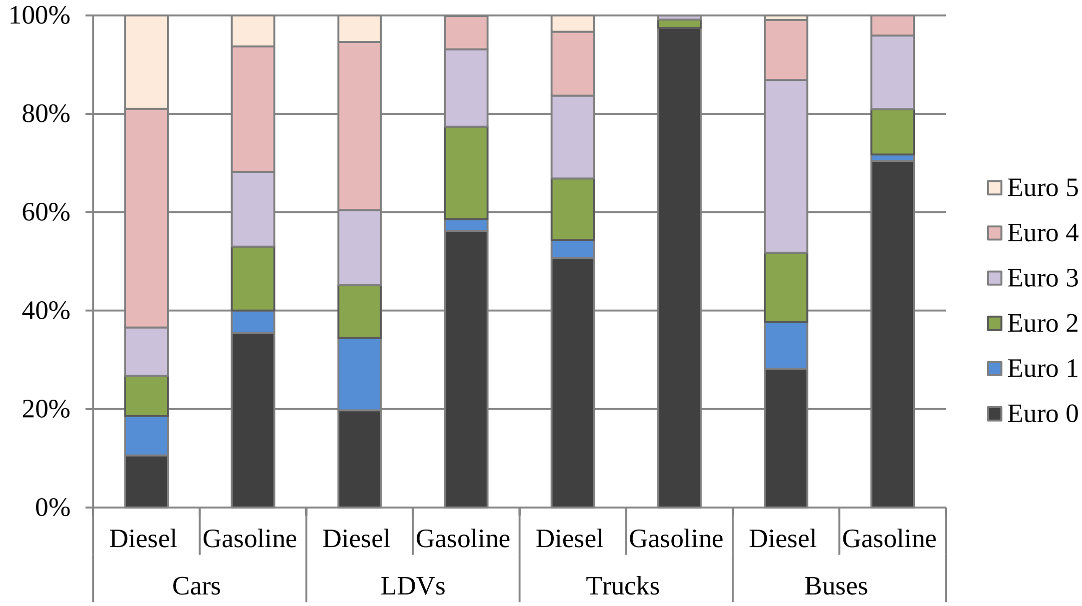

Figure 2. The distribution of diesel and gasoline vehicles by emission standard.

Source: (Avtostat, 2015b)

Superemitters

The concept of superemitters is not well defined in the literature. The common approach, however, is to define superemitters as vehicles that have very high emissions compared to regular vehicles (sometimes referred to as "high emitting vehicles"). In the vehicle testing studies, a cutoff level is used to determine the share of superemitters. For example, in Thailand, Subramanian et al. selected 4.7 g kg^{-1} as the cutoff for all diesel superemitters in their Bangkok study (Subramanian et al., 2009). In Chile, Faiz et al. used the cutoff level of 7.5 g kg^{-1} for buses in their Santiago study (Faiz et al., 1996).

For national emission inventories, the cutoff approach cannot be used for emission calculations. The commonly accepted approach is to define the share of superemitters in the fleet and use specific emission factors for these high-emitting vehicles. As a result, this study uses assumptions about the share of superemitters in the diesel fleet to provide a more realistic emission inventory.

Superemitters should be represented in inventories because they are responsible for a large share of emissions. For example, Ban-Weiss et al. (2009) measured emissions from 226 diesel trucks driving through a highway tunnel in California and found that 10% of the highest-emitting trucks were responsible for about 40% of total BC from trucks. In Beijing, Wang et al. (2011) found that approximately 5% of the trucks are responsible for 50 % of the BC emissions. In Slovenia, a study of 139 individual vehicles of different types showed that 25% of the highest-emitting diesel vehicles produce 63% of the BC emissions (Ježek et al., 2015). Preble at al. found that 20% of trucks emit 80% of the BC emissions from the Port of Oakland truck fleet (Preble et al., 2015).

Despite that superemitters emit a significant share of total emissions, there is a limited number of studies on their share of superemitters in the diesel fleet. For example, Subramanian et al. (2009) estimated that the fraction of superemitters in the studied diesel fleet in Bangkok is 15%. In their study of BC and PM emissions from 251 trucks in California, Ban-Weiss et al. (2009) found that about 13% of the diesel fleet are superemitters. Bond et al. (2004) assumed with a high uncertainty that the share of superemitters for countries "similar" to the United States is 5%. A recent study by the California Air Resources Board shows that 8 % of trucks were classified as high emitters (emitting over 5% opacity) from a sample of over 1800 truck tests (CARB, 2015). We should note that US EPA no longer uses the concept of superemitters to estimate vehicle emissions (EPA, 2015).

There are no known studies on superemitters in Russia. Bond et al. (2004) assumed that the share of superemitters in Eastern Europe and the former Soviet Union is 10%. This estimate also was used in other studies (Yan et al., 2011; Yan et al., 2014). This study uses the assumption that the share of superemitters in the Russian diesel fleet is 15%.

We use a logistic function from (Yan et al., 2011) to represent the rate at which normal vehicles become superemitters (Eq. 2).

$$fr\ (s) = \frac{gain}{1+\exp[\alpha\ \mathrm{sup}(1-{}^{s}/_{L50\ \mathrm{sup}})]} \tag{2}$$

where *fr* is the fractional rate at which normal vehicles become superemitters (fraction per year); *gain* is the maximum rate of superemitter transition, a_{sup} determines the slope of the transition curve with age, *s* is vehicle age, and $\mathrm{L}_{50,\mathrm{sup}}$ is the vehicle life at which the rate becomes half the maximum.

Since retired (inactive) vehicles were already from the registry, we modified the *gain* parameter in the formula to obtain the number of superemitters, which equal 15% of the total active diesel fleet. In this study, the parameters of the formula are as follows: a_{sup} = 5.5; $L_{50,sup}$ = 5.0; and *gain* = 0.024.

The share of superemitters in the fleet depends on the vehicle age. Using Formula 2 we calculated that this share is less than 3% for vehicles less than 5 years old, close to18% among 10 year-old vehicles, and 50% for 20 year-old vehicles. Since the age distribution varies by vehicle type, using Formula 1 we calculated the fraction of superemitters in the diesel fleet: 10% for cars, 17% for LCVs, 19% for trucks, and 15% for buses. As mentioned above, the overall share of superemitters in the diesel fleet is 15%.

Using the information on diesel consumption by vehicle type and the percentage of superemitters in the fleet, we calculated that superemitters consumed about 4,000 t of diesel or 18% of total diesel consumption by on-road vehicles. Based on Yan et al. (2011) we assume that PM emission factors for diesel on-road superemitters is 8.31 g kg^{-1} for older engine superemitters

(Euro 0 and Euro 1) and 2.92 g kg^{-1} for newer engine superemitters (Euro 2–Euro 5) (See Table A4 for detail). We also tested an assumption from (McClintock, 2011) that the emission factors of superemitters are six times higher than the average of the on-road diesel fleet. Using Russian-specific emission factors, we assume that the PM emission factor for superemitters is 0.39 g km^{-1} for cars, 0.59 g km^{-1} for LCVs, 0.8 g km^{-1} for trucks, and 1.31 g km^{-1} for buses. These two approaches yield very similar results (difference is about 3%).

We assume that the share of superemitters in the off-road fleet is the same as in on-road one (15 %). Following Bond et al. we assume that the PM emission factor for off-road superemitters is 12 g kg^{-1} and OC/BC ratio is 0.21 (Bond et al., 2004).

Annual distance traveled

The annual average distance traveled is one the most important parameters in the COPERT model. We use several sources to estimate the annual number of kilometers traveled by type of vehicles in Russia. NIIAT developed a methodology for assessing the residual value of vehicles based on their age and kilometers traveled (NIIAT, 1998). This methodology provides estimates of the annual average distance traveled by type of vehicles, country of production, and road type. In its emission calculation methodology (2008, 2012), NIIAT estimated the average annual distance traveled for the total fleet. Avtostat conducted an extensive study of vehicle activity and estimated the average annual kilometers traveled by Russian and foreign-made cars. Avtostat also provided its estimates on average kilometers traveled by LCVs, trucks, and buses. We use the Avtostat assumptions for emission calculations. Table A14 shows the assumptions on average of annual kilometers traveled in different models/methodologies. Supplement Table A15 provides details on our assumptions on annual kilometers traveled by vehicles by Euro class.

The average speed is assumed to be 25 km h^{-1} in cities, 40 km h^{-1} on rural roads, and 90 km h^{-1} on highways. The assumption on the speed in cities is based on actual speed in Moscow and other large cities. The assumptions on the average speed on rural roads and highways are based on maximum allowable (standard) speed on these types of roads in Russia. The share of vehicle-kilometers traveled (vkt) on urban roads is taken from the ICCT Roadmap model (ICCT, 2015). The share of vkt on urban roads is 75% for cars, light commercial vehicles, and buses and 50% for trucks. The rest of VKT is divided by 40:60 between rural roads and highways.

5 Off-road diesel sources

5.1 Rail

The total length of railroads is 86 000 km, and about 60% of them are electrified (GKS, 2014b). Given the size of the country, the density of railroads is low compared to other European countries. Rail cargo turnover was 2301 billion tonne-kilometers (tkm) in 2014, which is almost ten times larger than that of road transport (247 billion tkm). In 2013, diesel locomotives transported almost 15% of all rail cargo (GKS, 2014b) (See Table A16 for detail).

The Russian Railway Company (RZhD, based on the Russian acronym) is the largest owner of diesel locomotives in the country. RZhD owned 10 400 electric locomotives and 10 200 diesel locomotives in 2013, including 3,500 line haul and 6100 shunting locomotives (Balabin and Evpakov, 2013). In addition to RZhD's stock, large industrial companies also own about 12,000 locomotives to form trains. In 2012, RZhD started using Euro 3 diesel (350 ppm) for its diesel locomotives (RZhD, 2013) (Table A17).

The locomotive fleet is old: about 50% of long-line haul locomotives are more than 15 years old (Table A18). Diesel locomotives in Russia have no emission controls. The EEA guidebook presents the emission factors for diesel locomotives based on average European fleet (1.37 g kg^{-1}). Given that the Russian locomotives are older than those in Europe, we use the emission factor from Yan (2014) for locomotives without emission controls. Thus, we assume that the PM emission factor for diesel locomotives in Russia is 4.62 g kg^{-1}.

5.2 Domestic navigation and fishing

Domestic navigation and fishing represent different economic sectors but use similar combustion technologies. Liquid bulk ships, dry cargo carriers, and container ships mainly use heavy bunker fuel oil, while passenger ships, fishing boats, and tugs use diesel. Diesel ships tend to be smaller than those using bunker fuel oil. Almost all ships use diesel during maneuvering and while docked at shore. As a result, emissions from domestic navigation and fishing are presented in the same category.

Russia is a large marine state with the third longest coastline in the world. There are 67 sea ports in Russia; although only a few are ice-free in winter. The largest areas of maritime activity are the Baltic Sea, the Black Sea region, and the Far East. The Arctic region accounts for 5.6% of cargo turnover, but its maritime activity is rapidly expending given the increasingly ice-free Northern Sea Route.

Most marine and fishing vessels in Russia are old. For example, over 70% of river and lake vessels are older than 25 years (Mintrans, 2015). Similarly, over 80% of fishing ships are over 20 years old (WCIOM, 2015).

The cargo fleet has been shrinking: there were 3,830 sea-going vessels in 2000, 3,514 in 2005, and 2,712 in 2014. The number of river vessels decreased from 31,800 in 2000 to 21,800 in 2014 (GKS, 2015b).

Ships were estimated to have used 526 kt of diesel in 2014. This does not include military consumption, which could be very significant. Ships were assumed to have no emission controls since Russia has no emission standards for them.

5.3 Agriculture

According to estimates from the Ministry of Agriculture, agricultural companies in 2014 owned 420,000 agricultural tractors, 153,000 harvesters and 22,000 other motor vehicles (Ministry of Agriculture, 2015) (Table A19). In Russia, the agricultural fleet has been shrinking (Ministry of Agriculture, 2015). For example, there were 15,000 fewer tractors in 2014 than in 2013. In 2014, the retirement rate for tractors was 5.1% while the replacement rate was 3.2% (GKS, 2015a) (Tables A20-A21).

Tractors produced in Russia, Belarus, and Ukraine constitute over 90% of the tractor fleet (Table A22), and the majority of tractors are over 10 years old (Ministry of Agriculture, 2015). As a result, the availability of emission controls is very limited. Moreover, until recently, there were no emission standards for agricultural vehicles in Russia. Because of new emission standards for agricultural vehicles in Russia, emissions may possibly drop in the future.

Since Russia has limited production of agricultural tractors (about 3 % of new sales), foreign-made agricultural machinery dominates new sales (Agroinfo, 2015) (Table A23). The share of used tractors in the total imports was 20% in 2014. Tractors imported from Western countries were assumed to have emission controls; however, their share in the total agricultural fleet is very small (no more than 5%).

Over 80% of tractors in Russian have engine power less than 120 horsepower (Table A24). We assume that the distribution by emission standard is as follows: 95% is Stage 0 (without emission controls) and 5% meets Stage 2 standards.

5.4 Industry

Mining

The mining sector consumes about half of the industrial diesel. Russia is a major mineral and coal producer. Russia produced 357 million tons of coal in 2014 and is also a leading global producer of many other mined commodities, including aluminum, copper, iron ore, lead, and nickel, among others (USGS, 2016).

Open-pit mining is widespread in Russia due to its relatively lower production costs. Sixty-five percent of the coal produced in 2014 was in open-pit mines (EMIS, 2014; GKS, 2015b). Mining trucks consume 70–80% of the diesel at open pit mines both due to their large engines and the fact that mining operations continue nonstop. On average each truck operates well over 6300 h yr^{-1} (Mining Magazine, 2007). The Belarusian company BELAZ supplies the majority of the largest mining trucks (Petrovich et al., 2013), and most BELAZ trucks are equipped with Cummins and MTU engines. The average life of mining trucks is short: BELAZ trucks operate for 5–7 years (Zvonar, 2010), while Caterpillar mining trucks operate for 9-12 years (Anistratov, 2013).

Russia has no emission standards for off-road mining vehicles, and, as a result, Western companies can supply engines without emission controls. For example, about 88% of Cummins engines in Russia have no controls, and the remaining 12% meet US EPA Tier 1 requirements (Mueller, 2014). A small population of Caterpillar and Komatsu trucks also meet Tier 1 or Tier 2 requirements.

