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GAINS and EMEP modelling in the Russian Federation

Analysis on the regional level

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In cooperation with Scientific Research Institute for atmospheric air protection (SRI Atmosphere, JSC), Norwegian Meteorological Institute (MET Norway), and Finnish Environment Institute (SYKE)

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Preface

This report summarizes the results of the multilateral Nordic-Russian cooperation project "GAINS and EMEP modelling in the Russian Federation: further developments at the regional level". The project was financed partly by the Nordic Council of Ministers and partly by the in-kind work of the national experts.

The overall goal of the project is to promote and facilitate more active use of the EMEP and GAINS Russian models by national experts in the Russian Federation, both in the international context and as a basis for developing internal Russian air pollution abatement strategies on the regional and national levels. This purpose is reached by further strengthening Russian and Nordic experts' capacity in GAINS and EMEP modelling, joint modelling activities, and experience exchange via seminars and workshops, with the pronounced focus on the exploring advantages of the model regionalization. The present report summarizes the results of this work.

Organizations participating in the project are IVL Swedish Environmental Research Institute (project coordinator), JSC SRI Atmosphere in the Russian Federation, Norwegian Meteorological Institute, and Finnish Environment Institute (SYKE).

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-Anna Gran, Kaarle Kupiainen, and Signe van Zundert from the Nordic Council of Ministers for project supervision and necessary support.

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Summary

The **purpose of the project** is to promote and facilitate more active use of the EMEP and GAINS Russian models by national experts in the Russian Federation, both in the international context and as a basis for developing internal Russian air pollution abatement strategies on the regional and national levels. This purpose is reached by further strengthening Russian and Nordic experts' capacity in GAINS and EMEP modelling, joint modelling activities, and experience exchange via seminars and workshops.

The report summarizes the results of the integrated assessment modelling work with the focus on the exploring advantages of model regionalization. The main results are as follows:

- New region-specific complete input data sets for the GAINS Russia model of good quality, based on the national statistics and resulting in emissions corresponding well with the official emission inventory results for the base year 2010;
- New region-specific baseline scenarios in GAINS Russia for the years 2020 and 2030;
- Region-specific GAINS scenarios for NO_x and agricultural ammonia, reflecting potential emission reduction efforts within the Gothenburg Protocol under the UNECE CLRTAP and analysis of alternative ways to decide on spatial distribution of abatement measures and costs in order to reach a certain emission reduction target;
- Summary of historical black carbon emission estimates for the Russian Federation and their sectoral and regional structure;
- Region-specific GAINS scenarios for black carbon, targeting three large emitting sectors – flaring of associated gases in the oil industry, diesel non-road transport, and residential combustion; analysis of the resulting emissions, measures, costs and health benefits;
- Updated sets of gridded emission data for the Russian Federation for EMEP modelling;
- Analysis of the EMEP model performance and the impact of input data updates and fine resolution on the modelling results;
- Verification of EMEP modelling results for the Russian Federation with available observation data;
- Analysis of the fine resolution in the EMEP model on the resulting trans-boundary effects.

Considering the regional differences, instead of working on the aggregated level of the European Territory of Russia (ETR), enables more accurate and less uncertain integrated analysis and more precise spatial allocation of abatement measures and costs resulting from scenario analysis. The new region-specific data sets and emission reduction scenarios for black carbon, NO_x and NH_3 are developed for the purposes of supporting policy development and decision-making on the level corresponding to the administrative structure of the Russian Federation. They reveal **significant differences in the regional economic structure** and can be used both as supporting materials for country's internal policy-making, and for negotiating within international agreements such as the UNECE CLRTAP or UNFCCC conventions. The results of the black carbon analysis might be useful as supporting material for the Russian Federation's work within the Arctic Council – for example, when analyzing the emission reduction target set for 2025 and possible ways to reach it.

EMEP modelling results produced within this project with main focus on ETR, together with improved technical skills of the involved experts, stronger methodological basis, and widened expert network for sharing input data and modelling results, are expected to contribute to further development of effective air pollution abatement strategies at the regional and national levels – and to more active participation of the Russian Federation in the work under the UNECE CLRTAP.

Abbreviations and explanations

Abbreviations

ACAP – Arctic Contaminants Action Program

AMAP – Arctic Monitoring and Assessment Programme

BC – Black carbon

CCAC – Climate and Clean Air Coalition

CHP – Combined heat and power plant

CLRTAP – Convention on Long-Range Transboundary Air Pollution

CTM – Chemical transport model

CEIP – Centre for Emission Inventories and Projections

CPU – Central processing unit

EDGAR – Emissions Database for Global Atmospheric Research

EF – Emission factor

EMEP – European Monitoring and Evaluation Program

ETR – European Territory of the Russian Federation

FD – Federal district (of the Russian Federation)

GAINS – Greenhouse Gas – Air Pollution Interactions and Synergies (model)

GNFR – Gridded aggregated NFR sector data

SRI Atmosphere – Scientific Research Institute for atmospheric air protection

IAM – Integrated assessment modelling

IEA – International Energy Agency

IIASA – International Institute for Applied System Analysis

IMO – International Maritime Organization

INERIS – French National Institute for Industrial Environment and Risks

MET Norway – Norwegian Meteorological Institute

MSC-W – Meteorological Synthesizing Centre – West of EMEP

NFR – Nomenclature for reporting

NOAA – National Oceanic & Atmospheric Administration

PM – Particulate matter

RCP – Representative concentration pathway

RMSE – Root Mean Square Error

Rosstat – Federal Service for State Statistics in the Russian Federation

SYKE – Finnish Environment Institute

SLCF/SLCP – Short-lived climate forcer / Short-lived climate pollutant

SNAP – Selective Nomenclature for Air Pollution

SR – Source-receptor (relations, tables, fluxes), i.e. quantifying relations between emission sources and receptors of relevant impacts – concentrations or deposition of pollutants

TNO – the Netherlands Organisation for applied scientific research

TSAP – Thematic strategies for air pollution

UNECE – United Nations Economic Commission for Europe

UNFCCC – United Nations Framework Convention on Climate Change

VOLY – Value of life year lost

VSL – Value of statistical life

WHO – World Health Organization

WRF – Weather Research and Forecasting (model)

Explanation of GAINS model modules

GAINS Europe – an open online module covering Europe
http://gains.iiasa.ac.at/gains/EUN/index.login?logout=1&switch_version=v0 ;

GAINS Russia – an open online module covering the entire territory of the Russian Federation
https://gains.iiasa.ac.at/gains/RUN/index.login?logout=expired ;

GAINS Global – a closed module, only available for a limited number of experts and mostly used as a research tool.

Explanation of GAINS model scenarios

Baseline scenario – a scenario implying efficient enforcement of committed legislation only, with no further action assumed;

Maximum Feasible Reduction (MFR) – a scenario implying maximum possible implementation of the most efficient emission reduction measures available on the market.

Explanation of spatial and administrative units

Subject of the Russian Federation – an administrative unit; federal subject authorities are entitled to issue own local legislation; a subject can be e.g. a large city (such as Moscow), an "oblast" (region around a large city), an "autonomous okrug/oblast", or a "republic". Within the EMEP modelling activities, we have mostly worked with Murmansk oblast, which is a separate subject of the Russian Federation and which we often refer to as "Murmansk region".

Federal district – a higher-level administrative unit in the Russian Federation; there are nine federal districts – six of them belong to the European part of Russia and three are located within the Asian part.

GAINS region – a territory defined in the GAINS model, used as a unit for calculation of emissions, costs and, if possible, effects. In the GAINS Russia module, most of the regions correspond to federal districts but some – to one-two subjects (e.g. "Moscow" consists of two subjects – Moscow city itself and Moscow oblast).

EMEP region – a territory defined in the EMEP/MSC-W model, used as a unit for calculation of e.g. source-receptor relations; examples – "Other North-Western FD", "Murmansk".

1 Background and introduction

The integrated assessment model GAINS[1] and the European Monitoring and Evaluation Programme (EMEP) model are actively used by the United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution (CLRTAP) to simulate the impact on the environment and economy of air quality policies. Since a substantial part of trans-boundary emissions in the Nordic countries are attributable to emission sources in the Russian Federation, it is important to involve Russian experts in the modelling work, to further build up technical capacity, and to provide database maintenance and technical support for GAINS Russia and EMEP[2] models used by Russian experts.

In 2008, the first **Nordic-Russian cooperation project** with the focus on integrated assessment modelling (IAM) started. The project was financed by the Swedish EPA and involved experts from IVL Swedish Environmental Research Institute in Sweden (IVL), JSC SRI Atmosphere (SRI Atmosphere) in the Russian Federation, and Finnish Environment Institute (SYKE) in Finland, with technical support from the International Institute for Applied System Analysis (IIASA). During this project, a need for updating the GAINS Russia module was recognized, which became the main goal of the next cooperation project in 2009–2012. The second project was financed by the Nordic Council of Ministers and the scientific research program SCARP[3], and included Norwegian Meteorological Institute (MET Norway) and IIASA as operative partners. The results of both projects are summarized in Åström et al. 2013 and at the home page www.rusaco.se. One of the main outcomes of this cooperation was new regionalisation of the GAINS Russia module.

The project activities during 2008–2012 could not cover all interesting IAM aspects. Due to the lack of time and certain administrative constraints, activities such as collecting all necessary national emission precursor data for the GAINS model for all the newly introduced regions were performed for part of the regions and for prioritized economic sectors only. This resulted in rather limited development and analyses of GAINS Russia scenarios at the regional level based on the national data. The **advantages of modelling emissions, costs and effects on the regional level** have not yet been fully explored. This type of analysis is valuable considering the fact that legislation initiatives in the Russian Federation are taken on both national and regional levels.

Both **EMEP and GAINS models have been updated** since 2012; for instance, for EMEP modelling, several resolution scales are available, enabling analysis of dispersion of Russian emissions at finer resolution than the earlier used grid of 50x50 km^2. Furthermore**, new highly relevant policy issues** have arisen. One of the important policy changes was the revision of the Gothenburg Protocol under the UNECE CLRTAP (not ratified by the Russian Federation) in 2012. For the Arctic region, which includes a large part of the Russian territory, actions aimed at analysis and abatement of short-lived

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[1] GAINS is an integrated assessment model, an extension of the RAINS model, originally developed within the UNECE CLRTAP to identify and explore cost-effective emission control strategies for air pollutants (Amann et al. 2011a). Later, the possibility to analyse greenhouse gas emissions and measures was included. The model is developed and maintained by the International Institute for Applied System Analysis (IIASA) and is widely used as a unified tool for scientific analysis of economic and environmental consequences of air pollution abatement strategies and climate mitigation measures. With its broad database on abatement measures and in-built emission dispersion parameters, GAINS enables analysis of emissions, costs and health and environmental effects for relevant policy scenarios. Furthermore, a cost-optimization mode is available for determining the most cost-effective solutions to reach suggested health or/and environmental targets. In the GAINS model, a set of country-to-cell source-receptor matrices, calculated in the EMEP model, are used for the air pollutants dispersion simulations.

[2] Hereinafter by "EMEP model" we mean the model EMEP/MSC-W described in detail in Appendix 16.

[3] http://www.scarp.se/ accessed in August 2019

climate forcers (SLCFs) have become highly important. Producing emission inventories and modelling of SLCFs, black carbon in particular, became of high interest for both the Nordic community and Russian experts.

To include these new aspects into IAM activities in the Russian Federation, and to further encourage practical applications of the modelling results, a new multilateral cooperation project, involving the same Nordic and Russian partners, was suggested. The overall **goal of this project** is to promote and facilitate more active use of the EMEP and GAINS Russian models by national experts in the Russian Federation, both in the international context and as a basis for developing internal Russian air pollution abatement strategies on the regional and national levels. This purpose is reached by further strengthening Russian and Nordic experts' capacity in GAINS and EMEP modelling, joint modelling activities, and experience exchange via seminars and workshops with the main focus on the exploring advantages of the model regionalization. This report summarizes the results of the modelling work and related project activities.

The report is divided into several chapters, each covering one of the IAM aspects analysed in the project. In Chapter 2, we present the new set of region-specific input data developed for the GAINS Russia module and describe in detail the methodological aspects of data processing. Chapter 3 is focused on the analysis of black carbon emissions in the Russian Federation – there we first summarize the available data on the historical emissions, and then present region-specific emission reduction scenarios targeting main emitting sectors. Chapter 4 presents the scenarios relevant for potential reductions of NO_x and NH_3 within the Gothenburg Protocol under the UNECE CLRTAP. Finally, in Chapter 5 we summarize the results of the EMEP modelling work performed within the project.

2 New set of region-specific input data for the GAINS Russia module

The GAINS model has been used by Russian experts for about ten years, since 2008. It is a valuable tool for supporting policy decisions with analysis of emissions, effects, and cost-effective abatement measures for different development scenarios. However, to obtain reliable results from GAINS modelling, the important prerequisite is input data of high quality and on the required level of aggregation. The model's spatial resolution and regionalization are also important, especially when using GAINS for analysis on the country level. This is why the regional structure of the module specifically designed for integrated assessment modelling for the territory of the Russian Federation – **GAINS Russia** – was revised in 2012 (Åström et. al 2013). The new structure of the GAINS Russia is illustrated in Figure 1 – regions used in the current version are more consistent with the administrative structure of the Russian Federation than regions used in the previous version (Popov 2002). New regions correspond to federal districts (FD) of the Russian Federation, with exception of the Moscow region – the latter comprises Moscow city and Moscow oblast. Regions can further be aggregated into the European Territory or Russia (ETR) and the Asian Territory of Russia. Table 1 summarizes the regionalization in the GAINS Russia introduced in 2012.

Figure 1. Map of the new regions in the GAINS Russia module. Red area inside Central FD is Moscow region comprising the city of Moscow and Moscow oblast. Regions west of the blue line belong to ETR, regions east of the blue line – to the Asian part of the Russian Federation.

Table 1. Regions in the GAINS Russia model and the corresponding federal districts.

GAINS Russia region	Federal district	Aggregated region in GAINS Russia
North-West	Northwestern FD	European Territory of Russia
Moscow	Central FD	European Territory of Russia
Other Central	Central FD	European Territory of Russia
Volga	Volga FD	European Territory of Russia
South	Southern FD	European Territory of Russia
Northern Caucasus	North-Caucasian FD	European Territory of Russia
Ural	Urals FD	Asian Territory of Russia
Siberia	Siberian FD	Asian Territory of Russia
Far East	Far Eastern FD	Asian Territory of Russia

Being administrative parts of the same country, the nine federal districts in the Russian Federation have very different economic structure, determined by their geographical location, climate conditions, resources, population, political situation, infrastructure and other factors. Main characteristics of the federal districts are summarized in Table 2.

Table 2. Brief economic characteristics of the federal districts in the Russian Federation[4].

Federal district	Natural resources, industries, population
Northwestern FD	St. Petersburg is a large transport center; chemical industry, metallurgy, ship-building, production of machinery
Central FD (Moscow + Other Central regions in GAINS Russia)	Textile and chemical industries; production of machinery; high population density and relatively scarce natural resources; Moscow is a large transport center; agriculture; iron ore resources
Volga FD	Production of machinery and equipment, oil refineries, pulp-and-paper industry, chemical industry; oil, gas, salt
Southern FD	Developed agriculture; machinery
North-Caucasian FD	Gas, oil, coal, metal ores; mainly mining industries; developed agriculture (rice, grapes, tobacco, vegetables), recreation and tourism
Urals FD	Iron ore, non-iron metals, salt, oil, gas, coal, wood; heavy machinery production, metallurgy, pulp-and-paper industry, chemical industry; developed mining industry
Siberian FD	Oil, coal, gas, metals, wood, water resources; production of machinery, ship-building, fishing; population is concentrated in main cities; importance of shipping and air transport; hydropower resources, cheap coal power plants; developed mining industry
Far Eastern FD	Developed mining industry; diamonds and gold mining; metallurgy, production of machinery, pulp-and-paper industry; fishing; large shipping ports (Vladivostok, Nakhodka)

Differences in the economic structure of the federal districts have significant impact on which sectors generate most emissions in each district, as well as on potential abatement measures and their costs. It is thus very important to take these differences into consideration in the integrated assessment modelling, especially at the stage of the input data compilation.

In 2012, the attempt was done to compile high-quality input data sets for all new regions – however, at that time it was difficult to cover all the regions due to the lack of resources and administrative constraints. Available data on fuel combustion, industrial production and agriculture was found to be too fragmentary, too aggregated and in some cases confidential. Therefore, population data was used as a surrogate activity – so called proxy – to distribute available data on the level of ETR. For three of nine regions certain data refinements were done for the base year (2010) – see Åström et al. 2013. In cases where national data was missing, the numbers assumed in the latest baseline PRIMES scenario[5] for Europe (PRIMES_2010) were used.

Chapter 2 of this report summarizes a profound revision of the input data set for the GAINS Russia module conducted during 2015-2018. A range of improvements have been made during this project, and a new baseline scenario has been developed. This new baseline scenario is still partly based on the PRIMES_2010 scenario; however, national data has been used for nearly all sectors and regions.

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[4] https://businessman.ru/new-osnovnye-ekonomicheskie-rajony-rf-opisanie-specializaciya-i-sostav.html accessed in July 2019

[5] A **baseline scenario** implies efficient enforcement of committed legislation and includes measures already agreed and integrated in the current and planned legislation. Baseline scenarios in GAINS are updated on a regular basis to reflect new knowledge. In this report, we refer to the following recent publicly available baseline scenarios developed by IIASA:

- ECLIPSE_V5a_CLE_base (Stohl *et al*. 2015), referred to as **ECLIPSE_v5a**;
- WPE_2014_CLE, referred to as **TSAP_16.** This scenario belongs to the TSAP scenario group – a group of scenarios developed for the European Clean Air and Policy Package presented in 2013 and described in Amann *et al*. 2015;
- **PRIMES_2010**. PRIMES scenario group is the group of scenarios based on the outputs from the energy model PRIMES, see http://www.ec4macs.eu/ Tools

In cases where national data is too aggregated, it has been distributed by regions and sectors with the same shares as estimated by IIASA.

2.1 Baseline activity data and control strategy

The main sources used to revise the base year (2010) data are studies of Huang et al. 2015, information available at the home page of the National Statistical Committee (Rosstat), and recent articles focused on particle emissions from diesel consumption (Evans et al. 2015, Kholod et al. 2016). For the future years (2020, 2030), the same assumptions on development rates as in ELCIPSE_v5a are used. Control strategy is adopted from ELCIPSE_v5a as well.

2.1.1 Activity data for 2010 – methodology

Chapter 2.1.1 focuses more specifically on how the input data sets for each of the emission source sectors are compiled. The main principle is to use data at the lowest possible level of aggregation – such as, for instance, region-specific official statistics, data from published studies and expert estimates available for certain industrial production and agricultural activities. Where the data has been missing, we have applied numbers estimated by IIASA in the recent European baseline scenario ECLIPSE_v5a, sometimes combined with estimates in the earlier baseline scenario PRIMES_2010 for the whole country, available in the GAINS Russia module.

Data from ECLIPSE_v5a and a significant part of national statistics is only available for the entire ETR or on the country level – not by regions. To distribute such data by GAINS regions, we use proxies – the most relevant parameters for which data is available. For instance, number of plants and/or plant capacities in each region have been used to calculate region-specific production numbers for certain industries; production of fertilizers in tonnes has been used as proxy to distribute fertilizer production in ktonnes nitrogen available in the statistics, etc. Population data from Rosstat (see Figure 2) has been used as proxy where nothing more appropriate is available, and for all product consumption activities.

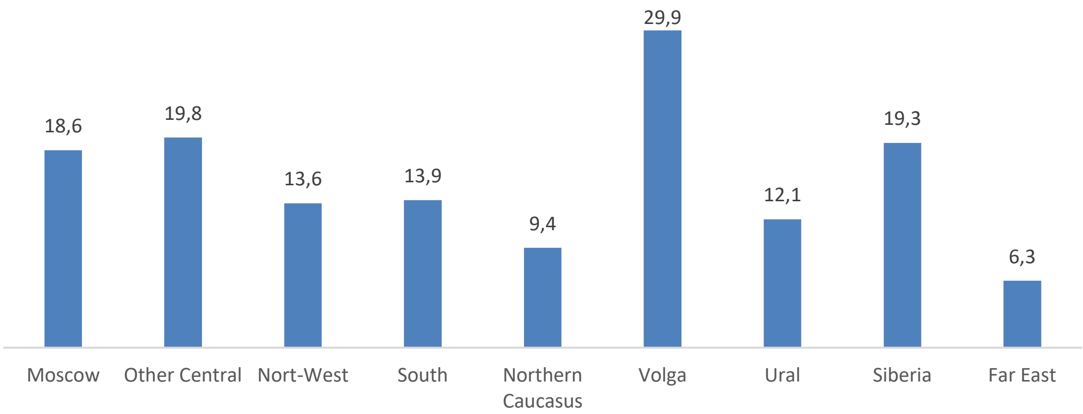

Figure 2. Population in the Russian Federation in 2010, by GAINS regions, million people[6].

[6] http://www.gks.ru/free_doc/new_site/perepis2010/croc/perepis_itogi1612.htm accessed in July 2017

Specific structure of the GAINS model requires further disaggregation of categories into sub-categories – such as distribution between liquid and solid manure management systems in the agricultural sector, production of steel by means of different technologies, or fuel split between different types of vehicles. Such distributions are made with either relevant national data, or with the same shares as assumed in ECLIPSE_v5a[7].

Following the predefined structure of the input data in the GAINS model, below we briefly present methodologies used for compilation of the activity data sets for power plants (PP), industrial combustion (IN), mobile fuel combustion (TRA), energy conversion sector (CON), non-energy use of fuels (NONEN), industrial processes (PROC), agricultural processes (AGR), and activities implying use of solvents (NMVOC). Model input parameters not supposed to be changed by user (such as age structure of boilers, or emission factors) are adopted from PRIMES_2010.

Stationary fuel combustion

A recent study by Huang et al. 2015 provides very detailed data on combustion of fossil fuels in the entire Russian Federation in 2010 and 2012. This data set was developed in cooperation with SRI Atmosphere and chosen to be the main source of energy data for the new GAINS baseline scenario in our study. Fuel consumption data in Huang et al. 2015 are given by subject of the Russian Federation, which enables quick and easy aggregation to the level of the GAINS Russia regions. Since data aggregation by sectors and fuels used in Huang et al. 2015 does not fully correspond to a predefined aggregation in the GAINS model, a fuel key and a sector key have been developed for the purposes of our study, see Appendix 1.

Power and district heating plants (PP) & Residential combustion (DOM)

In Huang et al. 2015, there is no specific category for small-scale residential combustion but instead the category "heat plants" incorporates both large Combined Heat-and-Power Plants (CHP) and small residential combustion (domestic sector). These two sectors are distinguished and disaggregated by inter alia using assumptions on sector-specific fuels (see Table 1.4 in Appendix 1) – e.g. it is reasonable to assume that most part of the wood is used in the domestic sector rather than in large power plants. Further disaggregation into fuels and sub-categories is based on the same shares as used in ECLIPSE_v5a*.

A number of Russian power plants produce electricity and heat based on renewable energy sources – primarily hydro- and nuclear energy. This production is not considered in the numbers provided in Huang et al. 2015, since that study only focuses on emission sources based on fuels combustion. However, to be able to consider future energy shifts, we have accounted for renewable sources in the heat and energy balances described below.

Combustion in the energy conversion sector (CON) and in manufacturing industries (IN)

To estimate fuel combustion in **manufacturing industries**, we use numbers from Huang et al. 2015. Distribution between different industry types and between combustion in boilers (IN_BO) and other industrial combustion (furnaces – IN_OTH) is done based on the ECLIPSE_v5a* shares.

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[7] Since focus in refining activity data in ECLIPSE_ v5a has been on future years (2015 and onwards) rather than on 2010, we have in some cases adjusted activity data reported in ECLIPSE_v5a when it seemed to be inconsistent between 2010 and 2015-2030. It has been considered necessary since the new baseline scenario developed for the purposes of this project is based on the assumption on the same development rates between 2010 and 2030 as in ECLIPSE_ v5a, and also to ensure similar sub-sector distributions as in ECLIPSE_ v5a. Adjustments are summarized in Appendix 1, Table 1.1. The adjusted activity data is referred to as ECLIPSE_v5a*.

Fuel combustion in the **energy conversion sector** (CON_COMB) in the GAINS model covers activities such as combustion in furnaces during fuel production (crude oil distillation furnaces or catalytic cracking installations in oil refineries) or use of coke oven gas for heating coke batteries at coke production plants. It does not include combustion in industrial boilers though – this should be separated and accounted for under industrial combustion. For the new GAINS activity data set, we use numbers available in Huang et al. 2015 support materials – they include both boiler and furnace combustion in the energy conversion sector. Then, part of this combustion, corresponding to the industrial combustion in boilers, is reallocated to the category "manufacturing industries" (IN). In this reallocation, we assume that like in the ECLIPSE_v5a*, 74% of brown coal, 100% of hard coal, 100% of heavy fuel oil and 20% of gas in the energy sector are combusted in boilers, and the remaining part – in furnaces.

Non-energy use of fuels (NONEN)

To estimate non-energy use of fuels (e.g. as feedstocks in industrial processes), we use the numbers earlier estimated by IIASA in PRIMES_2010 and in ECLIPSE_v5a*. These numbers are not directly used in the model calculations but needed for an overall energy balance.

Mobile combustion - Road transport (TRA_RD)

The data set in Huang et al. 2015 does not contain comprehensive data on road transport, so we use other available sources for our study - mainly Rosstat and recent articles on black carbon emissions from diesel sources and transport in Russia (Evans et al. 2015, Kholod et al. 2016). Distributions of data by fuel types, transport categories and regions are also done based more on national sources rather than on ECLIPSE_v5a* shares. More details are given in Appendix 1.

Mobile combustion - Non-road transport (TRA_OT(S))

To estimate fuel use in the non-road transport sector, we use the data set from Huang et al. 2015 support materials (except for aviation – this data is provided by SRI Atmosphere). Total diesel consumption in this category is estimated at 416 PJ (~ 9700 ktonnes) in Huang et al. 2015, which is only 10% lower than the number given for diesel mobile non-road sources in the national study by Evans et al. 2015 (~10700 ktonnes) indicating that numbers in Huang et al. 2015 are not significantly underestimated. Methodological details are given in Appendix 1.

Main non-road transport categories are machinery used in agriculture, construction and industries, as well as shipping, railway and aviation. According to Kholod et al. 2016, there is one "hidden" transport category that might be a large diesel consumer – military transport, allocated to non-road transport in the GAINS model. Fuel consumption by military vehicles is not included in the state statistics and is in general hard to find in open sources. This means that our GAINS input data set may underestimate fuel use in the non-road sector by not including military sources.

Non-emissive sources, losses (CON_LOSS) and energy balance

Input data sets for the GAINS model include both energy consumption and energy production numbers. Energy production covers electricity and heat output from heat and power plants as well as heat produced in industrial boilers. Electricity is produced from both fossil fuels and by renewable sources – emissive and non-emissive. Including in the model scenarios activity data for non-emissive energy sources is necessary to take into account potential switch to cleaner alternatives to fossil fuels in the scenario development.

Production, consumption by end-user sectors (the latter comprise domestic sector, transport and industries), own use in the energy sector and losses of electricity and heat should be distributed and balanced carefully for each region, when working on the input data set. The following criteria need to be addressed:

- Electricity saldo (difference between production, consumption and losses) corresponds to the reported import or export in a region;
- Heat saldo is close to zero (heat energy is usually not a subject to inter-regional import or export);
- Fuel conversion efficiency of heat and power plants and industrial boilers seems reasonable.

Electricity balance

In the Russian Federation in 2010, renewable electricity sources included mainly hydropower and nuclear power. According to the statistics, geothermal energy was used in one region (Far East), whereas input from wind power was less than 1% in all regions (Rosstat 2012). Total electricity production and consumption numbers by federal district are available from Rosstat (Rosstat 2015). Electricity flows between subjects of the federation are illustrated in Figure 3.

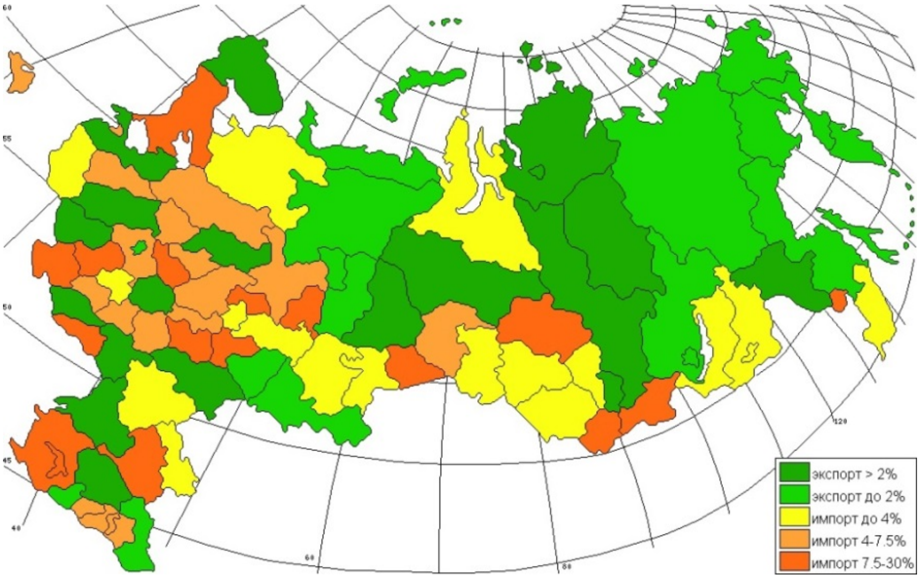

Figure 3. Export and import of electricity by subjects of the Russian Federation in 2009[8]. Green – export, yellow and red – import, in % to electricity consumption in the region[9].

On the country level, share of thermal power plants in electricity production was 67%, shares of nuclear and hydro energy – about 16% each (Rosstat 2012). However, nuclear plants and hydropower are not distributed evenly within the country, and their input may vary significantly between subjects, see Figure 4.

Data on electricity production by different sources in 2009, aggregated by regions (Figure 5), is provided by SRI Atmosphere. We assume that this distribution is valid for 2010 as well. Shares of different sources vary significantly between the regions. Nuclear power is concentrated in Other Central, South and North-West regions, whereas hydropower is essential in Siberia and Far East. In

[8] http://interfax-era.ru/reitingi-regionov/2009/obshchee-potreblenie-energii accessed in June 2016

[9] http://www.gks.ru/free_doc/new_site/business/prom/el_potr.htm accessed in June 2016

Moscow region, there is virtually no renewable energy used for electricity production – gas-fired heat and power plants dominate the sector.

Figure 4. Electricity production by nuclear and hydropower by subjects of the Russian Federation in 2009, mln kWh[10].

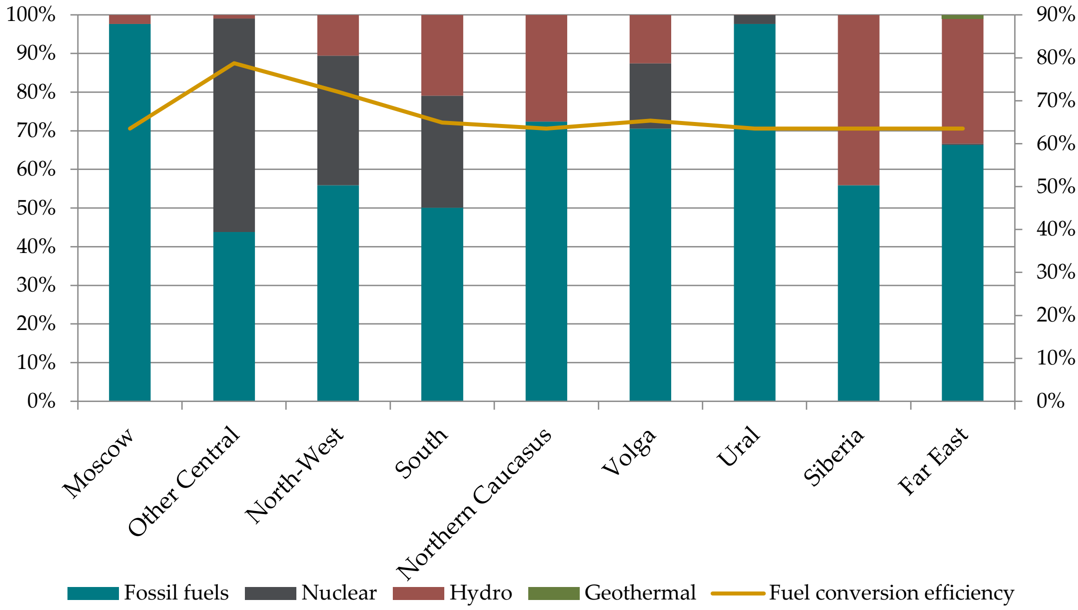

Figure 5. Region-specific heat and electricity generation based on data for 2011; left axis – percentage of different energy types in the total energy mix; right axis – fuel conversion efficiency.

Fuel amounts summarized in Huang et al. 2015 comprise both actual combustion of fuels and losses during fuel distribution and handling. In the GAINS model, these are two separate categories. For the modelling purposes we thus reallocate part of the total fuel consumption to a separate category "conversion losses" (CON_LOSS), so that the total fuel conversion efficiency for electricity and heat

[10] http://www.gks.ru/free_doc/new_site/business/prom/el_potr.htm accessed in June 2016

production in each region lies within the reasonable interval of 64%–85%. The resulting fuel conversion efficiency is shown in Figure 5.

Electricity output to the grid is further distributed between consumption by industries, domestic sector and transport, and transmission losses (10% of consumption). Shares of electricity consumed by different end-user sectors are calculated from Rosstat 2011c and assumed to be the same for all regions. The resulting electricity balance is presented in Table 3.

Table 3. Electricity balance by region in the Russian Federation (based on Rosstat 2011c).

Region	Produced, PJ	Consumed by end users, PJ				Losses, PJ	Net export, PJ	Net import, PJ
		Industries	Domestic	Transport	Total			
Moscow	296	197	92	31	320	37	61	
Other Central	528	215	100	34	348	40		140
Volga	687	365	169	57	591	68		28
North-West	399	211	98	33	341	39		18
South	182	122	56	19	197	23	38	
Northern Caucasus	90	45	21	7	74	8		8
Ural	634	360	167	56	583	67	17	
Siberia	760	435	202	68	705	81	26	
Far East	162	85	39	13	137	16		10
Russia, total	**3736**	**2034**	**944**	**318**	**3297**	**378**	**63**	

Heat balance

Total heat production by regions is available from Rosstat 2015. We assume that these numbers concern only heat and power plants and do not include heat produced in industrial boilers, which is a separate sub-category in the GAINS model. Heat produced in industrial boilers we estimate based on the thermal fuel efficiency of 85% (as assumed in ECLIPSE_v5a). Total heat production is further distributed by consumption sectors, with respect to losses.

Agricultural processes (AGR)

Region-specific national statistics available from Rosstat 2011a, Rosstat 2013 and provided by SRI Atmosphere is used to estimate livestock of cattle, pigs, poultry, sheep, horses, fur animals (rabbits) and camels, as well as for milk yield. Rosstat also provides data on areas of different types of land in the Russian Federation (Rosstat 2011b). Information on rice cultivation is missing in the open official statistics; data on rice production is taken from an alternative source[11] .

Numbers on production of fertilizers, burning of agricultural waste and nitrogen deposition are the same as in IIASA's recent baseline scenarios (PRIMES_2010, ECLIPSE_v5a), and are distributed by regions with suitable proxies, see Appendix 2.

Industrial processes (PROC)

Amounts of produced goods by federal district are reported in statistical tables in Rosstat 2015. Those are used as main data sources for the industrial processes data set – directly or as proxies for Rosstat/IIASA numbers available only on the level of ETR or the entire country. In some cases, number of plants or their capacities are used as proxy instead, see Appendix 2.

[11] https://ab-centre.ru/articles/rynok-risa-rossii-v-1990-2014-gg accessed in June 2016

For Central federal district, further split of production numbers between Moscow and Other Central GAINS regions is needed. It is done by using numbers on fuel combustion in the relevant industries, available in Huang et al. 2015, as proxy, as shown in Table 4.

Table 4. Proxies used for distribution of industrial process activities between Moscow and Other Central regions in GAINS Russia.

Processes as specified in the GAINS model	Sector in Huang et al. 2015 used as proxy
Production of iron and steel, sinter, pellets, metallurgical coke and briquettes, non-ferrous metals	Metallurgy
Pulp and paper industries	Manufacture of wood and paper
Crude oil delivered to refineries	Processing of oil and gas
Gas transportation in pipelines	Pipeline transport
Industrial waste	Sum of all manufacturing industries
Waste water from food and drink industries	Manufacture of food and beverage
Waste water from chemical industries	Chemical production
Waste water from pulp and paper industries	Manufacture of wood and paper

Flaring of associated gases in the oil and gas industry

Flaring of associated gases is not a separate category in the GAINS model but one of the processes listed within the "Waste handling" category. However, this activity is significant in the Russian Federation. In the recent years, flaring has been actively discussed as a large source of particle emissions, in particular, black carbon (see Huang et al. 2015, Eldvidge et al. 2016, Evans et al. 2017, Klimont et al. 2017). This is why gas flaring has been studied carefully when the new GAINS input data set has been developed. Main parameters used for calculation of the gas flaring in PJ (as used in the GAINS model) are volumes of gases flared in each federal district and their average calorific value.

Available estimates of the **flared gas volumes** vary greatly. According to Huang et al. 2015, ~35.6 billion m^3 (bcm) of associated gases was flared in the entire Russian Federation in 2010 – this is an estimate based on satellite observations. Evans et al. 2017 summarizes data from several sources; remarkably, for 2010 estimates for gas flaring by National Oceanic & Atmospheric Administration. (NOAA) are more than twice as high as data in the official national statistics (Minenergo), also reported to the United Nations Framework Convention on Climate Change (UNFCCC) – see Figure 6. For this study, we use the data by the Russian Ministry of Energy (Minenergo) as provided by SRI Atmosphere – 14.1 bcm gas flared in 2010.

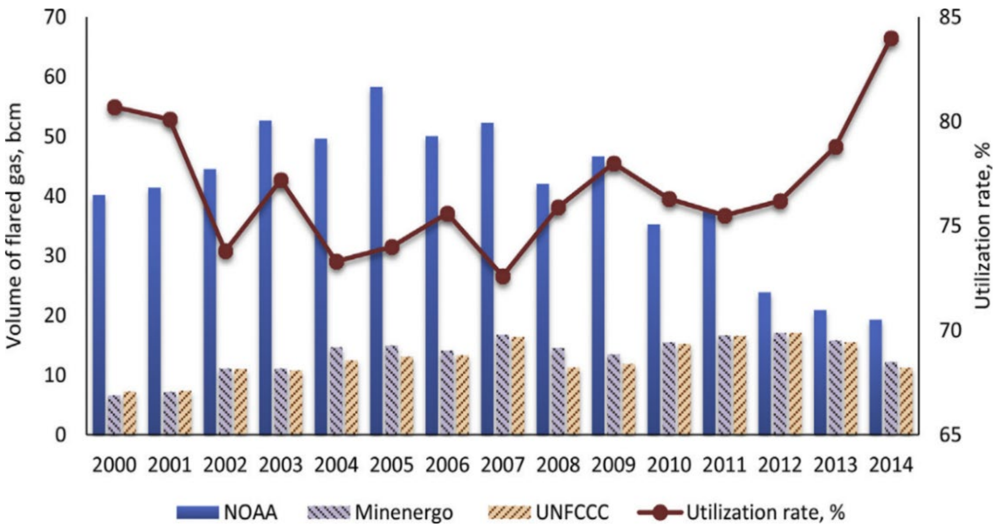

Figure 6. Volumes of flared associated gases and utilization rates in the Russian Federation, according to different sources (source – Evans et al. 2017).