The role of the mining industry in diesel consumption and BC emissions is especially important in the Russian Arctic. For example, in their study of BC emissions in the Arctic, Evans et al. (2015) found that the mining industry emits about 70% of all diesel BC emission in the Murmansk Region. A second study on BC emissions in the Russian Arctic found that the mining industry emits 80% of BC emissions from combustion in Russia’s Arctic zone (Morozova, 2015).

We assume that 88% of engines in the mining industry are Tier 0 (1991–Stage 1) and 12% are Tier 1 (Stage 1).

Construction

The construction industry is an important sector of the Russian economy. In 2013, 5.7 million people were employed in construction (8% of the labor force). Over 226 000 construction companies worked in Russia in 2014 (GKS, 2015b), indicating that most of them are small businesses.

The construction industry uses more varieties of diesel engines than any other sector of the economy (Table A25). Most of construction equipment is old and lacks emission controls (A26). About 30-50% of these excavators, loaders, bulldozers, and graders have reached their end of useful life (Rosstat, 2014). Though up to 60% of construction machinery is imported depending on type of vehicles, they do not necessarily have emission controls. We assume that the distribution by emission standard is as follows: 90% of construction machinery is Stage 0 (without emission controls) and 10% have some emission controls.

Other industry

Other types of industries that use diesel include production of iron, steel, non-ferrous metals, chemicals, machinery, food, paper, wood products, textiles, and other types of goods. In these industries, a huge variety of diesel machinery and equipment exists and is assumed to be primarily heavy industrial equipment with no emission controls.

5.5 Diesel generators

About 60% of Russia's territory is not connected to the centralized electricity grid (Suslov, 2012). Twenty million people live in these off-grid areas, which include cities, towns, and villages (Zatopliaev and Redko, 2004). Stationary diesel generators produce electricity in small isolated grids in remote locations.

About 47 000 diesel generators provide electricity; 12,000 of these are in the northern part of the country. The typical generator power capacity ranges from 100 kW to 3.5 MW. At the beginning of the 2000s, the installed capacity of diesel generators was about 17 million kW or 8% of the total installed capacity in Russia (Minenergo, 2012) (Table A27). According to the Russian Statistical Service, large diesel power stations generated 4,000 GWh of electricity in 2014 (Fedstat, 2015d). (Table A28)

In addition to electricity generation, diesel can be used to produce heat. Diesel boilers and heat pumps are used in areas without centralized district heating. The process of external combustion in boilers is quite different from that in diesel engines, and as a result PM emission factors and BC/PM ratios for external combustion are lower than those from internal combustion engines (Bond et al., 2004).

In 2014 diesel generators used 1.034 million tons of diesel and heat plants used an additional 315 kt.

6 Results of BC emission calculations

6.1 On-road vehicles

BC emissions from diesel on-road vehicles were calculated using the COPERT 4 model with NIIAT emission factors. Superemitters were excluded from our initial emission calculations with the COPERT model. Instead, emissions from superemitters were calculated using Formula 1 and added to COPERT results.

Table 4 shows the results of emission calculations from active diesel vehicles. Heavy-duty trucks emitted 60% of all on-road diesel BC, while passenger cars emitted only 5%.

Table 4. BC emissions from active on-road diesel vehicles in 2014, (Gg).

	Cars	LCVs	Trucks	Buses	Total
Euro 0	0.1	0.7	3.5	0.3	4.6
Euro 1	0.0	0.3	0.3	0.1	0.8
Euro 2	0.1	0.4	1.2	0.3	2.0
Euro 3	0.1	0.5	1.6	0.4	2.7
Euro 4	0.2	1.0	0.4	0.0	1.6
Euro 5	0.0	0.0	0.1	0.0	0.1
Total Euro 0-5	0.6	2.8	7.2	1.1	11.8

Superemitters	0.5	2.7	5.1	0.7	8.9
TOTAL	1.1	5.5	12.3	1.8	20.7

The results show that superemitters emitted 8.9 Gg of BC or 43% of all diesel on-road BC emissions. The role of superemitters in emissions by type of vehicles varies from to about 40% for buses and heavy-duty trucks to 44% for cars and 48% for light-duty vehicles.

The total BC emissions from on-road diesel vehicles are estimated at 20.7 Gg in 2014. Heavy-duty trucks emitted 60% of all on-road diesel BC emissions. We also estimated that normal vehicles have emitted 5.6 Gg of OC emissions, and superemitters produced an additional 4.9 Gg of OC in 2014 (see Table A29 for details).

As mentioned above, it is important to separate diesel vehicles from gasoline ones, exclude vehicles that are not in use, and factor in superemitters. If one assumed that all heavy-duty vehicles use diesel, BC emissions from trucks alone would be 39.66 Gg of BC, significantly overstating the total. Likewise, BC emissions from all registered diesel vehicles (as they appeared on the vehicle registry) are 29.09 Gg. Emissions from the adjusted fleet without accounting for superemitters would be 16.26 Gg (See Supplement Tables A30-A32 for details).

To show the distribution of BC throughout the Russian territory, we divided total BC emissions by the number of registered heavy duty trucks in the regions. Given that trucks consume 78% of diesel in Russia, this approach gives reasonable estimates of BC emissions. We divide regional BC emissions by the area of the regions to calculate BC emissions by square kilometer in each Russian region. (Table A33, Map A1)

6.2 Off-road diesel sources

Table 5 presents the results of emission calculations from off-road diesel sources in Russia as well as the total for on-road transportation in 2014. We estimate that all off-road sources emitted 22.9 Gg of BC and 5.3 Gg of OC. The largest emission contributors in the off-road sector are industry, locomotives, and diesel generators. This study also includes superemitters in the off-road diesel fleet. The role of superemitters in the off-road fleet is less important than for the on-road fleet due to differences in emission factors between normal engines and superemitters. We estimate that off-road superemitters are responsible for 21% of BC emissions from off-road sources.

Table 5. BC and OC emissions in Russia in 2014 (Gg).

Sector	BC	OC
On-road vehicles	20.7	10.5
Rail	8.4	1.7
Other industry	5.3	1.1
Mining	4.4	1.3
Agriculture	4.2	1.2
Diesel generators	4.1	0.8

Construction	1.2	0.4
Ships	0.5	0.1
Other sectors	0.4	0.1
Total	49.2	17.2

Rail is the largest source of off-road BC emissions because of outdated equipment and high emission factors, as well as the extensive use of diesel locomotives in off-grid parts of Russia. Industry is a large source because of the diversity of small uses without emission controls. Diesel generators without emissions controls produced more BC emissions than the mining industry because of the lack of emission controls and larger emission factors.

These results show that off-road diesel sources emit 57% of the total diesel BC in Russia. These high levels of emissions from off-road sources are a result of the limited use of emission control technologies, a function both of the equipment age and the lack of regulations for new equipment. This contrasts with emissions from on-road vehicles, where standards were introduced a decade ago, and emissions have subsequently dropped. While consuming 70% of the diesel fuel in the country, on-road vehicles produced 43% of BC emissions in 2014.

7 Comparison with other studies

There have been several studies looking at BC emissions in Russia across a range of sectors, but the majority of these studies use fuel-based, mass balance approaches to calculating emissions. In previous studies, emissions from on-road transport were estimated based on the number of registered vehicles or in the best case on vehicles separated into a few emission standards. A limited number of studies have assessed the existence of control technologies and other detailed, real-world activity data. None of the studies accounted for superemitters in the fleet.

Table 6 below shows the result of several previous studies covering total anthropogenic BC emissions, emissions from transport or all diesel sources.

Table 6. The results of BC emission studies for Russia.

Study	Base year	Emission source categories	BC emissions (Gg)
Bond et al. (2004)	1996	Agricultural burning, industry, open fire, power generation, residential biofuels, road-transport, off-road transport	200
Lamarque et al. (2010)	2000	Residential/domestic sources, forest fires, industry, diesel engines	360
		Diesel transport (including aircrafts and	32

		marine shipping)	
IIASA ECLIPSE dataset (Sand et al., 2016)	2010	All anthropogenic emissions (domestic, energy/industrial/waste, transport , agricultural fires, gas flaring)	182
		Transport	52
Huang et al. (2015)	2010	Flaring, residential, transport, industry, and power plants	224
		On-road transport	45
Russia's National Report to the Arctic Council (MNRE,2015)	2013	All anthropogenic emissions (agriculture, industry, transport, services)	359
		Transport	8 Gg
Donchenko (2006)	2006	On-road transport	54 Gg PM (29 Gg BC)*
Donchenko (2013)	2011	On-road transport	39 Gg PM (20 Gg BC)*
Evans et al. (2015)	2010	All diesel sources	46
		On-road diesel transport	20
This study	2014	All diesel sources	43
		On-road diesel transport	21

* - Assuming that BC/PM speciation ratio for on-road transport is 0.53 (EEA, 2013)

There are two wide categories of studies on Russian BC emissions. Emission estimates in the first category are based on fuel consumption, use global or regional emission factors, and mostly do not use Russian activity data. For example, Bond et al. (2004) combined fuel consumption data and application of combustion technologies and emission controls (Bond et al., 2004; Sarofim et al., 2009). Lamarque et al. (2010), updating the Bond data (2004), estimated that diesel engines are likely to be the fourth largest source of BC emissions in Russia after residential/domestic sources, forest fires, and industry (EPA, 2012b; Lamarque et al., 2010). The International Institute for Applied Systems Analysis (IIASA) uses the Regional Air Pollution INformation and Simulation (RAINS) model and Evaluating the Climate and Air Quality Impacts of Short-Lived Pollutants (ECLIPSE) model to estimate PM and BC emissions. BC emissions from transport were estimated to be 52 Gg in 2010 (Sand et al., 2016).

The second category of Russian BC studies is based on Russian activity data, where Russia-specific emission factors were used for on-road transport and/or bottom-up fuel consumption data. Some of these studies were completed in the framework of BC mitigation efforts in the Arctic. In 2015, Russia submitted its first report to the Arctic Council on BC and methane emissions reductions. The total Russia-wide BC emissions were estimated to be 358.5 Gg in 2013 (MNRE, 2015). Transport was not determined to be a significant source of BC emissions (7.7 Gg or just 2% of the emissions). An international group of scientists led by the US Department of Energy estimated BC emissions in the Russian Arctic and in Russia from anthropogenic sources (Huang et al., 2015). Drawing on local Russian information, Russian BC emissions were estimated to be 224 Gg in 2010. Using vehicle registry data, BC emissions from transport were estimated to be 45.3 Gg (Huang et al., 2015). The authors assumed that all registered vehicles are actively used and all vehicles use diesel fuel. The paper does not present the vehicular emissions by vehicle type or emission standard.

NIIAT estimated that Russian on-road vehicles emitted 53.9 Gg PM in 2006 (Donchenko, 2007) and 38.5 Gg PM in 2011 (Donchenko, 2013). NIIAT used the Russian PM emission factors and, until recently, had not calculated BC emissions. NIIAT used detailed information about the number of diesel vehicles and adjusted the registry to reflect the share of the active fleet. NIIAT does not account for superemitters in emission calculations.

Evans et al. (2015) used the IEA diesel data and estimated BC emissions from all diesel sources, including diesel transport, in Russia. Using fuel-based emission factors from the EEA emission guidebook and NIIAT emission factors, BC emissions from on-road transport were estimated to be about 20.0 Gg (Evans et al., 2015). Similarly, Kholod and Evans (2016) use the Global Change Assessment Model (GCAM) to build a forecast for BC emissions from on-road transport in Russia. Total BC emissions from on-road transport were estimated to be about 20.0 Gg in 2015. The model, however, does not calculate emissions from vehicles by emission standard, which is important for developing emission reduction strategies.

We can conclude that the results of the emission calculations presented in the current study are close to those studies that used detailed Russian activity data (number of active diesel vehicles, annual average distance traveled, and Russian emission factors). The advantages of the current study are that we present the BC emissions from on-road transport by vehicle types and emission standards, factor in superemitters, and also present OC emissions from on-road vehicles and off-road diesel sources.

8 Uncertainty

There are two major sources of uncertainty in BC emission inventories: 1) emission factors and 2) activity data. Emission factor uncertainty includes uncertainties in PM emission factors for normal vehicles and superemitters and BC/PM speciation ratios. NIIAT does not report the uncertainty in PM emission factors for on-road vehicles. In COPERT, the uncertainty for PM emission factors is estimated to be 20–30% (Kouridis et al., 2010). Uncertainty in PM emission factors for off-road sources is 30-60% for agricultural vehicles, 25-50% for ships, and an order of magnitude for industry (EEA, 2013).

Activity data also present uncertainties because of uncertainties in underlying surveys or estimation methodologies. This includes data on fuel consumption by sector, distribution by vehicle type, annual number of kilometers traveled, and assumptions about emission controls. Fuel data differ by a lot, as well as the average annual distance traveled. The distribution by vehicle type and controls for on-road transport is less uncertain. Off-road uncertainty on emission controls is larger because more emission controls may exist than was assumed. We use several approaches to minimize uncertainties in the activity data, including multiple approaches to data collection, cross-checks with the literature, and expert judgments.

Uncertainty in $BC/PM_{2.5}$ speciation ratios for on-road vehicles is 5–10% for light-duty vehicles and 20% for heavy-duty engines. The speciation ratio uncertainty for off-road diesel sources is 20% (EEA, 2013). The speciation ratios are not a major source of uncertainty in emission inventories for diesel BC sources.

Our data on fuel consumption are based on bottom-up calculations and are close to the Russian official statistics. While there is uncertainty in the distribution between economic sectors, the total domestic diesel supply is well determined.

Assumptions on emission controls do not significantly contribute to uncertainties in emissions because about 90–95% of off-road diesel engines is assumed to have no emission controls. However, real emission factors for Russian diesel sources are not well understood. For on-road vehicles, the distribution by emission standards is well determined based on the registry. The key uncertainty here is the assumption of the share of active vehicles.