Calorific value of the flared gases is also an issue under discussion. Officially, e.g. in the statistics reported by Minenergo, the number is 38.1 MJ/m^3 (SRI Atmosphere, personal communication). Höglund-Isaksson 2017 uses the number of 47.7 MJ/m^3 with the reference to Russian Energy[12]. These numbers are in line with the average calorific value of natural gas as specified in IPCC 2006 – 38.4 MJ/m^3. However, Huang et al. 2015 claims that methane (main component of the natural gas) constitutes only about 46% of the associated gas, while there is a number of other components with much higher calorific values – e.g. propane with the calorific value of 101 MJ/m^3 accounts for up to 21% of the associated gas composition. Complicated composition of associated gas in Russia thus might result in a much higher calorific value. In this study, we use the calorific value as estimated in Huang et al. 2015 with respect to inputs from all gas components – 75.5 MJ/m^3. Thus, chosen amount of flared gas is relatively low, while chosen calorific value is relatively high.

NMVOC-related processes (NMVOC)

The category "NMVOC-related processes" comprises mainly use of solvents. Solvents are emitted by a large variety of activities, including the production and use of paints, cosmetics, rubber, chemicals, etc., and also cleaning in industry and in households (Klimont et al. 2000). Use of solvents may be divided into industrial use and domestic use. In this study, domestic use of solvents is distributed by regions with population numbers used as proxy. For industrial processes, numbers of relevant industrial sites or available production statistics are used as proxy. In some cases, direct statistical numbers are available in Rosstat 2015 – in particular, for manufacturing of vehicles, shoes and PVC. To reflect new and developing technologies resulting in lower NMVOC emissions compared to conventional production and use of solvents, a sub-category NEW is used in GAINS – the shares of NEW in each category is the same in this study as assumed in ECLIPSE_v5a.

2.1.2 Activity data for 2010 – summary and comparisons to other studies

In Chapter 2.1.2, we summarize the resulting region-specific input data sets for 2010 and compare our results to similar data from other studies.

The total fuel consumption by sector according to our study, Huang et al. 2015 and ECLIPSE_v5a* (for ETR) are summarized in Figure 7. The total fuel consumption numbers in Huang et al. 2015 do not substantially differ from our new data set, and for ETR are estimated to ~13500 PJ. Huang et al. 2015 gives higher estimates for power plant sector and energy sector (fuel conversion sector) – presumably because numbers in Huang et al. 2015 seem to include both losses and actually combusted fuels – all fuels that were delivered to industrial enterprises but not necessarily combusted (they might be lost, used as feedstocks or bound in products). In our study, we make adjustments and reallocations with respect to reasonable fuel efficiency and losses. Also, reallocation of fuels between industrial boilers and the energy sector results in differences for these two categories between the two data sets, while in sum they are the same in both (~2200 PJ). Road transport is missing in Huang et al. 2015. In comparison to ECLIPSE_v5a*, the main difference in our data set is considerably lower estimates for industrial combustion. The total difference between this study and ECLIPSE_v5a* for ETR is 2200 PJ.

[12] http://www.russian-energy.ru/en/services/rusenpow/1250/ accessed in June 2016

Distribution of fuel consumption by sector and fuel type for each region is summarized in Appendix 3. In the country in total, dominating fuel is natural gas – it is the main fuel in all stationary combustion categories, except for industrial combustion where coal is prevailing – see Figure 8. Share of renewables – wood and waste – is 1% for the country in total, varying from 0.02% in Northern Caucasus to 4.1% in North-West.

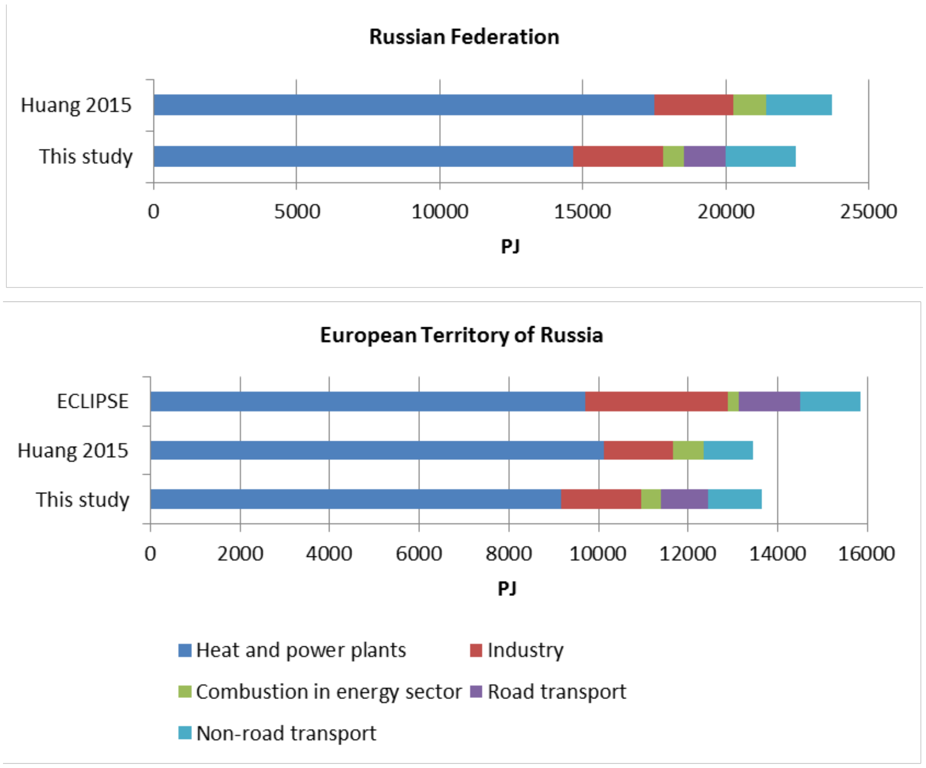

Figure 7. Sectoral distribution and total fuel consumption in 2010, according to Huang et al. 2015, ECLIPSE_v5a* and our study.

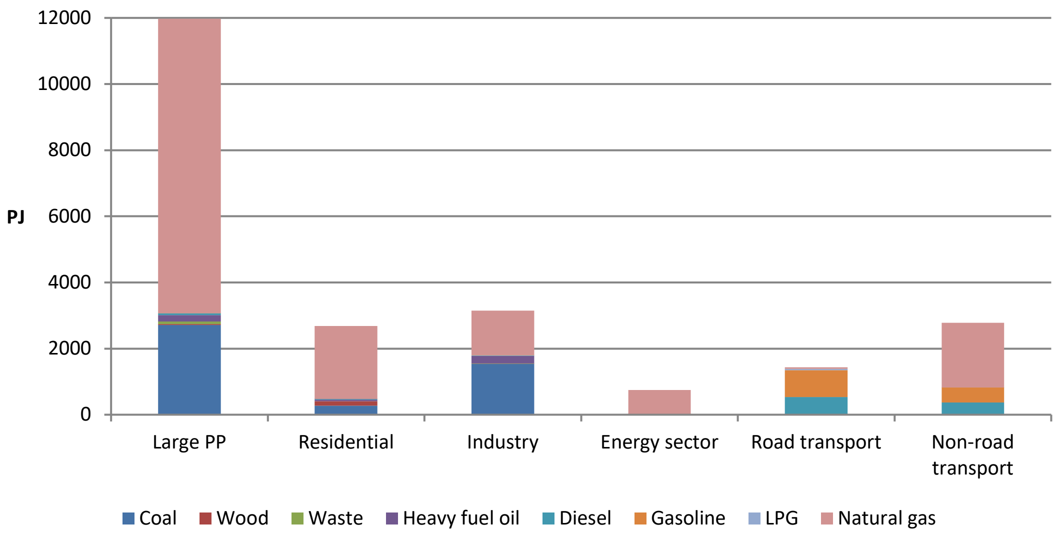

Figure 8. Fuel consumption 2010 in the Russian Federation, by sector and fuel.

There are significant differences in the regional split of fuel consumption by sectors and fuel types (Appendix 3). Coal, for instance, dominates in the production of heat and electricity in Far East and Siberia. Another example is comparatively different inputs of road and non-road transport, which depends on specialization of regions and the population density. Regional distribution of fuel use in the Russian transport sector is shown in Figure 9. A substantial part of industrial activities is concentrated in Ural – this is clearly seen in the region's contribution to the non-road fuel use. Road transport is significant in the European regions, especially in Central federal district. Two GAINS regions – Moscow and Other Central – together account for more than 25% of the road transport sector energy use in the country.

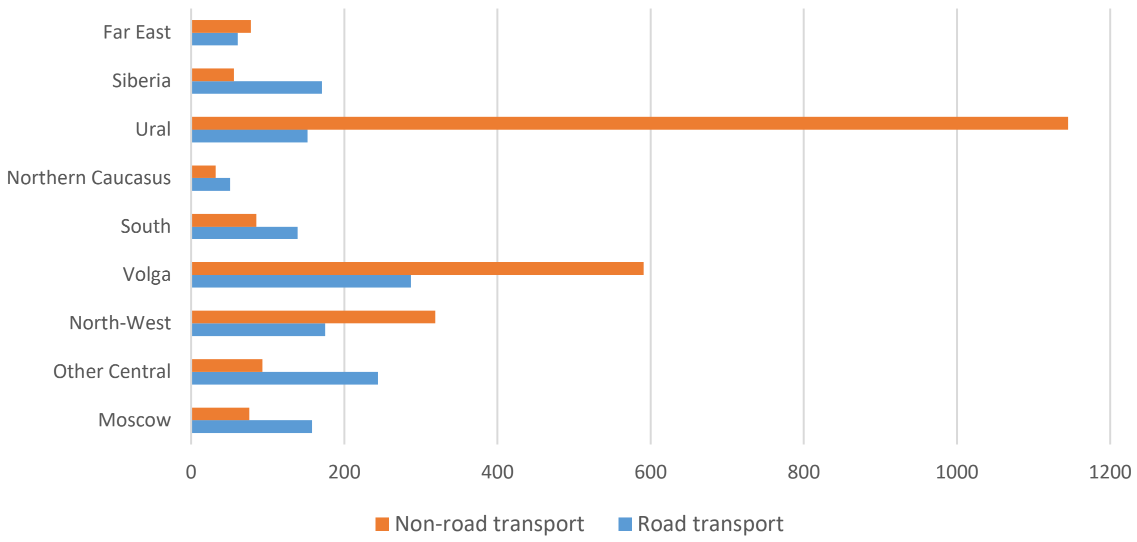

Figure 9. Fuel combustion by mobile sources in the Russian Federation in 2010, by region, PJ.

Several recent national studies had specific focus on the inventory of **diesel emission sources** and their input in emissions of black carbon in Russia. Analysis conducted for Murmansk region in 2015 (Evans et al. 2015) has been further scaled up to the country level in Kholod et al. 2016. The results of these studies are presented in Appendix 4, in comparison to the numbers used in the present study and to the data used in the recent scenarios developed by IIASA (PRIMES, ECLIPSE).

Residential combustion of fuel wood is in our study estimated at 131 PJ in the entire country, from which 72 PJ – in ETR. For comparison, Huang et al. 2015 gives a number of ~47 mln m^3 fuelwood for the whole Russian Federation, which corresponds to ~365 PJ. ECLIPSE_v5a estimate for ETR is 47 PJ, and official number in the national statistics by Rosstat (fuelwood sold to population) is only ~2.1 mln m^3, or ~16 PJ (SRI Atmosphere, personal communication).

Figure 10 illustrates distribution of fuelwood consumption in the residential sector by regions – according to Huang et al. 2015 and according to our study. In both cases, Siberia and North-West appear to be the two regions where most part of the country total is burnt. This is explained by cold winters and relatively high population density. Volga is the third largest wood-burning region. Fuelwood combustion in these three regions accounts for ~70-80% of the country total. Thus, although the total fuelwood consumption numbers differ substantially between Huang et al. 2015 and this study, the regional distribution looks similar.

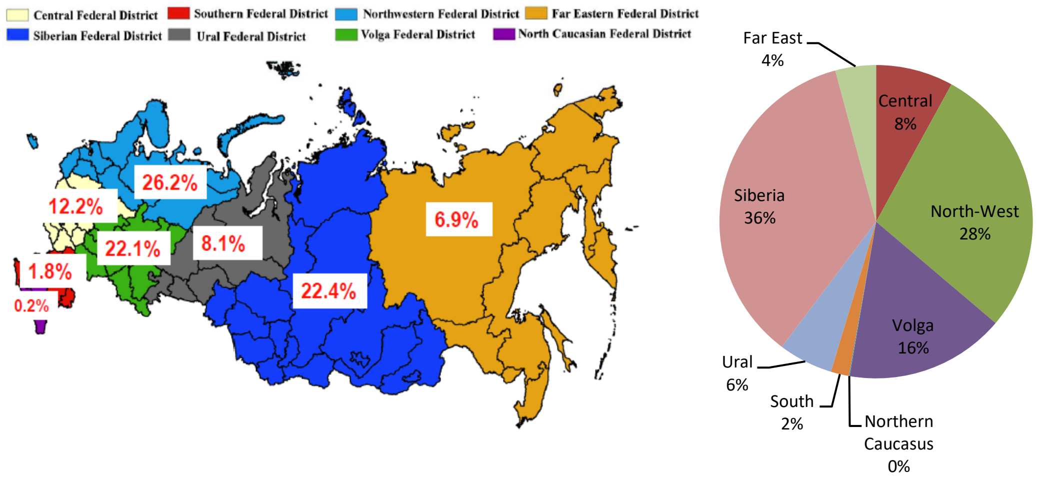

Figure 10. Regional distribution of fuelwood combustion in the residential sector; left – as presented in Huang et al. 2015, right – this study. Central FD includes Moscow + Other Central regions in the GAINS Russia model.

As shown in Figure 11, residential sector in the Russian Federation is dominated by natural gas. Our estimate for gas consumption in this sector is ~1600 PJ for ETR, while the corresponding number in ECLIPSE_v5a is ~1500 PJ.

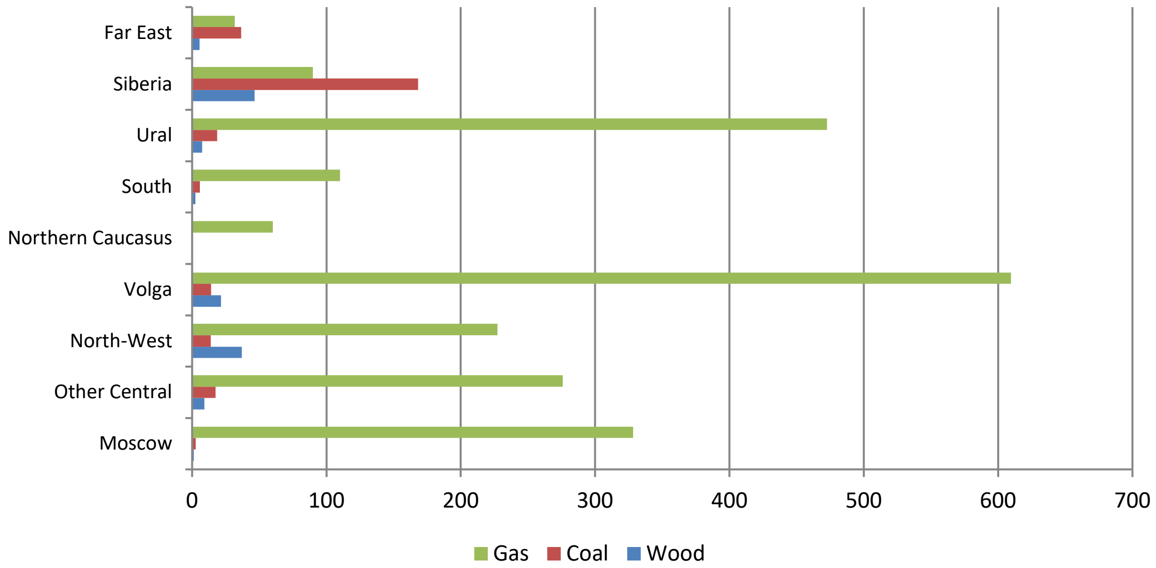

Figure 11. Residential sector in the Russian Federation – distribution by fuels and sectors.

With the data and assumptions described in Chapter 2.1.1, our estimate of the total amount of **flared associated gases** in the Russian Federation in 2010 is **~1065 PJ**. Major gas flaring areas are located in Ural, Siberia and North-West regions (see regional distribution in Figure 12). From Huang et al. 2015, the amount of flared gas can be calculated as 35.6 bcm*75.5 MJ/m^3 ≈ **2700 PJ**. The estimate in PRIMES _2010 for the entire Russia is **1048 PJ**, from which in the Asian regions – 615 PJ. ECLIPSE_v5a gives an estimate of **406 PJ for ETR**. Our study estimates that about 82% of flaring activity occurs in the three Asian regions of the Russian Federation, where the major part of oil and gas industries is concentrated.

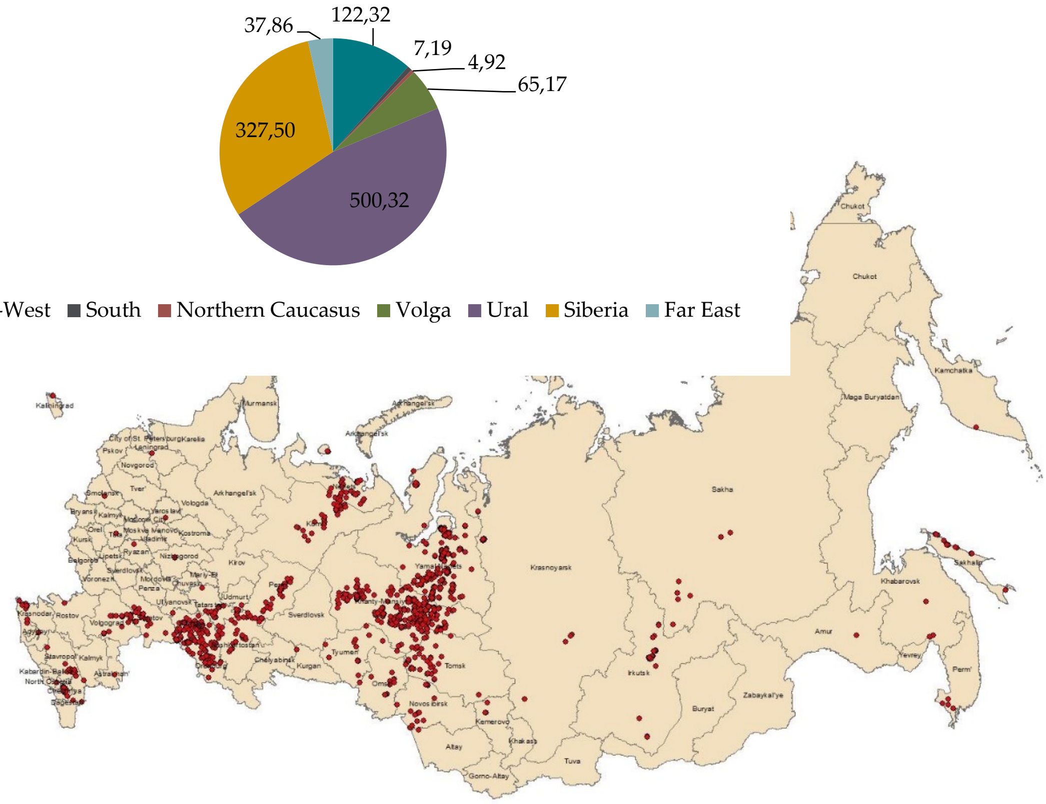

Figure 12. Associated gas flaring in the Russian Federation. Upper: numbers used as used in this study, PJ; lower – flaring sites according to Elvidge et al. 2016 cited in Evans et al. 2017.

2.1.3 Activity data for 2020 and 2030

To develop a consistent baseline scenario, it is important to make reasonable assumptions regarding future development rates. Those are usually based on available national and/or regional development plans for different economic sectors. Unfortunately, available development plans for the Russian Federation do not contain enough quantitative data that could be used in the modelling, which is why we chose to use the relative development rates as implied in the ECLIPSE_v5a*, and to apply those to the activity data for the base year 2010. The **main assumption** is thus that between 2010 and 2020/2030 the amount of PJ combusted in each sector and each region is increasing/decreasing with the same percentage as it does in ECLIPSE_v5a*. For simplicity and due to the lack of more detailed data, we assume this relative change is the same in all the regions, although in reality it is not necessarily so.

Similar assumption is then applied to each fuel type separately, too; fuel-specific numbers are then adjusted so that the relations between them within a sector remains similar to what's implied in ECLIPSE_v5a* – for instance, natural gas is still the main fuel in the residential sector in 2020/2030 in most regions, even though the total amount in our study is not the same as in ECLIPSE_v5a*.

Some renewable energy sources are not present in 2010 but assumed to appear by 2020/2030. For these sources, we assume the same relative share in the energy mix in 2020/2030 as assumed in ECLIPSE_v5a*.

Figure 13 illustrates the changes in the energy consumption in the Russian Federation assumed to happen between 2010 and 2020/2030 according to our study. The total increase by 2030 is about 9%, mainly due to much higher energy consumption in the energy sector and industries, and in the residential sector. Fuel use by power plants is assumed to be decreasing, being partly replaced by renewable energy sources.

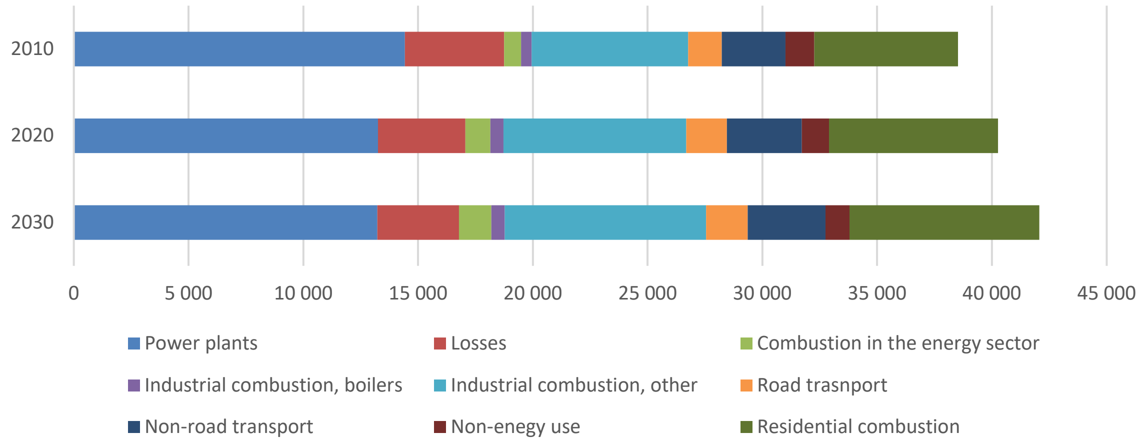

Figure 13. Energy consumption trends in the Russian Federation: sectoral distribution of fuel use, PJ.

2.1.4 Baseline control strategy

To assess available emission control measures and their actual application rates in Russia are at least as important as to compile a reliable set of activity data. However, this type of data is usually much less available in open sources, making data collection a very time-consuming and complicated task. For this study, we adopted control measures implied in ECLIPSE_v5a for 2010, 2020 and 2030, for all sectors except for non-road transport.

The status of emission control for non-road emission sources in Russia is investigated in Kholod et al. 2016. The article highlights that since there are no emission standards for most of the non-road sources, and due to a rather modest level of import from European countries, emission control on non-road mobile sources in Russia is mostly missing or very low. We chose to adjust control levels given in ECLIPSE_v5a in line with this assumption. In our scenarios, future implementation of control technologies is significantly delayed, compared to what is assumed in ECLIPSE_v5a, see Table 5.

Table 5. Implementation rates of control technologies in non-road transport in the Russian Federation.

Transport category	**Emission control**				
	Kholod et al. 2016	**ECLIPSE_v5a**	**This study**	**This study**	**This study**
	2010	**2010**	**2010**	**2020**	**2030**
Railway	No control	34% stage I	No control	34 % stage I	68 % stage I
Inland waterways	-	34% stage I	No control	34 % stage I	68 % stage I
National maritime shipping	No control	5% combustion modification	No control	5% combustion modification	23% combustion modification
Agriculture	95% no control, 5% stage I	34% stage I	5% stage I	39% stage I	73% stage I
Industrial machinery	88% no control, 12% stage I	34% stage I	12% stage I	46% stage I	80% stage I
Construction	90% no control, 10% stage I	34% stage I	10% stage I	44% stage I	78% stage I

We assume in the further modelling that the abatement level is similar in different regions of the Russian Federation. This is probably not the case in reality; however, it is a simplification necessary for this project.

2.2 Baseline scenario emissions

In this chapter, we present the resulting emissions generated by the GAINS model in our new baseline scenario. Emissions of the main pollutants (NO_x, SO2, NH_3, NMVOC, TSP and $PM_{2.5}$) on ETR are compared with Russia's official reporting to EMEP. For 2030, comparisons are made to the number available in alternative GAINS scenarios.

Regional and sectoral structure of the emissions of main pollutants in 2010 and in 2030 are illustrated in Appendix 5. There are large variations between the regions. In 2010, emissions of particles are highest in Siberia; they mainly origin from power plants and residential combustion. Ural is the region with second largest emissions – here mainly from industrial processes. Emissions of NO_x are highest in Volga and Ural regions; road and non-road machinery make large contributions to the totals in all nine regions. SO_x emissions are highest in Ural and Siberia and come mainly from industrial processes and power plants. NH_3 emissions are highest in Volga region, where agriculture is an important part of the regional economy. NMVOC emissions are highest in Ural. A large part of the NMVOC emissions originate from non-road machinery on gas (gas pipeline compressors), but also road vehicles on gasoline, as well as solvent use, make significant contribution.

In 2030, the regional distribution of emissions does not change much. The total emission trends are illustrated in Figure 14. While certain emissions (TSP, $PM_{2.5}$, NH_3) decrease due to more efficient abatement measures, others (NO_x, SO_x, NMVOC) are expected to increase with the overall economic development and population growth.

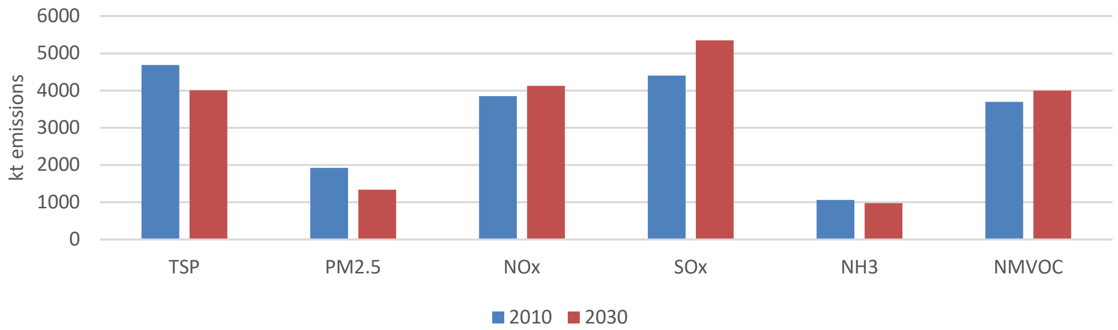

Figure 14. Emission trends in the Russian Federation, according to the baseline scenario.

Modelled emissions of six main pollutants in 2010, in the six European regions, are in Table 6 summarized and for ETR compared to the emissions officially reported by the Russian Federation to EMEP. The discrepancies between the data sets lie below 5% for all main pollutants except for particles. Modelled emissions of $PM_{2.5}$ and TSP exceed the reported values by 31% and 13%, respectively. This difference may be explained by the fact that certain transport categories are reported as NE ("Not estimated") in the official inventory and thus could be underestimated. Besides, in the Russian official inventory, $PM_{2.5}$ emissions are calculated as a standard fraction of TSP (0.4), which is not the case in the GAINS model, where fractions are sector- and technology-specific.

Table 6. Emissions of main pollutants in Russia in 2010 according to the baseline scenario, ktonnes.

	NO_x	SO_x	NMVOC	NH_3	$PM_{2.5}$	TSP
Moscow	272	66	274	45	21	106
Other central	489	309	433	17	151	417
North-West	490	491	461	82	124	262
Volga	908	340	1049	281	175	431
South	83	10	131	66	20	48
Caucasus	241	87	297	102	71	166
Ural	856	2021	921	59	238.	490
Siberia	576	1749	329	143	447	1705
Far East	217	276	99	28	88	380
TOTAL ETR	**2482**	**1303**	**2646**	**746**	**562**	**1430**
TOTAL ETR, as reported to EMEP[13]	**2434**	**1341**	**2669**	**786**	**429**	**1269**
TOTAL Russia	**4131**	**5349**	**3995**	**976**	**1335**	**4004**

For 2030, modelled emissions on ETR are compared to emissions generated in alternative GAINS scenarios – ECLIPSE_v5a and TSAP_16. This comparison is shown in Table 7.

Table 7. Emissions of main pollutants in Russia in 2030 according to baseline scenarios in GAINS, ktonnes.

	NO_x	SO_x	NMVOC	NH_3	$PM_{2.5}$	TSP
Moscow	213	125	162	50	27	139
Other central	493	383	320	190	273	682
North-West	406	856	474	90	222	431
Volga	881	326	974	303	228	518
Caucasus	195	98	227	111	88	203
South	67	9	94	69	20	54
Ural	911	924	1026	65	396	781
Siberia	503	1428	338	150	563	1560
Far East	185	255	78	30	102	318
TOTAL ETR	2254	1798	2251	813	858	2027
ECLIPSE_v5a ETR	2254	1808	1728	465	1021	2224
TSAP_16 ETR	1765	1681	1636	576	808	1779
TOTAL Russia	3853	4406	3693	1058	1919	4687

2.3 Analysis of PRIMES baseline scenarios

In this chapter, we investigate changes in the recent public baseline GAINS scenarios (PRIMES scenario group) developed by IIASA. The aim of the analysis is to determine if changes in the PRIMES baseline scenarios have a substantial influence on the modelled emissions and emission abatement costs for the European part of Russia and to assess whether the GAINS Russia module needs regular baseline PRIMES scenario updates to deliver up-to-date results correlating with the GAINS Europe results for ETR.

For the analysis, we have chosen the three latest baseline scenarios developed within the European work on Thematic Strategies for air pollution (TSAP) – PRIMES 2012, PRIMES 2014 and PRIMES 2015. Scenarios characteristics, underlying data, relevant reports and assumptions concerning ETR are given in Appendix 6.

[13] Submission 2017

2.3.1 Emission trends

For the main air pollutants, emission trends corresponding to the three chosen scenarios are presented in Appendix 7. During the period 2010–2030, the difference between emissions of certain pollutants becomes larger while for other pollutants scenario updates do not result in any significant changes. The absolute and the relative differences in emissions in 2030 according to PRIMES 2014 and PRIMES 2015 compared to PRIMES 2012 are presented in Table 8.

Table 8. Absolute and relative differences in the emissions in 2030 – PRIMES 2013 and PRIMES 2014 compared to PRIMES 2012.

Scenario	Difference	$PM_{2.5}$	BC	NO_x	NH_3	SO_x	NMVOC
PRIMES 2014	Absolute, kt	32.4	3.5	191	0.5	8.4	31
	Relative, %	4.2%	4.2%	12.2%	0.1%	0.5%	6.1%
PRIMES 2015	Absolute, kt	30.5	3.5	192	1.2	-2.1	37
	Relative, %	3.9%	4.2%	12.2%	0.2%	-0.1%	6.1%

The most recent PRIMES scenario at the moment of writing – PRIMES 2014 – indicates the following emission trends for the main air pollutants from 2005 to 2030 in ETR:

$PM_{2.5}$ increases by 7% (from 758 to 808 ktonnes = 51 ktonnes). Increase by 108 ktonnes in industries, including both processes (mainly aluminium production from bauxite and secondary steel) and combustion, is larger than decrease in other sectors, such as 28 ktonnes decrease in $PM_{2.5}$ from fugitive emissions (22 ktonnes from reduced flaring and 6 ktonnes from reduced coke production).

BC decreases by 23% (from 112 to 86 ktonnes = 26 ktonnes), 19 ktonnes of which is due to reductions in fugitive emissions (mainly from flaring).

NO_x decreases by 59% (from 2980 to 1765 ktonnes = 1214 ktonnes), 975 ktonnes of which is due to reductions in heat and power generation achieved by phasing out old plants and increasing renewable energy use for power generation.

NH_3 increases by 17% (from 493 to 576 ktonnes = 83 ktonnes), 80 ktonnes of which is due to substantial intensification of milk production in the agricultural sector.

SO_x decreases by 12% (from 1911 to 1681 ktonnes = 230 ktonnes). Emissions from industrial combustion are expected to increase by 155 ktonnes, but this increase will be compensated by huge emission reductions in the heat and power generation (206 ktonnes) and road transport (131 ktonnes) achieved by phasing out old power plants and transition to low-sulphur fuels.

NMVOC decreases by 39% (from 2684 to 1636 ktonnes =1049 ktonnes), 571 ktonnes of which is due to reductions in the road transport, and 267 ktonnes from solvent use (achieved by better control and product substitution).

2.3.2 Major differences in the emission trends between the considered scenarios

To analyze the largest differences in the emission trends between the scenarios, we first aggregate emissions by GNFR[14] sector, identify GNFR sectors with the largest absolute differences for each

[14] GNFR = Gridded aggregated NFR sector data; NFR = Nomenclature For Reporting.

pollutant, and then analyze changes introduced in activity data, emission factors and control strategies to find out the reasons for the identified differences.

GNFR aggregation of the emissions is presented in Appendix 8. Categories with the most noticeable changes between scenarios for each of the main air pollutants are presented in Table 9.

Table 9. GNFR sectors with large differences in emissions for the considered PRIMES scenarios.

GNFR code	Explanation	Large differences in emissions of main pollutants					
		$PM_{2.5}$	BC	NO_x	NH_3	SO_x	NMVOC
A	Public electricity and heat	x					
B	Industrial combustion		x	X	x	x	
G	Road and rail traffic	x	x	X			x
I	Off-road mobile sources	x	x	X	x	x	x
N	Waste incineration				x		x

The reasons for differences in emissions between the three considered scenarios are mapped in Appendix 9.

Changes in PRIMES 2014 compared to PRIMES 2012

The main change in the activity data is the re-allocation of gas consumption by gas pipeline compressors from the fuel transformation sector to the off-road transport where it should be accounted.

The following emission factor (EF) corrections are based on new information and new technologies in the GAINS model database. These changes are made for all countries and regions, not only ETR:

- Lower EF for BC from coal combustion in industrial boilers;
- Higher EF for $PM_{2.5}$ and BC from combustion of biomass in industrial non-boiler combustion;
- Higher EF for $PM_{2.5}$ from combustion of biomass at power plants (key change factor for $PM_{2.5}$);
- Lower EF for NO_x from diesel light commercial trucks with 4-stroke engines with high stages of emission control (V and VI) (key change factor for NO_x);
- Higher EF for NMVOC from motorcycles with 4-stroke engines (key change factor for NMVOC);
- Alterations in EF for $PM_{2.5}$ and BC from road abrasion and tyre and brake wear, see Table 10 (key change factor for particles);
- Change of EF for SO_x from gas in off-road sources with 4-stroke engines (including military sources, households and pipeline compressors) to non-zero – assumption on sulphur-containing gas consumed in this sector.

Changes in PRIMES 2015 compared to PRIMES 2014

Changes in PRIMES 2015 concern emission factor corrections only:

- From zero to non-zero EF for NO_x and NMVOC from two technological options in brick production – Tunnel Kiln with end of pipe abatement and Vertical Shaft Brick Kiln with basic dust control. The brick sector was completely revised by IIASA: new technologies were defined, and new emission factor sets were developed (Zbigniew Klimont, IIASA, personal communication);
- Alterations in EF for $PM_{2.5}$ and BC from road abrasion and tyre and brake wear, see Table 10 (key change factor for particles);
- Change of EF for SO_x from gas in off-road sources with 4-stroke engines (including military sources, households and pipeline compressors) to zero again – assumption on sulphur-free gas

consumed in this sector. Natural gas needs to be sulfur-free; otherwise it cannot be transported over long distances (Zbigniew Klimont, IIASA, personal communication);

- From zero to non-zero EF for NMVOC and HN_3 from residential waste combustion (key change factor for NMVOC and HN_3) that was also revised by IIASA.

Table 10. Particle emissions from road abrasion, tyre and brake wear.

BC, kt	$PM_{2.5}$, kt	E-vector	Scenario
1.11	6.53	MAY12	PRIMES 2012
0.40	9.30	MARCH13	PRIMES 2014
0.40	7.37	NOV14	PRIMES 2015

Abatement costs

The total emission abatement costs in ETR for the three considered scenarios are illustrated in Figure 15. Compared to 2005, abatement costs in 2030 increase by 740% (8100 million Euro). In PRIMES 2012, the total costs are estimated at ~8800 million Euro, whereas in the latest two scenarios – at ~9400 million Euro. The most significant differences are summarized in Appendix 10.

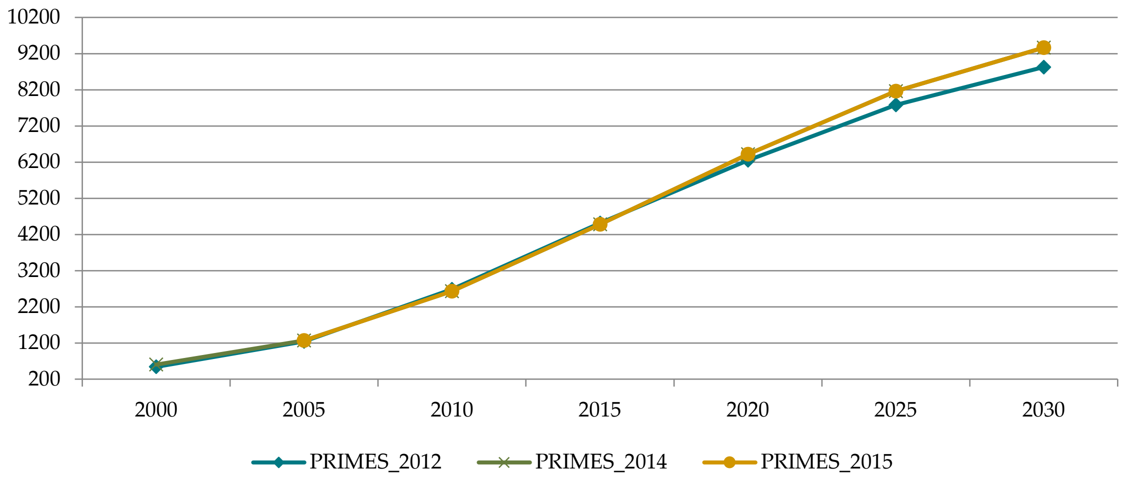

Figure 15. Emission abatement costs in ETR according to PRIMES scenarios, million Euro /year.

Most part of the significant differences is observed in the transport sector. Investment costs and costs associated with additional fuel demand (fuel penalties) are presented in Appendix 10 separately, marked with (I) and (F), respectively. PRIMES 2014 and PRIMES 2015 assume lower investment costs for all vehicles complying with Euro V than PRIMES 2012, except for heavy duty buses and trucks, for which higher investment costs are assumed. Also, higher extra cost of necessary fuel quality improvement is assumed in PRIMES 2014 and PRIMES 2015 (0.56 Euro/GJ for gasoline and 0.14 Euro/GJ for diesel) than in PRIMES 2012 (0.22 Euro/GJ for gasoline and 0.06 Euro/GJ for diesel). These assumptions are valid for all countries, not only for Russia, and explain higher fuel-related unit costs in the recent PRIMES scenarios.

For industries, costs differences are explained by different assumptions on wages and electricity costs in the latest PRIMES scenarios, compared to PRIMES 2012.

There is a continuously ongoing process at IIASA of revising emission factors and updating activity data as well as assumptions on applied control technologies, in accordance with the latest available knowledge. After PRIMES 2015 was developed, there was a revision of oil and gas industry sector in the model, with the purpose to consider the most recent information on the composition and properties of flared gases. All these revisions result in differences in the emissions, effects and costs produced by the GAINS model. Choosing the latest emission vector in the scenario development is the best way to consider possible updates in the emission factors.

Not all the changes are available in all GAINS modules. In the GAINS Russia, emission vectors are regularly updated, but new PRIMES baseline scenarios do not appear automatically. It is recommended to use the most recent baseline scenarios developed by IIASA as a basis for national scenarios rather than creating a data set from scratch; however, since this is not yet technically possible in the GAINS Russia module, it is important for national experts to assure that activity data and assumptions on control measures are in line with the recent statistics and projections – for the past years as well as for target years of developed scenarios.

***

A new set of input data developed within the project covers all regions and all sectors included in the GAINS Russia module. The data set is developed for the base year 2010, and for the future years 2020 and 2030. The input data for 2010 is based on the region-specific national statistics, data provided by national experts and the numbers available in the study by Huang et al. 2015, where the level of spatial aggregation (subjects of the Russian Federation) is very suitable for GAINS modelling purposes. This is the main difference from the latest data sets for the Russian Federation and for ETR developed by IIASA, where mainly international statistics was used. In the latest region-specific scenarios developed by IIASA in 2012 specifically for the GAINS Russia module, the main proxy for distribution of almost all economic activities was population. In the new data set, we instead use as proxy the number of plants and/or their capacities or fuel use summarized in Huang et al. 2015. The **major improvement in the current data set** is thus more correct spatial distribution of data available on a larger scale (ETR or country totals) and, whenever possible, use of local open sources and web-sites (including sources in Russian) instead of more aggregated international statistics.

Input data for 2020 and 2030 are based on the assumption that development rates are the same as in one of the latest publicly available scenarios developed by IIASA – ECLIPSE_v5a. The total use of fossil fuels in the Russian Federation is supposed to increase by 9% between 2010 and 2030.

The modelled emissions are compared to the emission outputs from other GAINS baseline scenarios, and to the officially reported to EMEP emissions from ETR. Nearly for all main pollutants, the discrepancies between the modelled and the reported emissions in 2010 are small (under 5%), which indicates that the modelling results are reliable. Specification of emissions by sectors and regions show great variation between the regions, due to very different economic structure.

The new data set is developed for the purposes of supporting policy development and decision-making on the level corresponding to the administrative structure of the Russian Federation. It can thus be used for the country's internal policy-making, but also as a valuable tool for negotiating within international conventions such as UNECE CLRTAP or UNFCCC.

There are certain aspects in the new data set with **potential for improvements**. In particular, we assumed for simplicity and due to the lack of better data that control strategies for all regions are the same and correspond to what is assumed in ECLIPSE_v5a. The similar assumption was made about the future development rates. More efforts should thus be taken to identify regional differences in emission controls, and to find and translate available region-specific and sector-specific development plans into the numbers that could be used in GAINS modelling. Also, more region-specific data need to be collected so that the number of currently used proxies decrease.

3 Black carbon analysis

In this chapter, we present the results of the integrated assessment of black carbon (BC) emissions in the Russian Federation. We have summarized available statistics, outcomes of relevant recent studies, modelling results and information in databases regarding black carbon emissions in Russia for the past years – on the level of country, federal districts, subjects and the Arctic territory of Russia. Furthermore, we have developed and analysed new region-specific GAINS scenarios corresponding to black carbon emission reduction measures in the most important sectors (transport, residential combustion, flaring of associated gases in the oil industry) in 2030 – for all the regions in the Russian Federation.

3.1 Scientific and policy context

Black carbon, or soot, is a component of particulate matter (PM). Black carbon particles are products of incomplete combustion in anthropogenic activities or natural fires. They are usually co-emitted with several other SLCFs, which can have either a warming or cooling impact in the atmosphere. Due to its strong light absorption, black carbon has the most potent warming impact of these substances. When black carbon is deposited on snow or ice, it decreases the light reflecting ability – albedo – of the surface, and its warming impact is therefore greatly increased in the Arctic area. Exposure to black carbon is also associated with negative health effects. Reduction of black carbon emissions has thus been recognized as a viable strategy for mitigating both climate change and the negative health impacts caused by human activities.

3.1.1 Health and environmental impacts and main emission sources of black carbon

Globally, black carbon emissions have been estimated to have the second largest climate warming impact after carbon dioxide (Bond et al. 2013, IPCC 2013). This impact is even more pronounced in the Arctic area, since deposition of black carbon on snow decreases the snowpack albedo and accelerates its melting. AMAP Assessment from 2015 concludes that one unit of black carbon emissions within the Arctic area is likely to have several times greater warming impact than the same emission amount outside the Arctic. Flanner et al. 2007 estimates that at least 80% of the black carbon deposition in the Arctic is due to anthropogenic emissions. The World Health Organisation (WHO) has shown that human exposure to black carbon is linked to similar health effects as exposure to $PM_{2.5}$ and PM_{10} (Janssen et al. 2012). For short-term health effects, black carbon is suggested to be a better indicator than unidentified particulate matter mass. It is suspected that black carbon may not be directly toxic but may operate as a carrier of a variety of toxic combustion-derived components.

The biggest anthropogenic sources of black carbon in the northern latitudes are residential combustion, diesel engines, agricultural waste burning, and gas flaring associated with oil production (AMAP 2015). Hegg et al. 2010 suggests that biomass combustion, including agricultural waste burning, is the dominant source of black carbon in the Arctic region, based on emission measurements. One source that has received increasing attention in recent years is gas flaring. Flaring is used to dispose residue gas resulting from oil and natural gas extraction. There are major uncertainties regarding the emission factors and the amount of gas being flared. Stohl et al. 2013 estimates that as much as 42% of the annual mean near-surface black carbon concentration in the

Arctic region could originate from flaring. Flaring is estimated to be one of the major sources of black carbon emissions from anthropogenic sources in Russia (Huang et al. 2015, Evans 2017).

3.1.2 Recent policy initiatives to reduce BC emissions

There is a number of international initiatives addressing black carbon emissions. The amended Gothenburg Protocol under the UNECE CLRTAP acknowledges black carbon as a component of $PM_{2.5}$ emissions, encouraging the member states to develop BC inventories and projections and to prioritize those $PM_{2.5}$ emission reduction measures that also target significant sources of BC emissions. Several members of the UNECE CLRTAP and the Arctic Council[15] have voluntarily reported their annual BC emission inventories in the recent years. The Arctic Council has been very active in the scientific and policy work related to black carbon and Arctic climate. After several years of preparatory work, the Arctic Council states agreed to adopt a quantitative BC reduction goal in 2017. In the 10th Arctic Council Ministerial Meeting in Fairbanks, the eight member states agreed to reduce their collective black carbon emissions by **25–33% below 2013 level by 2025**[16]. Although voluntary by nature, this agreement is the first attempt for setting a quantitative reduction goal for black carbon emissions.

The International Maritime Organization (IMO) is discussing the possibility to enforce a phase out of the use of heavy fuel oil ships in the Arctic area. The aim is to reduce black carbon emissions from shipping in the area where they have the largest warming impact on climate. So far, the IMO has agreed upon the definition of black carbon and is in the process of identifying suitable measurement methods to monitor shipping emissions (check with Erik/Hulda). In addition, there are parties such as the transnational Climate and Clean Air Coalition (CCAC), whose aim is to create and share practical solutions for voluntary reduction of black carbon emissions. CCAC currently has 65 state partners (including Russian Federation since 2014) and 75 non-state partners of intergovernmental and non-governmental organizations.

In 2018, a three-year EU Action called Black Carbon in the Arctic (EUA-BCA)[17] was launched. The project is coordinated by the secretariat of the Arctic Monitoring and Assessment Programme (AMAP). The goal is to develop international cooperation to protect the Arctic environment and contribute to collective reduction of black carbon emissions. The implementation plan includes four steps:

- Improve knowledge on black carbon emissions;
- Increase awareness and sharing of knowledge;
- Create technical advice documents and scenario analysis;
- Develop a roadmap for international cooperation on black carbon.

[15] The Arctic Council (https://arctic-council.org/index.php/en/) includes Canada, Denmark, Finland, Iceland, Norway, Russian Federation, Sweden and USA as member states, six international organizations representing Arctic indigenous peoples as permanent participants, and several states and organizations as observers.

[16] http://www.ccacoalition.org/en/news/arctic-countries-commit-reduce-black-carbon-emissions-much-third

[17] https://www.amap.no/documents/download/3107/inline

3.1.3 BC emission inventories and modelling – need for improved knowledge to reduce emissions

Robust and coherent emission inventories are needed to estimate the significance of black carbon emissions as well as to plan emission reduction policies that can most effectively mitigate climate change. Although most countries have only recently started to report their black carbon emission inventories, the understanding has been that emissions near the Arctic area have been decreasing in the past decades, along with other particulate emissions. However, ice core measurements from Svalbard show that black carbon concentrations actually have increased by about 5 times between 1970 and 2004 (Ruppel et al. 2014). Explaining this contradiction requires more accurate knowledge about the annual emissions, including their temporal and spatial distribution, as well as the effectiveness of black carbon dispersion in the atmosphere.

Bond et al. 2013 estimates that there is an uncertainty of about 200% in the global anthropogenic black carbon emissions. Since the methods for compilation of black carbon emission inventories are still under development, it is important to exchange knowledge and share best practices between experts in different countries. Robust and coherent emission inventories are needed to estimate the reduction potential of climate impacts associated with black carbon.

The Russian Federation is a major contributor to black carbon emissions in the Arctic, due to its location, size and a variety of activities that involve combustion of fuels. However, the estimates for Russian black carbon emissions vary notably between inventories, and the recent development of the GAINS model has also resulted in a significant change in its emission estimate for the past years. This highlights the uncertainty involved in black carbon emission inventory work. Most of the sectors that are important for BC emissions are also challenging in terms of gathering accurate data. Fuel use, shares of specific technologies in sectors like residential combustion and non-road machinery, amounts of openly burnt agricultural waste and gas flaring are often not being reported in the official statistics. Local information and expertise are necessary for creating an understanding of these conditions, so that the emissions can be modelled more accurately.

3.2 Historical BC emissions in Russia – inventories and modelling results

In this chapter, we summarize the available estimates of historical black carbon emissions in the Russian Federation according to a range of sources – models, databases, emission inventories, outcomes of scientific cooperation projects, etc. Some of the estimates are available in the form of gridded emissions – within this project we have aggregated those to the same level as used in the GAINS Russia model (the level of federal districts). We have also looked at the baseline scenarios in the GAINS Europe and GAINS Russia modules, reports from recent national and international studies addressing BC emissions in Russia, and the BC emission inventory for the Artic Zone of the Russian Federation.

3.2.1 Summary of gridded BC inventories for the Russian Federation

The analysis presented in Chapter 3.2.1 has been conducted by the Finnish Environment Institute (SYKE). The purpose is to analyze estimates of black carbon emissions in the Russian Federation by using available gridded emission sets from a range of databases. High-resolution emissions enable various options for their aggregation and comparisons of emissions from different sectors and geographical regions.

Emission inventories

The global black carbon emission inventories, from which the Russian emissions are extracted, were downloaded from the ECCAD-GEIA database[18]. The database contains gridded emission inventories, which we have aggregated to the level of federal districts for the purposes of this study. The following inventories are considered:

- ECLIPSE GAINS version 4 (Klimont et al. 2017);
- ACCMIP (Lamarque et al. 2010);
- RCP (van Vuuren et al. 2011);
- RCP3PD (van Vuuren et al. 2007);
- RCP4.5 (Clarke et al. 2007);
- RCP6.0 (Fujino et al. 2006);
- RCP8.5 (Riahi et al. 2007),
- PEGASOS (Radu et al. 2016)
- Junker-Liousse (Junker & Liousse 2008; Assamoi & Liousse 2010).

Newer versions of ECLIPSE – version 5 (Klimont et al. 2017; Stohl et al. 2015) and version 5a – were also included in the comparison, as well as the inventory in Huang et al. 2015.

Data from the Atmospheric Chemistry and Climate Model Inter-comparison Project ACCMIP[19] is based on a combination and harmonization of several existing regional and global emission inventories (including RETRO[20], EDGAR[21], EMEP[22], etc.). Representative Concentration Pathway (RCP) series build on historical emissions of ACCMIP, with four independently developed future emission scenarios. Junker & Liousse 2008 calculate emissions from simplified fuel usage and emission factor categories. There are individual emission factors for three fuel classes, three sector classes and three country development level classes. PEGASOS[23] is based mostly on data from the EDGAR database. ECLIPSE versions are based on the modelling in the GAINS Global module.

Russian emissions are extracted from the global data sets using the definition of ETR according to the EMEP grid definition, so that the territory of Russia west of 61° longitude is considered as ETR.

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[18] http://eccad.sedoo.fr

[19] https://www.giss.nasa.gov/projects/accmip/

[20] http://accent.aero.jussieu.fr/RETRO_metadata.php

[21] http://edgar.jrc.ec.europa.eu/

[22] http://www.ceip.at/webdab_emepdatabase/

[23] http://edgar.jrc.ec.europa.eu/overview.php?v=pegasos

Total black carbon emissions in the Russian Federation and in ETR

Figure 16 and Figure 17 show the total black carbon emissions according to different inventories in 2000, 2005 and 2010. ACCMIP, PEGASOS and Junker & Liousse 2008 only have emissions for the year 2000. RCP scenarios are built on ACCMIP. They are based on different models and the target year of the scenarios is 2100, which might explain the large differences in 2005 and in 2010.

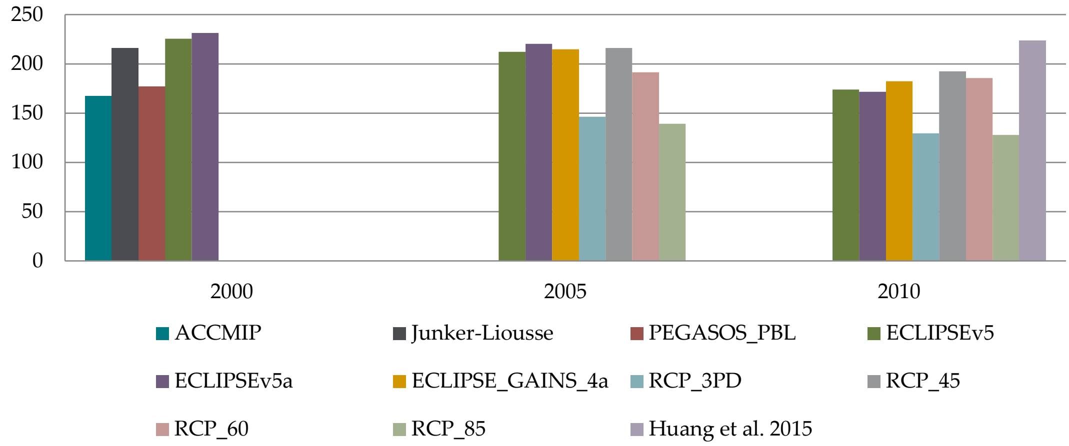

Figure 16. Total black carbon emissions, Russian Federation, ktonnes.

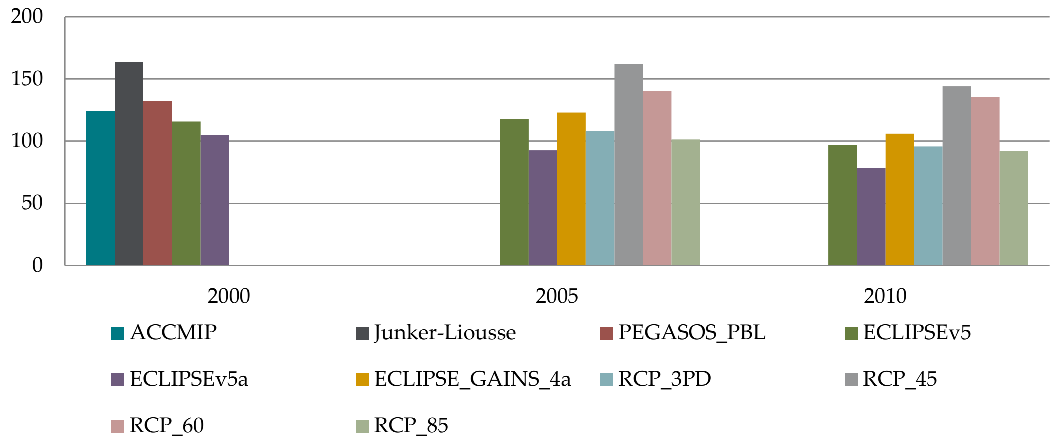

Figure 17. Total black carbon emissions, ETR, ktonnes.

In the inventories, total black carbon emissions are in the same order of magnitude. For the Russian Federation territory, ACCMIP and PEGASOS have the lowest emissions in 2000, and the inventory presented in Huang et al. 2015 has the highest emissions in 2010. The paper is based - to the extent possible - on local Russian information such as activity data, emission factors and other emission source data. It suggests that the other inventories may have underestimated Russian emissions, but the relative differences are not massive.

Most inventories propose that about half of the emissions are from the European part of Russia. Differences between the relative shares in Figures 16 and 17 suggest that the spatial allocation of emissions in Junker & Liousse 2008, RCP_45 and RCP_60 to a larger extent than in the other inventories are based on population densities.

Figures 11.1 and 11.2 in Appendix 11 show the spatial distribution of emissions in the ACCMIP and ECLIPSE inventories for the year 2000. The most apparent difference is the dominance of the gas flaring emissions in Figure 11.2, discussed below.

Black carbon emissions by source sector

Figures 12.1–12.4 in Appendix 12 show the emissions aggregated by source sectors in 2000 and 2010. In 2000, residential and commercial combustion is the largest or second largest emitting source in all the inventories, and the results according to the different sources match relatively well. ACCMIP and PEGASOS have higher emissions than ECLIPSE, and this difference is further pronounced for the European part of Russia. Agricultural waste burning and transport emissions, on the other hand, are notably higher in ECLIPSE.

ACCMIP and PEGASOS appear to have different allocation for gas flaring than ECLIPSE, which can partly explain the large differences in the energy and industrial sectors. It seems that the ACCMIP and PEGASOS estimates for flaring emissions are lower than ECLIPSE's, and they include flaring in the industrial sector while ECLIPSE has it in the energy sector. The difference in flaring emission in clearly seen in Figures 12.3 and 12.4 (Appendix 12).

For 2010, the method used by Huang et al. 2015 gives the highest combined emissions for the energy and industrial sectors, apparently mostly due to a high emission factor for flaring. It also results in higher emissions for residential and commercial combustion than ECLIPSE but does not present agricultural waste burning in a separate category.

Gridded emissions aggregated by GAINS Russia regions

In the emission summaries above, the European part of Russia has been considered as an area west of longitude +61˚ (according to, but not strictly congruent with, the definition of European part in EMEP). However, ETR is also sometimes defined as five federal districts (Central, Northwestern, Volga, Southern, and North-Caucasian) – in particular in the reporting of the total ETR emissions to EMEP, or when developing input data sets for GAINS modelling. In such cases, it is assumed that emissions from the part of Volga federal district east of longitude +61˚ are offset by emissions from the part of Ural federal district west of longitude +61˚ (see Figure 1 in Chapter 2). To assess how reasonable this assumption is, and in order to explore the differences between the federal districts (including the Asian part of Russia as well), we have also studied gridded emissions aggregated by federal districts.

The comparison of regional emissions for 2010 is shown in Table 11 and Figure 18. Different versions of ECLIPSE are very similar regarding the total emissions and spatial distribution of emissions. The most notable difference between the latest and the older versions is the emission distribution between Ural and North-West. RCP3pD and RCP85 are not inventories as such but scenarios based on ACCMIP. They show considerably lower total emissions, mainly due to smaller estimation for flaring emissions. This difference also has a notable effect on the relative share of regional emissions.

The most relevant inventories for 2010 are the latest versions in GAINS (ECLIPSE_v5a) and the inventory by Huang et al. 2015, which is the most recent effort in trying to include all available local information on activity data and emission factors. Although total emissions differ in the two inventories, the regional distribution of emissions is very similar between them. The regions with the highest emissions in both inventories are Ural, Siberia and Volga, all located in the center of the country. For ECLIPSE_v5a, this is visualized in Figure 19.

Regional emissions by sector for ECLIPSEv_5a and Huang et al. 2015 are shown in Figures 13.1–13.2 in Appendix 13. The inventories have somewhat different sectors, but also at this level the emission distribution is very similar. The most notable difference in the sectors is that agricultural waste burning is not specified in Huang et al. 2015, but flaring is an independent sector. In ECLIPSE_v5a, flaring is included in the category "Energy production and distribution". Flaring is the dominant contributor to black carbon emissions in Ural, which is the region with the highest emissions. In Siberia and Volga regions, emissions are more evenly distributed between sectors.

Table 11. BC emissions by region in 2010 in the studied inventories, ktonnes.

Region	ECLIPSEv5a	ECLIPSEv5	ECLIPSEv4	RCP3PD	RCP85	Huang et al. 2015
North-West	16	30	31	12	12	34
Moscow	6	6	7	13	10	13
Northern Caucasus	3	4	4	5	5	3
Other Central	13	13	15	20	20	15
South	13	13	15	15	14	8
Volga	21	25	28	28	28	30
Ural	56	42	42	12	12	75
Far East	10	9	9	5	6	13
Siberia	34	32	32	21	22	33
TOTAL	**171**	**174**	**183**	**131**	**129**	**224**

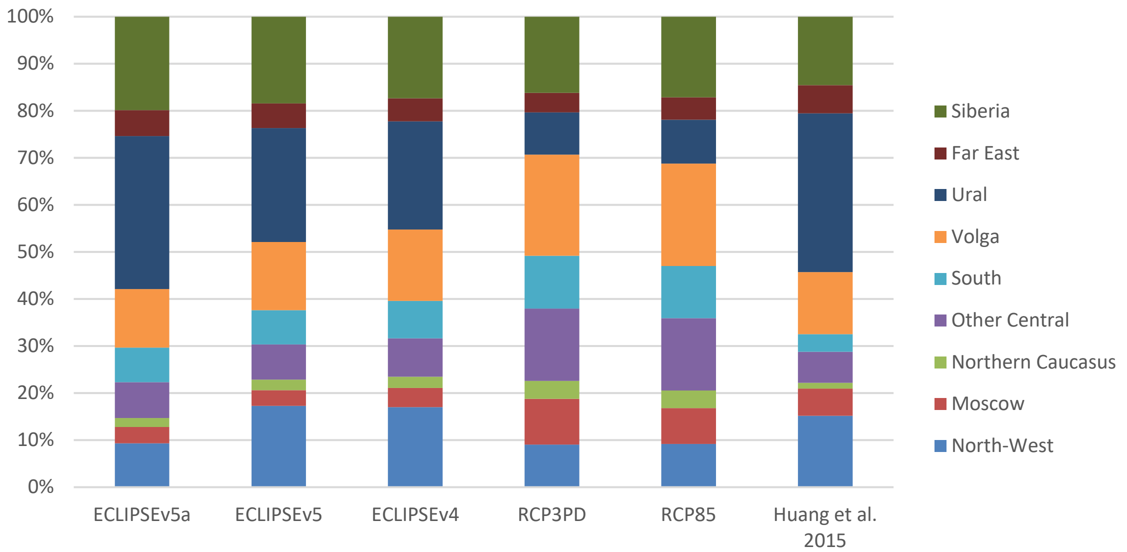

Figure 18. Regional contributions to the total BC emissions in 2010 in the studied emission inventories.

Figure 19. BC emission comparison by region in 2010 (ECLIPSE_v5a). Here, North-West is further split into several sub-regions, used in the GAINS Russia module before the revision in 2012 (Popov 2002).

Emissions for the European part of Russia are, according to the inventories, roughly 50% of the total Russian emissions. This is somewhat dependent on the definition, as shown in Table 12. The emissions in the European part are consistently higher (by 4-8%), when the longitude +61˚ is used as the border. This is mostly due to some major towns in Ural, like Yekaterinburg, which are located to the west from +61˚.

Table 12. BC emissions from the European part of Russia in 2010, as determined by the sum of the relevant GAINS Russia regions and the longitude +61˚.

Sector	ECLIPSEv5a		ECLIPSEv4		RCP3PD		Huang et al. 2015	
	sum of regions	+61˚	sum of regions	+61˚	sum of regions	+61˚	sum of regions	+61˚
Agricultural waste burning	18	18	18	18	5	5	-	-
Energy production and distribution	21	22	40	41	4	4	4	-
Industrial processes and combustion	3	4	4	4	24	25	35	-
Land transport	22	25	29	32	29	30	28	-
Residential and commercial combustion	7	9	8	10	30	31	35	-
Waste treatment and disposal	1	0	0	0	1	1	-	-
Sum of European part	72	78	100	106	92	96	102	-
Total sum	171	172	182	182	129	129	224	224
Share of European part	42 %	46%	55 %	58 %	71 %	74 %	46 %	-

3.2.2 BC emission inventory for the Arctic Zone of the Russian Federation

The first black carbon emission inventory for the Arctic Zone of the Russian Federation was developed by SRI Atmosphere (Morozova & Ignatieva 2017) and submitted to the Arctic Contaminants Action Program (ACAP) by the Ministry of the Natural Resources and Environment of the Russian Federation in 2015 (MNRE 2015). The inventory considered the year 2013 and only emissions from the region defined as the Arctic Zone of the Russian Federation by a President's decree from 2014[24], as illustrated in Figure 20.

As seen in Figure 20, the border of the Arctic Zone does not exactly follow the borders of the subjects of the Russian Federation it partly includes. The fact that some subjects are only included partly imposes difficulties in the process of collection of input data for the emission inventory (as most of the statistics is usually available per subject) and increases uncertainties in the results.

According to MNRE 2015, the total black carbon emissions in the Arctic Zone of Russia in 2013 amounted to **24.2 ktonnes**. Venting and flaring of the associated gases in the oil and gas industry is identified as a key emission source. The contribution of the residential combustion is 63.4 tonnes, which is comparable to ~70 ktonnes, estimated for this sector in ECLIPSE_v5a (Figure 12.1., Appendix 12). Forest fires result in 3.15 ktonnes black carbon according to Morozova & Ignatieva 2017. The distribution of the total emissions by key sectors is illustrated in Figure 21.

[24] http://static.kremlin.ru/media/events/files/41d4d8e8206d56fc949d.pdf

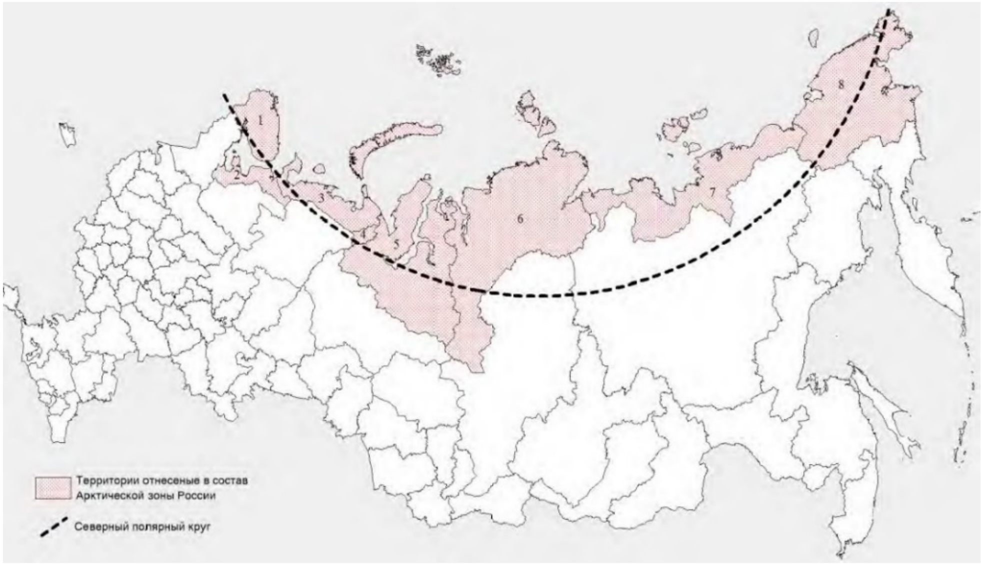

Figure 20. Map of the Arctic Zone of the Russian Federation (source – MNRE 2015).

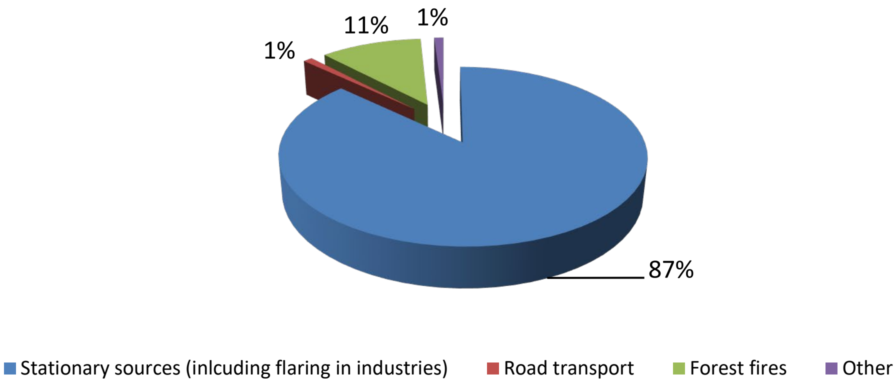

Figure 21. Emissions of BC in the Arctic Zone of Russia (source – Morozova & Ignatieva 2017).

MNRE 2015 and Morozova & Ignatieva 2017 also give an estimate for black carbon emissions in the entire Russian Federation – **358 ktonnes** in 2013. However, information about the underlying methodology for this rather high number is not provided.

3.2.3 Other available estimates of BC emissions in the Russian Federation

There is no official emission inventory of the anthropogenic black carbon emissions covering the whole territory of the Russian Federation or even ETR. A range of the latest unofficial estimates and modelling results is summarized in Figure 22, where in addition to earlier presented results of the aggregated emission inventories available in open databases, we present estimates from national studies (MNRE 2015, Evans et al. 2017[25]) and modelling results from the older PRIMES scenario produced by IIASA for the GAINS Russian module in 2012 (PRIMES_2010). Based on this summary, the range of estimated annual historical anthropogenic black carbon emissions in the entire country is estimated at **120—360 ktonnes.**

[25] Only anthropogenic sources (17% of the total estimate of 688 ktonnes) are included, wildfires are excluded.

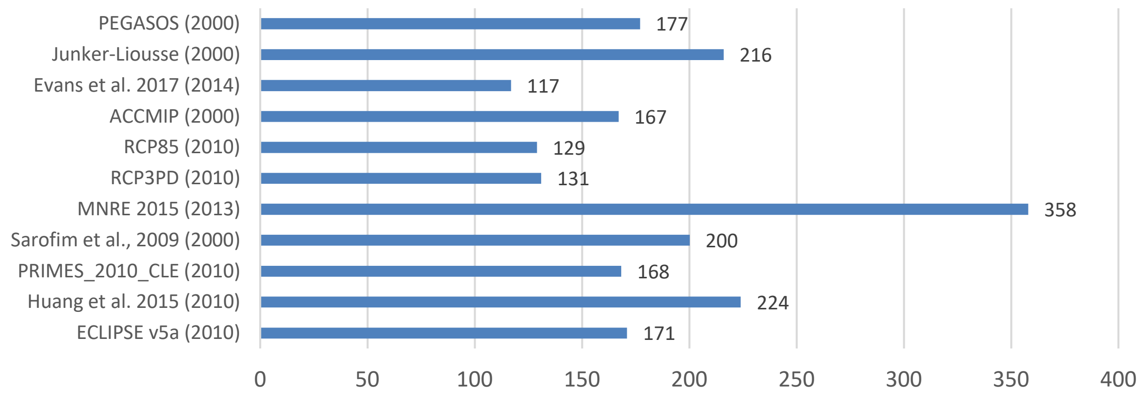

Figure 22. Estimates of total national emissions of black carbon in the Russian Federation for historical years (2010-2013, years are specified in parenthesis).

Although the estimates of the total black carbon national emissions in the Russian Federation differ, most of the available sources mention gas flaring and diesel-fuelled transport as major BC emission sources in the country. Besides, burning agricultural waste is an issue under discussion: officially, it is prohibited by legislation; however, certain observations (e.g. Global Fire Database GFED[26]) indicate that such illegal burning occurs and is one of the BC emission sources.

Diesel sources

Black carbon emissions from diesel sources in Russia have been investigated in a series of recent articles, in particular Kholod et al. 2016 and Kholod & Evans 2016. The total black carbon emissions from all diesel sources in the Russian Federation in 2014 are estimated at 49.2 ktonnes, from which the main contribution (~58%) comes from off-road vehicles (Kholod et al. 2016). Stationary generators account for about 8% of the total emissions from diesel sources. For the whole transport sector in the country, including also gasoline-fuelled and other sources, the estimate of 29.8 ktonnes in 2014 is made in Evans et al. 2017 – this is substantially lower than the estimate in Kholod et al. 2016, even considering that stationary sources like generators are excluded.

Murmansk oblast – a subject of the Russian Federation belonging to Northwestern federal district – was studied more specifically. Black carbon emissions in Murmansk oblast are estimated at 0.4 ktonnes in 2012 (Evans et al. 2015). The largest contributor to these emissions (69%) is non-road machinery in the local mining industry. On-road vehicles are found to be the second largest source responsible for 13% of black carbon emissions. Murmansk was chosen for an investment project aiming at reductions of the black carbon and other emissions by renewal of the bus fleet in the city (transportation is the largest air pollution source in Murmansk). During 2013-2014, 29 public buses with virtually zero abatement were replaced with the Euro V vehicles. This resulted in the black carbon emission decrease by 90%. Outcomes of the project are summarized in Kholod et al. 2015.

Forest fires

Forest fires do not belong to anthropogenic sources of emissions – these emissions thus do not need to be officially reported to EMEP. However, their significance in the climate effects in the Arctic Zone

[26] http://www.globalfiredata.org/data.html

and negative effects on people's health should not be neglected. Besides, forest fires are often incidentally caused by people.

Evans et al. 2017 estimate the contribution of the forest fires into the total black carbon emissions in the Russian Federation at 83% (~570 ktonnes) in 2014. Total emissions of black carbon from wild fires in 2014 are estimated at ~590 ktonnes in Hao et al. 2016, from which the contribution from forest fires is 85% (495 ktonnes) – the rest is fires in grassland, shrubland and savanna. In Smirnov et al. 2015, an estimate for forest fires in 2013 is 82 ktonnes as annual average for the period 2007–2012. Morozova & Golovina 2014 present the estimated trend for black carbon emissions from forest fires in Russia in 1992–2012, see Figure 23.

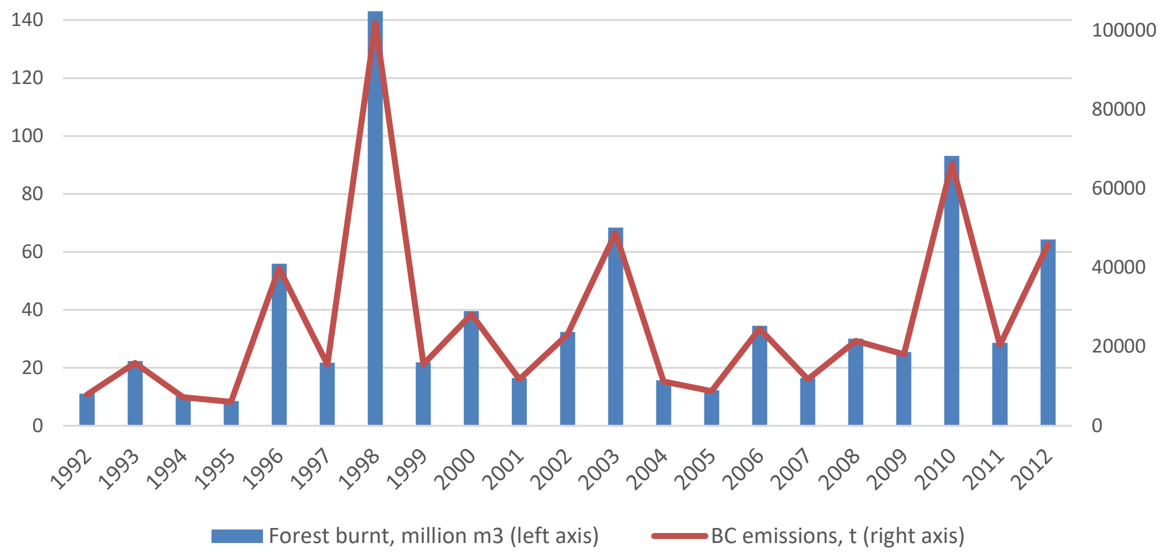

Figure 23. BC emissions from forest fires in the Russian Federation (source – Morozova & Golovina 2014).

Burning of agricultural waste

Burning of agricultural waste on fields is an anthropogenic source, resulting in black carbon emissions estimated at 9 ktonnes in 2014, according to Evans et al. 2017. Since such burning is illegal and no official statistics exist, available studies refer to satellite observations – in particular, Mc Carty et al. 2012, who estimates black carbon emissions from agricultural fires in 2003-2009 at 8.9 ktonnes. Sand et al. 2016 give an amount of 24 ktonnes black carbon for 2010. For comparison, emissions modelled with PRIMES_2010 scenario in the GAINS Russia model is 24.3 ktonnes in 2010. In 2012, a ban on agricultural burning was introduced on the country level – however, there is data implying that the ban is ineffective and that field burning might still occur (see Evans et al. 2017, ECLIPSE_v5a for future years, Global Fire Database GFED[27]). Lack of effective legislation results in continued practice of field burning, which often causes wildfires and air pollution problems in both Russia and in the neighbouring countries (see e.g. Karlsson et al. 2017).

[27] http://www.globalfiredata.org/data.html

3.3 BC – new GAINS Russia scenarios

This chapter is focused on the results of the new region-specific scenarios developed for GAINS Russia within the project. The purpose of these scenarios is to analyse possible measures to reduce black carbon emissions in the key source sectors – transport, residential combustion and flaring of associated gases in the oil and gas industry in the Russian Federation. We have chosen 2030 as target year for BC scenarios – the analysis below regards 2030 and the base year, 2010. However, the baseline scenario for 2020 is also available in the GAINS Russia module, and emissions in 2015 and in 2025 might be in a simplified way estimated by interpolation.

3.3.1 New baseline scenario for black carbon

The new baseline scenario in the GAINS Russia module and the underlying input data are described in detail in Chapter 2. Here, we analyse the resulting emissions of black carbon – the totals and their regional and sectoral distribution in 2010 and in 2030. Since modelled emissions depend on the inputs – activity data – we briefly analyse relevant activity data as well.

Key sources of BC emissions and underlying activity data

As concluded in Chapter 3.2, currently the largest BC emission sources in the Russian Federation are flaring of associated gases in the oil and gas industry, residential combustion, and transport. In this analysis, we focus on non-road (diesel) mobile sources rather than on road traffic, assuming that road traffic will follow the gradual replacement of the fleet with vehicles corresponding to newer Euro standards. Non-road transport is much less regulated but contributes to up to 35% of the total BC emissions in certain regions (17% on average in the country).