Another source of uncertainty is the share of superemitters in the on-road and off-road fleets. For emission calculations, the share of superemitters is assumed to be 15%. This number is to some extent arbitrary because it was determined based on a small number of studies. In addition, heavy-duty trucks are designed to meet emissions limits up to a specified maximum loading, and overloading can significantly increase the share of high-emitting vehicles (World Bank, 2014). There is evidence that Russian drivers tend to overload their trucks, especially on the long-haul routes, to save time and increase their short-term profit. According to the Russian Federal Road Agency, 30–40% of heavy-duty trucks are overloaded on average by 45% (Avtodor, 2015). As a result, the share of superemitters in the truck fleet might be higher. For on-road vehicles, three major sources of uncertainty were considered: the share of superemitters in the fleet, average annual distance traveled, and emissions factors for normal vehicles and superemitters. Supplement Table S10 shows the assumptions for uncertainty calculations for on-road vehicles.

The central value of BC emissions from on-road vehicles in 2014 is 20.7 Gg with an uncertainty range of -10.2 Gg and + 7.3 Gg. The central value of OC emissions is 10.5 Gg with an uncertainty range of -4.2 Gg and + 3.2 Gg.

The uncertainty in BC emissions from off-road sources is estimated in the range from 19.2 Gg to 42.1 Gg (or -33%/+48%) with the central value of 28.5 Gg. OC emissions from off-road engines are in the range from 4.5 Gg to 9.8 Gg with the central value of 6.7 Gg.

The total emissions from diesel sources in Russia are estimated to be 49.2 Gg of BC and 17.2 Gg of OC in 2014.

9 Conclusions

We estimate BC and OC emissions from diesel sources in Russia for the base year of 2014. We use detailed vehicle registry data containing information from about 49 million records to analyze on-road transport in Russia.

We differentiated diesel vehicles from gasoline ones, estimate the share of active vehicles in the fleet, use detailed information on distribution by vehicles types and emission standards, and use Russia-specific emission factors for emission calculations. This study also factors in the role of superemitters in BC emissions from on-road diesel vehicles. Emissions from on-road diesel vehicles are estimated at 20.7 Gg of BC and 10.5 Gg of OC in 2014. Heavy-duty trucks emitted 60% of BC, while diesel passenger cars emitted only 5% due to their small share in the total passenger fleet and availability of emission controls. Assuming that the share of superemitters is 15% in the on-road diesel fleet, we estimate that these high-emitting vehicles are responsible for 33% of all BC emissions from on-road vehicles. Under this assumption, the role of superemitters in emissions by vehicle type varies from about 40% for trucks and buses to 40% for cars and 48% for LCVs.

We also estimate BC emissions from off-road diesel sources including diesel locomotives, ships, off-road engines in industry, construction and agriculture, and from diesel generators. We estimate that off-road diesel sources emitted 28.5 Gg of BC and 6.7 Gg of OC in Russia in 2014. Stationary engines in industry are the largest source of off-road BC emissions followed by locomotives, agriculture, and diesel generators. Off-road diesel sources emitted 58% of all diesel BC emissions. Off-road superemitters emitted 43% of emissions from off-road diesel sources. These results do not include emissions from military diesel usage. Military vehicles can be a large source of BC emissions given that they use high-sulfur diesel.

The total emissions from diesel sources in Russia are estimated to be 49.2 Gg of BC and 17.2 Gg of OC in 2014.

References

Agroinfo, 2015. Russian market of agricultural machinery in 2014 (in Russian). Agroinfo, availbalbe at http://agroinfo.com/rossijskij-rynok-selxoztexniki-v-2014-godu-1603201505/ (last access: 26 February 2016).

Anistratov, K., 2013. Justification of mining fleet selection for trucks with payload capacity of 40-100 tons (in Russian). Mining Business 1, 1–10.

Avtodor, 2015. On roads without overloading. Russian Federal Road Agency, Moscow. Available at http://rosavtodor.ru/activity/123/15335.html (last access: 5 May 2016).

Avtostat, 2015a. Fuel consumption by on-road transport in Russia in 2014. Availble at http://www.autostat.ru/news/view/20962/ (last access: 28 October).

Avtostat, 2015b. Park of PC, LCV, HCV, BUS as of 01. 01.2015 (Russia, Russian regions). Dataset. Avtostat, Togliatti, Russia.

Avtostat, 2015c. Vehicle fleet in Russia in 2014 (in Russian). Avtostat. Available at http://avtostat-info.com/Article/130 (last access: 18 February 2016).

Avtostat, 2016. Vehicle fleet in Russia in 2015 (in Russian). Avtostat. Available at http://avtostat-info.com/Article/189 (last access: 21 May 2016).

Balabin, V.N., Evpakov, V.V., 2013. Production of switch and industrial diesel locomotives: Developmental problems of the industry (in Russian). Transport of the Russian Fedeartion 6, 30–33.

Ban-Weiss, G.A., Lunden, M.M., Kirchstetter, T.W., Harley, R.A., 2009. Measurement of black carbon and particle number emission factors from individual heavy duty trucks. Environ. Sci. Technol. 43, 1419–1424.

Bond, T., Streets, D., Yarber, K., Nelson, S., Woo, J.-H., Klimont, Z., 2004. A technology-based global inventory of black and organic carbon emissions from combustion. J. Geophys. Res. 109.

Bond, T., Sun, H., 2005. Can reducing black carbon emissions counteract global warming? Environ. Sci. Technol. 39, 5921–5926.

Bond, T.C., Doherty, S.J., Fahey, D.W., Forster, P.M., Berntsen, T., DeAngelo, B.J., Flanner, M.G., Ghan, S., Kärcher, B., Koch, D., Kinne, S., Kondo, Y., Quinn, P.K., Sarofim, M.C., Schultz, M.G., Schulz, M., Venkataraman, C., Zhang, H., Zhang, S., Bellouin, N., Guttikunda, S.K., Hopke, P.K., Jacobson, M.Z., Kaiser, J.W., Klimont, Z., Lohmann, U., Schwarz, J.P., Shindell, D., Storelvmo, T., Warren, S.G., Zender, C.S., 2013. Bounding the role of black carbon in the climate system: A scientific assessment. J. Geophys. Res. 118, 5380–5552.

CARB, 2015. Evaluation of particulate matter filters in on-road heavy-duty diesel vehicle applications. California Air Resources Board. Available at http://www.arb.ca.gov/msprog/onrdiesel/documents/DPFEval.pdf (last access: 10 May 2016).

Donchenko, V., 2007. Environmental performances of motor vehicles and fuels in the Russian Federation and CIS countries Scientific Research Institute of Automobiles and Transportation (NIIAT), Moscow. Available at http://www.unep.org/transport/pcfv/PDF/Session4-TbilisiRegionalWorkshop-VadimDonchenko.pdf (last access: 21 May 2016).

Donchenko, V., 2013. Environmental performances of motor vehicles and fuels in the Russian Federation. Scientific Research Institute of Automobiles and Transportation (NIIAT), Moscow.

Donchenko, V., Trofimenko Y., Kunin Y., Ruzski A., Baryshev L., Mekhonoshin V., Sazonova G., 2016. Assessment of pollutants and greenhouse gases emissions from motor vehicles in Moscow using a transport model. Presented at the "City Transportation and Environment of a Modern City" conference, 6 April 2016, Moscow.

EEA, 2013. EMEP/EEA air pollutant emission inventory guidebook – 2013. European Environment Agency, Copenhagen, Denmark. Available at http://www.eea.europa.eu/publications/emep-eea-guidebook-2013 (last access: 15 July 2014).

EMIS, 2014. Coal mining sector. Russia. Emerging Markets Information Service. Available at https://www.emis.com/sites/default/files/Russia%20Coal%20Mining%20Sector%20Report.pdf (last access: 15 May 2016).

Emisia, 2015. COPERT (COmputer Programme to Calculate Emissions from Road Transport). Prepared for the European Environment Agency, Version 11.0 ed. Available at http://www.emisia.com/copert/ (last access:15 July).

EPA, 2015. Exhaust emission rates for heavy-duty on-road vehicles in MOVES 2014. EPA-420-R-15-015a. US Environmental Protection Agency, Ann Arbor, MI. Available at http://www.epa.gov/otaq/models/moves/moves-reports.htm (last access: 13 May 2016).

EPA, 2016. Reduction of black carbon from diesel sources in the Russian Arctic. US Environmental Protection Agency, Availbale at https://www.epa.gov/international-cooperation/black-carbon-diesel-initiative-russian-arctic (last access: 26 May).

Eurasian Commission, 2011a. Technical Regulation TR CU 010/2011 dated 18 October 2011 "On safety of motor vehicles" (in Russian). Eurasian Commission, Moscow. Available at http://www.eurasiancommission.org/ru/act/texnreg/deptexreg/tr/Documents/P_823_1.pdf (last access: 26 October 2015).

Eurasian Commission, 2011b. Technical Regulation TR CU 013/2011 dated 18 October 2011 "On requirements for automobile and aviation gasoline, diesel and marine fuel, jet fuel and heating oil" (in Russian), Eurasian Commission, Moscow. Available at http://www.eurasiancommission.org/ru/act/texnreg/deptexreg/tr/Pages/trebBenzin.aspx (last access 13 April 2014).

Eurasian Commission, 2012. Technical Regulation TR CU 031/2012 dated 20 July 2012 "On Safety of Agricultural and Forestry Tractors and Trailers" (in Russian), Eurasian Commission, Moscow. Available at http://www.eurasiancommission.org/ru/act/texnreg/deptexreg/tr/Documents/P_60.pdf (last access: 26 October 2015).

Evans, M., Kholod, N., Malyshev, V., Tretyakova, S., Gusev, E., Yu, S., Barinov, A., 2015. Black carbon emissions from Russian diesel sources: case study of Murmansk. Atmos. Chem. Phys. 15, 8349–8359.

Faiz, A., Weaver, C.S., Walsh, M.P., 1996. Air pollution from motor vehicles: standards and technologies for controlling emissions. World Bank, Washington, DC.

Fedstat, 2015a. Average number of employees in micro enterprises (in Russian). Unified Interdepartmental Statistical Information System. Available at http://fedstat.ru/indicator/data.do?id=40651 (last access: 19 October 2015).

Fedstat, 2015b. Average number of employees in small enterprises (in Russian). Unified Interdepartmental Statistical Information System. Available at http://fedstat.ru/indicator/data.do?id=33434 (last access: 19 October).

Fedstat, 2015c. Diesel fuel used by vehicles owned by enterprises (in Russian). Unified Interdepartmental Statistical Information System. Available at http://fedstat.ru/indicator/data.do?id=37264 (last access: 19 October).

Fedstat, 2015d. Electricity produced by diesel generators, 2010-2015 (in Russian). Unified Interdepartmental Statistical Information System. Available at http://fedstat.ru/indicator/data.do?id=40557 (last access: 19 October).

Fedstat, 2015e. Fuels Used as a Motor Fuel. Unified Interdepartmental Statistical Information System. Available at http://fedstat.ru/indicator/data.do?id=40478 (last access 19 October).

Fedstat, 2015f. Number of micro enterprises (in Russian). Unified Interdepartmental Statistical Information System. Available at http://fedstat.ru/indicator/data.do?id=40652 (last access: 19 October).

Fedstat, 2015g. Number of small enterprises (in Russian). Unified Interdepartmental Statistical Information System. Available at http://fedstat.ru/indicator/data.do?id=33474 (last access: 19 October).

Fedstat, 2015h. Production of main goods in the Russian Federation (in Russian). Unified Interdepartmental Statistical Information System. Available at http://fedstat.ru/indicator/data.do?id=40557 (last access: 19 October).

GBD, 2016. The global burden of disease study 2013. Institute for Health Metrics and Evaluation, Seattle, WA. Available at http://ghdx.healthdata.org/gbd-data-tool (Last access: 12 July).

GKS, 2014a. Russian Statistical Yearbook 2014. Federal Statistics Service of the Russian Federation, Moscow. Available at
http://www.gks.ru/wps/wcm/connect/rosstat_main/rosstat/ru/statistics/publications/catalog/doc_1135087342078 (last access: 13 October 2015).

GKS, 2014b. Transport and Communication in Russia. 2014 Statistical Yearbook. Federal Statistics Service of the Russian Federation. Available at http://www.gks.ru/bgd/regl/B14_5563/IssWWW.exe/Stg/02-02.doc (last access 19 October 2015).

GKS, 2015a. Availability of machines and their power capacity in agricultural companies in the Russian Federation in 2014. Federal Statistics Service of the Russian Federation. Available at
http://www.gks.ru/wps/wcm/connect/rosstat_main/rosstat/ru/statistics/publications/catalog/doc_1265196018516 (last access: 26 February 2016), Moscow.

GKS, 2015b. Russian Statistical Yearbook 2015. Federal Statistics Service of the Russian Federation. Available at http://www.gks.ru/free_doc/doc_2015/year/year15.rar (last access: 26 February 2016).

Government of Russian Federation, 2015. Decisions of the meeting from 15 October 2015 on refinery modernizations. Available at http://government.ru/orders/20105/ (last access: 18 November 2015).

Hansen, J., and L. Nazarenko, 2003. Soot climate forcing via snow and ice albedos. PNAS 101, 423–428.

Huang, K., Fu, J.S., Prikhodko, V.Y., Storey, J.M., Romanov, A., Hodson, E.L., Cresko, J., Morozova, I., Ignatieva, Y., Cabaniss, J., 2015. Russian anthropogenic black carbon: Emission reconstruction and Arctic black carbon simulation. J. Geophys Res. 120, 11,306–311,333.

ICCT, 2015. Global Transportation Roadmap Model International Council on Clean Transportation, Available at http://www.theicct.org/global-transportation-roadmap-model (last access: 15 September).

IEA, 2015a. Energy balances of non-OECD countries. International Energy Agency, Paris.

IEA, 2015b. Key world energy statistics. International Energy Agency, Paris.

Ježek, I., Katrašnik, T., Westerdahl, D., Močnik, G., 2015. Black carbon, particle number concentration and nitrogen oxide emission factors of random in-use vehicles measured with the on-road chasing method. Atmos. Chem. Phys. 15, 11011–11026.

Koch, D., Del Genio, A.D., 2010. Black carbon semi-direct effects on cloud cover: review and synthesis. Atmos. Chem. Phys. 10, 7685–7696.