Figure 24 illustrates region-specific energy consumption by non-road transport and amounts of flared associated gases in 2010. Flaring occurs mostly in Ural and Siberia – regions with extensive oil extraction. Non-road diesel-fuelled transport is also concentrated in Ural because of the industrial profile of the region – many mining sites and heavy industry facilities (e.g. machinery production plants) are located there.

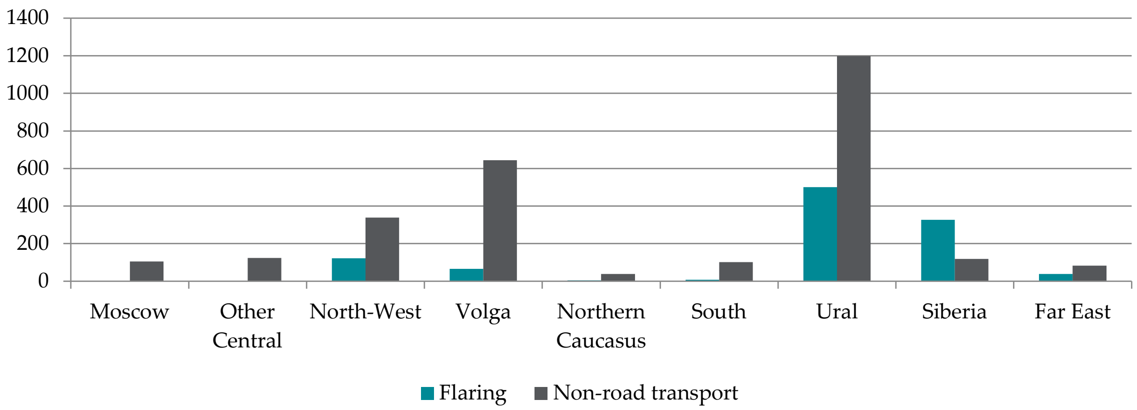

Figure 24. Energy consumption by non-road transport and flaring of associated gases in 2010, PJ.

Regional distribution of residential combustion is presented in Figure 25. Discussion of black carbon emissions from residential combustion in the literature is usually focused on wood fuels – this is, for instance, a substantial source of particle emissions in the Northern countries (Kindbom et al. 2018).

However, the fuel structure of the residential sector in the Russian Federation is rather specific and actually dominated by gas. Also, in a number of regions coal is combusted more than wood fuels for domestic purposes – this is especially pronounced in Siberia and Far East. Wood combustion in the residential sector is concentrated in North-West and Siberia.

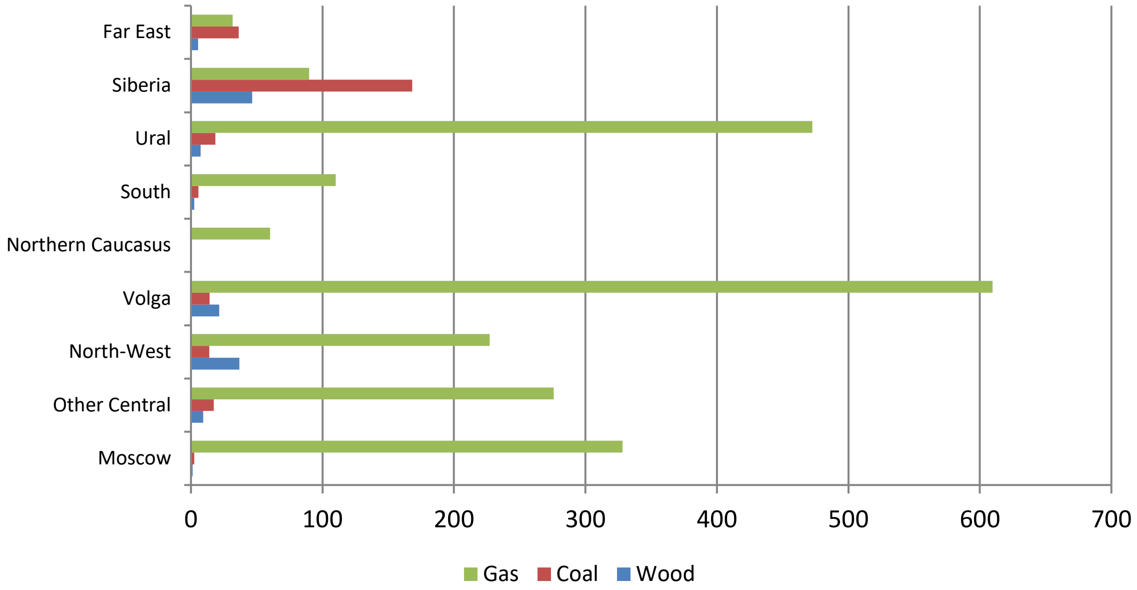

Figure 25. Regional and fuel structure of the residential sector in the Russian Federation in 2010, PJ.

The detailed methodology for development of the input data set for the year 2030 is given in Chapter 2.2. The main principle is the same development rates between 2010 and 2030 as assumed in the scenario ECLIPSE_v5a, applied sector by sector, as well as the same abatement strategy as in ECLIPSE_v5a for almost all sectors.

BC emissions in the new baseline scenario

According to the baseline scenario, total Russian black carbon emissions in **2010** amounted to **152 ktonnes** (from which in ETR – 67 ktonnes) and were distributed by sectors as shown in Figure 26. This number, compared to other available estimates, looks reasonable, although it is closer to the low end of the range presented in Figure 22 in Chapter 3.2.3. It is lower than the ECLIPSE_v5a estimate for the same year (171 ktonnes), probably because of the differences in the underlying input data – significantly higher numbers for industrial combustion in the ECLIPSE_v5a than in our baseline (see Chapter 2.1.2). The main emission source is gas flaring; it is responsible for 35% of the total BC emissions, followed by transport sector (29%) and industry and agriculture (22%). The large input from the agricultural sector is explained by the assumption on "no abatement" for agricultural waste combustion – following the ECLIPSE_v5a abatement strategy, we assume that ban on burning such residues is not effective in practice. Finally, residential combustion contributes to about 13% of the total black carbon emissions.

For comparison, we display the similar distribution diagram from Huang et al. 2015. The main difference in these two diagrams arises from the assumed amount of wood combustion in the residential sector – this number is much higher in Huang et al. 2015 than in our study.

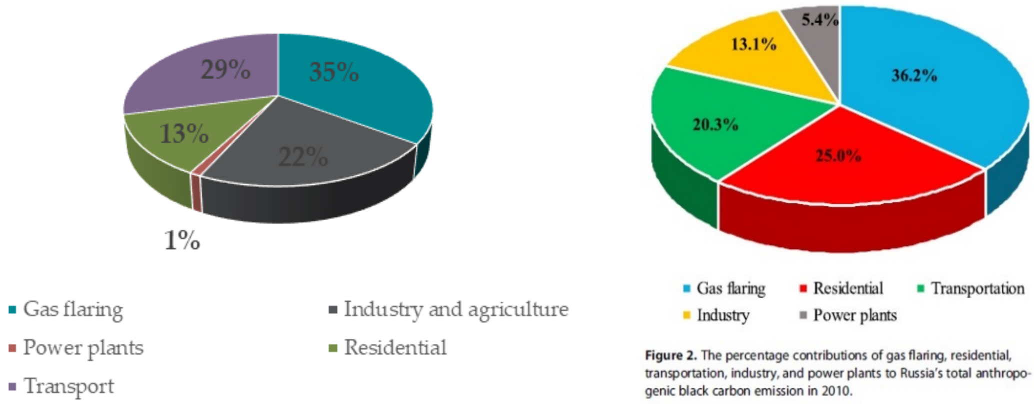

Figure 26. Sectoral distribution of BC emissions in the Russian Federation in 2010 according to the baseline scenario in this study (left) and according to Huang et al. 2015 (right).

Sectoral distribution of modelled BC emissions per region is shown in Figure 27 – for both 2010 and 2030. No significant changes in the emission structure are expected, except for the visible reduction of emissions from road transport due to the higher penetration rates of the newest Euro standards. Still, in Moscow region road traffic will be a leading BC emission source even in 2030, although its contribution to the regional totals is expected to decrease from ~60% to ~30%. Emissions from residential combustion, according to the model, will increase in line with the assumed increase in the activity[28] and become the dominating source in Siberia, Far East, and North-West. With our assumptions, Siberia will become the most BC emitting region in 2030 instead of Ural, which had the highest emissions numbers in 2010.

Our distribution of black carbon emissions in 2010 by sectors and regions can be compared to the distribution of emissions as in the study by Huang et al. 2015 and in ECLIPSE_v5a (compilation of gridded emissions) presented in Appendix 13. The patterns are very similar: the highest levels of black carbon emissions are observed in Ural and Siberia, followed by Volga and North-West. The key emission sectors are in all three cases flaring (within "energy production"), transport and residential combustion.

Our estimate of the total black carbon emissions in the Russian Federation in **2030** is 165 ktonnes – this is an increase by 9% compared to the level of 2010. The increase is mainly caused by substantially higher volumes of fuelwood combustion in the domestic sector in 2030, compared to 2010, as assumed in the ECLIPSE_v5a and adopted in our baseline. Estimates of the national totals for 2030, produced in other baseline GAINS scenarios, are summarized in Table 13. Our estimate for ETR is the lowest in this table; however, for the Asian part of the country it is significantly higher than the estimate by PRIMES_2010 – probably because of the thorough revision of the input data based on the national sources, and better accounting of flaring in the oil and gas industry. ECLIPSE_v5a gives slightly higher estimates of the total emissions, and emissions in the European and Asian parts of the country in 2030, compared to our study – by 7%, 6% and 9%, respectively.

[28] Assumptions about fuel use change between 2010 and 2030 are adopted from the ECLIPSE_v5a scenario. The total fuel combustion in the domestic sector increases by 60%, whereas consumption of the fuelwood in this sector increases by factor 2.5

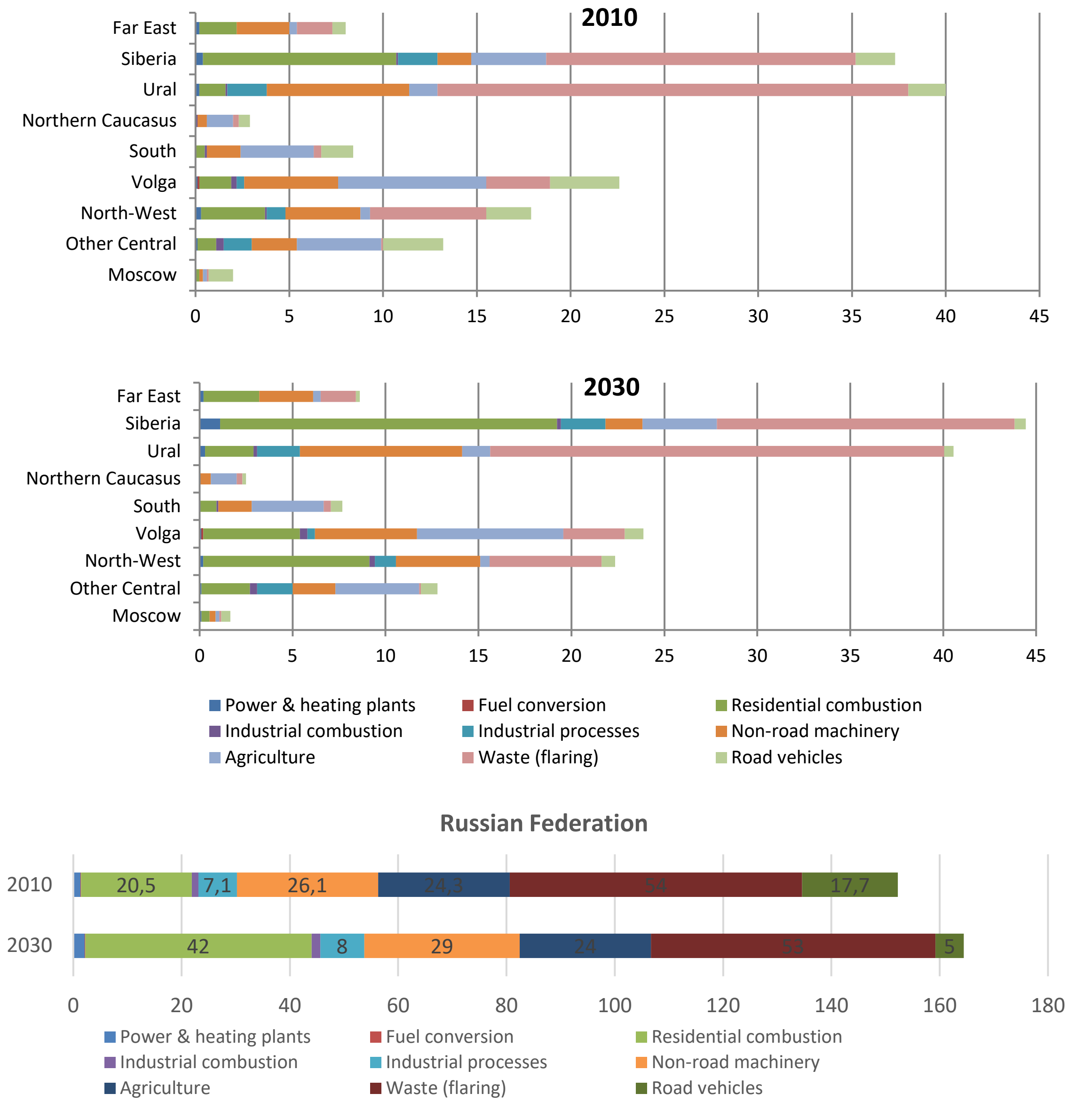

Figure 27. BC emissions in the Russian Federation in 2010 and in 2030, according to the baseline scenario, ktonnes. Upper – region- and sector-specific emissions; lower – sector-specific emissions for the whole Russian Federation.

Table 13. BC emissions in the Russian Federation in 2030, according to the current study and other available baseline scenarios in GAINS, ktonnes.

GAINS scenario	Developed in	Europe	Asia	Total
This study (baseline)	2018	71	94	165
PRIMES_2010	2012	84	71	155
ECLIPSE_v5a	2015	75	102	177
TSAP_16	2014	86	-	-
EO Outlook 2017 BL	2017	58	-	-

3.3.2 Sector-specific scenarios for BC emission reductions

To investigate possible options for black carbon emission reductions, we have developed three sector-specific scenarios, each focusing on one of the key emitting sectors:

1. Non-road transport;
2. Residential combustion;
3. Flaring in oil and gas industries.

In addition, a combined scenario was analysed – the scenario covering abatement measures in all three considered sectors (flaring + residential + non-road).

In each of the sector-specific scenarios, we apply for this particular sector a control strategy adopted from the SLCP mitigation scenario of the ECLIPSE scenario group[29]. The SLCP mitigation scenario assumes maximum possible application rates of SLCP mitigation measures that both reduce climate forcing and do not have negative effects on air quality (Klimont et al. 2017). The three developed sector-specific scenarios can thus be considered as Maximum Feasible Reduction (MFR) scenarios for the three considered sectors, respectively. Measures applied in each of the scenarios are specified in Table 14; they are assumed to be the same for all regions.

Table 14. Abatement strategies in the sector-specific scenarios for black carbon, as adopted from scenario ECLIPSE_V5_SLCP_base (Klimont et al. 2017).

Sector	Examples of measures	Baseline application rate	Application rate in the relevant scenario
Flaring	Good practice (93.22% efficiency)	0%	100%
Residential, wood	Pellets in heating stoves	0%	100%
Residential, coal	High efficiency dedusters on automatic boilers	0%	100%
	Cyclones on manual boilers	50%	100%
Non-road	Control stage IV for diesel sources in agriculture, construction industries, inland waterways, railways	0%	100%
	Combustion modification for shipping	23%	39%

[29] ECLIPSE_V5_SLCP_base

The resulting scenario-specific emissions for each of the Russian regions are presented in Figure 28. Reductions of emissions from flaring are pronounced in Ural and Siberia where flaring is the main source of BC emissions. The difference between the baseline and the other scenarios in the residential combustion sector is large for North-West and Siberia, while in the non-road sector – for Ural, North-West and Volga. Scenarios that result in the largest emission reductions vary from region to region and depend on the shares of the three considered sectors in the economic structure of the region. The flaring scenario results in the lowest emissions (among the considered three scenarios) in Ural and Siberia, non-road scenario – in Moscow, South, Northern Caucasus and Far East, and residential scenario – in Central, North-West and Volga regions.

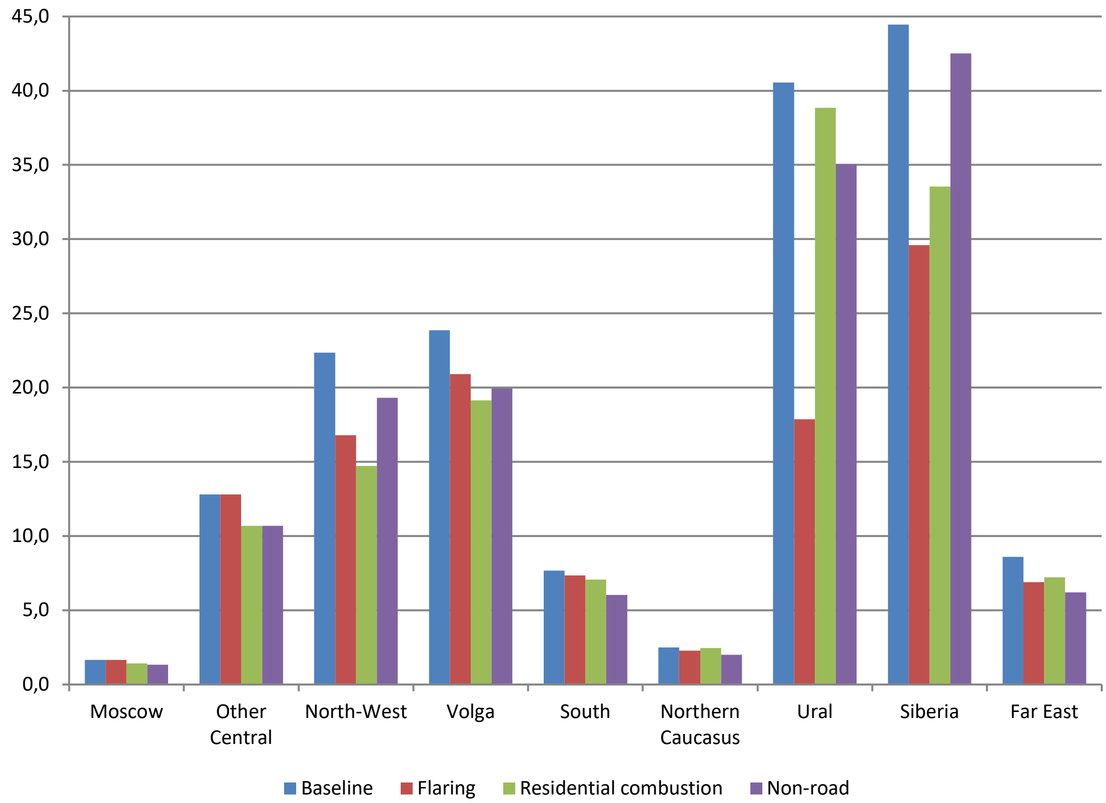

Figure 28. Scenario-specific BC emissions in the Russian Federation in 2030, by region, ktonnes.

Scenario-specific emission reductions in the whole country are presented in Table 15. In relation to the baseline, the largest emission reductions (except for the combined scenario, which obviously is the most beneficial in terms of emission reductions) can be achieved in the flaring scenario (~50 ktonnes), followed by the residential scenario (~30 ktonnes), and finally the non-road scenario (~20 ktonnes). The total BC emissions in the country can be reduced from 165 to 65 ktonnes if measures in all three sectors are applied, at the cost of about 9 billion Euro. Costs per tonne of removed BC vary considerably depending on the sector: while introducing good practice in the oil and gas industries seems to be relatively cheap (12 Euro/kg removed BC), measures in the residential sector (replacement of appliances with improved and new installations) cost about 180 Euro/kg removed BC. The average cost in the combined scenario is ~90 Euro/kg removed BC.

Table 15. Scenario-specific BC emission reductions and abatement costs in the Russian Federation in 2030.

Scenario	BC emissions, kt	Emission reduction, kt	Additional abatement costs, MEuro[30]	Costs, Euro/kg removed BC
Baseline	165	-	-	-
Flaring	116	49	560	12
Residential	136	29	5230	180
Non-road	143	22	2770	130
Flaring + residential +non-road = Combined	65	100	8560	90

Reduction of BC emissions results in reduction of a coarser $PM_{2.5}$ fraction, health effects of which are well-studied and could be quantified and valued in monetary terms. Using the Alpha RiskPoll model[31], we have estimated how the BC and respective $PM_{2.5}$ emission reductions affect people's health[32], and have calculated benefits related to avoided premature mortality from air pollution. This analysis is only possible to conduct for the European part of Russia as the Asian part is not presented in the Alpha RiskPoll. The results are summarized in Table 16.

Table 16. Scenario-specific emission reductions of $PM_{2.5}$ in ETR, related health effects and external costs, 2030.

Scenario	Emissions			Concentrations of $PM_{2.5}$, μg/m³		Benefits (health), MEuro	
	BC, kt	$PM_{2.5}$, kt	BC/$PM_{2.5}$	Concentration	Change	VOLY	VSL
Baseline	71	858	8%	-	-	-	-
Flaring	62	846	7%	0.039	332	1100	106
Residential	56	770	7%	0.336	2862	9480	2824
Non-road	60	814	7%	0.165	1406	4655	1474
Flaring + residential +non-road = Combined	35	714	5%	0.551	4694	15547	4404

Numbers in Table 16 indicate a quite low average share of BC in the $PM_{2.5}$ emissions from ETR. To investigate this issue, we have summarized the BC/$PM_{2.5}$ shares by sector in our baseline scenario and in ECLIPSE_v5a. The resulting shares (see Table 17) vary a lot between sectors but are very similar for the two compared baselines. They do, however, differ from the shares given in the EMEP/EEA Guidebook 2016, extensively used for compilation of black carbon emission inventories. In the EMEP/EEA Guidebook 2016, significantly higher shares are implied for e.g. diesel non-road transport (~60%), power plants on coal (2.2%), and flaring of associated gases (24%). The reasons for the discrepancies between the GAINS baselines and the EMEP/EEA Guidebook 2016 seem to be lying somewhere in the model assumptions and emission factors. For example, application rates of technologies used in GAINS are not necessarily the same as implied in average BC emission factors calculated for the same sectors based on the EMEP/EEA Guidebook 2016 share. Besides, the shares in the EMEP/EEA Guidebook 2016 reflect the current state of abatement technologies, which will most probably develop towards higher abatement efficiency by 2030. A more detailed investigation

[30] Currency year 2005 is used through the present report for assessments of costs and benefits.

[31] The ALPHA RiskPoll model (Holland et al. 2013) enables analysis of a wide range of chronic and acute health effects from exposure to fine particles, ozone and nitrogen dioxide. As an input, the model uses country-specific and scenario-specific population-weighted average concentrations, that can be calculated with the GAINS model.

[32] For this particular task, the modelling has been performed in the GANS Europe module, since due to technical difficulties calculations of health and environmental effects in the GAINS Russia module was not possible. The calculation is done in a simplified way, by simulating scenarios with emission reductions of $PM_{2.5}$ on the ETR level corresponding to the calculated emission reductions of $PM_{2.5}$ in our BC scenarios developed in GAINS Russia. Only $PM_{2.5}$ emission reductions have been simulated so that potential effects from reductions of other pollutants resulting from the four BC specific scenarios (e.g. reduction of NO_x and consequently, of secondary $PM_{2.5}$ emissions in the non-road scenario), are not taken into consideration. Thus, our calculated health benefits are at least for some of the scenarios underestimated.

of the discrepancies is outside of the scope of the project; this is, however an interesting issue for further research.

Table 17. Emissions and BC/$PM_{2.5}$ shares in the baseline GAINS scenarios for 2030, for ETR.

Sector	Our baseline scenario			ECLIPSE_v5a		
	BC, kt	$PM_{2.5}$, kt	Share	BC, kt	$PM_{2.5}$, kt	Share
Power & heating plants	0.5	54.1	1%	0.6	42.3	1%
Fuel conversion	0.1	11.9	1%	0.1	3.6	3%
Residential combustion	18.1	110.6	16%	14.7	101.5	14%
Industrial combustion	1.3	24.9	5%	1.4	33	4%
Industrial processes	3.5	419.6	1%	6	570	1%
Fuel production & distribution	0	0.1	0%	0	0.6	0%
Road vehicles	3.8	9.5	40%	4.3	12.1	36%
Non-road machinery	15	52.3	29%	13.5	56.3	24%
Agriculture	18.3	156.5	12%	18.3	163.7	11%
Waste (includes flaring)	10.2	18.5	55%	16.1	38.1	42%
TOTAL	**71**	**858**	**8%**	**75**	**1021**	**7%**

Comparison of technical costs and related health benefits for the four considered scenarios are presented in Figure 29 – for ETR only. Valuation of benefits is done using Value of statistical life (VSL) and Value of year lost (VOLY) metrics[33].

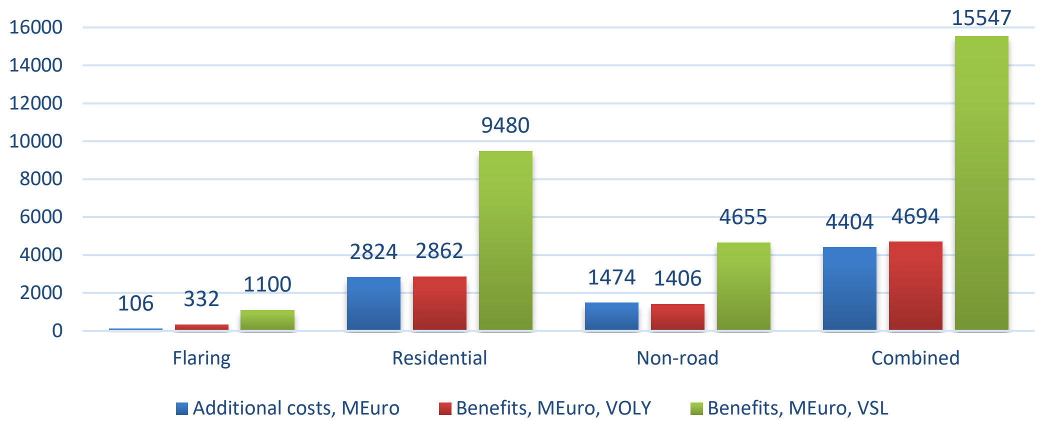

Figure 29. Costs and benefits of BC scenarios in ETR, 2030, million Euro.

The potential health benefits from BC emission reductions are estimated at up to ~15 billion Euro – this is for the scenario combining measures in all three sectors and using VSL as a valuation metric. For all scenarios except for non-road, gross benefits expressed in VOLY exceed costs, implying that the scenario brings positive net benefit to society – however, with the VOLY metric the difference between the costs and the benefits is rather low (except for the flaring scenario, where benefits are three times higher than costs). The flaring scenario, resulting in very cost-effective emission reductions on the level of the country (see Table 15), does not seem to bring any significant health benefits on the European level. This is predictable since flaring is mostly located in the Asian regions. In the current version of the GAINS Russia module, it is technically not possible to analyse the effects of emission reductions in the Asian regions on the population of the European regions. However, this effect most certainly exists and should be considered when analysing spatial aspects of BC reduction measures. Reducing emissions from e.g. flaring in Ural would definitely result in

[33]The VOLY and VSL approaches differ in terms of how many life years that are assumed to be lost when a fatality occurs. The VOLY method is based on life tables; it takes into account at what age people die from air pollution and gives results in terms of life expectancy. The VSL method does not use life tables and instead operates with mortality rates. As the VSL method does not take into account age or death reasons, it is sometimes considered to be overestimating health benefits from air pollution reduction (Desaigues *et al*. 2011) while VOLY approach is considered as more conservative.

decreased premature mortality in the neighbouring regions such as Volga and North-West, even though this decrease currently cannot be calculated in the GAINS model.

3.4 BC emissions and emission factors in the ECLIPSE scenarios – inter-country comparisons and review of the most recent changes

Results of the GAINS model scenarios are meant as supporting material to be used by policy-makers when taking decisions regarding cost-effective emission reduction measures and instruments. Baseline emissions and estimated emission reduction potentials for BC emissions depend on applied emission factors, which are associated with large uncertainties. In this chapter, we make a short review of the emission factors currently used in the GAINS model and compare emission factors between Russia and two Nordic countries – Finland and Sweden.

3.4.1 Country-specific aggregated BC emission factors

In the GAINS model, emission calculation parameters include fuel use, emission factors for a specific sector, and efficiency of a possible emission reduction measure. When comparing the emission factors in different countries, it is necessary to include the prevalence of each specific technology and fuel into the assessment. Also, emission factors for some sectors may vary considerably between countries, but if the application rate of a particular technology is low, the impact on emissions can be insignificant.

Appendix 14 shows black carbon emissions in 2015 by key fuels and sectors in the three assessed countries, according to the scenario ECLIPSE_v5a. For each country, residential combustion of biomass, road vehicles and non-road machinery are important sources. Dividing the emissions presented in Appendix 14 by the relevant fuel use gives the aggregated emission factors for each key sector – these are presented in Tables 18-20, with the important sources highlighted in color**.** Values 0.0 are an indication of low, but non-zero emission factors.

Table 18. Aggregated BC emission factors for key sectors in ETR, mg/MJ.

Sector	Coal	Liquid fuels	Gaseous fuels	Biomass
Power & heating plants	0.2	8.4	0.0	0.3
Fuel conversion	0.0	0.2	0.0	
Residential combustion	55.3	1.1	0.0	75.8
Industrial combustion	0.1	0.3	0.0	8.3
Road vehicles		6.9	0.0	
Non-road machinery		22.1	5.1	

In the Russian Federation, large black carbon emissions occur in sectors where fuel is not combusted for energy purposes. These are, for instance, coke ovens (category "industrial processes" in GAINS), agricultural waste burning (category "agriculture" in GAINS) and flaring in oil and gas industries (category "waste" in GAINS). The emission factors for agricultural waste burning (0.83 t/kt) and flaring (2.5 mg/MJ) are the same for all three countries, but only Russia has notable activity in those sectors. For coke ovens, the Russian emission factor (0.55 t/kt) is twice as high as in the other two countries, and there are also significantly higher activity levels in Russia.

Table 19. Aggregated BC emission factors for key sectors in Sweden, mg/MJ.

Sector	Coal	Liquid fuels	Gaseous fuels	Biomass
Power & heating plants	0.0	0.3	0.0	0.2
Fuel conversion	0.0	0.0	0.0	0.0
Residential combustion		1.0		32.4
Industrial combustion	0.0	0.0	0.0	0.8
Road vehicles		1.8	0.0	
Non-road machinery		6.8		

Table 20. Aggregated BC emission factors for key sectors in Finland, mg/MJ.

Sector	Coal	Liquid fuels	Gaseous fuels	Biomass
Power & heating plants	0.0	0.0	0.0	0.1
Fuel conversion	0.0	0.2	0.0	1.0
Residential combustion	0.0	3.4	0.0	50.0
Industrial combustion	0.0	0.3	0.0	0.1
Road vehicles		5.1	0.0	
Non-road machinery		10.7		

Tables 18-20 show that Russia has the highest aggregated emission factors for all the highlighted sources, and Sweden has the lowest. For heating stoves and residential wood boilers, the emission factors for appliances are very similar between the countries, but the appliance stock varies. The respective control strategies assume that Russia has the least modern appliance stock and Sweden has the most modern appliance stock. The same is true for road vehicles and non-road machinery (except for "other non-road machinery" subsector, where the Finnish emission factors are notably lower than the other two countries'). There are minor variations in the emission factors for diesel-fuelled vehicles, but the differences in aggregated emission factors are due to the varying age of the vehicle and machinery fleet.

3.4.2 Recent developments in activity data and emission factors in GAINS Europe

The earliest ECLIPSE scenario still available in GAINS Europe is version 4a, released in January 2014. Version 3 (released in November 2013) is no longer accessible, but some scenarios from early 2013 are. Appendix 15 presents a comparison of black carbon emissions in ETR in 2010 between three scenarios: TSAP_mar2013, ECLIPSE_v4a and ECLIPSE_v5a. Separate comparisons are made for sources where fuel is combusted for energy, and for non-combustion sources.

In most cases, the emissions highlighted with color are lower in the latest model version. The only two sectors where this is not the case are industrial processes and agricultural waste burning, where emissions have remained the same. The majority of these lower emission estimates are due to updates in activity data. The scenarios have different sources for activity data, and ECLIPSE_v5a is the only one that uses statistics reported to International Energy Agency (IEA 2012). Even with the same source, the activity data between GAINS scenarios from different time periods may vary, since GAINS and IEA sectors are not identical, and the allocation of fuels to GAINS sectors is regularly updated. Also, the statistics that countries report for a single historical year are also subject to changes during later reporting.

The only difference in the BC emission factors in the studied sector/fuel combinations are for gas flaring, but also the activity data for flaring has been updated. Emission factors for flaring depend on the chemical composition of the associated petroleum gas. The change in the gas flaring emission factor between ECLIPSE_v5a and ECLIPSE_v4a is due to an updated assumption of the calorific heat value of associated petroleum gas in the Russian oil industry. Sources for the currently used BC emission factors are presented in Klimont et al. 2017.

***

Being a harmful air pollutant and a short-lived climate forcer at the same time, black carbon is a subject to active interest in the scientific community and a "hot potato" in the policy-making arena. Black carbon emissions are included in the latest revision of the Gothenburg Protocol under the UNECE CLRTAP; reduction of black carbon emissions is on the agenda of the Arctic Council and IMO, it is studied on the EU level, and the transnational Climate and Clean Air Coalition is built specifically to create and share practical solutions for voluntary reduction of black carbon emissions. The Russian Federation is involved in several of these initiatives.

We have summarized and analysed available data on the black carbon emissions in Russia – both estimates for the historical years and modelled emissions for the future years. Current black carbon emissions from the entire territory of Russia are estimated at 120-360 ktonnes; there is, however, no official black carbon emission inventory covering the whole country. The official inventory for the Arctic Zone of Russia, submitted to ACAP, gives an estimate of 24.2 ktonnes in the year 2013.

Most studies agree that the major BC emitting sources in the Russian Federation are flaring of the associated gas in the oil and gas industry, road and non-road transport and residential combustion. The relative inputs of these sectors for each particular region, however, vary significantly – e.g. while in Moscow road traffic is the largest source, in Ural and Siberia the main emitting source is flaring. The regions where the highest amounts of black carbon are emitted are Ural and Siberia. Among the regions within ETR, the leader is Volga, where most part of black carbon originates from transport and agricultural waste burning, according to our modelling results. Treating the entire ETR as one region in the GAINS modelling, as it is done in the GAINS Europe module, does not allow taking differences between the regions into account. Besides, a significant part of the black carbon is emitted in the Asian part, not included in the GAINS Europe module at all. By treating the Russian regions separately in one module, GAINS Russia provides a tool that allows integrated assessment analysis on the regional level – for both the European and Asian regions of the country.

We have analysed three scenarios for black carbon emission reductions, each focusing on one specific sector (flaring, non-road, and residential combustion), and one combined scenario including measures in all the three sectors. The results indicate that the most cost-effective way to reduce black carbon emissions, considering the whole country, seems to be by taking measures to reduce flaring in the oil and gas industry – the costs of these measures are estimated at 12 Euro per kg removed black carbon. This sector also has the largest emission reduction potential (except for the combined scenario) in 2030 – 49 ktonnes. If only ETR is considered, residential combustion is the sector with the largest emission reduction potential of 15 ktonnes. Gross health benefits that result from avoided mortality due to reduced exposure to $PM_{2.5}$ emissions in this scenario are 2.9 – 9.5 billion Euro (depending on the chosen valuation metric), which is 1.01 – 3.4 times higher than the associated technical costs. Combining measures in all three main emitting sectors would result in emission reductions by 36 ktonnes black carbon in ETR, and 100 ktonnes – in the entire country.

New baseline and black carbon emission reduction scenarios are region-specific, which enables more specific and more accurate analysis of spatial allocation of emissions, abatement measures, associated costs and health benefits. The results calculated for the target year 2030 can be used as supporting material for national and regional policy-making, as well as for negotiations on the international BC reduction goals, such as the one set for 2025 by ACAP.

4 Gothenburg Protocol scenarios

In this chapter, we present the results of the scenario analysis for scenarios developed with specific focus on reduction of emissions regulated by the Gothenburg Protocol under the UNECE CLRTAP. The Russian Federation has not yet ratified the revised Gothenburg Protocol. Like for other European countries, integrated assessment modelling (GAINS and Alpha RiskPoll modelling in particular) has a potential to contribute to building scientific basis for policy decisions on this level.

The Gothenburg Protocol includes several air pollutants; we have chosen to focus on oxidised and reduced nitrogen. NO_x and NH_3 emissions affect people's health and put ecosystems at risk by eutrophication and acidification (Hettelingh et al. 2017). Both also contribute to formation of harmful secondary particles ($PM_{2.5}$) that increase premature mortality and cause a range of adverse health effects (asthma, bronchitis, cardiovascular problems) in the population. Current emissions of NO_x and NH_3 are significant in Russia – the country with a well-developed agriculture in many regions as well as intense industry and fossil-based energy production system. Investigation of region-specific potentials and measures for NO_x and NH_3 emission reductions can thus be a useful underlying material for developing emission reduction policies.

The current target year in the Gothenburg Protocol scenario is 2020. However, for scenarios to be useful in the actual policy-making process, they need to consider a wider time horizon. While the target year of the Gothenburg Protocol will be discussed during the next revision of the Protocol, in the analysis presented below we have chosen 2030 as the target year.

This analysis is performed for ETR only, since emissions in the Asian part of Russia are not covered by obligatory EMEP reporting and all negotiations within the UNECE CLRTAP only concern the European part of Russia. Besides, the analysis of environmental and health effects included in our study, is technically available for ETR only as well – both in the GAINS Europe and in the GAINS Russia modules.

4.1 Scenarios for NH_3 emission reduction

Like in many other countries, the largest part of ammonia (NH_3) emissions in ETR originates from agriculture – more than 90% of the national totals[34]. NH_3 from agricultural sources makes a significant contribution to formation of fine particle fractions ($PM_{2.5}$). Several studies (e.g. Bauer et al. 2016, Lelieveld et al. 2015, Backes et al. 2016) show that $PM_{2.5}$ concentrations in Europe and in the Russian Federation to a larger extent are attributable to emissions from agriculture (mainly ammonia) than to emissions from other anthropogenic sources. This makes agricultural ammonia emissions in ETR, as well as reduction possibilities, a highly interesting subject to integrated assessment.

Our analysis of NH_3 emissions is focused on region-specific emission reduction potentials – the difference between the baseline emissions and emissions in case all most efficient measures are applied to the maximum possible extent. We have developed MFR scenarios for agricultural

[34] https://www.ceip.at/ms/ceip_home1/ceip_home/data_viewers/official_tableau/ accessed in October 2019

ammonia for six regions in GAINS Russia that belong to ETR (Moscow, Other Central, North-West, Volga, South and Northern Caucasus).

Modelled baseline emissions in 2030 by region are presented in Figure 30, together with contributions from different emission sources. Dairy cattle and poultry seem to make the largest contribution to the total ammonia emissions in the ETR regions.

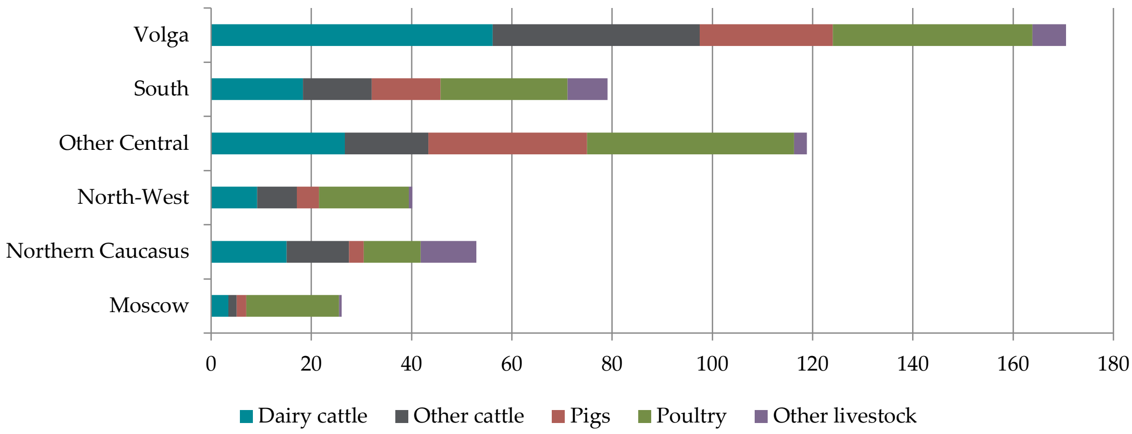

Figure 30. Baseline NH_3 emissions in 2030 by region and emission source, ktonnes.

Emission reductions to the minimum possible level can be achieved by applying the following measures in the agricultural sector (numbers in the parenthesis mean application rates of the measures in relation to the total activity level):

- Cows – low N feed + house adaptation + low ammonia application (44%)
- Other cattle – low ammonia application, high efficiency (84%)
- Lying hens – low N feed + house adaptation + low ammonia application (48%)
- Other poultry – low N feed + bio-filtration + covered outdoor storage + low ammonia application (39%)
- Pigs – low N feed + bio-filtration + covered outdoor storage + low ammonia application (70%)
- Other animals – low ammonia application, high efficiency (23%)
- Urea application – urea substitution (90%)
- Mineral N fertilizer production – combination of STRIP (100%)

The total abatement costs in the MFR are estimated at 857 million Euro, see the cost structure in Figure 31. Measures for poultry and pigs together contribute to ~60% of the total costs.

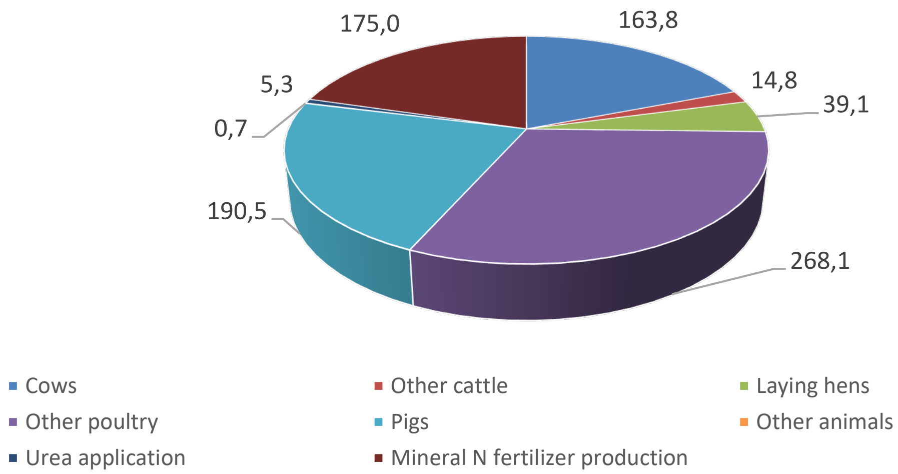

Figure 31. Costs of the ammonia abatement in the MFR scenario for ETR, million Euro.

The resulting region-specific baseline and MFR emissions in 2030, as well as emissions in 2010 (base year), are illustrated in Figure 32. The total ammonia emissions in ETR increase by 65 ktonnes (9%) between 2010 and 2030 (from 747 to 812 ktonnes), if no further reduction measures are applied. In the MFR scenario, emissions in 2030 amount to 573 ktonnes, implying that the total emission reduction potential is 239 ktonnes. The largest emission reduction potential is seen in Volga region (82 ktonnes), followed by Other Central (62 ktonnes) – regions where agriculture plays an important role in the economic system.

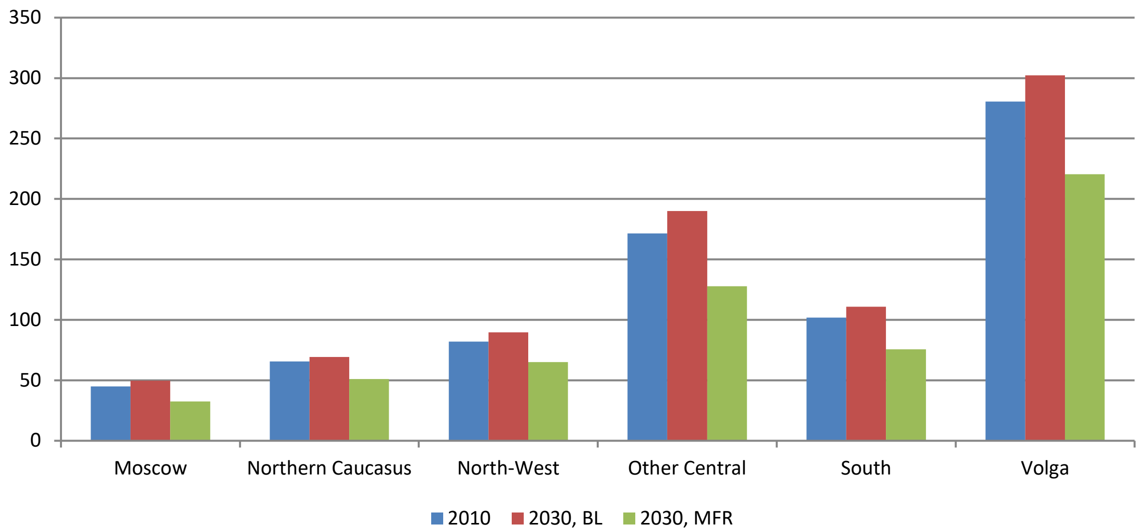

Figure 32. Ammonia emissions on ETR – baseline and MFR scenarios, ktonnes.

The emission reduction by 239 ktonnes would result in the reduction of average population-weighted $PM_{2.5}$ concentration in ETR by 0.351 µg/m^3. This corresponds to the gross health benefits of 3000 million Euro, alternatively 9900 million Euro, depending on the chosen valuation metric (VOLY, VSL), see Figure 33. Irrespective of the chosen valuation metric, full implementation of the MFR scenario in the agricultural sector of ETR results in the significant positive net benefits for society due to avoided mortality from secondary $PM_{2.5}$ – 9000 million Euro for VSL and 2100 million Euro for VOLY. Benefit-to cost ratios are 11.6 for VSL and 3.5 for VOLY.

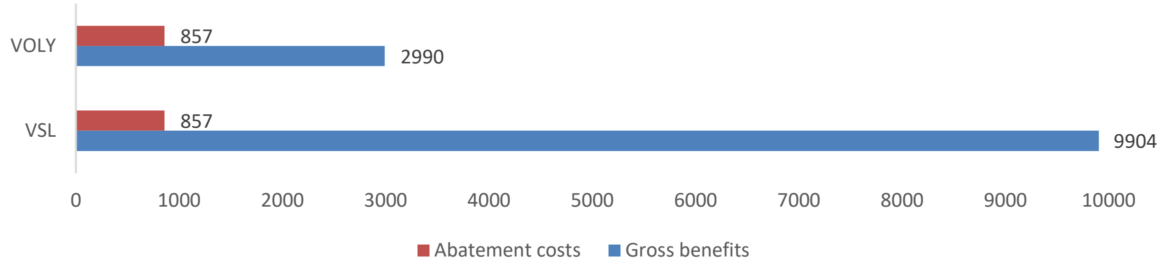

Figure 33. Costs and benefits of the MFR scenario for ETR, million Euro.

4.2 Scenarios for NO_x emission reduction

In the region-specific analysis of NO_x emissions, we focus on two alternative methods to identify cost-effective abatement measures needed to achieve a certain emission reduction target. The emission reduction target is expressed in percentage reduction in 2030 compared to the emissions in 2010. This is the same approach to setting emission reduction targets as in the Gothenburg Protocol, where the base year is 2005 and the target year – 2020.

As Figure 34 shows, sources of NO_x emissions vary between the regions. The total amount of emitted NO_x in the baseline scenario is expected to decrease between 2010 and 2030 by 9%, see Table 21. The decrease in NO_x emissions is seen in the modelling results for all regions except for Other Central.

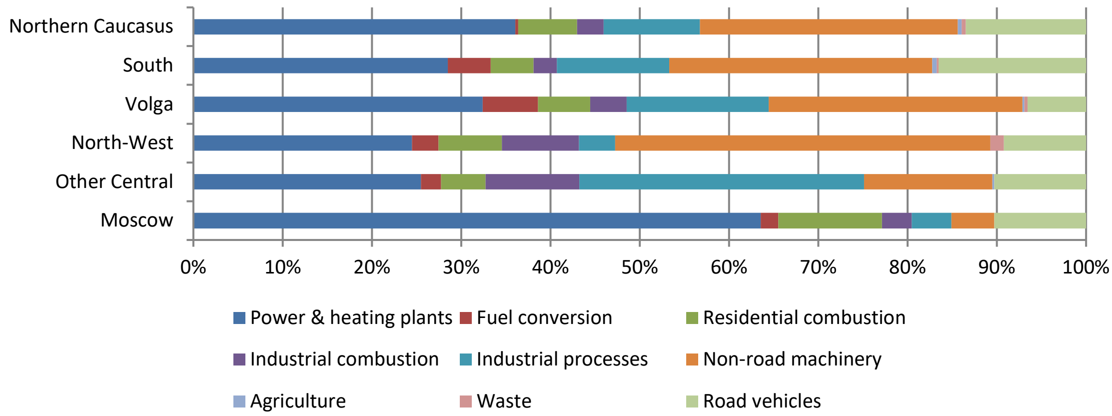

Figure 34. Contribution of sectors to the baseline NO_x emissions in 2030, by region.

The **emission reduction target** should therefore be not lower than 9%. We chose to set the target at **22%**, which corresponds to **315 ktonnes NO_x** according to the baseline scenario numbers. This can be compared to the targets set in the scenario analysis presented in Amann et al. 2011b. Scenarios presented in Amann et al. 2011b were developed during the last revision of the Gothenburg Protocol with the aim to explore emissions and effects for several emission reduction ambition levels (from low to high) for each country in Europe. For the Russian Federation, the low emission reduction level corresponds to 33% emission reduction between 2005 and 2020; at the same time, the baseline in Amann et al. 2011b implies 31% reduction, so the additional reduction compared to the baseline is only 2%. The additional NO_x emission reduction of 13%, assumed in our analysis (the difference between the target 22% and the baseline 9%), would correspond to the ambition level somewhere between the mid and high level.

Table 21. Aggregated NO_x emission trends between 2010 and 2030, by region.

Region	Baseline NO_x emissions		% change
	2010	2030	
Moscow	272	213	-22%
Other Central	489	493	+1%
North-western	490	406	-17%
Volga	908	881	-3%
South	241	195	-19%
NCAU	83	67	-19%
ETR total	**2482**	**2254**	**-9% (228 kt)**

We further apply **two different approaches** to reach the total emission reduction of 315 ktonnes on the level of ETR. Within one approach (referred to as "equal amounts"), we reduce NO_x emissions by the same amount in each region[35]. The alternative approach is to assume the same percentage of emission reduction between 2010 and 2030 in each region. This approach is referred to as "equal percentages".

Emitting sectors in all regions have been ranked, and additional control measures for further emission reductions have been chosen first for the largest emitting sector[36], then for the second largest emitting sector – and so on, until the region-specific target level is reached. Although this approach does not result in the most cost-effective set of abatement measures, it minimizes the number of considered sectors where the measures are taken and thus provides the set of measures that might by relatively easy to implement from the administrative perspective.

The resulting control measures, their costs, emission reductions and unit costs per kg removed NO_x are summarized in Table 22 and Table 23.

The results show that depending on which approach is chosen to distribute suggested emission reductions by regions, the resulting sets of abatement measures and their total costs are different. It depends mainly on the different economic structure of the regions, and on how large emission reductions are assumed to happen in the baseline. For example, in **Moscow** region, the modelled decrease in the emissions is 22% in the baseline, implying that no further measures are needed with the equal percentages approach. In the same region, equal amounts would result in the additional measures for power plants, with the cost of 23 million Euro. In **Other Central** region, equal percentages mean that needed emission reduction is 112 ktonnes, which is almost twice as large as in the equal amounts approach, and results in additional measures in the cement, lime and chemical industries. In **Volga**, high emission reductions assumed in the equal percentages result in a cost increase from 24 million Euro to 306 million Euro, compared to the equal amounts approach. For the combined **South + Northern Caucasus** the situation is the opposite: rather low emissions assumed in the baseline mean that it is much more difficult and costly to assure emission reductions by 63 ktonnes NO_x (equal amounts) than by 22% corresponding to 9 ktonnes NO_x.

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[35] Regions South and Northern Caucasus are in this analysis combined in one aggregated region because of larger uncertainties associated with the data for Northern Caucasus. Until 2010, both regions belonged to the same (Southern) federal district. Separate input data for Northern Caucasus are rather scarce, and several data gaps are filled with assumptions and splits between these two regions. It thus seems more reasonable to consider these two regions as one in this particular analysis.

[36] Except for road transport, for which we assume that application rates of Euro standards are the same as in the baseline.

Table 22. Emission reduction strategies in the scenario where the target emission reduction between 2010 and 2030 is reached by equal amounts (63 ktonnes) in each region. Numbers in parenthesis indicate application rates of the technologies.

Region	Additional measures	Total additional costs, MEuro	kt NO_x reduced	Costs, Euro /kg NO_x
Moscow	Combustion modification on existing oil and gas power plants (88%)	23	63	0.37
Other Central	Control of process emissions in the cement industry: 68% of stage 2 (60% removal efficiency) and 32% of stage 3 (80% removal efficiency).	37	63	0.59
North-West	Control of non-road machinery on gaseous fuels – 91% of Euro 1 and 9% of Euro 2	2.4	63	0.04
Volga	Combustion modification on existing oil and gas power plants (40%)	24	63	0.37
South + Northern Caucasus	Control of other non-road machinery of gaseous fuel – 100% of Euro 4 Control of diesel non-road machinery in agriculture, construction and railways – 100% of Stage 4 Combustion modification on existing oil and gas power plants (56%)	293	63	4.65
TOTAL ETR		**379**	**315**	**1.20**

Table 23. Emission reduction strategies in the scenario where the target emission reduction between 2010 and 2030 is reached by equal percentage (-22%) in each region. Numbers in parenthesis indicate application rates of the technologies.

Region	Additional measures	Total additional costs, MEuro	kt NO_x reduced	Costs, Euro /kg NO_x
Moscow	-	-	-	-
Other Central	Control of process emissions in the cement and lime industries: 100% of stage 3 (80% removal efficiency). Control of process emissions in the nitric acid production: 46% of stage 1 (40% removal efficiency) and 54% of stage 2 (60% removal efficiency).	93	112	0.83
North-West	Control of non-road machinery on gaseous fuels – 38% of Euro 1	0.9	24	0.04
Volga	Combustion modification on existing oil and gas power plants (63%) Combustion modification + selective catalytic reduction on existing oil and gas power plants (37%)	306	170	1.77
South + Northern Caucasus	Control of other non-road machinery of gaseous fuel – 72% of Euro 1	0.3	9	0.04
TOTAL		**400**	**315**	**1.26**

The example calculations of reaching the same reduction goal by using different approaches to the regional distribution are given here to illustrate advantages of the new regionalization provided in the GAINS Russia module. There are other approaches available, the most cost-effective of which is **costs optimization**. Cost optimization means that the target emission reduction is reached by the set of the reduction measures resulting in the minimum costs – the measures can be chosen in each region and sector. Within this approach, the resulting suggested region-specific emission reductions depend entirely on what is the most cost-effective for ETR as one larger unit – and that, in turn, depends on the sectoral structure of the regions. For analyzing scenarios corresponding to different ambition levels relevant for the Gothenburg Protocol, this approach would be the most suitable. This feature is, however, not yet available in the GAINS Russia module.

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In the scenario analysis relevant for the Gothenburg Protocol under the UNECE CLRTAP, we have investigated emission reduction potentials for agricultural ammonia and two possible approaches to reaching a certain emission reduction target set for NO_x. Both scenario sets are focused on ETR and 2030 as target year.

The total emission reduction potential for agricultural ammonia in ETR is estimated at 239 ktonnes. Full implementation of the MFR scenario would cost 857 million Euro, with the resulting gross benefits from avoided premature mortality of 3-10 billion Euro. The largest emission reduction potential is seen in Volga and Other Central regions.

In the analysis of scenarios for NO_x reductions down to a chosen ambition level of 22% compared to the level of 2010, we focused on how the resulting regional allocation of measures and costs depend on the method. Choice between equal amounts in each region, or equal percentages, or cost optimization, or another possible method to distribute suggested emission reduction between the Russian regions, affects not only the cost burden of each region but also the total costs. Allocation of suggested emission reductions to certain regions should thus be treated with care in the policy-making processes.

5 EMEP modelling and research

One of the essential parts of integrated assessment is modelling of pollution dispersion in the atmosphere. For proper estimates of pollution impacts on health and environment, it is necessary to track the path of emitted substances to their end-points, often located long away from the place where the harmful substances are emitted. A number of physical and chemical processes determine the fate of the pollutants during their atmospheric transport: the gaseous species react with each other or condense on the existing particles, thus forming new species; both gases and particles experience dry deposition and wet scavenging from the air. These complex processes are accounted for in so called chemical transport models (CTMs), relating the emissions to pollutant depositions and atmospheric concentrations.

One of such CTMs developed specifically for simulation of the long-range transport of air pollution over Europe to facilitate the work of the UNECE CLRTAP is the EMEP MSC-W [37] model. EMEP MSC-W is an open-source model extensively used in scientific work and providing policy-relevant outputs, such as annual assessments of European air pollution and acidification and eutrophication and source-receptor matrices showing countries' and regions' inputs into impacts of air pollution in other countries and regions (EMEP Status Report 1/2016). Country-to-cell source-receptor matrices produced in the EMEP model are also used in the GAINS model for quick simulations of pollution dispersion (Amann et al. 2011a). A comprehensive model description can be found in Simpson et al. 2012, and for further model developments and updates see the web-page with all EMEP Status Reports[38]. Appendix 16 provides a brief description of the EMEP MSC-W model, mainly focusing on the differences between the version described in Simpson et al. 2012 and the version rv4.8 used for simulations in this study. Chapter 5 describes the background for the EMEP modelling and research carried out in this project and discusses the main results.

5.1 Background, objectives and methods of the EMEP research

For official EMEP reporting, operational runs with the EMEP MSC-W model are performed with the input based on official national emission inventories. Gridded emission data, necessary for model runs, is prepared by the Centre on Emission Inventories and Projections (CEIP) of EMEP. Countries are requested to report their gridded emissions to CEIP every four years – from 2017 at the new, fine resolution of 0.1°x0.1° longitude-latitude. Countries are also invited to report gridded emissions at the new resolution at any time[39]. Russian experts have been regularly submitting gridded emissions at the resolution 50x50 km^2 – but not at the fine resolution (0.1x0.1°) yet, because of the lack of technical capacity. Emission gridding at the new resolution might represent a technical challenge even despite the available guidance documents (EEA/EMEP Guidebook 2016). In addition to EMEP reporting (which is done for ETR only), preparation of gridded emissions is needed for EMEP modelling on the level of the whole country, or federal districts, or even subjects – in certain type of tasks (such as source-receptor calculations), there is often a need for additional data (regional

[37] MSC-W = Meteorological Synthesizing Centre – West of EMEP

[38] www.emep.int

[39] http://www.ceip.at/ms/ceip_home1/ceip_home/new_emep-grid/

fractions of emissions, source point locations, etc.) not available at the CEIP homepage. Besides, the EMEP/MSC-W model is open for using own meteorological data instead of the default meteorology. One of the objectives of this study is therefore further **development of technical skills and methods for preparation of necessary input data** for EMEP modelling (gridded emissions, meteorological data) – by working with a pilot region.

Another aim of the study is to investigate **new model resolution (0.1x0.1°) and its effects on the model performance and modelling results**, including potential impact on transboundary effects (source-receptor (SR) tables).

Quality of input data is another issue of concern. Preparing 50x50 km^2 gridded emissions for the Russian Federation for the EMEP/MSC-W model, CEIP mainly uses proxy data from the database EDGAR[40]. Some significant discrepancies have been discovered between the spatial distribution of emissions constructed by CEIP and that prepared by the national experts. Analysis and possible minimization of these discrepancies is included in the current study as a part of the **input data quality improvements**. Further improvements include: review of other available gridded emission data sets for the Russian Federation (such as TNO-INERIS[41] data)[42], compilation of gridded emission data for ETR at the resolution 50x50 km^2 for 2013, compilation of gridded emission data for a pilot region at the resolution 0.1x0.1° for 2013, model runs with the new data sets, and verification of the modelling results (including those produced at the fine resolution) by comparison to available observation data.

Finally, the study is aimed at further **capacity building, strengthening the experience in the operational use of the EMEP/MSC-W model**, and development of the contact network regarding EMEP modelling issues.

Many of the presented results are produced for **Murmansk region**. This subject, described in detail in Appendix 17, has been chosen as a pilot region for analysis for several reasons. It is located in the North-Western part of the country and has borders with two of the Nordic countries – Finland and Norway. Some large point sources of emissions in Murmansk region are located close to these borders, which makes the region interesting in terms of EMEP modelling and investigation of transboundary effects. The subject is already defined as a separate region in the EMEP/MSC-W model, and the quality of the available data regarding emissions and emission sources is considered by national experts as very good.

5.2 EMEP training, test model runs and verification

5.2.1 EMEP training workshop

Experts of SRI Atmosphere have been working with the EMEP/MSC-W model since 2008. During the Nordic-Russian multilateral cooperation projects “Capacity building on decision support for air

[40] EDGAR =Emissions Database for Global Atmospheric Research http://edgar.jrc.ec.europa.eu/overview.php?v=432_GHG

[41] TNO = the Netherlands Organisation for applied scientific research. INERIS = French National Institute for Industrial Environmental and Risks

[42] As countries were required to report their emissions at the resolution 0.1x0.1° from 2017, no official CEIP emission datasets at fine resolution was available upon the project beginning (in 2015), so the project team used the only available complete data set at this resolution – the one produced by TNO-INERIS for emissions in 2009.

pollution policies – results from Nordic-Russian cooperation", conducted during 2009 – 2012 and partly financed by the Nordic Council of Ministers, The EMEP/MSC-W model was used to test calculation of SR tables for some of the regions (Åström et al. 2013).

The EMEP/MSC-W model is constantly being further developed and improved (see Appendix 16), and the Open Source version is updated every year. Thus, there is a need for technical and methodological support in the operational use of the model, and to provide such support, MSC-W (hosted by MET Norway) holds biennial User Workshop. The 2-nd **workshop**[43]**,** organized in October 2015, covered several technical and methodological aspects of the modelling, in particular:

- Introductory information, including structure of the model, main principles, input data needed, outputs, computation requirements, resolution;
- Meteorological input data and working with WRF[44] Meteorology;
- Gas phase chemistry, chemistry module choices;
- Calculations of source-receptor tables.

The workshop made a useful contribution to improvement of the technical skills of the national experts in the Russian Federation. It also facilitated further contacts between EMEP modelling experts from different countries (including technical data exchange) and provided necessary methodological basis for further operational work with the model – within the current project and beyond.

For the purposes of the current study, model version EMEP rv4.8 was used. A series of **model runs** have been made, as summarized in Table 24. All four runs have been made using meteorological data for the year 2013, provided by MET Norway and adjusted to different resolutions. The results are presented below in the relevant chapters of the report.

Table 24. Summary of the EMEP/MSC-W model runs performed within the study.

Run N	Emission data	Run domain	Emission year	50x50 km²	0.1x0.1°	Performed by
1	EMEP /CEIP (EMEP Status Report 1/2015)	EECCA	2013	x		SRI
2	EMEP /CEIP with own data for ETR	EECCA	2013	x		SRI
3	TNO-INERIS	EMEP01 (cut at 60°E)	2009		x	SRI&MET
4	TNO-INERIS with own data for Murmansk region = "updated TNO" [45]	EMEP01 (cut at 60°E)	2009 + 2012	x	x	SRI

5.2.2 Test EMEP/MSC-W model runs and model verification

To verify that the model version has been correctly installed on the SRI Atmosphere server and works properly, a test run at the EMEP 50x50 km² resolution have been made, as recommended by MSC-W (run 1 in Table 24). The results of this test run (Figure 35, right) have been translated into a

[43] http://www.emep.int/meetings/EMEP_Training_2015/Agenda_October2015_1.pdf

[44] WRF = Weather Research and Forecasting Model https://www.mmm.ucar.edu/weather-research-and-forecasting-model

[45] Due to the scarcity of available emission datasets at the time these tasks have been conducted, it was decided to use the TNO-INERIS set of emissions for model runs at the resolution 0.1x0.1° (Bessanget et al. 2014). Own data available for Murmansk region has been incorporated in the TNO-INERIS data – this combined data set is referred to as "improved TNO".

table format and compared to the results provided on the Open Source page[46]. In Figure 35, the comparison example is given for ground-level annual-average NO_2 concentrations; it shows good visual correspondence between the MSC-W and SRI Atmosphere results, suggesting successful model installation. Relative differences in the concentrations do not exceed 1.8% and for most part of the considered territory it is within 1%. Those differences are mainly associated with technical reasons (i.e. different compilers, machine configuration, etc.)

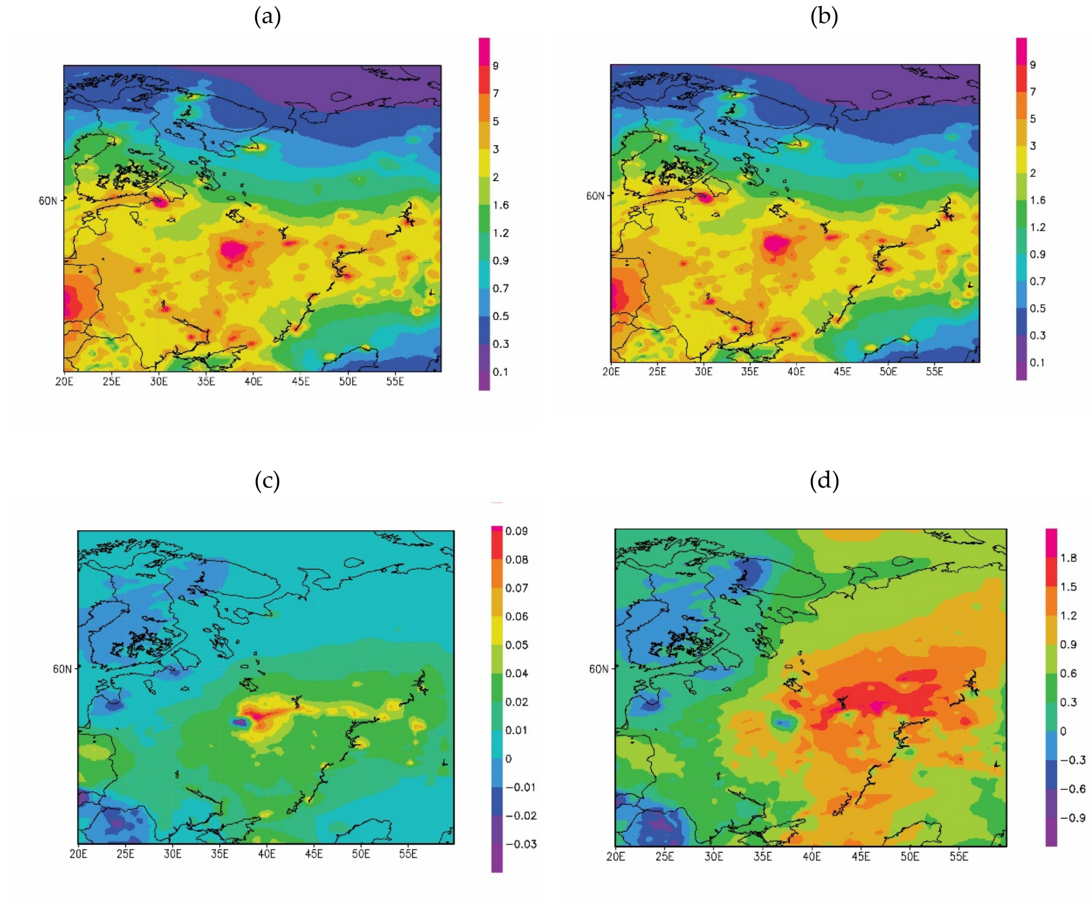

Figure 35. Model test run at the resolution 50x50 km²: ground-level annual-average NO_2 concentrations as displayed on the model home-page (a) and as modelled by SRI Atmosphere (b), μg/m³, their difference in μg/m³ (c), their relative difference in % (d).

Furthermore, model testing at the resolution 0.1x0.1° (run 1 in Table 24) has been performed to assure that all input data (TNO-INERIS emission data set and meteorological data) are used correctly and the model works properly at the fine resolution as well. This model run was made in parallel by SRI Atmosphere and by MET Norway. The results are presented in Appendix 18 and show very similar concentration fields for NO_2 and SO_2. Based on these results it can be concluded that the model also works properly at the 0.1x0.1° resolution, and that the input data is prepared and used correctly.

[46] https://wiki.met.no/emep/page1/emepmscw_opensource

5.3 Improvements in the EMEP modelling input data

To improve gridded emissions input to the EMEP/MSC-W model, we have first analysed available data sets for ETR, focusing on the chosen pilot region – Murmansk region. The data sets analysed were the set developed by CEIP at the resolution 50x50 km^2 and the set by TNO-INERIS at the resolution 0.1x0.1°. Then, two new national gridded emission data sets, compiled by national experts (SRI Atmosphere) – the one for ETR at the resolution of 50x50 km^2 and the one for Murmansk region at the resolution 0.1x0.1° - were integrated in the CEIP and TNO-INERIS data, respectively. The resulting updated emission inputs were used in the model runs, and the results are compared with calculations using the original emissions.

5.3.1 Analysis of gridded emissions for ETR compiled by CEIP in 50x50 km^2

As highlighted in Chapter 5.1, gridded emission data for ETR, provided by CEIP to MSC-W, show discrepancies with gridded national data developed by national experts in the Russian Federation – both on the level of totals and by grid cells. In this chapter, we present the discrepancies in the emissions of SO_2. The year chosen for the data sets comparison in 2012; however, a year in this case is not crucial for the results since the distribution keys used by CEIP and by national experts for gridding are usually relatively constant from year to year, and thus certain emission discrepancies are recurrent.

Appendix 19 shows subject-specific emissions as estimated by national experts and as summarized from gridded data compiled by CEIP[47]. Subjects with the largest discrepancies are highlighted. In Murmansk region the difference constitutes 180 ktonnes SO_2 (emissions estimated by national experts are higher than the CEIP estimates by a factor of 15) – this is the largest observed difference in ETR. Murmansk region seems therefore to be even more suitable as a pilot region for further work with input data and EMEP/MSC-W model runs.

The difference for the whole ETR constitutes 130 ktonnes (the national totals are higher in the CEIP estimates). This data, however, are not complete since certain estimates (such as emissions from transport) are only available on the ETR level and are not presented by subject. The total SO_2 emissions in 2012, as officially reported to EMEP in 2014, are 1 200 900 tonnes, making the total difference between the emission data sets around 100 ktonnes, or ~8% of the national estimates. At the same time, CEIP emissions have been updated later in 2015, after the comparison was made, so that the total difference at the time of writing is estimated at 320 ktonnes.

[47] CEIP data for 2012 – as available in 2015 (was updated in later submissions)

To look deeper into these differences, the national experts compared emission data sets at the level of grid cells with 50x50 km^2 resolution. This comparison, together with the main recommendations to CEIP regarding possible data corrections, are summarized in Appendix 20. The differences are also illustrated in Figure 36.

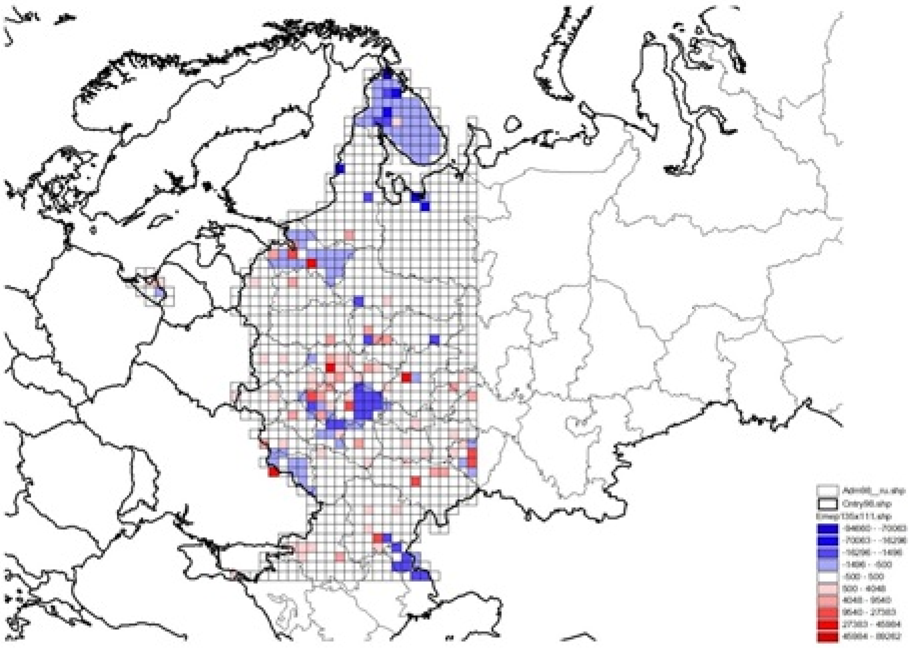

Figure 36. SO_2 emissions in 2012 by EMEP grid cell: differences between CEIP data and national data, tonnes. Blue cells mean that CEIP estimates are lower than national estimates. Red cells mean CEIP estimates are higher than national estimates.

The results of this comparison, beside the quantitative emission differences, indicated that some significant point sources seemed to have incorrect locations in the data sources used by CEIP, which affected distribution keys and the resulting gridded emissions. CEIP uses[48] EDGAR proxy data sets to compile gridded emissions for countries missing national estimates, and there is a risk that some emission point sources might be dislocated in this database. The results of this analysis were discussed with CEIP experts, and it became clear that CEIP continued using EDGAR data, even after the national data was submitted, due to administrative issues regarding submissions of the Russian national experts (national emissions were submitted too late to be included in the CEIP data set). It was preliminarily agreed that in the next compilation run (in 2019), data provided by the national experts for year will be used for the Russian Federation. In fact, the data used by CEIP was partly improved regarding locations of important emission sources within ETR; however, further communication with CEIP is necessary to make the national set of gridded emissions, and the set used by CEIP, more harmonized.

The comparative analysis of the national and CEIP data sets was a useful verification procedure that resulted in improved communication with CEIP and expected replacement of the data set for the Russian Federation used for official EMEP/MSC-W model runs with the set based on the national data (for 2015). The analysis highlights the importance of updates in the CEIP/EMEP data sets based on the in a timely manner provided national information. Further communication on this issue with CEIP and EDGAR database developers might be useful to improve quality of the data used in EDGAR and in the EMEP/MSC-W model runs based on CEIP data.

[48] http://www.ceip.at/new_emep-grid/

5.3.2 Analysis of gridded emissions for ETR compiled by TNO-INERIS at resolution 0.1x0.1°

The gridded emission data set compiled for the entire EMEP grid by TNO-INERIS is not supposed to be used as a proxy for official emission distribution and in general does not show good correlation with the officially reported gridded emissions (either prepared by CEIP or compiled by the national experts). TNO-INERIS emissions are not developed in the framework of and for EMEP, but within other European projects (e.g. CAMS, Eurodelta etc.). At the time of the project initiation (in 2015), it was the best available emission set for Europe at fine resolution since CEIP data at the same resolution became available much later. TNO-INERIS emissions are based as far as possible on the official EMEP national totals, but for gridding different approach/auxiliary information is used. Here, a quick analysis of this data set is included in the data improvement task. Our analysis covers comparisons of emissions from large point sources.

The analysis was conducted as follows. First, all large point sources on ETR, corresponding to SNAP[49]1 level of the EMEP/MSC-W model (heat and electricity production) have been listed and matched to relevant grid cells at the resolution 0.1x0.1°. Emissions from large point sources in 2012 have been compared to emissions in the TNO-INERIS data set, cell by cell. For certain cells, this comparison shows significant differences in emissions – the examples are shown in Table 25. Grid cells specified in Table 25 correspond to the locations of large power plants that within the period between 2009 (TNO-INERIS data set) and 2012 (national data set) were renovated and put into operation on gas instead of coal and peat. As a result, SO_x emissions have substantially decreased – the change is not reflected in the TNO-INERIS data set.

Table 25. Gridded emissions of SO_x from certain large point sources on ETR.

City	Latitude(°)	Longitude(°)	National estimate, 2012, t/year	TNO-INERIS, 2009, t/year
Saint-Petersburg	59.8700	30.2870	2.0	3 515
Ryazan	54.6190	39.7320	0.0	49 670
Ufa	54.7500	55.9700	0.0	25 560

Total emissions from large point sources, corresponding to SNAP1 level of the EMEP/MSC-W model, have also been compared to the TNO-INERIS estimates for ETR. This comparison is presented in Table 26. The largest differences between the two data sets are observed for SO_x – TNO estimates for this pollutant are much higher than the national data. The total difference constitutes 119 tonnes, from which 78 tonnes (66%) origin from the differences shown in Table 26.

Table 26. Emissions from ETR large point sources, tonnes.

Pollutant	National estimates, 2012	TNO-INERIS, 2009
NO_x	175 788	166 185
SO_x	31 669	150 307
$PM_{2.5}$	10 780	5 506
PM_{coarse}[50]	5 390	7 099
CO	16 832	24 955

The comparison of the national emissions from large point sources to the correspondent data in the TNO-INERIS set highlights the importance of the regular submissions of the national data to EMEP,

[49] SNAP = Selected Nomenclature for sources of Air Pollution

[50] PM_{coarse} = particle fraction between $PM_{2.5}$ and PM_{10}

so that all the latest changes in the emission structure and amounts are reflected in the official data summarized by CEIP and further used for official EMEP modelling and in scientific projects.

5.3.3 Updated (national) emission gridded data – methodology and results

National gridded emissions (before 2017 at 50x50 km^2 resolution) are prepared by national experts on a regular basis, for the purposes of official emission reporting. For EMEP modelling, a level of aggregation of gridded emission data is different from what is required for the reporting. If EMEP modelling is supposed to be used to compile SR tables or fluxes, there is also a need for calculation of regional fractions of emissions – shares of area attributable to different regions in a cell when emissions are distributed by EMEP grid cells. In the present study, EMEP/MSC-W model runs are performed with two national emission data sets – ETR at 50x50 km^2 resolution (for 2013, unextended grid[51]) and "updated TNO" at 0.1x0.1° resolution with SRI-prepared data for Murmansk region (for 2012) replacing respective TNO data (for 2009). Considered pollutants are: $PM_{2.5}$, PM_{10}, NO_x, SO_2, NMVOC, and CO. Below, the methodology for emission preparation and gridding is described in brief, and the results of these model runs are presented.