Kouridis, C., Gkatzoflias, D., Kioutsioukis, I., Ntziachristos, L., Pastorello, C., Dilara, P., 2010. Uncertainty estimates and guidance for road transport emission calculations. Report EUR 24296 EN–2010. Institute for Environment and Sustainability, Luxembourg.

Lamarque, J.F., Bond, T.C., Eyring, V., Granier, C., Heil, A., Klimont, Z., Lee, D., Liousse, C., Mieville, A., Owen, B., Schultz, M.G., Shindell, D., Smith, S.J., Stehfest, E., Van Aardenne, J., Cooper, O.R., Kainuma, M., Mahowald, N., McConnell, J.R., Naik, V., Riahi, K., van Vuuren, D.P., 2010. Historical (1850–2000) Gridded Anthropogenic and Biomass Burning Emissions of Reactive Gases and Aerosols: Methodology and Application. Atmos. Chem. Phys., 10, 15,7017-7039, doi: 10.5194/acp-10-7017-2010.

Lim, S.S., et.al., 2012. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. The Lancet 380, 2224–2260.

McClintock, P., 2011. Enhanced remote sensing performance based pilot program. Environmental Systems Products Inc, Tiburon, CA/USA.

Minenergo, 2012. Performance and development of the energy system in Russia in 2011 (in Russian). Ministry of Energy of the Russian Federation, Moscow. Available at http//minenergo.gov.ru/system/download-pdf/3399/3196 (last access: 21 May 2016).

Minenergo, 2015. Production and domestic supply of oil products in 2014 (in Russian). Ministry of Energy of the Russian Federation, Moscow. Available at http://minenergo.gov.ru/node/92 (last access: 18 November).

Mining Magazine, 2007. BELAZ at Apatity. Mining Magazine, UK, 47, October.

Ministry of Agriculture, 2015. National Report 2014 (in Russian). Ministry of Agriculture of the Russian Federation. Moscow. Available at http://mcx.ru/documents/file_document/v7_show/32460..htm (last access: 13 October).

Mintrans, 2015. Transport of the Russian Federation in 2014 (in Russian). Ministry of Transport of the Russian Federation, Moscow. Available at http://www.mintrans.ru/upload/iblock/5cd/stat_2014.pdf (last access: 21 May 2016).

MNRE, 2015. National report on the actions for black carbon and methane emissions reductions. Ministry of Natural Resources and Environment of the Russian Federation, Moscow, Available at https://oaarchive.arctic-council.org/bitstream/handle/11374/1168/EDOCS-%232709-v1-Russia_2015_Black_Carbon_Methane_National_Report.PDF?sequence=4&isAllowed=y (last access: 30 July).

Morozova, I., 2015. Recent Russian BC emissions inventory: Case of the Russian Arctic. Presenation at the TFEIP / US DOE workshop “Improving black carbon emission estimates & abatement”, Milan, Italy, 14 May 2015. Available at http://www.tfeip-secretariat.org/2015-meeting-milan/ (last access: 15 August).

Mueller, R., 2014. Personal correspondence with Ralf Mueller, Territory Manager - Mining Business, Europe, Middle East & CIS; e-mail response to technical questions about Cummins products

NIIAT, 1998. The assessment methodology for estimating the residual value of vehicles with regard to technical condition. Scientific Research Institute of Automobiles and Transportation, Moscow.

NIIAT, 2006. Calculation instruction (methodology) for inventory of emissions from vehicles into the air (in Russian). Scientific Research Institute of Automobiles and Transportation, Moscow.

NIIAT, 2012. Calculation instruction (methodology) for emissions inventory from vehicles on the territory of the largest cities (based on Moscow example) (in Russian: Расчетная инструкция (методика) по инвентаризации выбросов загрязняющих веществ от автотранспортных средств на территории крупнейших городов (на примере Москвы)). Scientific Research Institute of Automobiles and Transportation, Moscow.

Ntziachristos, L., Gkatzoflias, D., Kouridis, C., Samaras, Z., 2009. COPERT: A European road transport emission inventory model. Information Technologies in Environmental Engineering.

Petrovich, A.A., Belyavskiy, D.A., Garavskiy, A.O., 2013. BELAZ trucks at open pit mines in Russia (in Russian). Mining J. 1, 75–77.

Pope III, C.A., Burnett, R.T., Turner, M.C., Cohen, A., Krewski, D., Jerrett, M., Gapstur, S.M., Thun, M.J., 2011. Lung cancer and cardiovascular disease mortality associated with ambient air pollution and cigarette smoke: shape of the exposure-response relationships. Environ. health perspect 119, 1616–1621.

Preble, C.V., Dallmann, T.R., Kreisberg, N.M., Hering, S.V., Harley, R.A., W., K.T., 2015. Effects of particle filters and selective catalytic reduction on heavy-duty diesel drayage truck emissions at the Port of Oakland. Environ Sci Technol 49 (14), 8864–8871.

Quinn, P.K., Bates, T.S., Baum, E., Doubleday, N., Fiore, A.M., Flanner, M., Fridlind, A., Garrett, T.J., Koch, D., Menon, S., Shindell, D., Stohl, A.,Warren, S.G., 2008. Shortlived pollutants in the Arctic: their climate impact and possible mitigation strategies. Atmos. Chem. Phys. 8, 1723–1735.

Quinn, P.K., Stohl, A., Arneth, A., Berntsen, T., Burkhart, J.F., Christensen, J., Flanner, M., Kupiainen, K., Lihavainen, H., Shepherd, M., Shevchenko, V., Skov, H., Vestreng, V., 2011. The impact of black carbon on Arctic climate. Arctic Monitoring and Assessment Programme (AMAP), Oslo. Available at http://www.amap.no/documents/doc/the-impact-of-black-carbon-on-arctic-climate/746 (last access: 1 May 2015).

RAMR, 2012. Corporate truck fleet in Russia. Russian Avtomotive Market Research, Moscow. Available at http://www.napinfo.ru/page/id/10180 (last access: 21 May 2016).

Rosstandard, 2013. Diesel fuel. Specifications (in Russian). Federal Agency for Technical Regulation and Metrology, Moscow. Available at http://protect.gost.ru/document.aspx?control=7&id=185725 (last access: 24 May 2016).

Rosstandard, 2015. About 43% of fuesling stations, checked by Rosstandard, violate the requirements. Press-release from 1 October 2015, Available at http://gost.ru/wps/portal/pages/news (last access: 19 Novermber).

Rosstat, 2014. Construction in Russia. Statistical yearbook (in Russian). Federal State Statistics Service (Rosstat), Moscow.

RZhD, 2013. Annual report 2012. Russian Rail Road Company, Available at http://www.e-disclosure.ru/portal/files.aspx?id=4543&type=2 (last access: 1 May 2016).

Sand, M., Berntsen, T.K., von Salzen, K., Flanner, M.G., Langner, J., Victor, D.G., 2016. Response of Arctic temperature to changes in emissions of short-lived climate forcers. Nature Clim. Change 6, 286–289.

Sarofim, M.C., DeAngelo, B.J., Grano, D., Meitiv, D.L., Alnes, L.W.H., Rive, N., Berntsen, T., Torben, K.M., Myhre, G., Bieltvedt Skeie, R., Klimont, Z., Weitz, K.A., Zapata, A., Bahner, M.A., Zaitchik, B., 2009. Current policies, emission trends and mitigation options for black carbon in the Arctic region. Draft working paper for the Task Force on short-lived climate forcers, Arctic Council. Available at https://oaarchive.arctic-council.org/handle/11374/955 (last access: 23 May 2016).

Subramanian, R., Winijkul, E., Bond, T.C., Thiansathit, W., Oanh, N.T.K., Paw-armart, I., Duleep, K.G., 2009. Climate-relevant properties of diesel particulate emissions: Results from a piggyback study in Bangkok, Thailand. Environ. Sc. Technol. 43, 4213–4218.

Suslov, K.V., 2012. A microgrid concept for isolated territories in Russia, 2012 IEEE Innovative Smart Grid Technologies Conference, Berlin, October 2012. Available at http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6465614 (last access: 23 May 2016).

USGS, 2016. 2013 Minerals Yearbook: Russia. US Geological Survey, Washington DC.

Wang, X., Westerdahl, D., Wu, Y., Pan, X., Zhang, K.M., 2011. On-road emission factor distributions of individual diesel vehicles in and around Beijing, China. Atmos. Environ. 45, 503–513.

Warren, S.G., Wiscombe, W.J., 1980. A model for the spectral albedo of snow. II: snow containing atmospheric aerosols. J. Atmos. Sci. 37, 2734–2745.

WCIOM, 2015. Development of fishery complex in Russia (in Russian). Russian Public Opinion Research Center (VCIOM), Moscow. Available at http://www.wciom.com/index.php?id=139 (last access: 23 May 2016).

WHO, 2012. Health effects of black carbon. WHO Regional Office for Europe, Copenhagen, Denmark. Available at http://www.euro.who.int/__data/assets/pdf_file/0004/162535/e96541.pdf (last access: 19 April 2015).

WHO, 2013. Health effects of particulate matter: Policy implications for countries in Eastern Europe, Caucasus and Central Asia. World Health Organization. Available at http://www.euro.who.int/__data/assets/pdf_file/0006/189051/Health-effects-of-particulate-matter-final-Eng.pdf (last access: 19 April 2015), Copenhagen, Denmark.

World Bank, 2014. Reducing black carbon emissions from diesel vehicles: Impacts, control strategies, and cost-benefit analysis. The World Bank, Washington D.C. Available at https://openknowledge.worldbank.org/bitstream/handle/10986/17785/864850WP00PUBL0l0report002April2014.pdf (last access: 1 May 2015).

Yan, F., Winijkul, E., Jung, S., Bond, T.C., Streets, D.G., 2011. Global emission projections of particulate matter (PM): I. Exhaust emissions from on-road vehicles. Atmos. Environ. 45, 4830–4844.

Yan, F., Winijkul, E., Streets, D.G., Lu, Z., Bond, T.C., Zhang, Y., 2014. Global emission projections for the transportation sector using dynamic technology modeling. Atmos. Chem. Phys. 14, 5709–5733.

Zatopliaev, B., Redko, I., 2004. The role of small power engineering in Russia's fuel balance. Small Power Engineering 1, 4–11.

Zvonar, A., 2010. From modernization experience at Apatite mine (in Russian). Available at http://www.slavutich-media.ru/catalog/gornaya_tehnika/0/iz_opita_modernizatsii_proizvodstvennih_moshchnostey.html (last access: 21 May 2016).

Appendix

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I. GENERAL INFORMATION

Table A1. Population, territory and roads by region.

	Territory, thousand km^2	Population, thousand	Inhabitants per 1 km^2	Length of all roads	Density of roads, km /thousand km^2
Russia	**17125,2**	**146267,3**	**8,5**	**1,450,348.3**	**60**
Central Federal District	**650,2**	**38951,5**	**59,9**	**337,318.5**	**345**
Belgorod Region	27,1	1547,9	57,0	20,375.8	675
Bryansk Region	34,9	1233,0	35,4	16,430.6	307
Vladimir Region	29,1	1405,6	48,3	14,335.7	332
Voronezh Region	52,2	2331,1	44,6	28,534.7	323
Ivanovo Region	21,4	1036,9	48,4	11,391.1	340
Kaluga Region	29,8	1010,5	33,9	16,083.9	319
Kostroma Region	60,2	654,4	10,9	13,525.5	130
Kursk Region	30,0	1117,4	37,2	16,860.9	352
Lipetsk Region	24,0	1157,9	48,2	16,518.5	514
Moscow Region	44,3	7231,1	163,1	39,463.7	709
Orel Region	24,7	765,2	31,0	15,471.7	363
Ryazan' Region	39,6	1135,4	28,7	14,866.0	261
Smolensk Region	49,8	964,8	19,4	23,377.9	279
Tambov Region	34,5	1062,4	30,8	19,387.3	286
Tver' Region	84,2	1315,1	15,6	32,131.8	244
Tula Region	25,7	1513,6	58,9	13,728.2	393
Yaroslavl' Region	36,2	1271,6	35,2	18,480.4	264
Moscow City	2,6	12197,6	4762,8	6,354.8	2438
Northwest Federal District	**1687,0**	**13843,6**	**8,2**	**141,891.7**	**61**
Karelia, Republic of	180,5	632,5	3,5	10,659.8	47
Komi, Republic of	416,8	864,5	2,1	7,585.2	15
Arkhangel'sk Region	589,9	1183,3	2,0	19,477.1	21
including:					
Nenets Autonomous Okrug	176,8	43,4	0,2	382.0	1.2
Arkhangel'sk Region(w/t auton. okrugs)	413,1	1139,9	2,8	19,095.1	29
Vologda Region	144,5	1191,0	8,2	28,786.2	118
Kaliningrad Region	15,1	969,0	64,1	8,600.4	511
Leningrad Region	83,9	1775,5	21,2	22,914.7	212
Murmansk Region	144,9	766,3	5,3	3,493.2	23
Novgorod Region	54,5	618,7	11,4	14,820.6	196
Pskov Region	55,4	651,1	11,8	22,264.0	292
Saint Petersburg	1,4	5191,7	3700,4	3,290.5	2290

Southern Federal District	**420,9**	**14003,8**	**33,3**	**117,095.6**	**207**
Adygeya, Republic of	7,8	449,2	57,6	4,773.4	564
Kalmykia, Republic of	74,7	280,5	3,8	4,571.0	47
Krasnodar Krai	75,5	5453,3	72,2	39,348.0	438
Astrakhan' Region	49,0	1021,3	20,8	6,695.3	87
Volgograd Region	112,9	2557,4	22,7	26,343.7	140
Rostov Region	101,0	4242,1	42,0	35,364.2	260
North Caucasus Federal District	**170,4**	**9659,0**	**56,7**	**81,449.9**	**374**
Dagestan, Republic of	50,3	2990,4	59,5	23,727.3	370
Ingushetia, Republic of	3,6	463,9	127,9	3,664.4	644
Kabardino-Balkar Republic	12,5	860,7	69,0	8,751.7	565
Karachay-Cherkess Republic	14,3	469,0	32,9	6,756.3	334
North Ossetia-Alania, Republic	8,0	705,2	88,3	6,287.5	697
Chechen Republic	15,6	1370,3	87,6	12,286.1	510
Stavropol' Krai	66,2	2799,5	42,3	19,976.6	264
Volga Federal District	**1037,0**	**29715,5**	**28,7**	**327,020.7**	**217**
Bashkortostan, Republic of	142,9	4072,0	28,5	41,822.7	260
Mariy-El Republic	23,4	687,4	29,4	9,584.9	209
Mordovia, Republic of	26,1	808,9	31,0	13,064.1	276
Tatarstan, Republic of	67,8	3855,0	56,8	38,305.0	416
Udmurt Republic	42,1	1517,5	36,1	17,143.7	240
Chuvash Republic	18,3	1238,1	67,5	12,253.2	409
Perm' Krai	160,2	2637,0	16,5	30,402.3	128
Kirov Region	120,4	1304,4	10,8	24,678.0	114
Nizhny Novgorod Region	76,6	3270,2	42,7	31,462.5	290
Orenburg Region	123,7	2001,1	16,2	25,687.8	168
Penza Region	43,4	1355,6	31,3	15,107.1	279
Samara Region	53,6	3212,7	60,0	31,153.7	301
Saratov Region	101,2	2493,0	24,6	26,846.7	173
Ul'yanovsk Region	37,2	1262,6	34,0	9,509.0	198
Ural Federal District	**1818,5**	**12275,8**	**6,8**	**95,451.0**	**39**
Kurgan Region	71,5	869,8	12,2	16,448.2	130
Sverdlovsk Region	194,3	4327,4	22,3	30,374.8	121
Tyumen' Region	1464,2	3581,3	2,4	28,353.7	14
including:					
Khanty-Mansi Autonomous Okrug	534,8	1612,1	3,0	6,691.8	10.3
Yamal-Nenets Autonomous Okrug	769,3	540,0	0,7	2,399.4	2.8
Tyumen (without okrugs)	160,1	1429,2	8,9	19,262.5	83
Chelyabinsk Region	88,5	3497,3	39,5	20,274.3	190

Siberian Federal District	**5145,0**	**19312,2**	**3,8**	**251,049.0**	**35**
Republic Gorno-Altay	92,9	213,7	2,3	5,885.8	47
Buryat Republic	351,3	978,5	2,8	13,780.0	24
Tyva Republic	168,6	313,8	1,9	5,497.9	20
Khakass Republic	61,6	535,8	8,7	7,017.0	88
Altay Kray	168,0	2384,8	14,2	55,560.7	224
Zabaykal'ye Kray	431,9	1087,5	2,5	21,913.3	34
Krasnoyarsk Kray	2366,8	2858,8	1,2	32,173.8	11
Irkutsk Region	774,8	2414,9	3,1	29,098.4	29
Kemerovo Region	95,7	2725,0	28,5	19,984.6	176
Novosibirsk Region	177,8	2746,8	15,5	26,140.1	102
Omsk Region	141,1	1978,2	14,0	23,544.7	98
Tomsk Region	314,4	1074,4	3,4	10,452.7	24
Far Eastern Federal District	**6169,3**	**6211,0**	**1,0**	**84,263.1**	**9.1**
Sakha (Yakutia) Republic	3083,5	956,9	0,3	27,686.1	3.7
Kamchatka Krai	464,3	317,2	0,7	2,095.4	4.1
Primorye Krai	164,7	1933,3	11,7	16,828.9	89
Khabarovsk Krai	787,6	1338,3	1,7	10,328.2	12
Amur Oblars	361,9	809,9	2,2	15,313.6	31
Magadan Region	462,5	148,1	0,3	2,759.2	5.3
Sakhalin Region	87,1	488,4	5,6	4,300.7	22
Yevrey Autonomous Region	36,3	168,4	4,6	2,834.2	69
Chukotka Autonomous Okrug	721,5	50,5	0,1	2,116.8	0.9

Source: Rosstat (2015).

Table A2. Emission standards for on-road vehicles in the EU and Russia.

Passenger cars*	Introduced in the EU	Introduced in Russia	Heavy-duty diesel engines	Introduced in the EU	Introduced in Russia
Euro 1	1992	-	Euro I	1992	-
Euro 2	1996	2006	Euro II	1996	2006
Euro 3	2000	2008	Euro III	2000	2008
Euro 4	2005	2013	Euro IV	2005	2013
Euro 5	2009	2014	Euro V	2008	2016
Euro 6	2014	n/a	Euro VI	2013	n/a

* By convention, light-duty vehicles are marked with Arabic numerals while Roman numbers are used for heavy-duty vehicles (trucks and buses).

Table A3. COPERT and NIIAT emission factors and BC speciation for hot operation stage.

Type	Subcategory	COPERT EF, g/km			Blended NIIAT EFs, g/km			EC/PM*	OC/EC*
Cars		Urban	Rural	Highway	Urban	Rural	Highway		
Euro 0		0.271	0.199	0.146	0.250	0.150	0.170	0.55	0.70
Euro 1		0.07	0.057	0.087	0.073	0.040	0.050	0.70	0.40
Euro 2		0.058	0.047	0.045	0.073	0.040	0.050	0.80	0.23
Euro 3		0.035	0.029	0.038	0.053	0.030	0.030	0.85	0.15
Euro 4		0.034	0.029	0.025	0.016	0.090	0.090	0.87	0.13
Euro 5		0.003	0.002	0.002	0.004	0.002	0.002	0.20	2.00
LCV									
Euro 0		0.281	0.285	0.337	0.290	0.210	0.230	0.55	0.70
Euro 1		0.099	0.07	0.118	0.087	0.060	0.100	0.70	0.40
Euro 2		0.099	0.07	0.118	0.087	0.060	0.100	0.80	0.23
Euro 3		0.066	0.047	0.079	0.057	0.040	0.060	0.85	0.15
Euro 4		0.035	0.024	0.041	0.033	0.020	0.030	0.87	0.13
Euro 5		0.002	0.001	0.001	0.002	0.001	0.002	0.20	2.00
Trucks									
Euro 0	<=7,5 t	0.4	0.297	0.211	0.543	0.180	0.180	0.50	0.80
Euro I	<=7,5 t	0.157	0.116	0.09	0.360	0.140	0.140	0.65	0.40
Euro II	<=7,5 t	0.069	0.056	0.064	0.220	0.080	0.080	0.65	0.40
Euro III	<=7,5 t	0.082	0.061	0.04	0.153	0.060	0.060	0.70	0.30
Euro IV	<=7,5 t	0.017	0.014	0.015	0.030	0.010	0.010	0.75	0.25
Euro V	<=7,5 t	0.021	0.018	0.015	0.030	0.010	0.010	0.75	0.25
Euro 0	7,5 - 12 t	0.423	0.301	0.201	0.893	0.400	0.400	0.50	0.80
Euro I	7,5 - 12 t	0.262	0.182	0.129	0.640	0.330	0.330	0.65	0.40
Euro II	7,5 - 12 t	0.115	0.087	0.098	0.230	0.100	0.100	0.65	0.40
Euro III	7,5 - 12 t	0.133	0.095	0.062	0.153	0.060	0.060	0.70	0.30
Euro IV	7,5 - 12 t	0.027	0.021	0.02	0.030	0.010	0.010	0.75	0.25
Euro V	7,5 - 12 t	0.034	0.026	0.021	0.030	0.010	0.010	0.75	0.25
Euro 0	12 - 14 t	0.452	0.32	0.232	1.073	0.550	0.550	0.50	0.80
Euro I	12 - 14 t	0.28	0.199	0.147	0.697	0.480	0.480	0.65	0.40
Euro II	12 - 14 t	0.128	0.095	0.109	0.310	0.180	0.180	0.65	0.40
Euro III	12 - 14 t	0.141	0.099	0.071	0.193	0.130	0.130	0.70	0.30
Euro IV	12 - 14 t	0.03	0.023	0.02	0.040	0.020	0.020	0.75	0.25
Euro V	12 - 14 t	0.036	0.028	0.023	0.040	0.020	0.020	0.75	0.25
Euro 0	> 14 t	0.625	0.439	0.29	1.073	0.550	0.550	0.50	0.80
Euro I	> 14 t	0.386	0.271	0.175	0.697	0.480	0.480	0.65	0.40
Euro II	> 14 t	0.164	0.118	0.129	0.310	0.180	0.180	0.65	0.40
Euro III	> 14 t	0.199	0.139	0.087	0.193	0.130	0.130	0.70	0.30
Euro IV	> 14 t	0.039	0.029	0.023	0.040	0.020	0.020	0.75	0.25
Euro V	> 14 t	0.049	0.037	0.028	0.040	0.020	0.020	0.75	0.25

Buses									
Euro 0	<=15 t	0.858	0.574	0.388	0.880	0.270	0.295	0.50	0.80
Euro I	<=15 t	0.294	0.221	0.173	0.650	0.215	0.230	0.65	0.40
Euro II	<=15 t	0.142	0.114	0.107	0.398	0.195	0.175	0.65	0.40
Euro III	<=15 t	0.146	0.11	0.099	0.197	0.105	0.100	0.70	0.30
Euro IV	<=15 t	0.035	0.027	0.022	0.040	0.025	0.025	0.75	0.25
Euro V	<=15 t	0.042	0.031	0.038	0.037	0.025	0.025	0.75	0.25
Euro 0	15 - 18 t	0.767	0.52	0.312	1.523	0.430	0.500	0.50	0.80
Euro I	15 - 18 t	0.412	0.294	0.217	0.890	0.310	0.400	0.65	0.40
Euro II	15 - 18 t	0.197	0.157	0.138	0.680	0.310	0.270	0.65	0.40
Euro III	15 - 18 t	0.195	0.148	0.108	0.250	0.130	0.120	0.70	0.30
Euro IV	15 - 18 t	0.049	0.037	0.027	0.050	0.030	0.030	0.75	0.25
Euro V	15 - 18 t	0.055	0.042	0.036	0.050	0.030	0.030	0.75	0.25
Euro 0	>18 t	0.957	0.675	0.395	1.523	0.430	0.500	0.50	0.80
Euro I	>18 t	0.517	0.37	0.227	0.757	0.310	0.400	0.65	0.40
Euro II	>18 t	0.265	0.212	0.174	0.583	0.310	0.270	0.65	0.40
Euro III	>18 t	0.24	0.17	0.125	0.250	0.130	0.120	0.70	0.30
Euro IV	>18 t	0.06	0.045	0.029	0.050	0.030	0.030	0.75	0.25
Euro V	>18 t	0.066	0.049	0.04	0.050	0.030	0.030	0.75	0.25

Sources: (Emisia, 2015; NIIAT, 2012).

* EC/PM and OC/EC speciation factors are derived from the COPERT model.

Table A4. PM emission factors of new vehicles and super emitters.

Emission Standard	New Vehicle PM Emission Factors (g/kg-fuel)	
	Light-duty diesel	Heavy-duty diesel
Non-regulation	1.9	4.2
Opacity	1.5	2.9
Euro I	1.3	1.7
Euro II	0.8	0.7
Euro III	0.5	0.5
Euro IV	0.3	0.1
Euro V	0.04	0.1
Euro VI	0.05	0.06
Older engine superemitter[1]	8.3[1]	8.3[1]
Newer engine superemitter[2]	2.9[2]	2.9[2]

[1] Euro 0 and Euro 1

[2] Euro 2-5

Source: Yan et al. (2011).

Table A5. Emission factors for uncontrolled off-road diesel vehicles.

	Power range in kW							
	0-20	20-37	37-75	75-130	130-300	300-560	560-1000	>1000
$PM_{2.5}$ (grams/kWh)	2.09	1.7	1.42	1.16	1.03	1.03	1.03	1.03
PM (grams/kWh)	2.22	1.81	1.51	1.23	1.1	1.1	1.1	1.1

Source: EEA (2013).

Table A6. Emission factors for off-road diesel vehicles.

NFR Code	NFR Sector	Emission factors	Before 1981	1981-1990	1991-Stage I	Stage I	Stage II
1.A.4.c.ii	Agriculture	$PM_{2.5}$ (g/ton fuel)[a]	5,137	3,755	1,644	832	627
		$BC/PM_{2.5}$[a]	0.55	0.55	0.54	0.79	0.77
		OC/BC[b]	0.3	0.3	0.3	0.3	0.3
1.A.4.c.ii	Forestry	PM2.5 (g/ton fuel)[a]	5493	3731	2044	787	595
		$BC/PM_{2.5a}$	0.55	0.55	0.54	0.79	0.76
		OC/BC[b]	0.3	0.3	0.3	0.3	0.3
1.A.2.f.ii and 1.A.4.a.ii	Industrial, construction and commercial vehicles	$PM_{2.5}$ (g/ton fuel)[a]	6,027	4,038	3,551	967	1,031
		$BC/PM_{2.5}$[a]	0.55	0.55	0.55	0.80	0.80
		OC/BC[b]	0.3	0.3	0.3	0.3	0.3

Sources:
[a] EEA (2013).
[b] (EPA (2012).

Table A7. Emission factors for diesel locomotives.

	$PM_{2.5}$ (g/kg fuel) [a]	$BC/PM_{2.5}$ ratio (f-BC) [a]	Uncertainty (%)[a]	OC/BC[b]
Line-haul locomotives	1.1	0.65	20	0.2
Shunting locomotives	2.0	0.65	20	0.2

Sources:
[a] EEA (2013). 1.A.3.c
[b] (EPA (2012).

Table A8. Emission factor for ships using marine diesel oil/marine gas oil.

	$PM_{2.5}$ (g/kg fuel) [a]	$BC/PM_{2.5}$ ratio (f-BC) [a]	Uncertainty at sea (%)[a]	OC/BC[b]
Ships	1.4	0.31	25	0.2

Sources: [a] EEA (2013) (1.A.3.d). [b] EPA (2012).

II. ACTIVITY DATA

Table A9. Registered on-road cars and trucks, 2000-2013.

(at the end of year; million units)

	2000	2005	2010	2011	2012	2013
Passenger cars	20,4	25,6	34,4	36,4	38,8	41,4
Owned by individuals	19,1	24,1	32,6	34,6	36,9	39,2
Trucks	4,4	4,8	5,4	5,5	5,8	6,0
Owned by individuals	1,6	2,3	2,9	3,1	3,3	3,5

Source: GKS (2014).

Table A10. Share of diesel vehicles in the Russian bus and truck fleet, %.