5.3.3.1 Emission gridding – general methodological aspects

Main information sources for compilation of gridded emission data sets for ETR are:

- Estimates provided by Rosstat for emissions on a subject or a city level, by economic sectors;
- Emission data for large point sources – in particular, heat and power plants and large industrial facilities – and their geographical locations;

After emission data for a certain year is collected, it is checked for completeness; in case of data gaps they are filled by using statistics for previous years, expert estimates or other suitable proxies. Then, another check is done to assure that the sums of emissions in cities within each subject do not exceed the total emission estimates for a whole subject. Emission differences are calculated for all subjects and distributed by grid cells relevant for each subject (with respect to its share in the grid cells). Emissions from large point sources are distributed in the grid cells by using the source coordinates. Emissions from a range of sources[52] are not accounted for in national statistics provided by Rosstat – these emissions are estimated for the whole ETR using methodologies specified in the EMEP/EEA Guidebook 2016. They are then evenly distributed by grid cells relevant for each subject.

Russian own official classification of economic sectors according to OKVED[53] differs from the conventional SNAP classification needed for emission gridding for EMEP modelling purposes. For translation of emission aggregation between the formats a special key has been developed by JSC SRI Atmosphere experts.

Since there is no national official methodology to estimate $PM_{2.5}$ and PM_{10} emissions on the level of facilities, these are calculated with the assumption of 40% and 60% of TSP, respectively – except for

[51] Unextended grid = an elder EMEP modelling domain, see Appendix 16

[52] SNAP 2 (non-industrial combustion plants), 7 (road transport), 8 (other mobile sources and machinery), 9 (waste treatment and disposal) and 10 (agriculture)

[53] All-Russian Classifier of Types of Economic Activities

the mobile sources, for which particle emissions (only exhaust emissions, not tyre and break wear) are assumed to consist of the $PM_{2.5}$ fraction by 100%.

5.3.3.2 Compilation of regional fractions – general methodological aspects

Regional fractions needed for certain EMEP modelling tasks (e.g. for compilation of SR tables and fluxes) are not available for all regions and resolutions and often need to be calculated separately. In this study, fractions have been developed for six EMEP regions as specified in Table 27 – they correspond to four whole federal districts and one federal district split into two EMEP regions – Murmansk region and the remaining Northwest federal district.

Table 27. EMEP regions within ETR relevant for the present study.

Region	EMEP identification code
Murmansk region	551
Remaining Northwest FD	708
Central FD	700
Northern Caucasus FD	702
Volga FD	709
South FD	701

The ArcView tool is used to link regions' areas and borders to the EMEP grid cells. The results of these splitting procedures for the considered regions are illustrated in Figure 37.

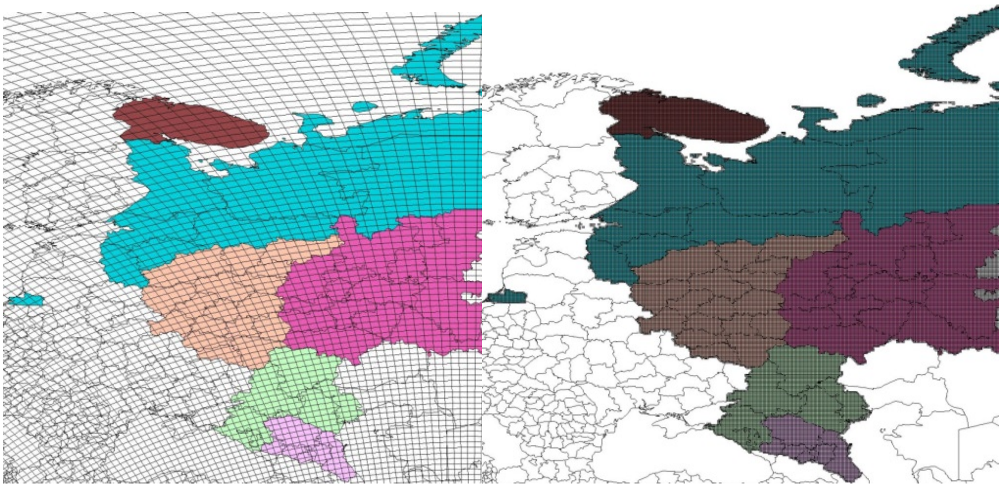

Figure 37. EMEP regions of ETR split by EMEP grid cells at the resolutions 50x50 km² (left) and 0.1x0.1° (right).

To calculate regional fractions, areas of each region in a cell are divided by the total cell area – this is also done in ArcView. The fractions can then be used in further EMEP modelling.

5.3.3.3 European Territory of Russia, 50x50 km² resolution, emissions for 2013

In order to explore potential effects of input data improvements for ETR, EMEP/MSC-W model runs at 50x50 km² resolution have been made with two input data sets: the new national gridded emission data for 2013 (run 2 in Table 24) and the emission data set prepared by CEIP for the same year and available at the EMEP/MSC-W model homepage (run 1 at 50x50 km² resolution in Table 24). The results of modelled ground-level annual concentrations and corresponding emissions of nitrogen oxides and sulphur oxides are displayed in Appendix 21. Significant differences are observed for both pollutants. For certain regions, such as Murmansk region, modelling based on the national emission data results in much higher concentrations – especially regarding sulphur oxides. There are clear indications of large emission point sources assumed in the national emission data set but not accounted for in the data set prepared by CEIP (pointed out in the analysis of CEIP data in Chapter 5.3.1). Differences for NO_x are not as much pronounced – but there are some red spots (indicating higher concentrations) that can be noticed in the upper part of the concentration map based on the national emission data and not present on the map based on the CEIP data. The results presented in Appendix 21 for 50x50 km^2 resolution modelling indicate good spatial correlation between the concentrations and the underlying emissions in both data sets.

5.3.3.4 Murmansk region, 0.1x0.1° resolution, emissions for 2012/2009

Murmansk region is chosen as a pilot region for testing of several important technical and methodological aspects of EMEP modelling in the Russian Federation – in particular, for development of gridded emissions and regional fractions at the resolution 0.1x0.1° and for implementation of national emission data pieces into existing data sets in different formats. Calculation of the regional fractions at the fine resolution is done as described above – the result of the subject split by EMEP grid cells is shown in Figure 38. Emissions are distributed between the grid cells using available data on geographical coordinates of large point sources, national and regional statistics, and the developed regional fractions. Part of the emissions is calculated on the ETR level (see above) – those are evenly distributed between the grid cells with respect to the fractions of the subject in each cell.

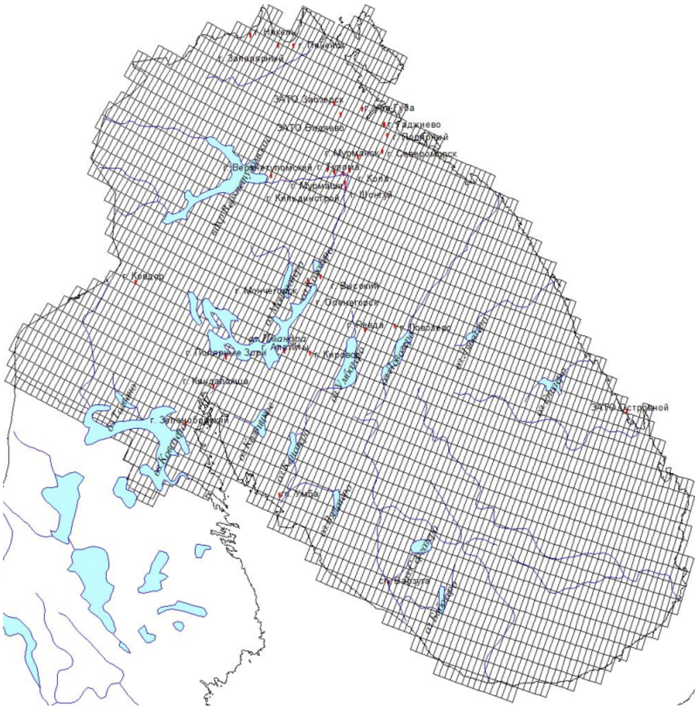

Figure 38. Murmansk region split by EMEP grid cells at 0.1x0.1° resolution.

This new emission data set at the fine resolution, developed for Murmansk region, has been introduced into the existing data set with the same resolution – TNO-INERIS. This combined emission data set is further referred to as “updated TNO”, as opposed to the initial TNO-INERIS data. Although the emission estimates consider different years (national data is compiled for 2012 while TNO-INERIS data use 2009 emissions), it should not significantly affect the results of the model runs that are more dependent on meteorological parameters – and they consider the same year (2013) in both cases.

Two EMEP runs have been made to investigate potential effects of the data improvements at the fine resolution – one with the initial TNO-INERIS data set (run 3 in Table 24) and one with the "updated TNO" data (run 4 at 0.1x0.1° resolution in Table 24). The results for modelled concentrations, concentration differences and corresponding emission differences for NO_x and SO_2 are displayed in Appendix 21. As expected, modelled concentrations are identical on the whole grid except for Murmansk region. For Murmansk region, using the initial TNO-INERIS data set results in generally higher concentrations than in case the "updated TNO" is used as input data. However, there are some visible point sources of emissions in the national data that seem to be missing in the initial TNO-INERIS data. The results presented in Appendix 21 for 0.1x0.1° resolution modelling indicate good spatial correlation between the differences in concentrations and the underlying emissions between the two data sets.

The analysis of the existing emission data sets for ETR points out discrepancies regarding both emission levels and distribution of emissions by grid cells – partly due to incorrect point source locations implied in certain data sets and changes in emissions not accounted in the outdated emission data sets. Such discrepancies are identified within the whole ETR during comparison of the national emission data to the CEIP data set used for EMEP modelling by MSC-W (the results of this modelling are also used for dispersion simulation in the GAINS model). Based on this analysis, the recommendations for data corrections have been formulated and communicated to CEIP. CEIP will probably use the national set of gridded emissions in the next reporting period(s). As CEIP emission data at the fine resolution were not available at the time this analysis was performed, they were thus not considered – although there is certainly a need for similar data sets comparisons for 0.1x0.1° resolution. Such comparison would be especially valuable for Murmansk region, for which a national emission data set at the fine resolution has within this project been compiled and used for EMEP modelling.

Using input data with better resolution is aimed at increasing accuracy of modelling results and thus improving their quality. The following chapters are focused on the effect of fine resolution on the model performance in general and on source-receptor relations.

5.4 Fine resolution's effects on EMEP/MSC-W model general performance: summary for Europe

Working with high resolution in the EMEP/MSC-W model is relatively new and available input emission data sets are not plentiful. In this study, we have summarized the effects of fine resolution (horizontal and vertical) on the EMEP/MSC-W model performance by using the emission data sets available for Europe.

5.4.1 Effect of grid horizontal resolution on the model performance

A series of calculations has been performed for the meteorological conditions of 2014 with EMEP/MSC-W model at two resolutions – 50x50 km^2 and 0.1x0.1°. For the 0.1x0.1° run, the emission data set for 2014 prepared by EMEP/CEIP (as of October 2016) was used. These emissions were based on official country sectoral submission to EMEP and were considered a preliminary data set before countries started reporting at 0.1x0.1° in 2017. An additional model run at 0.1x0.1° was performed for which officially submitted to EMEP country/sector totals for 2014 were gridded according to TNO's 0.125x0.0675° distribution. The main emission data sets used in this analysis are as follows:

1. EMEP 50x50 km^2, as prepared by CEIP;
2. Preliminary 0.1x0.1°, as prepared by CEIP;
3. 0.1x0.1°, as officially submitted to EMEP and gridded according to TNO.

The modelling results were evaluated using EMEP regional background monitoring data[54] and background/rural and urban/suburban observational data from European Environment Agency's Air Quality e-Reporting data base (in the scientific community often referred to as 'AirBase')[55]. The results are illustrated by figures in Appendix 22.

5.4.1.1 Regional background (EMEP observations)

Comparison with EMEP observations (Table 28) does not show a single clear pattern of model performance change, rather the verification statistics in Table 28 are quite variable. There is a general tendency for somewhat lower values of regional concentration and deposition levels from the 0.1x0.1° (CEIP emissions) run. This results in slight increases of negative and decreases of positive biases. The spatial correlations of the model results with observations are in general slightly lower for 0.1x0.1° run, with the exception of mean ozone, PM_{10}, $PM_{2.5}$ and SO_x wet deposition (somewhat lower correlation for wet deposition of NO_x and NH_y is partly due to the effect of lower correlation of input precipitation, which appears compensated for in SO_x results).

Table 28. Comparison statistics for EMEP/MSC-W model vs. EMEP observations.

Parameter	50x50 km^2		0.1x0.1° (CEIP)	
	Bias. %	Correlation	Bias. %	Correlation
SO_2	0	0.64	-4	0.57
NO_2	-16	0.84	-23	0.78
O_3 mean	9	0.69	11	0.69
O_3 max	0	0.73	2	0.69
$PM_{2.5}$	-13	0.77	-16	0.78
PM_{10}	-24	0.74	-24	0.81
SO_x wet deposition	-16	0.60	-19	0.64
NO_x wet deposition	2	0.72	1	0.70
NH_y wet deposition	14	0.80	12	0.75
Precipitation	2	0.86	-3	0.51

5.4.1.2 Regional/rural (AirBase)

From the AirBase database, measurement data of the pollutants related to adverse health effects, namely PM_{10}, $PM_{2.5}$, NO_2 and SO_2, are available. Compared against AirBase regional and rural NO_2, $PM_{2.5}$ and PM_{10}, the calculations on 0.1x0.1° with CEIP emissions give slightly (by a few per cents) larger underestimation, whereas the spatial correlation does not change significantly (Table 29).

For SO_2, 0.1x0.1° (CEIP) run provides a considerably smaller underestimation, but worse correlation, which is due to several sites with large overestimations (see Figures 1a and 5a in Appendix 22). As we consider CEIP 0.1x0.1°emissions provisional and still uncertain, we have compared the results with the run using EMEP/TNO emissions (Table 29, last columns). This run still gives a negative (but

[54] ebas.nilu.no

[55] www.eea.europa.eu/data-and-maps/data/aqereporting-8

better than 50x50 km^2 run) bias, while the correlation is considerably improved for SO_2. It can be noted that the agreement between the model and AirBase observations is worse compared to that with EMEP data. Partly this is because not only regional background sites are included in the AirBase data set, and the measurements at rural sites may be affected by local emissions. Then, much more sites with data are present in AirBase in the areas where the model tends to underestimate observed SO_2 (in Spain, South-Eastern Europe, etc.). This over-representation causes a larger negative mean bias, and in combination with positive biases in Central and Northern Europe results in a poor spatial correlation.

Table 29. Comparison statistics for EMEP/MSC-W model vs. AirBase regional/rural observations.

Pollutant	50x50 km^2		0.1x0.1° (CEIP)		0.1x0.1° (EMEP/TNO)	
	Bias. %	Correlation	Bias. %	Correlation	Bias. %	Correlation
SO_2	-51	0.47	-30	0.36	-47	0.50
NO_2	-31	0.70	-38	0.71	-36	0.76
$PM_{2.5}$	-21	0.66	-24	0.66	-22	0.70
PM_{10}	-32	0.47	-34	0.46	-32	0.52

For NO_2 the results are only slightly different, with some correlation improvement in the both 0.1x0.1° runs. Slightly larger underestimation at the fine resolution runs at regional/rural sites is probably because a larger portion of emissions is allocated to urban areas (Figures 2a and 5b in Appendix 22).

In addition, small differences between 50x50 km^2 and 0.1x0.1° with CEIP emissions are found for $PM_{2.5}$ and PM_{10}, whereas 0.1x0.1° with EMEP/TNO emissions produces somewhat better correlation (Figures 3a, 3b, 5c, 5d in Appendix 22).

5.4.1.3 Suburban/urban (AirBase)

Greater effects on model results from using the finer scale are expected in the areas of large emission sources and primary pollution gradients associated with among others traffic, domestic heating and industry in urban/suburban areas. Of course, here the accuracy of model calculations would even more rely on the correctness of emission data, both in terms of emission amounts and spatial distribution.

Differently from NO_2 and PM, most of the SO_2 emissions originate from large power plants located typically beyond urban areas, so an accurate gridding of the large point sources are crucial for model calculations, and the importance of this increases for finer grid calculations. Similar to regional/rural sites, 0.1x0.1° runs provide smaller underestimations and worse correlations for SO_2 (Table 30, Figures 1b and 6a in Appendix 22). This indicates considerable uncertainties in the current SO_2 emission data.

Table 30. Comparison statistics for EMEP/MSC-W model vs. AirBase suburban/urban observations.

Pollutant	50x50 km^2		0.1x0.1° (CEIP)		0.1x0.1° (EMEP/TNO)	
	Bias. %	Correlation	Bias. %	Correlation	Bias. %	Correlation
SO_2	-64	0.20	-40	0.08	-48	0.14
NO_2	-64	0.54	-43	0.61	-50	0.67
$PM_{2.5}$	-37	0.47	-35	0.43	-34	0.51
PM_{10}	-49	0.27	-49	0.24	-47	0.35

For NO_2 (Table 30, Figures 2b and 6b in Appendix 22), model negative bias (-64.2% for the standard run) is reduced in 0.1x0.1° runs to -43% (CEIP emissions) and -50% (EMEP/TNO emission), and the spatial correlation is improved from 0.54 to 0.61 and 0.67, respectively. The model is found to especially underestimate lower NO_2 concentrations. The least underestimation with CEIP emission is partly due to the model overestimation at some sites with high NO_2 levels. This overshooting is not seen in the run with EMEP/TNO emissions, which gives slightly large bias, but the highest spatial correlation.

For $PM_{2.5}$ (Table 30, Figures 4b and 6c in Appendix 22), the effect of resolution is not very large. The underestimation by -37% 50x50 km² run gets only 2-3% smaller for 0.1x0.1° runs. The best performance is obtained when using EMEP/TNO emissions (-34% bias and 0.51 spatial correlation).

Also, for PM_{10} (Table 30, Figures 3b and 6d in Appendix 22), we see only a moderate effect of resolution, with 1-2% improvement of negative bias in the 0.1x0.1° runs. As for $PM_{2.5}$, the run with EMEP/TNO emissions gives the best correspondence with the observations (-47 % bias and 0.35 spatial correlation).

5.4.2 Effect of grid vertical resolution on the model performance

Further model development towards using finer resolution involves improvement of vertical resolution as well, in particularly reducing the thickness of the lowest layer. The operational model uses 92 m thick lowest layer, whereas tests were performed with 50 m thick layer, as presented in EMEP Status Report 1/2014. Table 31 compares verification statistics from four model runs, where the horizontal resolution was reduced from 56x56 km to 0.1x0.1°, applying in each of the runs the thickness of lowest layer of 92 and 50 m.

Table 31. Model verification statistics for 2009 with AirBase data. Here: h56 and h01 – horizontal resolution of 56x56 km and 0.1x0.1°; v92 and v50 – 92 and 50 m thick lowest layer. Source – EMEP Status Report 1/2014.

Runs	Bias. %	R spatial	RMSE	Bias. %	R spatial	RMSE
	PM10 regional			PM10 sub-urban/urban		
h56_v92	-27	0.56	8.92	-42	0.46	15.5
h56_v50	-21	0.58	8.27	-38	0.49	14.5
h01_v92	-29	0.60	8.93	-41	0.49	15.0
h01_v50	-24	0.61	8.26	-36	0.50	14.3
	PM2.5 regional			PM2.5 sub-urban/urban		
h56_v92	-18	0.68	5.95	-36	0.57	9.23
h56_v50	-10	0.70	5.58	-29	0.59	8.45
h01_v92	-21	0.75	5.59	-34	0.63	8.69
h01_v50	-13	0.76	5.08	-26	0.64	7.84

Here again, the effect of using finer resolutions on calculated concentrations is more pronounced at suburban/urban sites compared to regional/rural. Decreasing the thickness of the lowest layer appears to be the main factor for reducing model biases and Root Mean Square Error (RMSE) for PM_{10} and $PM_{2.5}$. Increasing horizontal and vertical resolution also leads to improving the spatial correlation, especially for $PM_{2.5}$.

Finally, this investigation of grid resolution effects on model calculations has shown that the results are quite sensitive to emission vertical distribution assumed in the runs and thus stress the need for accurate information about emission vertical profiles.

5.5 Verification of EMEP modelling results for ETR with available observation data

When basing the design of environmental policies on numerical model computations, the confidence in the accuracy of model results is essential. Therefore, before discussing the results of source-receptor simulations of air pollution from Murmansk region, we present here the evaluation of model performance against observations in the Russian Federation. Rather limited observational data is available from a few EMEP measurement sites in Russia for the year 2013, which are shown in Figure 39. In total, there were four EMEP sites performing measurements: Janiskoski (RU0001) in north-west of Murmansk subject, Pinega (RU0013) in the north, and Lesnoy (RU0018) and Danki (RU0020) in the centre of ETR. All the four sites measured concentrations of sulphate (SO_4^{2-}) in precipitation, whereas only Lesnoy and Danki also measured SO_2 and SO_4^{2-} concentrations in the air. No observations of oxidized and reduced nitrogen were available, and neither particulate matter was measured. In addition, the EMEP site Pallas/Matorova (FI0036) in the north of Finland has been included in the evaluation, as it is expected to be exposed to transboundary pollution from the Russian Federation, and especially from sources in Murmansk region.

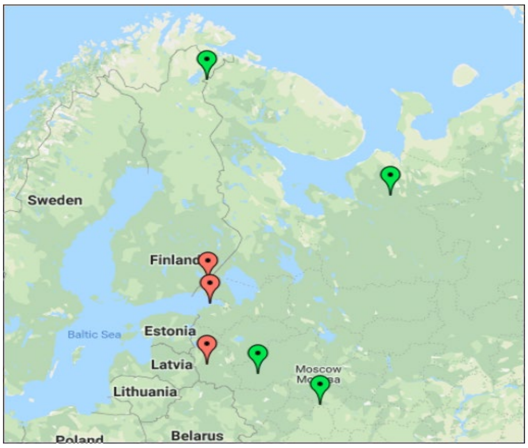

Figure 39. Observation stations in ETR; green – active EMEP observation sites; red – closed sites.

Figures in Appendix 23 show the time series of observed and modelled daily concentrations, comparing the evaluation of the following model results:

1. From Run 1 in Table 24: computed at 50x50 km² using EMEP-CEIP emissions (EMEP Status Report 1/2015);
2. From Run 2 in Table 24: computed at 50x50 km² using SRI emissions for ETR and EMEP-CEIP emissions elsewhere (if exists).
3. From Run 4 in Table 24: computed at 0.1x0.1° using SRI emissions for Murmansk region and TNO-INERIS emissions elsewhere ("updated TNO");

Thus, we can investigate the effect on model results due to using the emission inventory for the Russian Federation prepared by national experts (SRI Atmosphere) compared to official EMEP emissions at 50x50 km² (comparison 1-2, and see Figure 21.2 in Appendix 21 for emission differences); and also a combined effect due to the finer grid resolution of 0.1x0.1° and updated emissions for Murmansk region (comparison 2-3, see Figure 21.3 in Appendix 21 for emission differences). It should be noted that the comparison between 1 and 2 is not totally consistent since

SRI Atmosphere emissions for the Russian Federation do not covered the whole area as EMEP emissions in run 1, but only ETR. That means that under the conditions of easterly transport, in comparison 1-2 the modelled pollution levels at the considered measurement sites can be expected to be lower than observations, in particularly for secondary, long-transported, pollutants. Therefore, we only look at Janiskoski and Pinega sites, less affected by this, for all three runs.

For **Janiskoski,** the correspondence between the modelled and observed sulphate wet deposition in the runs with SRI Atmosphere emissions, both at 50x50 km^2 (run 2) and 0.1x0.1° (run 4) is somewhat better compared to the EMEP operational run with CEIP emissions (run 1). In particular, the bias considerably improves; and somewhat better correlation is seen for run 2. The correspondent improvements are also found for Pinega, but less pronounced as it's far away both from the major ETR sources and from Murmansk region sources.

At FI0036 (**Matorova**), air concentrations of SO_2 and SO_4^{2-} were measured in 2013. Here as well, the model results from runs 2 and 4 (both resolutions, with emissions produced by SRI Atmosphere) are in a better agreement with observations than the EMEP operational run with CEIP emissions in terms of bias and correlation. The improvement is larger for the primary pollutant SO_2, which emissions were improved by the national experts, than for the secondary pollutant SO_4^{2-}.

5.6 Effects of the fine resolution on trans-boundary effects

In order to understand where the emission reduction measures should be taken, policy-makers need to know relative inputs to air pollution in a certain region from sources outside this region. Such relationships are illustrated by source-receptor tables calculated with the EMEP/MSC-W model. As mentioned above, SR tables are also adopted in the GAINS model to simulate pollution dispersion in a quick way. Within this study, we made use of the results of earlier studies to analyse the effect of fine grid resolution on SR relationships for European countries. However, one of the main efforts within the project was calculations of transboundary fluxes from Murmansk region, performed at 0.1x0.1° (i.e. SR tables for Murmansk region as the source and other countries/ districts being receptors).

5.6.1 Effects of resolution on source-receptor tables – summary of modelling results for Europe

Several studies of the effect of using fine grid resolution on EMEP/MSC-W model calculated source-receptor relationships have been performed in the latest years.

The first, rather limited, such study was published in EMEP Status Report 1/2009. In that study, SR calculations were made on 25x25 km^2 grid for three countries only (as such calculations are very CPU[56] demanding). The UK, the Netherlands and Germany were chosen for that test because of their different locations in Europe causing different specifics in SR relationships (with domestic emissions contributions dominating in the UK and the transboundary pollution contributing greatly in the

[56] CPU time = the amount of time for which a central processing unit (CPU) was used for processing instructions of a computer program or operating system

Netherlands, while Germany is an important emitter and receiver). Only SO_x wet deposition and primary PM were considered. The study separated the effects of fine resolution meteorology (i.e. run grid), while keeping the same emissions, and the effects of finer emission data. Both tests were compared to EMEP operational calculations on 50x50 km^2.

Running the model on 25x25 km^2 grid with unchanged (50x50 km^2) emissions appeared to have negligible effects on pollution export calculation (near zero changes for SO_x wet deposition, and within 5% for PM). The comparison of the test with 25x25 km^2 emissions with operational 50x50 km^2 run was not completely consistent, as TNO emissions with spatial distribution different from EMEP were used in that test. Still, the results showed that the emission effects are rather small for Germany and the Netherlands. For the UK it was found that its export to Germany and the indigenous contribution increased by at least 25%.

All in all, that preliminary analysis of the scale effect on SR tables concluded that increasing the grid resolution from 50 to 25 m only had a minor impact on the results, at least for the largest contributions from the three considered countries. However, it was anticipated that the effects could be larger for components characterized with chemical non-linearities (ozone, NO_x, secondary PM).

The second scale dependency analysis was performed within the EMEP Eurodelta project in 2013. The EMEP/MSC-W model was run with 56 and 14 km resolution, using consistent emissions. The pollutants of interest were elemental carbon from primary PM, SO_2. SO_4.

It was a priori anticipated that the domestic contribution should grow, while the impact of transboundary contribution decreases due to less artificial dilution at finer scales. Also, larger effects were expected for smaller countries (as they have relatively more emissions in border cells, which are more efficiently diluted at coarser scales).

However, the results did not appear to be conclusive and only supported the anticipations for some of the countries, as seen from the ratios of SR tables calculated at 14 km and at 56 km runs, plotted for PM_{10} and SO_2 (Figure 40). The increase of domestic contribution would have manifested in all diagonal values in excess of 1.0 that we cannot see in Figure 40. Neither can we clearly see the larger effect expected for smaller countries.

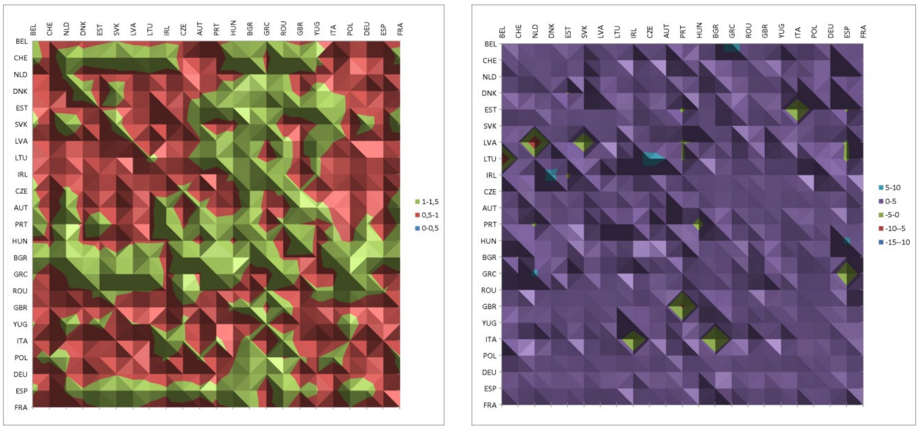

Figure 40. Ratios of concentration from run on 14x14 km to run on 56x56 km grid. Left – PM_{10}, right – SO_2.

5.6.2 Recent studies into the effect of model resolution on source-receptor calculations

In 2017, the new EMEP grid with 0.1x0.1° resolution became official, i.e. from 2017 the member countries are obliged to report their emissions at the resolution of 0.1x0.1°. In 2017, EMEP/MSC-W model performed status calculations on the new grid (EMEP Status Report 1/2017) for the first time. The evaluation with observations indicated for most of the reporting countries a fairly good quality of the new emission data. For 2018 reporting (EMEP Status Report 1/2018), SR calculations have for the first time been made at a resolution finer than 50x50 km^2. As SR calculations at 0.1x0.1° would have been extremely CPU expensive, a series of test runs have been made to study the effect of different resolutions with the aim of optimising the compilation of SR tables. For the purpose of this test, SR calculations were performed at the resolutions of 0.1x0.1°, 0.3x0.2°, and 0.4x0.3° (longitude-latitude) for five selected source-countries, namely Bulgaria, Italy, the Netherlands, Norway, and Poland. The detailed results of the study can be found in Chapter 5 of the EMEP Status Report 1/2018, whereas here we summarise the main conclusions.

SR calculations were analysed for depositions of oxidised sulphur, oxidised and reduced nitrogen, for PM_{10} and $PM_{2.5}$, and maxO_3. As to the indigenous contributions (country-to-itself), the effect of using the different resolution was well within 10%, the largest effects being found for ozone and PM (due to considerable chemical non-linearity).

However, somewhat larger effects of different resolutions on the transboundary transport from the source-countries was found, and especially so for PM. In particular, the relative PM pollution in Switzerland caused by Italian sources differs by 30% calculated at different resolutions. This is probably due to the effect of resolution on the transboundary transport across the Alps (clearly, the complex topography is better resolved on 0.1x0.1° grid compared to the coarser ones). Still, the absolute value of Italy-to-Switzerland pollution is rather small compared to the other countries.

Based on the test results, SR calculations for the year 2016 (reported in 2018) have been performed on 0.3x0.2° grid. Note that also the description of countries' borders differs at different resolutions, which effect SR tables, but those effects were also limited (as discussed in the EMEP Status Report 1/2018). Besides, the accuracy of countries' border description should be better at the finer resolutions.

5.6.3 Fine resolution and source-receptor relationships: case analysis of transboundary pollution from Murmansk region

As discussed above, the earlier studies showed relatively moderate and somewhat irregular effects of the modelling grid resolution on SR results. In the framework of this project, we have made a new endeavor to investigate this, focusing on Murmansk region, for which the first emission inventory on 0.1x0.1° was constructed by SRI Atmosphere experts (therefore it is referred to as a "pilot region"). To explore potential effects of the fine grid resolution on SR relations for the pilot region (Murmansk), SR calculations with the EMEP model have been performed by MET Norway for 2013 at the resolution of 50x50 km^2 on polar-stereographic grid (PS50 runs) and 0.1x0.1° (EMEP01 runs). The same emission data, namely TNO-INERIS-SRI at the 0.1x0.1° grid (as in Run 4 in Table 24), were used in both of the runs, so that the only difference between them is the grid resolution.

The SR calculations have been performed according to the operational EMEP routine. In addition to the run with all emissions included (Base run), a series of model runs were made with individual reduction by 15% of SO_x, NO_x, NH_3, NMVOC and PM emissions from Murmansk region. Then, pollution from Murmansk to each of the receptor-regions has been calculated as the difference between the Base run and the runs with reduced emissions.

The transboundary transport of the pollution from Murmansk region to all EMEP countries has been calculated (Appendix 24), and pollution to the major region-receptors have been analysed in more detail, including all federal districts within ETR as well as closely located Nordic countries – Finland, Sweden and Norway.

5.6.3.1 NO_x, SO_x and NH_y – concentrations and deposition

Figures in Appendix 25 summarize calculations of transboundary fluxes from emissions originating in Murmansk region, based on the model runs performed at the two different resolutions. The graphs illustrate the faith of emissions originating in Murmansk region – percentages indicate where these emissions are in the end deposited. Note that each of the diagrams in Appendix 25 shows the six major region/country-receivers for the given deposition obtained in a specific run. That means that the diagrams for the same pollutant, calculated at the two different resolutions, do not necessarily include the same receivers.

The presented percentages are different for the two analysed resolutions – the difference is especially pronounced for deposition of oxidised sulphur (SO_x). ~5% of the total emitted SO_x are estimated to be deposited in either Murmansk region itself (0.1x0.1° resolution) or in Norway (50x50 km^2 resolution). This is because one of the large point sources (Kola Mining & Metallurgical Company) is located very close to the border. At the 50x50 km^2 resolution, both this source and a part of Norway are located in the same cell. Mathematics implied in the model methodology results in an instant smearing of a considered effect within a cell so that only regional fractions affect the shares of deposition in Norway and in Murmansk region itself. At the fine resolution, however, the cell with this point source does not cover the Norwegian territory; several cells are located between the source and the border with Norway. This means that model mathematics does not have the same strong effect on the resulting SO_x deposition – in this case, estimated shares of deposition are mostly determined by relevant meteorological parameters. Thus, modelling at the fine resolution seems to result in more correct estimates of transboundary fluxes, which may be especially important in cases if large point sources are located close to interregional borders.

Spatial distribution of the oxidized sulphur deposition at different grid resolutions is further illustrated in Appendix 26. The maps compare annual mean fields of SO_2 and SO_4^{2-} concentrations and SO_X deposition. Clearly, the results at 0.1x0.1° resolution provide finer details for pollutant distributions and with more pronounced hot-spots compared to the fields from 50x50 km^2 simulations.

Oxidized nitrogen deposition does not change significantly at high resolution – shares of the Murmansk itself, the remaining Northwestern FD, and Finland increase by about 1% while the share of “other” recipients decreases. Unlike SO_x, a large part of which comes from large point sources, NO_x emissions originate mostly from road and non-road traffic, which is spread more evenly on the map. This is probably why a change in the spatial resolution does not seem to have much effect on the resulting deposition shares.

Most part of the reduced nitrogen (ammonia) emissions in the Russian Federation originates from the agricultural sector. Higher resolution results in an increased share of the ammonia deposited in

Murmansk region itself (from 61% to 63%) while the shares deposited in the remaining Northwestern FD and Norway decrease. Dispersion of nitrogen-based substances is a complex issue, and the reasons for differences in the deposition pattern need further investigation.

5.6.3.2 PM_{10} and $PM_{2.5}$ pollution from Murmansk region

Figure 41 shows the maps of annual mean PM_{10} and $PM_{2.5}$ concentrations due to 15% of all emissions from Murmansk region calculated with the EMEP model on 0.1x0.1° and 50x50 km² grids. The PM concentration fields calculated at the coarse and fine resolutions show similar general pattern, but the maps on 0.1x0.1° provide much finer details in PM spatial distribution. Remarkably, the calculations performed on the 0.1x0.1° grid allow resolving PM hotspots associated with large point sources' emissions, with PM_{10} and $PM_{2.5}$ annual levels exceeding 4 and 3 µg/m³, respectively. Compared to those, the PM fields on 50x50 km² appear much smoother, with maximum PM concentrations below 0.5 µg/m³. This should be due to a more detailed distribution of emissions facilitated by using the higher resolution grid, in particular emissions from large point sources and emissions along the border of the Murmansk subject (e.g. Kola Mining & Metallurgical Company). For those sources, the emissions are typically larger in correspondent 0.1x0.1° grid cells, whereas they get smeared out at 50x50 km².

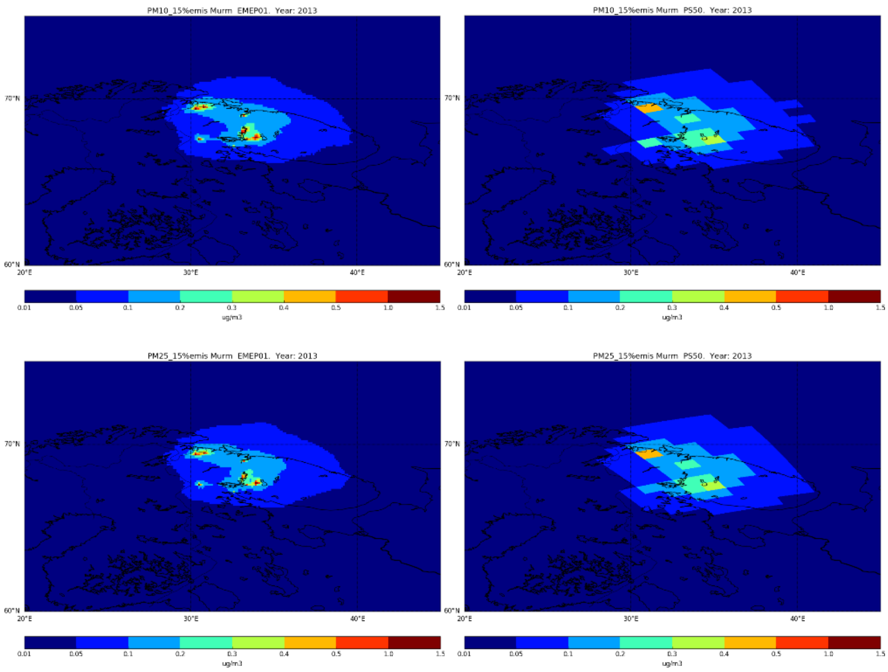

Figure 41. Annual mean in 2013 concentrations of PM_{10} and $PM_{2.5}$ due to 15% of all emissions from Murmansk region, calculated on 0.1x0.1° (left) and 50x50 km² (right) grid.

It should also be noted that due to larger grid size in the latter case, the medium-level PM concentrations (0.1-0.3 µg/m³) are smeared over larger areas compared to the 0.1x0.1° fields which show rather steep PM gradients. This should be kept in mind when looking at the indigenous PM pollution in Murmansk region discussed below.

Table 32 summarizes the calculation results for annual mean PM_{10} and $PM_{2.5}$ concentrations (ng/m³) due to 15% emissions in Murmansk subject in the studied receptor-regions. Those can also be described as the reductions in PM_{10} and $PM_{2.5}$ concentration levels which would result from 15% reductions of all emissions from Murmansk region. The calculation results for both resolutions agree that the largest receptor of PM_{10} and $PM_{2.5}$ is by far Murmansk region itself, followed by Finland, the remaining Northwestern FD, Norway, Sweden, etc.

Table 32. PM concentrations (ng/m³) in the studied receptor-regions due to 15% of emissions in Murmansk region.