	2010	2011	2012	2013
Buses	35.7	38.3	41.1	43.3
Trucks	46.6	49.1	53.2	55.8

Source: MNRE (2013)

Table A11. On-road fleet in 20 regions with the largest registered diesel fleet.

(sorted by the number of diesel trucks)

Region	Cars		LCV		Trucks		Buses	
	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline
Moscow City	297,587	3,539,332	128,613	154,141	141,323	39,677	13,868	1,438
Moscow Region	146,442	2,369,440	76,217	128,705	111,036	34,677	9,949	3,956
Krasnodarsky Kray	63,936	1,550,574	46,557	98,731	90,511	39,779	7,849	7,150
Khanty-Mansi Autonomous Okrug	25,702	508,305	7,828	42,073	87,515	13,400	4,110	4,404
Tatarstan	24,862	1,132,933	12,260	77,494	80,876	22,789	6,032	7,124
Saint Petersburg	119,857	1,525,531	70,357	65,286	70,102	16,558	9,887	2,358
Primorye Kray	88,993	1,037,989	101,186	137,114	67,665	34,680	5,822	4,088
Rostov Region	33,863	1,187,687	24,574	81,980	64,724	45,817	6,454	6,056
Irkutsk Region	31,347	681,855	34,025	66,221	64,721	45,527	3,887	8,366
Sverdlov Region	39,683	1,140,848	19,309	74,298	61,123	24,597	4,972	4,960
Krasnoyarsk Kray	33,774	795,175	17,824	52,696	53,599	34,048	4,691	6,330
Chelyabinsk Region	23,478	957,257	13,465	60,636	46,613	19,519	2,667	3,963
Samara Region	23,733	943,935	10,654	58,910	45,297	19,756	3,731	4,660
Novosibirsk Region	20,571	759,087	13,363	57,004	43,521	61,785	3,369	7,368
Nizhny Novgorod Region	32,135	807,595	13,443	61,597	43,042	29,762	3,244	5,872

Bashkortostan	25,670	1,084,552	13,040	62,387	39,755	24,032	2,402	4,515
Voronezh Region	22,509	662,905	12,884	44,065	38,691	27,399	3,334	3,966
Voronezh Region	22,509	662,905	12,884	44,065	38,691	27,399	3,334	3,966
Orenburg Region	11,242	619,110	4,851	48,532	38,195	55,715	1,992	7,469
Kemerovo Region	20,939	617,154	10,249	37,009	31,208	16,453	3,900	5,314
All other regions	521,825	16,444,669	444,780	1,405,976	1063,800	764,815	71,699	113,435
Top 20 regions	1,108,832	22,584,169	643,583	1,452,944	1,258,208	633,369	105,494	103,323
Total	1,630,657	39,028,838	1,088,363	2,858,920	2,322,008	1,398,184	177,193	216,758
Share of top 20 regions in the Russian fleet	68%	58%	59%	51%	54%	45%	60%	48%

Source: Avtostat (2015).

Table A12. Number of active diesel vehicles by type and emission standard in Russia, 2014.

	Cars	LCVs	Trucks	Buses
Euro 0	100,620	150,345	470,737	24,994
Euro 1	103,529	119,732	43,093	10,038
Euro 2	113,576	94,135	173,337	17,541
Euro 3	144,298	140,923	293,520	49,725
Euro 4	691,199	353,189	271,189	19,481
Euro 5	329,941*	58,703	77,404	1,615
Total	1,483,163	917,027	1,329,280	123,394

* - includes 2110 Euro 6 cars.

Calculated based on Avtostat (2015).

Table A13. Number of registered gasoline vehicles, 2014

Emission class	Cars	LCVs	Trucks	Buses
Euro 0	13,834,469	1,606,211	1,362,407	152,606
Euro 1	1,781,490	69,879	112	2,872
Euro 2	5,075,003	536,816	23,856	20,004
Euro 3	5,931,941	448,769	11,293	32,303
Euro 4	9,922,420	192,897	493	8,973
Euro 5	2,479,610	4,348	23	-
Euro 6	3,905			
Total	39,028,838	2,858,920	1,398,184	216,758

Source: Avtostat (2015).

Table A14. The annual average distance traveled by type of vehicles, thousand km per year.

	Cars	LCVs	Trucks	Buses
NIIAT (1998)	15 10 for 5-year old		35 in cities 60 suburban	Russian: 50 in cities

	Russian cars 10 for 10-year old foreign cars		100 intercity	65 suburban 80 intercity Foreign: 60 in cities 80 suburban 105 intercity
NIIAT (2008)	14-16 owned by individuals 25-30 owned by companies		30-40	40-50
Avtostat (2010)	16.7 15.3 Russian 18 foreign-made	55	63	65
ICCT (2015)	10	10	13-38	56

Table A15. Average number kilometers traveled by type of vehicles.

Vehicle type	Subsector	Emission standard	Annual distance traveled, km per year
Passenger Cars	Diesel 1,4 - 2,0 l	Conventional	10,000
	Diesel 1,4 - 2,0 l	PC Euro 1 - 91/441/EEC	10,000
	Diesel 1,4 - 2,0 l	PC Euro 2 - 94/12/EEC	15,000
	Diesel 1,4 - 2,0 l	PC Euro 3 - 98/69/EC Stage2000	15,000
	Diesel 1,4 - 2,0 l	PC Euro 4 - 98/69/EC Stage2005	18,000
	Diesel 1,4 - 2,0 l	PC Euro 5 - EC 715/2007	20,000
Light Commercial Vehicles	Diesel <3,5 t	Conventional	37,000
	Diesel <3,5 t	LD Euro 1 - 93/59/EEC	37,000
	Diesel <3,5 t	LD Euro 2 - 96/69/EEC	55,000
	Diesel <3,5 t	LD Euro 3 - 98/69/EC Stage2000	55,000
	Diesel <3,5 t	LD Euro 4 - 98/69/EC Stage2005	66,000
	Diesel <3,5 t	LD Euro 5 - 2008 Standards	73,000
Heavy Duty Trucks	Rigid <=7,5 t	Conventional	42,000
	Rigid <=7,5 t	HD Euro I - 91/542/EEC Stage I	42,000
	Rigid <=7,5 t	HD Euro II - 91/542/EEC Stage II	63,000
	Rigid <=7,5 t	HD Euro III - 2000 Standards	63,000
	Rigid <=7,5 t	HD Euro IV - 2005 Standards	75,000
	Rigid <=7,5 t	HD Euro V - 2008 Standards	84,000
	Rigid 7,5 - 12 t	Conventional	42,000
	Rigid 7,5 - 12 t	HD Euro I - 91/542/EEC Stage I	42,000
	Rigid 7,5 - 12 t	HD Euro II - 91/542/EEC Stage II	63,000
	Rigid 7,5 - 12 t	HD Euro III - 2000 Standards	63,000
	Rigid 7,5 - 12 t	HD Euro IV - 2005 Standards	75,000
	Rigid 7,5 - 12 t	HD Euro V - 2008 Standards	84,000

	Rigid 12 - 14 t	Conventional	42,000
	Rigid 12 - 14 t	HD Euro I - 91/542/EEC Stage I	42,000
	Rigid 12 - 14 t	HD Euro II - 91/542/EEC Stage II	63,000
	Rigid 12 - 14 t	HD Euro III - 2000 Standards	63,000
	Rigid 12 - 14 t	HD Euro IV - 2005 Standards	75,000
	Rigid 12 - 14 t	HD Euro V - 2008 Standards	84,000
	Rigid 14 - 20 t	Conventional	42,000
	Rigid 14 - 20 t	HD Euro I - 91/542/EEC Stage I	42,000
	Rigid 14 - 20 t	HD Euro II - 91/542/EEC Stage II	63,000
	Rigid 14 - 20 t	HD Euro III - 2000 Standards	63,000
	Rigid 14 - 20 t	HD Euro IV - 2005 Standards	75,000
	Rigid 14 - 20 t	HD Euro V - 2008 Standards	84,000
Buses	Urban Buses Midi <=15 t	Conventional	43,000
	Urban Buses Midi <=15 t	HD Euro I - 91/542/EEC Stage I	43,000
	Urban Buses Midi <=15 t	HD Euro II - 91/542/EEC Stage II	65,000
	Urban Buses Midi <=15 t	HD Euro III - 2000 Standards	65,000
	Urban Buses Midi <=15 t	HD Euro IV - 2005 Standards	78,000
	Urban Buses Midi <=15 t	HD Euro V - 2008 Standards	87,000
	Urban Buses Standard 15 - 18 t	Conventional	43,000
	Urban Buses Standard 15 - 18 t	HD Euro I - 91/542/EEC Stage I	43,000
	Urban Buses Standard 15 - 18 t	HD Euro II - 91/542/EEC Stage II	65,000
	Urban Buses Standard 15 - 18 t	HD Euro III - 2000 Standards	65,000
	Urban Buses Standard 15 - 18 t	HD Euro IV - 2005 Standards	78,000
	Urban Buses Standard 15 - 18 t	HD Euro V - 2008 Standards	87,000
	Urban Buses Articulated >18 t	Conventional	43,000
	Urban Buses Articulated >18 t	HD Euro I - 91/542/EEC Stage I	43,000
	Urban Buses Articulated >18 t	HD Euro II - 91/542/EEC Stage II	65,000
	Urban Buses Articulated >18 t	HD Euro III - 2000 Standards	65,000
	Urban Buses Articulated >18 t	HD Euro IV - 2005 Standards	78,000
	Urban Buses Articulated >18 t	HD Euro V - 2008 Standards	87,000

Not: our assumptions based on Avtostat data.