Region	PM_{10}		$PM_{2.5}$	
	PS50	EMEP01	PS50	EMEP01
Murmansk region	110.8	99.7	103.2	92.4
Remaining Northwest FD	12.2	11.6	11.9	11.3
Central FD	3.5	3.5	3.4	3.4
Volga FD	2.7	2.5	2.6	2.4
South FD	0.9	0.8	0.8	0.7
Northern Caucasus	037	0.28	0.35	0.28
Rest of ETR	10.7	9.2	9.7	8.8
Norway	9.2	6.7	8.9	6.5
Sweden	6.2	5.5	6.1	5.4
Finland	19.9	17.3	19.4	16.8

Unlike the deposition of nitrogen and sulphur, the calculations on the higher resolution grid (EMEP01) give consistently lower PM_{10} and $PM_{2.5}$ due to Murmansk region in the district itself and in the major receptors compared to the coarse resolution run (PS50). This is consistent with and can partly be explained by larger depositions of inorganic species within the region (seen from the deposition results in the previous section). On the other hand, in more distant countries (e.g. Poland, Denmark, Germany, Czech Republic, etc.), this indicates that PM, which has a longer lifetime, are transported to larger distances on the 0.1x0.1° grid. PM is a very complex pollutant, consisting of different inorganic and organic particles originating (or formed from gaseous precursors) from a variety of anthropogenic and natural sources, both within Murmansk region and in the surrounding countries. Therefore, it is difficult to give an accurate explanation to this somewhat longer PM transport on the 0.1x0.1° grid without a very scrupulous investigation, which is beyond the scope of this project. Anyway, the latter differences between the two resolutions are rather small and could well be due to the differences in the transport and removal processes as described at the coarse and fine scales.

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During the working period of 2015 – 2018, the modelling team of the project has jointly been testing new flexibility features of the EMEP/MSC-W model and their possible applications to Russian territories. A series of model runs has been performed to analyse the effects of different grid resolutions (polar-stereographic on 50x50 km² and latitude-longitude on 0.1x0.1°) and emission input (EMEP official and TNO-INERIS vs. the correspondent data sets where the emissions from the Russian Federation were substituted by national expert estimates).

While EMEP operational model simulations consider the entire Russian Federation as one SR region, the main focus of this project has been on “transboundary” pollution between the federal districts. Thus, following the “exploring the new regionalization” approach of the project, ETR was split into six regions. For the model simulations on 50x50 km², new emissions for all the six federal districts were prepared by the experts from SRI Atmosphere, while for the 0.1x0.1° grid, only emissions for the pilot region - Murmansk – were available.

The results from the model runs have then been used to evaluate the model performance at different grids and with different emission inputs and, as far as possible, to investigate the effects on the model results from the improvements in emission data and resolution. The main outcomes of this work are visualised and summarized in a form of maps, graphs and tables. However, one of the main results of the project is the new experience, improved technical skills, strengthened methodological basis and a widened contact network, also achieved by the experts performing operational work within the project.

To improve emission inputs into the model, the expert team both analysed the existing data sets for ETR and compiled new data sets – at the coarse resolution for the whole ETR and at the fine resolution for Murmansk region. The analysis of the data sets developed by TNO-INERIS (0.1x0.1°, 2009) and CEIP (50x50 km^2, 2013) revealed significant discrepancies from the national data regarding total emissions and spatial distribution of emissions within ETR. In particular, some large point source locations assumed in the CEIP data set seem to be different in the national data, and the reasons for that probably lie in the EDGAR database currently used by CEIP for emission gridding. As proper source location is important for modelling, the results of this comparison analysis have been communicated to CEIP, and it was clarified that submitted national data could not be used at the time it was submitted – but in the next emission gridding run(s), data provided by the Russian experts probably can be used. For improvements in the emission data quality, it is important to regularly conduct such verification procedures and to identify and analyse discrepancies between different emission data sets. For example, a further comparison of the available national data and CEIP data at 0.1x0.1° resolution (not conducted within the project frame since CEIP data at fine resolution became available only in 2017) would be very useful.

Comparison of model results with rather limited available observations in Russia and the north of Scandinavia (Finland) shows a certain improvement in modelled sulphur air concentrations and wet deposition at the finer (0.1x0.1°) resolution compared to 50x50 km^2. Moreover, using the by SRI Atmosphere improved national emission data set for Murmansk region contributed to further improvement of the agreement between model calculations and observations at the sites affected by the Murmansk region emissions (Janiskoski and Matorova).

As summarized in the report, the earlier attempts to investigate the effects of the fine resolution on transboundary effects in Europe were little conclusive. Recently, a new test was carried out (EMEP Status Report 1/2018), analysing SR calculations at 0.1x0.1°, 0.3x0.2°, and 0.4x0.3° for five source-countries. The main findings were that the effect of using the different resolutions was well within 10% for the indigenous contributions (country-to-itself), the largest effects being found for ozone and PM. However, somewhat larger effects of different resolutions on the transboundary transport from the source-countries was found, and especially so for PM (the largest difference of 30% was for the relative PM pollution in Switzerland coursed by Italian sources).

The analysis of SR fluxes from emissions in the pilot region – Murmansk – shows that the choice of resolution might affect results regarding SO_x deposition – at least in case some large point sources are located close to borders with neighbouring regions (as it is in Murmansk region). NO_x and NH_3 emissions are less dependent on location of point sources (e.g. power plants) and are more evenly spatially distributed since a large part of them originates from transport and agriculture, respectively. The effects of resolution of their deposition are thus much less pronounced, although some differences are noticed.

As far as PM_{10} and $PM_{2.5}$ concentrations are concerned, the model simulations on 0.1x0.1° grid give consistently lower PM pollution due to Murmansk in the region itself and in its main receptors compared to the run on 50x50 km^2 grid. One possible reason to that could be more efficient depositions of inorganic species within the region. At the same time in more distant countries, PM pollution from Murmansk region seems to slightly increase. We suggest this can be attributed to a longer lifetime of PM calculated on 0.1x0.1° grid, so that the pollutants can be transported over larger distances. Due to a complex nature of particulate matter and a large variety of its sources and processes involved in its formation and atmospheric transport, finding good explanations to that would require an in-depth investigation, which is beyond the scope of this project.

EMEP modelling is not new for experts in the Russian Federation, but as the model is constantly developing and getting new features, regular EMEP training seminars are of great use for national experts. Before the operational work within this project started, Russian experts attended one of such seminars organized by MET Norway to update the technical and methodological skills, to learn about the recent changes and new features, and to further develop the contact network. After the training seminar, an updated model version was successfully installed and tested at SRI Atmosphere, with necessary methodological and technical support from MET Norway.

The operational project work has further sharpened Russian experts' skills in the analysis and preparation of the modelling input data, especially gridded emissions and regional fractions – these steps often include familiarization with new tools as well as development of own new tools. During the project, some suggestions for further improvements of these procedures have been made. Currently, the Russian Federation does not have enough technical capacity and resources to compile and submit gridded emissions at the resolution 0.1x0.1° for the whole ETR. However, technical issues and methodology regarding emission gridding and production of regional fractions for the Russian Federation have now been extensively tested at the resolution 0.1x0.1°, which would enable smoother transition to official reporting of gridded emissions at fine resolution when considered relevant.

Preparation of the input data, modelling runs and analysis of SR relations at the resolution 0.1x0.1° are not only of importance for EMEP/MSC-W model experts in Russia. From the MSC-W/MET Norway perspective, these tasks were valuable for fine-tuning of modelling techniques used in preparation to the period of the official EMEP reporting at the fine resolution (started 2017), which requires model down-scaling from 50x50 km^2 to 0.1x0.1° resolution.

Murmansk region has been extensively studied and used for modelling within the project. Even earlier, this region was of interest for the experts in Russia – in particular, Åström et al. 2013 presents emission fluxes calculated at the coarse resolution for Murmansk region and the surrounding regions. These fluxes were later updated by request of the local oblast authorities to be used in their policy work. This example indicates high potential for extension of the technical and methodological skills improved and developed within the project, to a broader number of Russian regions, and for developing cooperation with policy-makers on the level of administrative subjects and federal districts. The experts' level of mastering EMEP procedures and methods will increase the credibility of modelling results and enhance further operational work with the EMEP/MSC-W model on all possible levels.

Conclusions

The **overall focus** of the project was on exploring the advantages of GAINS and EMEP modelling on the level of regions. Existing significant variations between the regions regarding their economic structure, emissions, population and even data availability should be taken into consideration both in EMEP and GAINS Russia, which since 2012 operates with regions reflecting the current administrative division of the Russian Federation. Considering the regions separately, compared to on the aggregated level of ETR or the entire country, enables more accurate and less uncertain integrated analysis and more precise spatial allocation of abatement measures and costs resulting from scenario analysis.

GAINS modelling

The first step in the GAINS modelling is collecting necessary **input data** and processing the data into the needed format, determined by the model structure. A complete and consistent set of input data is a prerequisite for obtaining reliable modelling results. In this project, input data sets have been developed for all regions and all sectors in the model – for the base year 2010 and future years 2020 and 2030. The input data for 2010 are based on available region-specific national statistics, data provided by national experts and the numbers available in the recent study by Huang et al. 2015, where the level of special aggregation is highly suitable for GAINS modelling purposes. Input data for 2020 and 2030 are based on the assumption that development rates are the same as in one of the latest publicly available scenarios developed by IIASA – ECLIPSE_v5a. The total use of fossil fuels in the Russian Federation is supposed to increase by 9% between 2010 and 2030.

The modelled emissions are compared to the emission outputs from other GAINS baseline scenarios, and to the officially reported to EMEP emissions on ETR. Nearly for all main pollutants, the discrepancies between the modelled and the reported emissions in 2010 are small (under 5%) – this is an indirect verification of the high quality of the new input data sets. Emission outputs from the model depend not only on the assumed activity rates and implementation rates of the abatement measures, but also on the technology-specific emission factors. Those are reviewed by IIASA from time to time, as our analysis of several recent baseline (PRIMES) scenarios shows. It is thus important to use the most recent available set of emission factors.

There are certain aspects in the new input data set with **potential for improvements**. More efforts should thus be taken to identify regional differences in emission controls, currently assumed to be the same in all regions. It is also important to find more available region-specific and sector-specific development plans and to translate them into the numbers that could be used in GAINS modelling. Lack of quantified development plans for Russian regions on the needed level of aggregation has always been a problem – which is why we use the assumption on the same development rates as used in the IIASA's latest baseline. Also, more region-specific data need to be collected to minimize the number of sectors where we use proxies (such as population numbers) to distribute numbers available on the more aggregated level of ETR or the whole country.

One of the substances analyzed in detail on the level of regions is **black carbon**. Being a harmful air pollutant and a short-lived climate forcer at the same time, black carbon is a subject to active interest in the scientific community and among policy-makers. We have summarized and analysed available data on the black carbon emissions in Russia – both estimates for the historical years and modelled emissions for the future years. Current black carbon emissions from the entire territory of Russia are estimated at 120-360 ktonnes; there is, however, no official black carbon emission inventory covering the entire country. The official inventory for the Arctic Zone of Russia, submitted to ACAP, gives an estimate of 24.2 ktonnes in the year 2013.

Most studies agree that major black carbon emitting sources in the Russian Federation are flaring of the associated gas in the oil and gas industry, road and non-road transport and residential combustion. The relative inputs of these sectors for each particular region, however, vary significantly – e.g. while in Moscow road traffic is the largest source, in Ural and Siberia the main emitting source is flaring. The regions where the highest amounts of black carbon are emitted are Ural and Siberia. Among the regions within ETR, the leader is Volga, where most part of BC originates from transport and agricultural waste burning, according to our modelling results.

We have developed three scenarios for black carbon emission reductions, each focusing on one specific sector (flaring, non-road, and residential combustion), and one combined scenario including measures in all three sectors. The results indicate that the most cost-effective way to reduce black carbon emissions, considering the whole country, seems to be by taking measures to reduce flaring in the oil and gas industry – the costs of these measures are estimated at 12 Euro per kg removed black carbon. This sector also has the largest emission reduction potential (except the combined scenario) in 2030 – 49 ktonnes. If only ETR is considered, residential combustion is the sector with the largest emission reduction potential of 15 ktonnes. Gross health benefits that result from avoided $PM_{2.5}$ emissions in this scenario are 2.9 – 9.5 billion Euro (depending on the chosen valuation metric), which is 1.01 – 3.4 times higher than the associated technical costs. Combining measures in all three main emitting sectors would result in black carbon emission reductions by 36 ktonnes in ETR, and 100 ktonnes – in the entire country.

In the scenario analysis relevant for the **Gothenburg Protocol** under the UNECE CLRTAP, we have focused on the reduced and oxidised nitrogen. Both are harmful pollutants that contribute to the formation of the secondary particles $PM_{2.5}$, exposure to which directly effects people's health and increases premature mortality. We have investigated emission reduction potentials for agricultural ammonia and two possible approaches to reach certain established emission reduction targets for NO_x. Both scenario sets are focused on ETR and 2030 as target year.

The total emission reduction potential for agricultural ammonia in ETR in 2030 is estimated at 239 ktonnes. Full implementation of the MFR scenario would cost 857 million Euro, with the resulting gross benefits from avoided premature mortality of 3–10 billion Euro. The largest emission reduction potential is seen in Volga and Other Central regions.

In the analysis of scenarios for NO_x reductions down to a chosen ambition level of 25% compared to the level of 2010, we focus on how the resulting regional allocation of measures and costs depends on the method. Depending on whether it is assumed that all regions should reduce the same amounts of NO_x, that they reach the same percentage reduction compared to the 2010-level, or use cost optimization for this purpose, the resulting total costs and the cost burden for each region is different.

The new region-specific data sets and emission reduction scenarios for black carbon, NO_x and NH_3 are developed for the purposes of supporting policy development and decision-making on the level corresponding to the administrative structure of the Russian Federation. They reflect significant differences in the regional structure and can be used both as supporting materials for the country's internal policy-making, and for negotiating within international agreements such as UNECE CLRTAP or UNFCCC conventions. The results of the black carbon analysis might be useful as supporting material for the Russian Federation's work within the Arctic Council – for example, when analyzing the emission reduction target set for 2025 and possible ways to reach it.

EMEP modelling

In this project, new flexibility features of the EMEP/MSC-W model are tested with regard to their possible applications to Russian territories.

To **improve emission inputs** into the model, the expert team has both analysed the existing data sets for ETR and compiled new data sets – at the coarse resolution for the whole ETR and at the fine resolution for Murmansk region. The analysis of the data sets developed by CEIP (50x50 km^2, 2013) revealed significant discrepancies from the national data regarding total emissions and spatial distribution of emissions within ETR. In particular, some large point source locations assumed in the CEIP data set seem to be different in the national data, and the reasons for that probably lie in the EDGAR database currently used by CEIP for emission gridding. As proper source location is important for modelling, the results of this comparison analysis have been communicated to CEIP, and it was clarified that submitted national data could not be used at the time it was submitted – but in the next emission gridding run, data provided by the Russian experts probably can be used. For improvements in the emission data quality, it is important to regularly conduct such verification procedures and to identify, analyse and discuss discrepancies between different emission data sets.

Comparison of model results with rather limited available observations in Russia and the north of Scandinavia (Finland) shows a certain improvement in modelled sulphur air concentrations and wet deposition at the finer (0.1x0.1°) resolution compared to 50x50 km^2.

The **analysis of SR fluxes** from emissions in the pilot region – Murmansk – shows that the choice of resolution might affect results regarding SO_x deposition – at least in case some large point sources are located close to borders with neighbouring regions. NO_x and NH_3 emissions are less dependent on location of point sources and are more evenly spatially distributed; the effects of resolution of their deposition are thus much less pronounced, although some differences are noticed. For PM_{10} and $PM_{2.5}$, the model simulations on 0.1x0.1° grid give consistently lower PM pollution due to Murmansk in the region itself and in its main receptors compared to the run on 50x50 km^2 grid. One possible reason to that could be more efficient depositions of inorganic species within the region. At the same time, in more distant countries, PM pollution from Murmansk region seems to slightly increase. We suggest this can be attributed to a longer lifetime of PM calculated on 0.1x0.1° grid, so that the pollutants can be transported over larger distances.

The operational project work has further sharpened Russian **experts' skills** in the analysis and preparation of the modelling input data, especially gridded emissions and regional fractions. During the project, some suggestions for further improvements of these procedures have been made. MSC-W/MET Norway finds the project tasks valuable for fine-tuning of modelling techniques used in preparation to the period of the official EMEP reporting at the fine resolution.

For efficient work with air pollution abatement at the policy level, knowledge of the pollutants' transport, transformations in the atmosphere and the ultimate faith is crucial. This information, obtained with CTM models like EMEP, is a necessary scientific basis for further development of air pollution abatement strategies aimed at specific economic sectors in specific regions in the European countries. EMEP modelling results produced within this project with main focus on ETR, together with improved technical skills of the involved experts, strengthened methodological basis, and a widened expert network for sharing input data and modelling results, are expected to contribute to further development of effective air pollution abatement strategies on the regional and national levels – and to more active participation of the Russian Federation in the work under the UNECE CLRTAP.

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Appendix 1. National data for 2010 into the GAINS format – methodological details for energy and mobile sectors.

Table 1.1. Adjustments for 2010 in ECLIPSE_v5a.

Parameter	Original value, PJ	Adjusted value, PJ	Comment
Gas, industrial boilers	0	409	Re-allocated from NONEN. Same value as for 2015
Gas, other industrial combustion	1199	1561	Re-allocated from NONEN. Same value as for 2015
Gas, NONEN	1104	0	Re-allocated to industry and road transport
Gas, passenger cars	0	46	Re-allocated from NONEN. Same value as for 2015
Gas, heavy duty trucks	3.16	0.01	Re-allocated from NONEN. Same value as for 2015
Heavy fuel oil, NONEN	188	276	Fuel re-allocation in NONEN. Same % 2015/2010 as 2020/2015. Same total value.
LPG, NONEN	171	82	
HC in industries	89	250	Same value as for 2015
DC in industries	41	434	Same value as for 2015
Heavy fuel oil, industrial boilers	21	237	Same value as for 2015
Coal in energy sector	19	0.3	Same value as for 2015
Heavy fuel oil in energy sector	66	0	Same value as for 2015
LPG in energy sector	237	1.1	Same value as for 2015
Coal in CON_LOSS	547	1731	Same value as for 2015
Wood at power plants	36	0	Same value as for 2015
Waste at power plants	107	0	Same value as for 2015
Gasoline at power plants	30	0	Same value as for 2015

Table 1.2. Fuel key for translations between Huang et al. 2015 and GAINS Russia.

Huang et al. 2015	GAINS	
Block heating peat	BC1	Brown coal/lignite (includes peat)
Heating Peat	BC1	Brown coal/lignite (includes peat)
Lignite	BC1	Brown coal/lignite (includes peat)
Hard Coal	HC1	Hard coal, grade 1
Crude Oil (Including gas condensates)	HF	Heavy fuel oil
Heavy Heating Oil (Mazut)	HF	Heavy fuel oil
Other Oil Products	HF	Heavy fuel oil
Other Oil Products (Marine heavy oil, gas turbine fuel)	HF	Heavy fuel oil
Domestic Stove Fuel	HF	Heavy fuel oil
Diesel Oil	MD	Medium distillates (diesel, light fuel oil; includes biofuels)
Dry Gas (From oil refineries)	GAS	Natural gas (incl. CNG and derived gases)
Firewood	FWD	Fuelwood direct
Gasolines	GSL	Gasoline and other light fractions of oil; includes biofuels
Liquefied Gas	LPG	Liquefied petroleum gas
Natural and Associated Gas	GAS	Natural gas (incl. CNG and derived gases)
Metallurgical Coke	DC	Derived coal (coke, briquettes)
Synthetic Coke Gas	DC	Natural gas (incl. CNG and derived gases)
Other Solid Fuel		See Table 1.4

Table 1.3. Sector key for translations between Huang et al. 2015 and GAINS Russia.

Huang et al. 2015	GAINS, fuel combustion and non-energy use of fuels	
CHP	PP	Power and district heating plants
Electricity plants	PP	Power and district heating plants
Heat plants	PP / DOM	District heating /residential
Coal & Peat Mining & Processing	CON_COMB	Fuel combustion in the energy sector
Extraction of Oil & Gas	CON_COMB	Fuel combustion in the energy sector / gas flaring
Processing of Oil & Gas	CON_COMB	Fuel combustion in the energy sector
Chemical production	IN_CHEM	Chemical industry
Manf. Non-Metal Bldg. Materials	IN_NMMI	Non-metallic minerals
Manf. Wood & Paper	IN_PAP	Pulp and paper industry
Manf. Food & Beverage	IN_OTH	Other industry
Manf. Rubber & Plastic	IN_OTH	Other industry
Manf. Textiles & Leather	IN_OTH	Other industry
Metallurgy	IN_ISTE / NFME	Iron and steel, non-ferrous metals
Maritime transport	TRA_OTS / OT_INW	Maritime transport
Off-road transport	TRA_OT (AGR, CNS, LD2)	Off-road transport
Pipeline transport	TRA_OT_LB	Pipeline compressors
Rail transport	TRA_OT_RAI	TRA_OT_RAI

Table 1.4. "Other solid fuels" distribution.

Sector in Huang et al. 2015	Sector in GAINS	Fuels assumed in GAINS
CHP, electricity plants	PP	FWD, WSNFR
Heat plants	PP / DOM	FWD in DOM / FWD, WSNFR in PP
Processing of Oil & Gas	CON_COMB	BC, HC
Manf. Non-Metal Building Materials	IN_NMMI	FWD, WSNFR
Manf. Wood & Paper	IN_PAP	FWD, WSNFR
Other industries	IN_OTH	FWD, WSNFR
Metallurgy	IN_ISTE / NFME	FWD, WSNFR

Road transport

Calorific values used for all estimates are from IPCC 2006.

Distribution of fuel consumption – diesel

According to IEA 2012 cited in Evans et al. 2015, total diesel consumption by road transport in Russia in 2010 is 12508 ktonnes (~538 PJ). Rosstat 2011 gives an estimate of 11200 ktonnes (~482 PJ), but this number excludes small business. We use numbers from Evans et al. 2015 in the further analysis. Distribution between major transport categories is also adopted from Evans et al. 2015 citing Donchenko 2013:

- passenger cars – 4.4% (~24 PJ)
- trucks – 81.1% (~436 PJ)
- buses – 14.5 % (~78 PJ)

Further fuel distribution by region is based on Rosstat statistics on the number of vehicles (for cars and buses) and transport work (for trucks) presented in Table 1.5.

Table 1.5. Regional distribution of fuel consumption by road transport (source – Rosstat 2014).

	Absolute numbers (diesel and gasoline)			Regional shares of fuel use		
Type	**Passenger cars**	**Trucks**	**Buses**	**Passenger cars**	**Trucks**	**Buses**
Unit	**Registered cars, th***	**10^6 t-km**	**Units in use**			
Moscow	5453	6008	13030	16%	5%	19%
Other Central	4941	25078	9773	15%	19%	15%
North-West	3454	18155	8360	10%	14%	12%
Volga	6258	28494	12386	19%	21%	19%
South	3189	13418	4568	10%	10%	7%
Northern Caucasus	1459	4327	2360	4%	3%	4%
Ural	3070	15515	6918	9%	12%	10%
Siberia	4142	16054	7705	12%	12%	12%
Far East	1481	5586	1796	4%	4%	3%
TOTAL	33447	199341**	66897	100%	100%	100%

*Calculated via number of vehicles multiplied with population, same for buses
** Total include small business; regionals do not

The total number of buses in the country is actually much higher – about 890 thousand vehicles (Rosstat 2014). Many of them have private owners. In the numbers in Table 1.5, we only include vehicles that are a part of the public transport system.

Distribution of fuel consumption – other fuels

Main non-diesel fuel options for road transport in the Russian Federation are gasoline, LPG and compressed natural gas. Hydrogen was not present on the market in 2010[57]. Total consumption of these fuels in the country is estimated based on shares of diesel fuels vehicles in each of the three main transport categories as given in Kholod et al. 2016:

- passenger cars – 4.2% of diesel; 95.8% of other fuels =562 PJ
- trucks – 62% of diesel; 38% other fuels = 278 PJ
- buses – 45% of diesel; 55% other fuels = 99 PJ

Total consumption of non-diesel fuels on Russian roads amounts to 902 PJ according to this estimate. For comparison, Rosstat 2011 gives a number of 6 mln tonnes (266 PJ) gasoline, which excludes small business. IIASA's estimate (PRIMES 2010) is 850 PJ of gasoline. Both Kholod et al. 2016 and IIASA assumed that gasoline use was higher than diesel use in 2010 so 6 mln tons seems be a largely underestimated number. For GAINS scenarios, we use the number 902 PJ covering all main non-diesel fuels.

Estimates for LPG and natural gas consumption are hard to find in the open source Rosstat data. To calculated those, we use data for ETR provided by SRI Atmosphere – 43700 tonnes of LPG and 85000 thousand m^3 of gas in 2010. Gas density is assumed to be 0.717 kg/m^3[58]. Both LPG and natural gas constitute about 3-4% of the consumption of main fuels - diesel and gasoline. This can be compared to IIASA's (ECLIPSE_v5a) estimates for consumption of these secondary fuels at 0.05 – 1% of diesel and gasoline. The ratio of 3-4% for ETR is further used to calculate amounts of LPG and natural gas consumed in the whole Russian Federation.

Further split of natural gas by sub-categories is done with shares specified by the National Gas Engine Association[59] – 26% cars, 51% trucks and 23% buses. Similar split of LPG is done with IIASA's

[57] SRI Atmosphere, personal communication

[58] http://avtotrans-consultant.ru/7-szhatyj-prirodnyj-gaz/ accessed in August 2017

[59] https://aftershock.news/?q=node/382210 accessed in August 2017

shares (ECLIPSE_v5a), and the remaining non-diesel fuel in each category is assumed to be gasoline. A part of gasoline is further allocated to motorcycles and category LD2 (vehicles and small machines with 2-stroke engines) using the same shares as in ECLIPSE_v5a. To distribute consumption of non-diesel fuels by regions, the same shares are used as for diesel-fuelled vehicles – see Table 1.5. We thus assume that the share of diesel-fuelled vehicles in the road transport is approximately the same in all Russian regions.

Other parameters relevant for road transport

Beside fuel consumption, there are two other important parameters used for calculations of emissions and costs in the GAINS model – number of vehicles and traffic work. Those three parameters are linked and can be calculated via each other. Available estimates in the literature are presented in Table 1.6.

Table 1.6. Available estimates for road transport parameters relevant for the GAINS model.

Parameter	Source	Unit	Passenger cars	Trucks	Buses
Mileage per vehicle	Evans et al. 2015	km/year	15000	35000	45000
Mileage per vehicle	ECLIPSE_v5a	km/year	9200	35300*	8600
Vehicle number (active)	Huang et al. 2015	thousands	17189	3246	388
Stock use	Huang et al. 2015	%	50%	60%	50-75%
Vehicle number (total)	Rosstat 2014	thousands	34354	5414	902

*Heavy duty trucks. For light duty trucks – 12 200 km

We use Evans et al. 2015 for average mileage per vehicle and Huang et al. 2015 for number of active vehicles to calculate traffic work by each category. Regional distribution of vehicle number is made with the shares specified in Table 1.5. Specific fuel consumption implied in this study is presented in Table 1.7 together with the numbers presented in other relevant studies.

Table 1.7. Specific fuel consumption by road transport category.

Fuel	Source	Passenger cars	Trucks (light and heavy)	Buses	Heat value, MJ/kg
		Unit fuel consumption, MJ/100 km			
Diesel	This study	219	619	993	43
	ECLIPSE_v5a, ETR	324	333-1160	1278	
	Kupiainen&Klimont 2004	250-357	1071		42
Gasoline	This study	219	619	993	44.3
	ECLIPSE_v5a, ETR	324	350-1276	1406	

Non-road transport

For non-road transport, number of vehicles for the whole Russian Federation from PRIMES_2010 is distributed by regions, fuels and sub-categories in proportion to updated fuel consumption in PJ.

Consumption of aviation gasoline and kerosene by civil aviation is estimated based on data provided by national experts. According to SRI Atmosphere, fuel use in 2010 amounts to 3.2 million tons, or 141 PJ. IIASA's estimates are much higher – 446 PJ corresponding to 10.3 million tonnes. There are some reasons to suspect that this high estimate is based on market consumption - sold fuel whereas amount actually used by civil planes is much lower. The reason of such a large discrepancy between sold and used fuel amounts need to be further investigated. For the new GAINS in-data scenario set, we use data provided by SRI Atmosphere.

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Appendix 2. National data for 2010 into the GAINS format – methodological details for processes.

GAINS code	Parameter	Unit	Data sources	Data processing details
AGRICULTURE				
AGR_COWS, BEEF, PIG, POULT, OTANI	Animal livestock: cattle, pigs, poultry, sheep, horses, rabbits, camels	M animals	Rosstat 2011a Rosstat 2013	Region-specific statistics. ECLIPSE-based distribution between solid and liquid manure management systems. For poultry, horses and rabbits, distribution between Moscow and Other Central regions is based on statistics for 2011.
PR_FERT	Fertilizer production	Mt	Rosstat 2015 ECLIPSE	For European regions, IIASA's number is split between regions with proxy - regional statistics on fertilizer production in kt nutritious substances. For Asian regions, ratio Mt fertilizers / kt N fertilizers (calculated for Europe) is used.
FERTPRO	Fertilizer production	kt N	Rosstat 2015, Rosstat 2011b ECLIPSE Ibprom[60]	For European regions, IIASA's number is split between regions with proxy - regional statistics of fertilizer production in kt nutritious substances. For Asian regions, proxy is arable agricultural land. Distribution between Moscow and Other Central regions is based on number of plants producing mineral fertilizers.
FCON	Fertilizer use	kt N	Rosstat 2011b	Number for Russia is split between regions with proxy - arable agricultural land.
WASTE_AGR	Agricultural waste burning	Mt	ECLIPSE	IIASA's numbers are split between regions with proxy - arable agricultural land.
AGR_ARABLE	Arable agricultural land	M ha	Rosstat 2011b	Region-specific statistics.
RICE_FLOOD	Rice area harvested	M ha	Fb.ru[61]	Region-specific statistics. All rice area is assumed to be intermittently flooded rice cultivation area (>3 days aeration during the vegetation period).
GRASSLAND	Grassland and soils	M ha	Rosstat 2011b	Region-specific statistics.
FOREST	Forest area	M ha	Rosstat 2011b	Region-specific statistics.
HISTOSOLS	Organic soils area	M ha	ECLIPSE	IIASA's numbers are split between regions with proxy - arable agricultural land.
ATM_DEPO	Atmospheric deposition on forest	kt N	ECLIPSE	IIASA's number is split between regions with proxy – forest area. For Asia, no deposition numbers are available.
CROP_RESID	N from crop residues	kt N	ECLIPSE Rosstat 2015	IIASA's number is split between regions with proxy – regional statistics on yields of major crops and vegetables.
AGR_COWS_MILK	Milk yield	kg/animal	Rosstat 2011a	Region-specific statistics.

[60] http://ibprom.ru/zavody_mineralnyh_udobreniy accessed in August 2016

[61] http://fb.ru/article/155686/risovoe-pole-tehnologiya-vyiraschivaniya-risa accessed in August 2016

GAINS code	Parameter	Unit	Data sources	Data processing details
AGRICULTURE				
CONSTRUCT	Construction	M m^2	Rosstat 2015	Region-specific statistics.
MINE_BC, MINE_HC	Coal mining (brown and hard coal)	Mt	Rosstat 2015 Rosstat 2012 CFO[62]	Region-specific statistics on coal mining. Share of hard coal is 76.2% (assumed to be the same for all regions). Distribution between Moscow and Other Central regions is 1/6 and 5/6. The coal field in the region covers 6 oblasts including Moscow oblast.
MINE_OTH	Ore mining	Mt	Rosstat 2015	Region-specific statistics on ferrous ore mining.
PR_ALPRIM	Al production - primary	Mt	ECLIPSE/PRIMES Mineral.ru[63]	IIASA's number for Russian Federation (4.33 Mt) is split between regions with proxy – data on primary aluminium production in 2007 (3.96 Mt).
PR_ALSEC	Al production - secondary	Mt	TDSM[64]	Secondary aluminium market is developing. Ratio 510 kt secondary Al/ 3348 kt primary Al (production in 2012, assumed to be the same for all regions) is used to estimate secondary production.
PR_BAOX, EARC, HEARTH	Steel production in basic oxygen, electric arc and hearth furnaces	Mt	Rosstat 2015 Rosstat 2012 Huang et al. 2015	Region-specific statistics on for steel production is split by types with percentages for Russia in total (64% in BAOX, 29% in EARC and 7% in HEARTH – assumed to be the same for all regions). Distribution between Moscow and Other Central regions is based on fuel use in metallurgy according to Huang et al. 2015.
PR_PIGI(_F), PR_CAST(_F)	Pig iron and cast-iron production	Mt	Rosstat 2015 Rosstat 2012 Huang et al. 2015	Region-specific statistics on for iron production is split by types with percentages for Russia in total (99.1% of PIGI and 0.9% of CAST – assumed to be the same for all regions). Distribution between Moscow and Other Central regions is based on fuel use in metallurgy according to Huang et al. 2015.
PR_BRIQ, PR_COKE, PR_PELL, PR_SINT(_F)	Production of briquettes, metallurgical coke, sinter and pellets	Mt	ECLIPSE Rosstat 2015	Same ratios to PIGI in t/t as in ECLIPSE are used to estimate production of coke (0.5), briquettes (0.003), pellets (0.9), and sinter (1.1). For Siberia, available national number for coke is used (higher than obtained with this method).
PR_BRICK	Brick production	Mt	Rosstat 2015 Skolko-vesit.ru[65]	Region-specific statistics on brick production in items is translated into Mt using average weight 4 kg/item for a ceramic brick and 5 kg/item – for a stone or cement

[62] http://cfo.gov.ru/acts/3 accessed in August 2016

[63] http://www.mineral.ru/Facts/russia/131/279/index.html accessed in August 2016

[64] http://www.tdsm.ru/article/view/rossijskaa-aluminievaa-promyslennost-i-nekotorye-sovremennye-tendencii-razvitia-mirovogo-rynka-aluminia accessed in August 2016

[65] http://skolko-vesit.ru/kirpich.htm accessed in August 2016

GAINS code	Parameter	Unit	Data sources	Data processing details
AGRICULTURE				
			Sortork.com[66]	brick. Distribution between Moscow and Other Central regions is based on number of plants.
PR_CBLACK	Carbon black production	Mt	Rosstat 2015 Tpribor[67] Yarpromportal[68]	Region-specific statistics. The leading company in Russian and one of the leading in the world is located in Yaroslavl (Central Federal District). In Moscow region, production of carbon black started in 2012. For 2010 we assume that no production occurs in Moscow.
PR_GLASS	Glass production	Mt	Rosstat 2015 Steklo[69], Russteklo[70] Leader-glass[71]	Region-specific statistics on flat glass (assumed 3 mm thick, density 7.5 kg/m²) and container glass (240 g/bottle assumed). Distribution between Moscow and Other Central regions is based on number of plants.
PR_NIAC	Nitric acid production	Mt	ECLIPSE/PRIMES Sostav.ru[72] Infomine.ru[73]	IIASA's number for Russian Federation (5.48 Mt) is split between regions with proxy – distribution for 2013. No large plants in Moscow region – thus no production assumed.
PR_OTHER	Production of glass fiber, gypsum, PVC, other	Mt	ECLIPSE/PRIMES	IIASA's number for Russian Federation (1.29 Mt) is distributed between regions with proxy – population.
PR_OT_NFME	Non-ferrous metal production	Mt	ECLIPSE/PRIMES Huang et al. 2015	IIASA's number for Russian Federation (2.86 Mt) is distributed by regions with data on fuel use in metallurgy according to Huang et al 2015.
PR_PULP	Pulp and paper production	Mt	ECLIPSE/PRIMES Huang et al 2015	IIASA's number for Russian Federation (15.21 Mt) is distributed by regions with data on fuel use in manufacture of wood and paper according to Huang et al 2015.
PR_REF	Crude oil input into refineries	Mt	Rosstat 2015 Huang et al 2015	Region-specific statistics. Distribution between Moscow and Other Central regions is based on fuel use in oil refineries according to Huang et al 2015.
PR_SUAC	Sulphuric acid production	Mt	Rosstat 2015	Region-specific statistics. Distribution between Moscow and Other Central regions is based on number of plants.

[66] http://sortork.com/k_centralnyy_federalnyy_okrug.html accessed in August 2016

[67] http://www.tpribor.ru/v-podmoskove-zapushheno-proizvodstvo-texnicheskogo-ugleroda.html accessed in August 2016

[68] http://www.yarpromportal.ru/catalog/org/?SECTION_ID=284&ELEMENT_ID=6070 accessed in August 2016

[69] http://steklo-kom.ru/ accessed in August 2016

[70] http://www.russteklo.com/products/ accessed in August 2016

[71] http://www.leader-glass.ru/ accessed in August 2016

[72] http://www.sostav.ru/blogs/32702/15094/ accessed in August 2016

[73] http://www.infomine.ru/files/catalog/108/file_108_eng.pdf accessed in August 2016

GAINS code	Parameter	Unit	Data sources	Data processing details
AGRICULTURE				
			NSK-com.ru[74]	
CRU_PROD, GAS-PROD	Crude oil and gas extracted	PJ	Rosstat, 2015 Rosteplo[75]	Region-specific statistics. Implied calorific value of crude oil – 42.62 MJ/kg, of natural gas – 39.02 MJ/m^3. Shares of coalbed gas, shale gas and tight gas are the same as in ECLIPSE.
STH_AGR	Storage and handling: crops	Mt	ECLIPSE/PRIMES Rosstat 2011a	IIASA's numbers are split between regions with proxy – total yield of crops and vegetables.
STH_COAL	Storage and handling: coal	Mt	ECLIPSE/PRIMES Rosstat 2015	IIASA's numbers are split between regions with proxy – coal mining (HC + BC).
STH_FEORE	Storage and handling: iron ore	Mt	ECLIPSE/PRIMES	IIASA's numbers are split between regions with proxy – mining or iron ore.
STH_NPK	Storage and handling: NPK fertilizers	Mt	ECLIPSE/PRIMES	IIASA's numbers are split between regions with proxy – fertilizer production.
STH_OTH_IN	Storage and handling: other industrial products	Mt	ECLIPSE/PRIMES	IIASA's numbers are split between regions with proxy – population.
GAS_TRANS	Transportation of gas	PJ	ECLIPSE/PRIMES Huang et al. 2015	IIASA's number for Russian Federation (24535 PJ) is distributed by regions with data on fuel use in pipeline transport according to Huang et al. 2015.
WASTE_RES	Open burning of residential waste	Mt	ECLIPSE/PRIMES	IIASA's numbers are split between regions with proxy – population.
WASTE_FLR	Flaring in gas and oil industry	PJ	Huang et al. 2015 SRI pers.com.	Region-specific data (in m^3) provided by SRI Atmosphere. No associated gas flaring occurs in Central Federal District. Calorific value assumed – 75.5 MJ/m^3.
MSW_TOT	Municipal solid waste	Mt waste	ECLIPSE/PRIMES	IIASA's numbers are split between regions with proxy – population.
INW_TOT	Industrial solid waste	Mt waste	ECLIPSE/PRIMES Huang et al. 2015	IIASA's number for Russian Federation is distributed by regions with data on fuel use in all manufacturing industries according to Huang et al. 2015.
IND_PAP, FOOD, OCH	Wastewater from specific industries	Mm^3 wastewater	ECLIPSE/PRIMES Huang et al. 2015	IIASA's number for Russian Federation is distributed by regions with data on fuel use in manufacture of wood and paper / food and beverage / chemical production according to Huang et al. 2015.
PR_CEM	Cement production	Mt	Rosstat 2015 Rucem.ru[76]	Region-specific statistics. Distribution between Moscow and Other Central regions is based on a plant capacity.
PR_LIME	Lime production	Mt	Rosstat 2015 Soyuzizvest[77]	Region-specific statistics. Distribution between Moscow and Other Central regions is based on a number of plants.