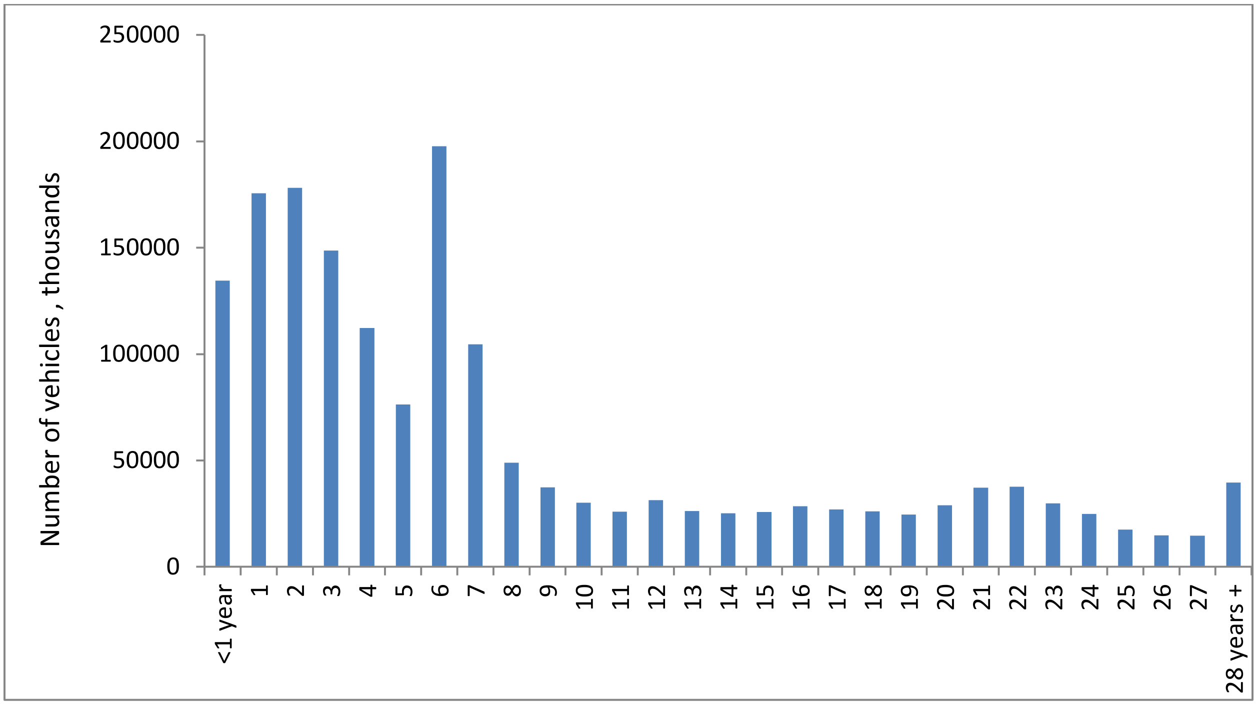


Figure A1. The age distribution of registered diesel cars

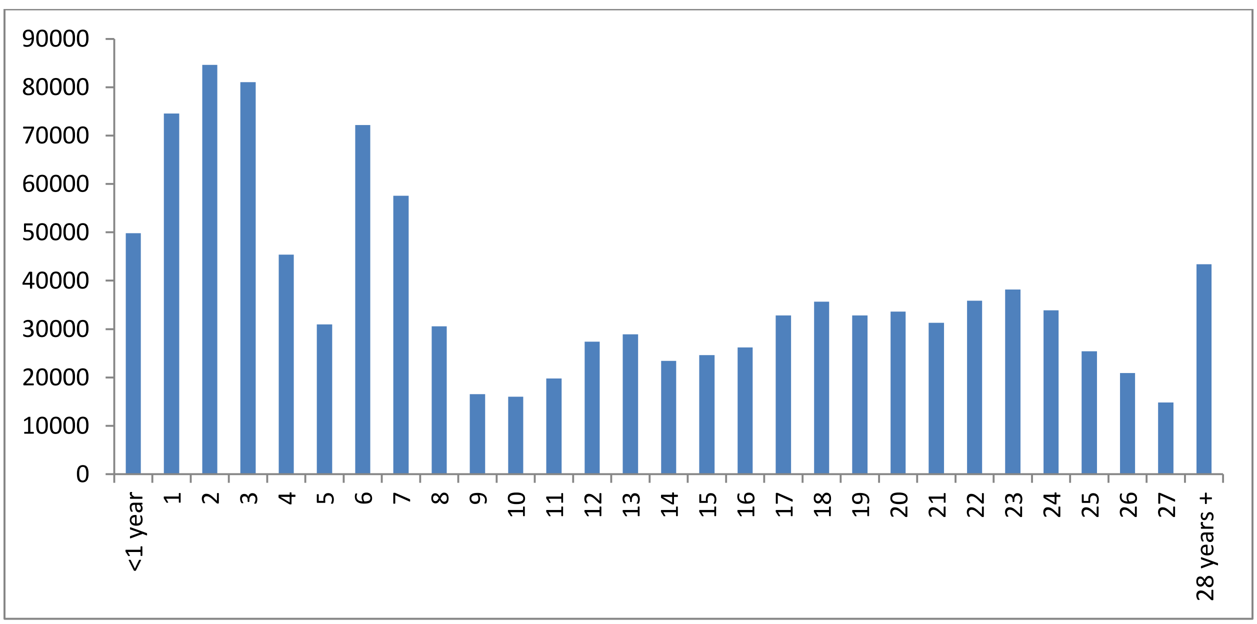


Figure A2. The age distribution of registered diesel light commercial vehicles

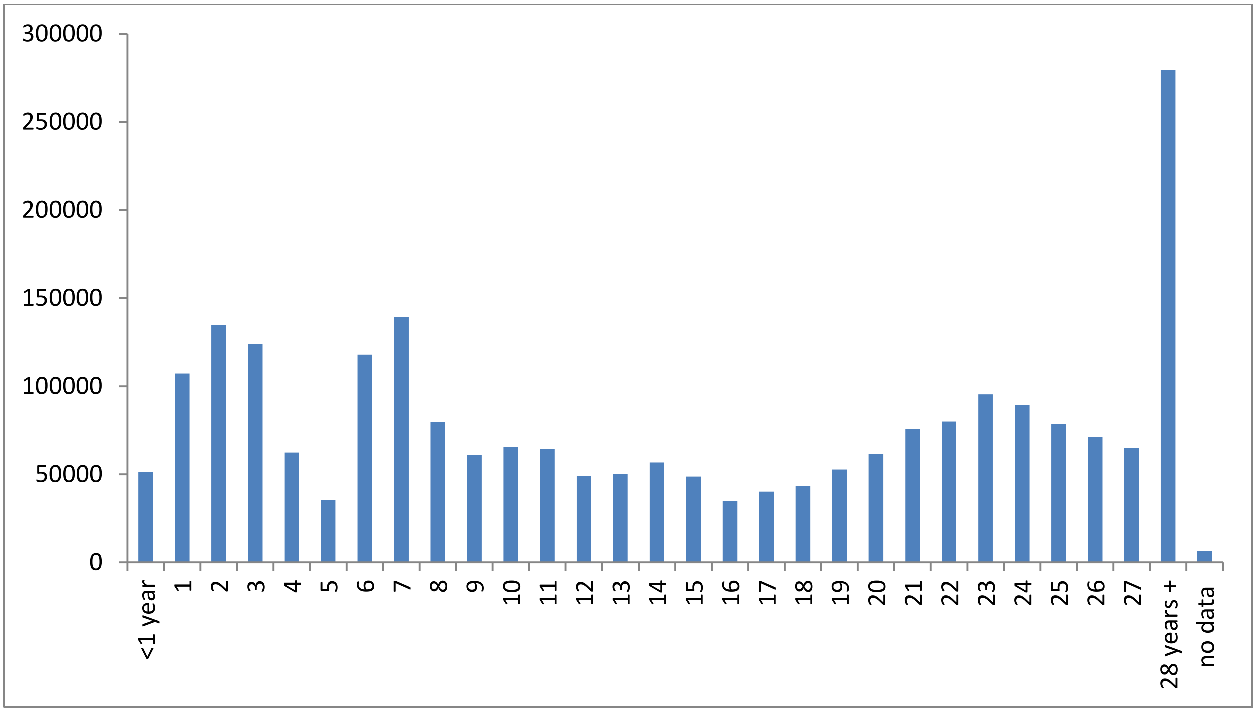


Figure A3. The age distribution of registered diesel trucks

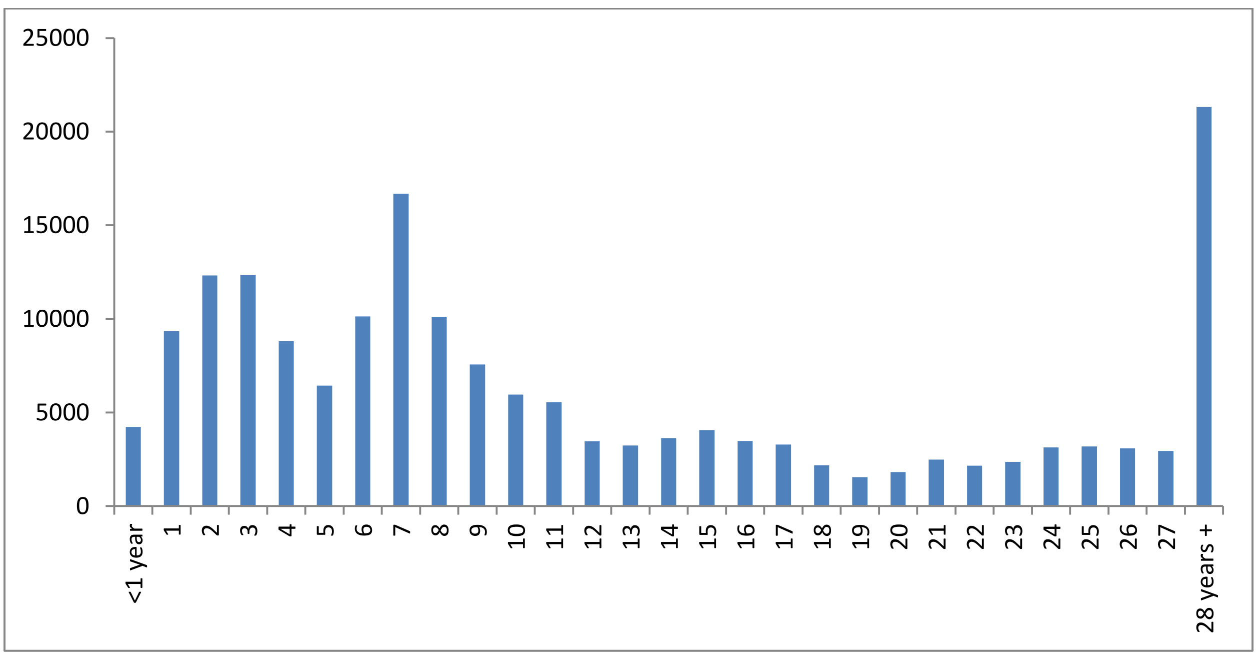


Figure A4. The age distribution of registered diesel buses

III. OFF-ROAD DIESEL ENGINES

Table A16. Cargo turnover by electric and diesel locomotives, 2000-2013.

	2000	2005	2010	2011	2012	2013
Cargo turnover, billion ton-kilometers	1373	1858	2011	2128	2222	2196
Electric locomotives, %	79,0	84,7	86,3	86,1	86,0	85,6
Diesel locomotives, %	21,0	15,3	13,7	13,9	14,0	14,4

Source: GKS (2014).

Table A17. Diesel locomotives in Russia, 2000-2013.

	2000	2005	2010	2011	2012	2013
Industrial locomotives, thousand units	13,0	…	9,6	8,8	9,7	10,5
Production of diesel locomotives, units			33	39	42	66
Import of diesel locomotives, units*					191	199
Total length of railroads, thousand km	86	85	86	86	86	86
Used by locomotives	52,4	49,7	49,6	49,5	49,4	49,4
Length of industrial railroads, thousand km	53	…	38	36	35	34
Freight turnover by diesel locomotives, billion t-km	288	284	276	296	311	316

Source: GKS (2014).

Table A18. Age distribution of diesel locomotives, %, 2012.

	1-5 years	5-10 years	10-15 years	15-20 ears	> 20
Long-line haul	7.6	17.5	26.7	21.5	26.7
Shunting	8.1	27.7	27.5	18.6	18.1

Source: Balabin and Evpakov (2013).

Table A19. Number of agricultural vehicles registered by Rostekhnadzhor, 2013-2014.

	2013	2014
Tractors	435,766	420,563
Harvesters:		
Grain	134,188	127,750
Forage	19,168	17,564
Other	6,716	7,670
Other motor vehicles	16,592	21,532

Source: Ministry of Agriculture (2015).

Table A20. Replacement rates of agricultural machinery, 2008-2014.

	2008	2009	2010	2011	2012	2013	2014

Tractors	4.0	2.0	2.4	3.4	3.3	3.0	3.2
Harvesters, grain	7.0	4.3	3.5	5.3	4.9	4.7	5.2
Harvesters, potato	8.0	5.4	4.8	7.0	5.1	3.0	4.5
Harvesters, forage	7.0	3.5	4.1	6.4	4.7	4.0	4.5
Harvesters, corn	6.0	2.2	2.9	5.1	4.7	3.2	5.3
Harvesters, flax	3.0	2.8	2.4	1.1	2.7	1.5	1.2
Harvesters, beet	3.0	3.2	4.2	5.8	4.7	3.8	4.1

http://fedstat.ru/indicator/data.do?id=33751 .

Table A21. Age structure of tractor fleet, 2011.

Type	Share of equipment over 10 years old, %	Share of equipment over 10 years old, still used %
Grain harvesters	63	60
Forage harvesters	68	52
Tractors	80	62

Source: Rosagroleasing (2012).

Table A22. Structure of tractor fleet by country of origin, 2011.

Origin	Share, %
Production in the countries of the Former Soviet Union	90-95
Imported from other countries	5-10

Source: Rosagroleasing (2012).

Table A23. Agricultural and forestry tractors sold in Russia in 2013 and 2014.

	2013	2014
Imported from Belarus	23,246	17,019
Imported from other countries	11,913	17,116
Belorussian tractors produced in Russia	3,539	2,555
Imported used tractors	3,244	3,590
Foreign models produced in Russia	2,683	2,254
Russian tractors	934	1,316
Total	45,559	43,850

Source: Agroinfo (2015).

Table A24. Distribution of tractors by horsepower, 2011.

Engine power, horsepower .	Share, %
Up 120	84
120–200	5
200–300	9
Over 300	2

Source: (Rosagroleasing, 2012).

Table A25. Number of construction vehicles, 2005-2014.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Motor graders	5,944	5,798	5,733	5,592	5,568	5,199	5,137	4,941	4,752	4,559
Bulldozers	15,718	15,607	15,542	15,025	14,358	13,668	13,135	12,455	11,669	10,776
Loaders	6,639	6,654	6,938	8,889	8,066	7,474	7,676	7,910	7,822	7,935
Scrapers	1,200	1,140	1,007	909	869	772	717	677	520	444
Excavators	16,801	16,246	16,630	16,495	15,711	15,224	14,392	14,113	13,638	13,349

Source: Fedstat (2015b).

Table A26. Number of construction vehicles with expired useful lifetime, 2005-2014.

	2005	2006	2007	2008	2009	2011	2012	2013	2014
Motor graders	2,652	2,737	2,822	2,812	2,846	2,575	2,338	2,269	2,098
Bulldozers	9,048	8,814	8,526	7,877	7,508	6,381	5,904	5,528	5,002
Loaders	2,791	2,861	2,894	2,699	2,816	2,852	2,698	2,516	2,483
Scrapers	852	817	724	665	599	486	470	366	339
Excavators	7,857	7,263	7,029	6,211	5,898	4,990	4,532	4,261	4,127

Source: Fedstat (2015a).

Table A27. The age distribution of power plants and diesel generators in the centralized energy system, MW.

Year of commissioning	Total installed capacity	Diesel power stations
Before 1960	19,650	5
1961-1965	20,473	1
1966-1970	28,110	33
1971-1975	29,830	24
1976-1980	34,155	22
1981-1985	30,520	69
1986-1990	21,648	59
1991-1995	8,477	39
1996-2000	5,402	141
2001-2004	10,053	96
2005-2010	9,497	105
2011	4,615	12
Total	222,427	604

Source: Minenergo (2012).

Table A28. Electricity produced by large diesel generators, gigawatt-hours, 2010-2014, GWh.

Region	2010	2011	2012	2013	2014
Central Federal District	18.3	22.2	18.7	45.1	130.9
Northwest Federal District	168.9	187.4	199.3	232.2	170.2
Southern Federal District	5.7	20.2	24.9	25.0	54.3
North Caucasus Federal District	0.1	0.1	0.2	0.2	0

Volga Federal District	102.7	114.7	186.9	204.2	176.9
Ural Federal District	1228.9	1438.2	1403.6	1426.7	1,417.6
Siberian Federal District	714.2	832.3	935.9	1045.6	764.6
Far East Federal District	1047.0	1049.7	1057.8	1070.4	1,220.5
Total Russia	3285.8	3664.8	3827.3	4049.4	3,935.0

Source: Fedstat (2015c).

IV. RESULTS OF EMISSION CALCULATIONS

The results in Tables A29-A32 are from the COPERT 4 model with NIIAT emission factors. The assumptions on average annual kilometers traveled remain the same.

Table A29. OC emissions from the adjusted diesel fleet with superemitters (Gg).

	Cars	LCVs	Trucks	Buses	Total
Euro 0	0.07	0.47	2.83	0.20	3.58
Euro 1	0.02	0.11	0.14	0.05	0.31
Euro 2	0.03	0.10	0.49	0.10	0.72
Euro 3	0.02	0.08	0.49	0.12	0.70
Euro 4	0.03	0.13	0.09	0.01	0.26
Euro 5	0.01	0.01	0.03	0.00	0.05
Total	0.18	0.88	4.07	0.48	5.62

Table A30. BC emissions, assuming that all registered trucks and buses use diesel fuel (Gg).

	Trucks	Buses
Euro 0	33.2	3.8
Euro 1	1.1	0.3
Euro 2	2.5	0.8
Euro 3	2.3	0.8
Euro 4	0.4	0.1
Euro 5	0.1	0.0
Total	39.7	5.7

Table A31. BC emissions from all registered diesel vehicles (Gg).

	Cars	LCVs	Trucks	Buses	Total
Euro 0	0.36	1.85	15.39	0.66	18.26
Euro 1	0.10	0.54	1.06	0.20	1.91
Euro 2	0.18	0.68	2.33	0.32	3.51
Euro 3	0.16	0.66	2.27	0.42	3.52
Euro 4	0.27	1.03	0.42	0.04	1.77
Euro 5	0.01	0.00	0.12	0.00	0.13
Total	1.08	4.77	21.58	1.66	29.09

Table A32. BC emissions from the adjusted diesel fleet without accounting for superemitters (Gg).

	Cars	LCVs	Trucks	Buses	Total
Euro 0	0.20	1.30	6.16	0.46	8.11
Euro 1	0.08	0.41	0.53	0.16	1.18
Euro 2	0.14	0.54	1.40	0.29	2.37
Euro 3	0.14	0.56	1.71	0.42	2.82
Euro 4	0.24	0.98	0.38	0.05	1.65
Euro 5	0.01	0.00	0.12	0.00	0.13
Total	0.80	3.79	10.28	1.39	16.26

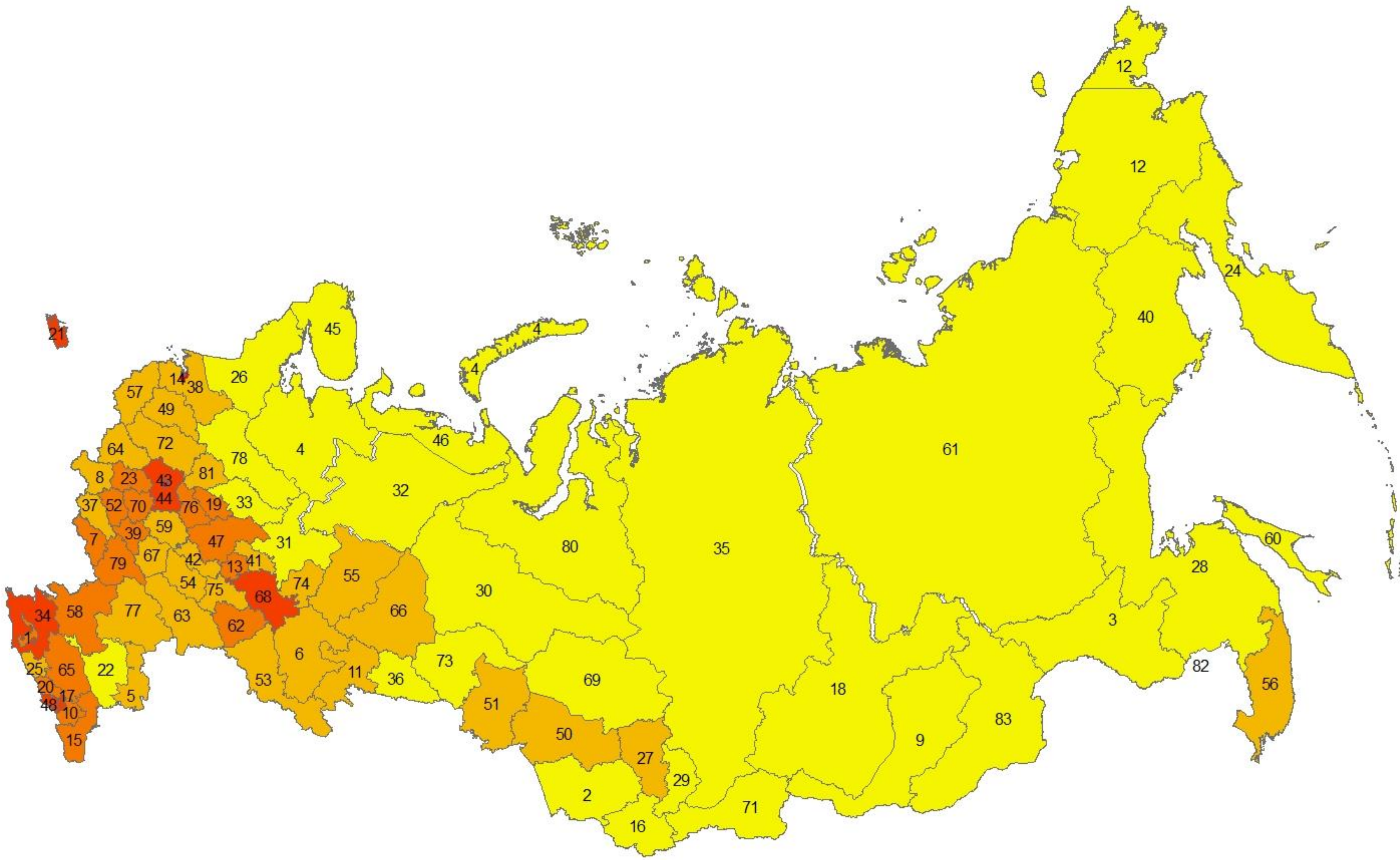
Table A33. BC emissions from on-road diesel vehicles in the Russian regions*.

#on a map	Region	BC emissions, kg	Area, thousands sq.km	BC per sq.km, kg/km^2
1	Adygey Respublika	56,977	7.8	7,305
2	Altay Kray	280,449	168	1,669
3	Amur Oblast	166,087	361.9	459
4	Arkhangel'sk Oblast	140,234	589.9	238
5	Astrakhan' Oblast	104,213	49	2,127
6	Bashkortostan Respublika	368,789	142.9	2,581
7	Belgorod Oblast	264,623	27.1	9,765
8	Bryansk Oblast	167,006	34.9	4,785
9	Buryat Respublika	121,643	351.3	346
10	Chechnya Respublika	127,608	15.6	8,180
11	Chelyabinsk Oblast	432,408	88.5	4,886
12	Chukot Avtonomnyy Okrug	20,798	721.5	29
13	Chuvash Respublika	128,016	18.3	6,995
14	City of St. Petersburg	650,304	1.4	464,503
15	Dagestan Respublika	387,120	50.3	7,696
16	Gorno-Altay Respublika	35,344	92.9	380
17	Ingush Respublika	48,526	3.6	13,479
18	Irkutsk Oblast	600,387	774.8	775
19	Ivanovo Oblast	158,657	21.4	7,414
20	Kabardin-Balkar Respublika	75,780	12.5	6,062
21	Kaliningrad Oblast	207,720	15.1	13,756
22	Kalmyk Respublika	36,188	74.7	484
23	Kaluga Oblast	198,240	29.8	6,652
24	Kamchatka Kray	82,691	464.3	178
25	Karachay-Cherkess Respublika	47,329	14.3	3,310
26	Karelia Respublika	101,856	180.5	564
27	Kemerovo Oblast	289,502	95.7	3,025

28	Khabarovsk Kray	219,446	787.6	279
29	Khakass Respublika	71,513	61.6	1,161
30	Khanty-Mansiy Avtonomnyy Okrug	811,837	534.8	1,518
31	Kirov Oblast	172,980	120.4	1,437
32	Komi Respublika	234,474	416.8	563
33	Kostroma Oblast	98,471	60.2	1,636
34	Krasnodar Kray	839,629	75.5	11,121
35	Krasnoyarsk Kray	497,214	2366.8	210
36	Kurgan Oblast	98,248	71.5	1,374
37	Kursk Oblast	149,863	30	4,995
38	Leningrad Oblast	282,397	83.9	3,366
39	Lipetsk Oblast	172,154	24	7,173
40	Maga Buryatdan Oblast	71,494	462.5	155
41	Mariy-El Respublika	68,248	23.4	2,917
42	Mordovia Respublika	104,500	26.1	4,004
43	Moscow City	1,310,989	2.6	504,227
44	Moskva Oblast	1,030,031	44.3	23,251
45	Murmansk Oblast	80,214	144.9	554
46	Nenets Avtonomnyy Okrug	13,089	176.8	74
47	Nizhegorod Oblast	399,281	76.6	5,213
48	North Ossetia Respublika	96,754	8	12,094
49	Novgorod Oblast	119,844	54.5	2,199
50	Novosibirsk Oblast	403,725	177.8	2,271
51	Omsk Oblast	288,677	141.1	2,046
52	Orel Oblast	155,141	24.7	6,281
53	Orenburg Oblast	354,318	123.7	2,864
54	Penza Oblast	167,859	43.4	3,868
55	Perm' Kray	333,111	160.2	2,079
56	Primor'ye Kray	627,697	164.7	3,811
57	Pskov Oblast	130,280	55.4	2,352
58	Rostov Oblast	600,415	101	5,945
59	Ryazan' Oblast	177,952	39.6	4,494
60	Sakhalin Oblast	138,749	87.1	99,107
61	Sakha Respublika	233,880	3083.5	76
62	Samara Oblast	420,200	53.6	7,840
63	Saratov Oblast	289,187	101.2	2,858
64	Smolensk Oblast	200,049	49.8	4,017
65	Stavropol' Kray	353,733	66.2	5,343
66	Sverdlovsk Oblast	567,010	194.3	2,918
67	Tambov Oblast	153,601	34.5	4,452
68	Tatarstan Respublika	750,250	67.8	11,066
69	Tomsk Oblast	171,802	314.4	546

70	Tula Oblast	221,014	25.7	8,600
71	Tuva Respublika	32,561	168.6	193
72	Tver' Oblast	204,038	84.2	2,423
73	Tyumen' Oblast	285,142	1464.2	195
74	Udmurt Respublika	190,447	42.1	4,524
75	Ul'yanovsk Oblast	142,163	37.2	3,822
76	Vladimir Oblast	151,662	29.1	5,212
77	Volgograd Oblast	288,389	112.9	2,554
78	Vologda Oblast	202,924	144.5	1,404
79	Voronezh Oblast	358,919	52.2	6,876
80	Yamal-Nenets Avtonomnyy Okrug	347,685	769.3	452
81	Yaroslavl' Oblast	155,224	36.2	4,288
82	Yevrey Avtonomnaya Oblast	-	36.3	-
83	Zabaykal'ye Kray	171,032	431.9	396

Note: BC emissions from on-road diesel vehicles by region were calculated as ratios of total BC emissions from active diesel vehicles (normal vehicles and 15% of superemitters) divided by the number of registered heavy-duty trucks in the regions. Given that trucks consume 78% of diesel in Russia, this approach gives reasonable estimates of BC emissions by region. We divide regional BC emissions by the area of the regions to calculate BC emissions by square kilometer in each Russian region.



Map A1. BC emissions from on-road vehicles by region, kg/km^2

(please see Table A 32 for the description of regions)

References

Agroinfo, 2015. Russian market of agricultural machinery in 2014 (in Russian). Agroinfo, availbalbe at http://agroinfo.com/rossijskij-rynok-selxoztexniki-v-2014-godu-1603201505/ (last access: 26 February 2016).

Autostat, 2010. Average mileage of cars in Russia is 16,700 kilometers per year (in Russian) (Средний пробег легкового автомобиля в России - 16,7 тыс. км в год).

Avtostat, 2015. Park of PC, LCV, HCV, BUS as of 01. 01.2015 (Russia, Russian regions). Dataset. Avtostat, Togliatti, Russia.

Balabin, V.N., Evpakov, V.V., 2013. Production of switch and industrial diesel locomotives: Developmental problems of the industry (in Russian). Transport of the Russian Fedeartion 6, 30–33.

EEA, 2013. EMEP/EEA air pollutant emission inventory guidebook – 2013. European Environment Agency, Copenhagen, Denmark. Available at http://www.eea.europa.eu/publications/emep-eea-guidebook-2013 (last access: 15 July 2014).

Emisia, 2015. COPERT (COmputer Programme to Calculate Emissions from Road Transport). Prepared for the European Environment Agency, Version 11.0 ed. Available at http://www.emisia.com/copert/ (last access:15 July).

Fedstat, 2015a. Availability of Main Construction Vehicles with Expired Useful Lifetime. Unified Interdepartmental Statistical Information System. Available at http://fedstat.ru/indicator/data.do?id=33409 (accessed October 19, 2015).

Fedstat, 2015b. Availability of Main Construction Vehicles. Unified Interdepartmental Statistical Information System. Available at http://fedstat.ru/indicator/data.do?id=33409 (accessed October 19, 2015).

Fedstat, 2015c. Electricity produced by diesel generators, 2010-2015 (in Russian). Unified Interdepartmental Statistical Information System. Available at http://fedstat.ru/indicator/data.do?id=40557 (last access: 19 October).

GKS, 2014. Transport and Communication in Russia. 2014 Statistical Yearbook. Federal Statistics Service of the Russian Federation. Available at http://www.gks.ru/bgd/regl/B14_5563/IssWWW.exe/Stg/02-02.doc (last access 19 October 2015).

ICCT, 2015. Global Transportation Roadmap Model International Council on Clean Transportation, Available at http://www.theicct.org/global-transportation-roadmap-model (last access: 15 September).

Minenergo, 2012. Performance and development of the energy system in Russia in 2011 (in Russian). Ministry of Energy of the Russian Federation, Moscow. Available at http//minenergo.gov.ru/system/download-pdf/3399/3196 (last access: 21 May 2016).

Ministry of Agriculture, 2015. National Report 2014 (in Russian). Ministry of Agriculture of the Russian Federation. Moscow. Available at http://mcx.ru/documents/file_document/v7_show/32460..htm (last access: 13 October).

MNRE, 2013. The status and protection of the environment in the Russian Ferderation in 2013 (in Russian). Ministrty of Natural Resources and Environment of the Russian Federation, Moscow. Available at https://www.mnr.gov.ru/regulatory/detail.php?ID=138762 (accessed 30 July 2016).

NIIAT, 1998. The assessment methodology for estimating the residual value of vehicles with regard to technical condition. Scientific Research Institute of Automobiles and Transportation, Moscow.

NIIAT, 2012. Calculation instruction (methodology) for emissions inventory from vehicles on the territory of the largest cities (based on Moscow example) (in Russian: Расчетная инструкция (методика) по инвентаризации выбросов загрязняющих веществ от автотранспортных средств на территории крупнейших городов (на примере Москвы)). Scientific Research Institute of Automobiles and Transportation, Moscow.

Rosagroleasing, 2012. Program of Agricultural Fleet Upgrade Rosagroleasing. Available at https://www.rosagroleasing.ru/client/get.php?ID=488222, Moscow.

Rosstat, 2015. Russian Statistical Yearbook. Rosstat, Moscow. Available at http://www.gks.ru/bgd/regl/b15_13/.

Yan, F., Winijkul, E., Jung, S., Bond, T.C., Streets, D.G., 2011. Global emission projections of particulate matter (PM): I. Exhaust emissions from on-road vehicles. Atmos. Environ. 45, 4830–4844.