[74] http://nsk-com.ru/prkisloty/862186/ accessed in August 2016

[75] http://www.rosteplo.ru/Npb_files/npb_shablon.php?id=1562 accessed in August 2016

[76] http://www.rucem.ru/factorys/ accessed in August 2016
[77] http://soyuzizvest.ru/about.html accessed in August 2016

GAINS code	Parameter	Unit	Data sources	Data processing details
NMVOC-related PROCESSES				
VEH_AUTO_P	Vehicles manufacturing	1000 vehicles	Rosstat 2015	Region-specific statistics on production of buses, passenger cars and trucks. Distribution between Moscow and Other Central regions is assumed to be 50%/50%. Share of new installations in 2010 – 50%.
PNT_DECO_P	Decorative paints	kt	ECLIPSE/PRIMES	IIASA's number for Russian Federation is split by regions with proxy – population.
SLV_DEGR	Degreasing	kt	ECLIPSE/PRIMES	IIASA's number for Russian Federation is split by regions with proxy – population. Share of new installations in 2010 – 50%.
POP_DOM_OS	Domestic use of solvents other than paint	mln	ECLIPSE/PRIMES	IIASA's number for Russian Federation is split by regions with proxy – population.
TEX_DRY	Dry cleaning	kt	ECLIPSE/PRIMES	IIASA's number for Russian Federation is split by regions with proxy – population. Share of new installations in 2010 – 50%.
EMI_EXD_GAS	Production & distribution of natural gas	kt	ECLIPSE/PRIMES	IIASA's number for Russian Federation is split by regions with proxy – gas transportation. Share of new installations in 2010 – 50%.
EMI_EXD_LQ	Extraction of oil	kt	ECLIPSE/PRIMES	IIASA's number for Russian Federation is split by regions with proxy – crude oil to refineries. Share of new installations in 2010 – 20%.
POP_FOOD	Food and drink industry	mln	ECLIPSE/PRIMES	IIASA's number for Russian Federation is split by regions with proxy – population.
ADH_GLUE	Industrial application of adhesives	kt	ECLIPSE/PRIMES	IIASA's number for Russian Federation is split by regions with proxy – population.
EMI_IND_OTH	NMVOC from other industrial sources	kt	ECLIPSE/PRIMES	IIASA's number for Russian Federation is split by regions with proxy – population.
PNT_IND_P_OT	Industrial paint use	kt	ECLIPSE/PRIMES	IIASA's number for Russian Federation is split by regions with proxy – population.
EMI_INORG	Inorganic chemical industry	kt	ECLIPSE/PRIMES	IIASA's number for Russian Federation is split by regions with proxy – population.
EMI_ORG_STORE	Organic chemical industry - storage	kt	ECLIPSE/PRIMES	IIASA's number for Russian Federation is split by regions with proxy – population.
EMI_OTH_ORG_PR	Organic chemical industry - downstream units	kt	ECLIPSE/PRIMES	IIASA's number for Russian Federation is split by regions with proxy – population.
SLV_PHARMA	Pharmaceutical industry	kt	ECLIPSE/PRIMES Rosstat 2015	IIASA's number for Russian Federation (271.5 kt) is split by regions with proxy – medicine production.
PG_PIS	Products incorporating solvents	kt	ECLIPSE/PRIMES	IIASA's number for Russian Federation is split by regions with proxy – population.
EPS_PLSTYR_PR	Polystyrene processing	kt	Techart.ru[78]	Production trend 2003-2009 is extrapolated to estimate total national number in 2010 – 5.8 mln m^3. With density of 25 kg/m^3 this equals to 145 kt. This number is split by regions with proxy – population.

[78] http://www.techart.ru/files/publications/Stirol.pdf accessed in August 2016

GAINS code	Parameter	Unit	Data sources	Data processing details
NMVOC-related PROCESSES				
			Plastics.ru[79]	
INK_PRT_OFFS, PACK	Printing: offset, packaging	kt	ECLIPSE/PRIMES	IIASA's number for Russian Federation is split by regions with proxy – crude oil to refineries. Share of new installations in 2010 –30%.
INK_PRT_ PUB, SCR	Printing: publication, screen	kt	ECLIPSE/PRIMES	IIASA's number for Russian Federation is split by regions with proxy – crude oil to refineries. Share of new installations in 2010 –50%.
PVC_PVC_PR	Polyvinylchloride production by suspension process	kt	Plastics.ru[80] Mrcplast.ru[81]	National data on production in 2010 (525.3 kt) and distribution by region – 47% in Siberia, 38% in Volga and 15% in South.
SHO_SHOE	Manufacturing of shoes	mln pairs	Rosstat 2015 Souzlegprom[82]	Region-specific statistics. Distribution between Moscow and Other Central regions is based on a number of plants.
EP_STCRACK_PR	Steam cracking (ethylene & propylene production)	kt	EY.com[83]	National data on production in 2010 (2130 kt) and distribution by region.
TYR_TYRES	Tyre production	kt	ECLIPSE/PRIMES Rosstat 2015 Wiki-prom.ru[84]	IIASA's number for Russian Federation (686 kt) is split by regions with proxy – tyre production in items. Distribution between Moscow and Other Central regions is based on a number of plants.
PNT_VEHR_P	Vehicle refinishing	kt	ECLIPSE/PRIMES	IIASA's number for Russian Federation is split by regions with proxy – population. Share of new installations in 2010 –50%.
POP_VEHTR	(De)Waxing and underbody treatment of vehicles	mln	ECLIPSE/PRIMES	IIASA's number for Russian Federation is split by regions with proxy – population.
EMI_WASTE_VOC	Waste treatment and disposal	kt	ECLIPSE/PRIMES	IIASA's number for Russian Federation is split by regions with proxy – population.
TIM_WOOD(_CR)	Wood preservation (creosote-free and with creosote)	million m^3	ECLIPSE/PRIMES	IIASA's number for Russian Federation is split by regions with proxy – population.

79 http://www.plastics.ru/pdf/journal/2015/04/Hazova.pdf accessed in August 2016

80 http://www.plastics.ru/pdf/journal/2014/05/Kiliachkov.pdf accessed in August 2016

81 http://www.mrcplast.ru/news-news_open-37722.html accessed in August 2016

82 http://www.souzlegprom.ru/ru/tsentralnyj-federalnyj-okrug.htm accessed in August 2016

83 http://www.ey.com/Publication/vwLUAssets/EY-petrochemical-industry-in-russia-2015-rus/$FILE/EY-petrochemical-industry-in-russia-2015-rus.pdf accessed in August 2016

84 http://www.wiki-prom.ru/18otrasl.html accessed in August 2016

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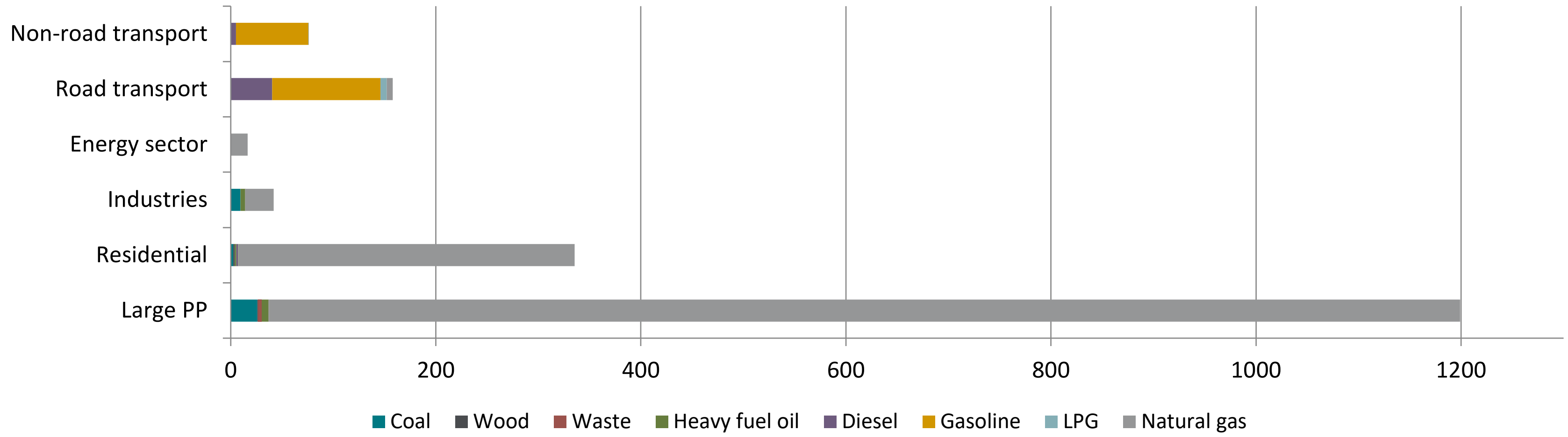
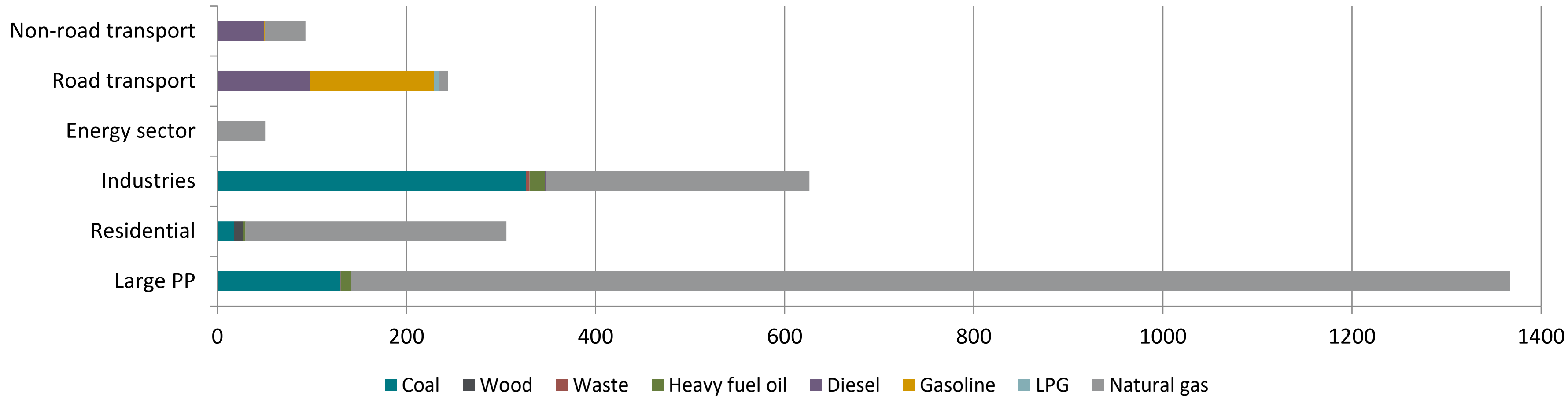
Rosstat. 2015. Industry in Russia in 2014 (in Russian)

Appendix 3. National data for 2010 into the GAINS format – summary of fossil fuel consumption by GAINS region, PJ.

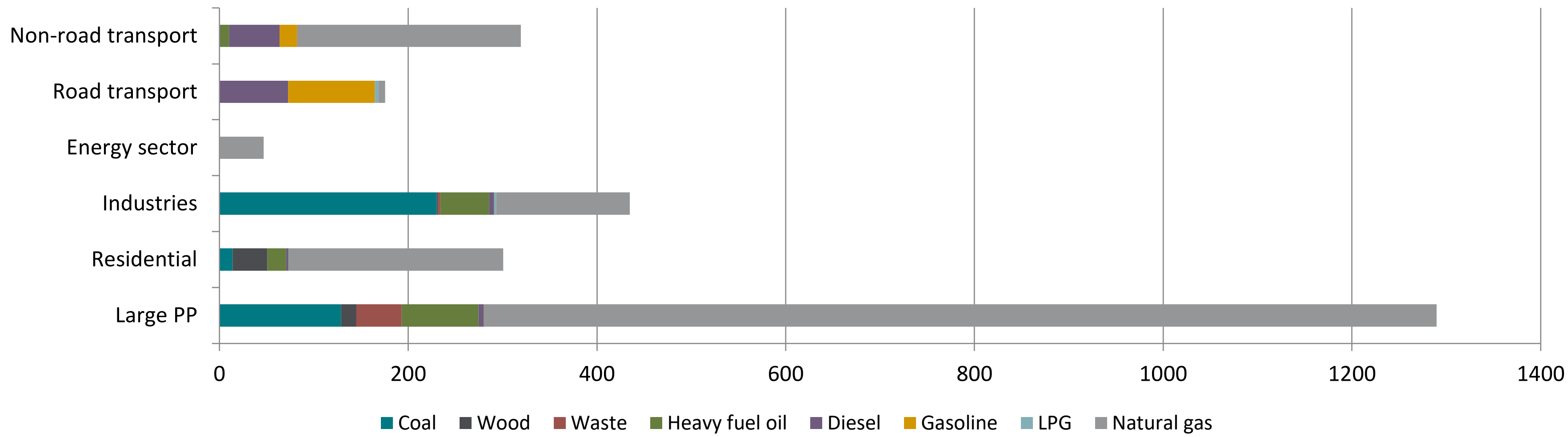
Moscow



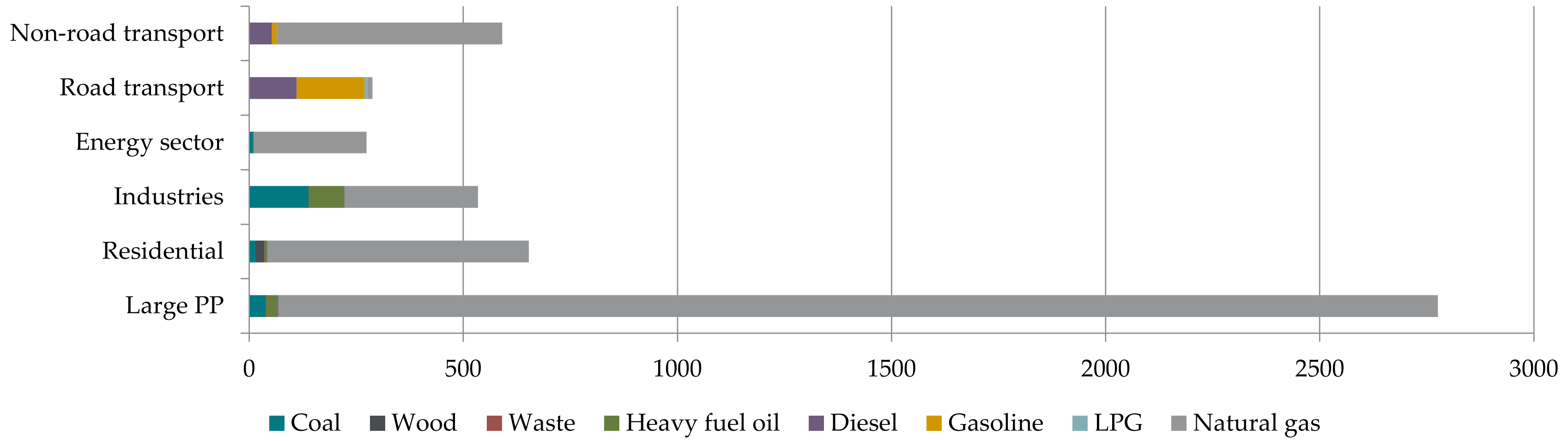
Other Central



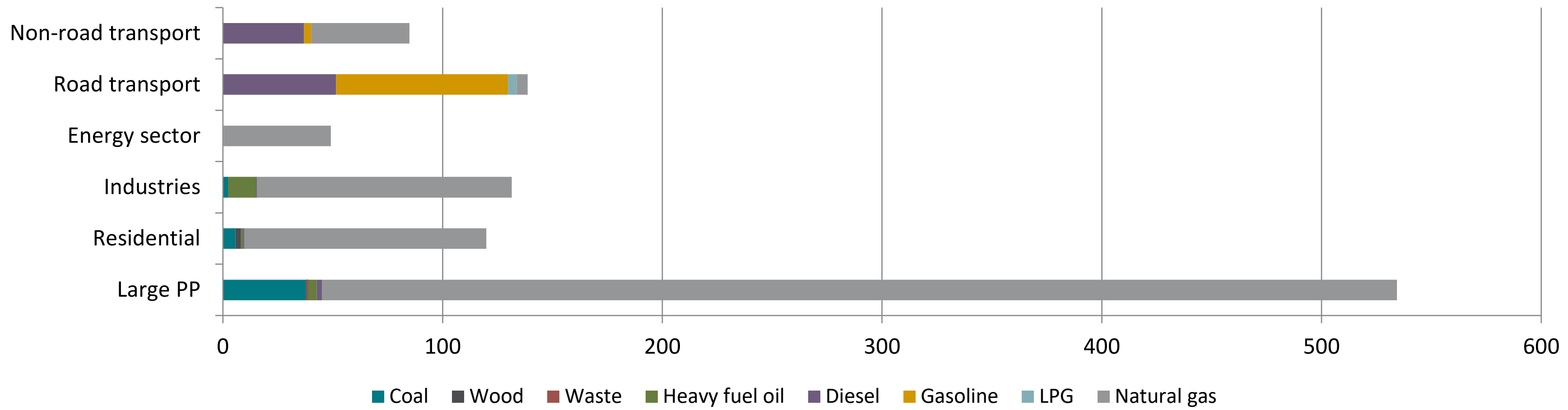
North-West



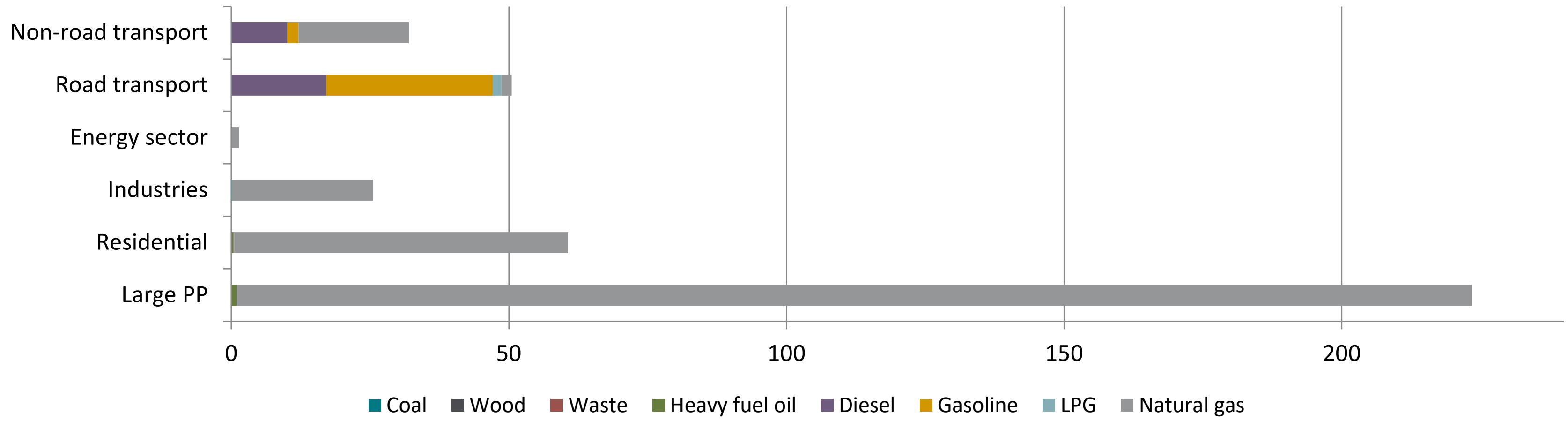
Volga


Non-road transport
Road transport
Energy sector
Industries
Residential
Large PP
0
500
1000
1500
2000
2500
3000
Coal
Wood
Waste
Heavy fuel oil
Diesel
Gasoline
LPG
Natural gas

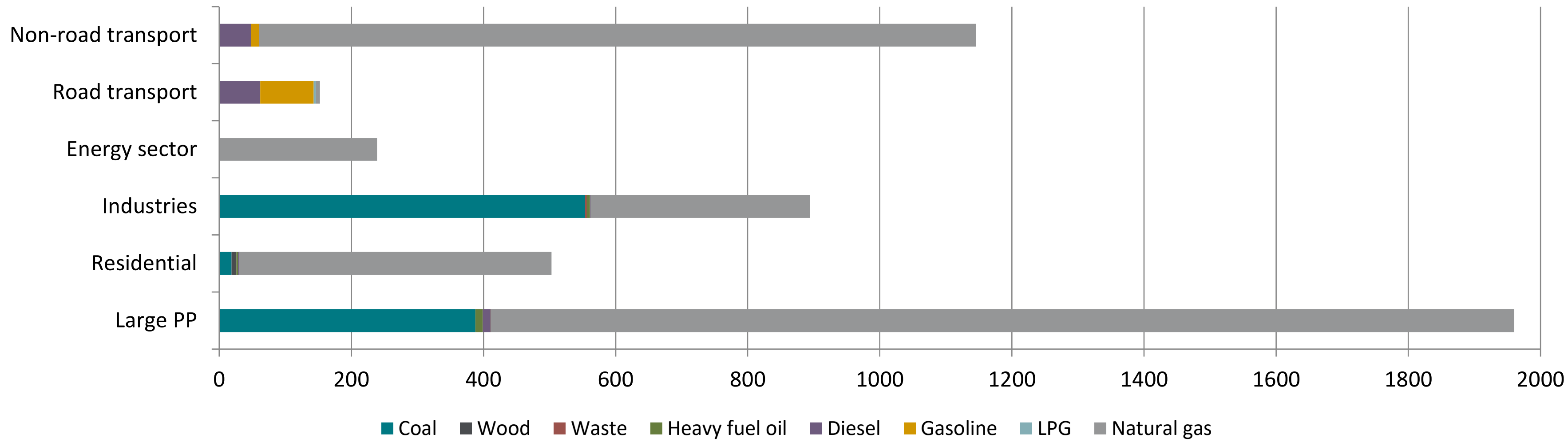
South


Non-road transport
Road transport
Energy sector
Industries
Residential
Large PP
0
100
200
300
400
500
600
Coal
Wood
Waste
Heavy fuel oil
Diesel
Gasoline
LPG
Natural gas

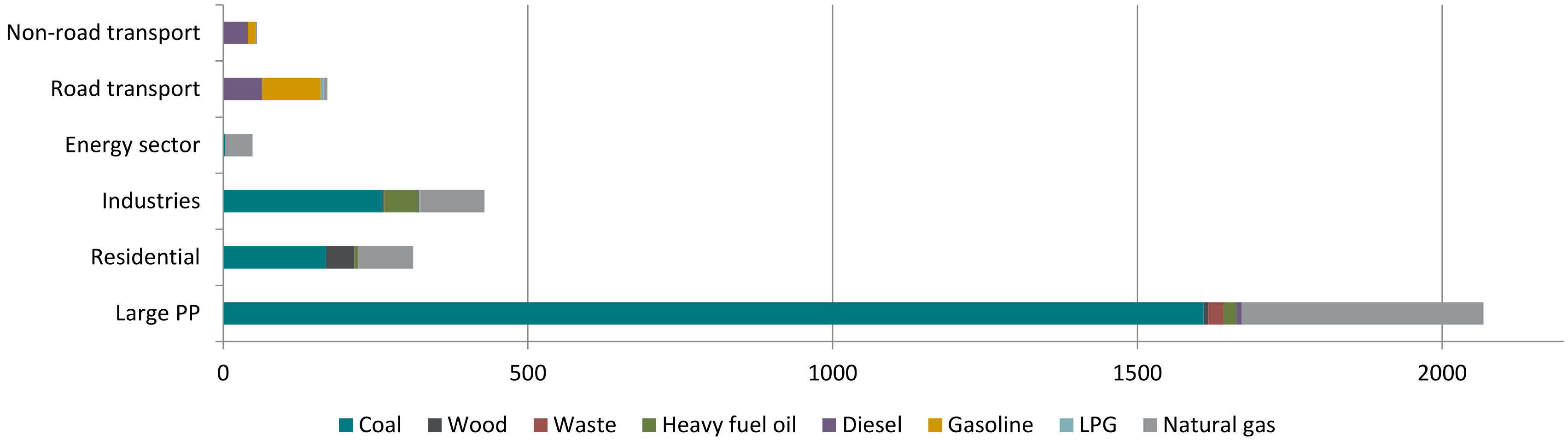
Northern Caucasus



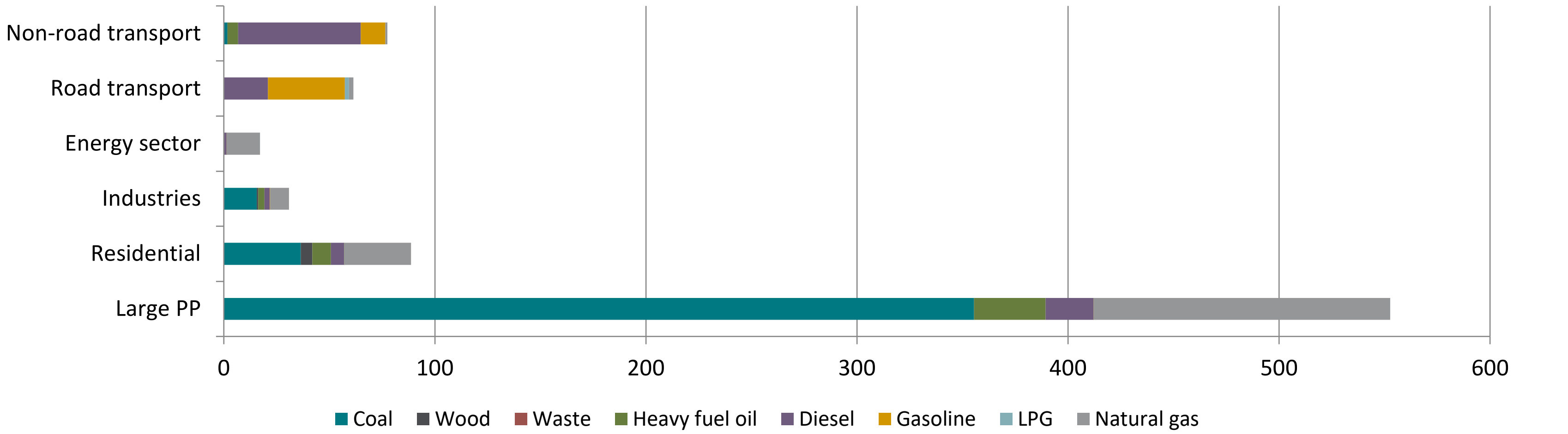
Ural



Siberia



Far East



Appendix 4. Comparison of activity data available for diesel sources.

Table 4.1. Diesel use in the stationary sources, estimates for the whole Russian Federation.

Sector	Kholod et al. 2016 (2013)		Evans et al. 2015 (2010)		This study (2010)	
	PJ	%	PJ	%	PJ	%
Heat and power plants	52	4%	108	11%	70	7%
Industries	-	-	-	-	31	3%
Energy sector (oil, gas, coal)	7	1%	-	-	6	1%
Rail	100	8%	62	6%	133	13%
Maritime	18	1%	-	-	3	0.3%
Road transport	906	69%	538	54%	538	53%
Other mobile (construction, agriculture, mines, fishing)	221	17%	291	29%	239	23%
TOTAL	1306	100%	1000	100%	1020	100%

Table 4.2. Diesel use in the stationary sources, estimates for ETR.

Sector	ECLIPSE_v5a* (2010)		This study (2010)	
	PJ	%	PJ	%
Heat and power plants	100	14%	18	3%
Industries	54	8%	19	3%
Energy sector (oil, gas, coal)	21	3%	3	0.4%
Rail	40	6%	88	14%
Maritime	19	3%	1	0.2%
Road transport	355	50%	391	61%
Other mobile (construction, agriculture, mines, fishing)	120	17%	118	19%
TOTAL	707	100%	638	100%

Table 4.3. Diesel use in the stationary sources, estimates for Murmansk / North-West.

Sector	Murmansk		North-West district			
	Evans et al. 2015 (2012)		PRIMES 2010 (2010)		This study (2010)	
	PJ	%	PJ	%	PJ	%
Heat and power plants	0.4	4%	16	12%	8	6%
Industries	-	-	10	8%	11	8%
Energy sector (oil, gas, coal)	-	-	1	1%	1	0.4%
Rail	0.9	9%	7	5%	29	20%
Maritime	0.1	1%	9	7%	1	1%
Road transport	2.8	27%	62	49%	73	50%
Other mobile (construction, agriculture, mines, fishing)	6.2	60%	23	18%	24	16%
TOTAL	10.4	100%	127	100%	147	100%

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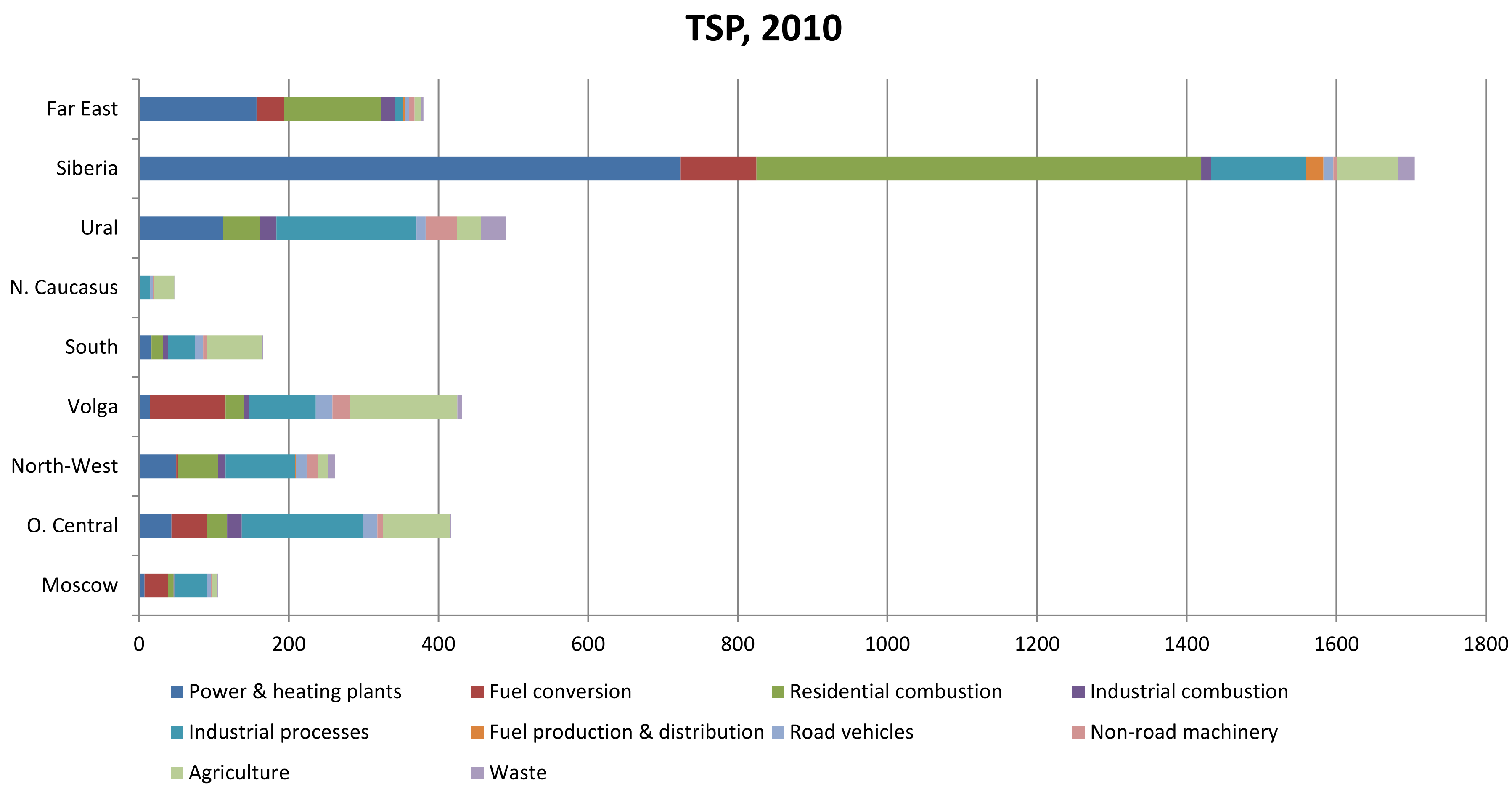
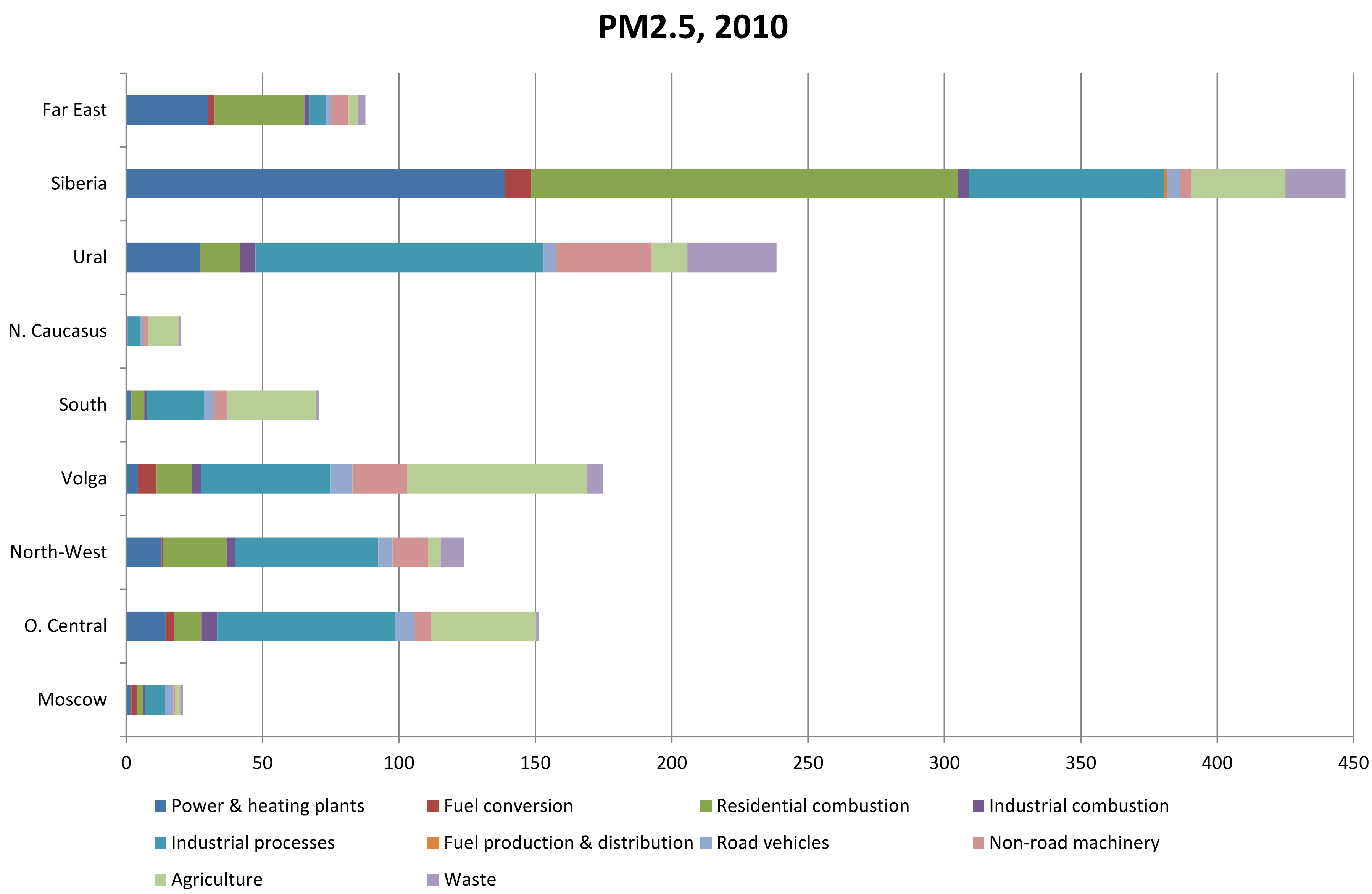
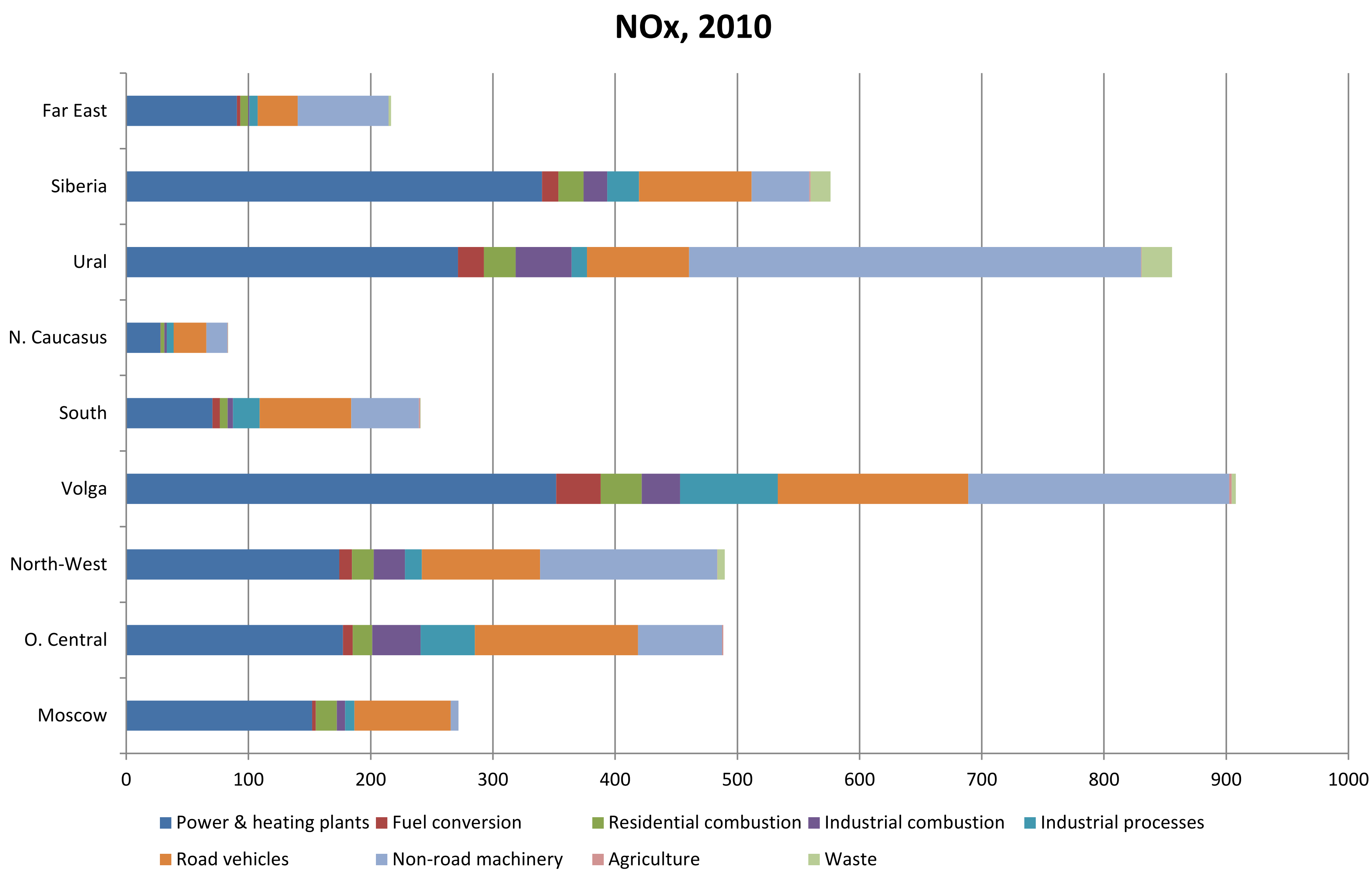
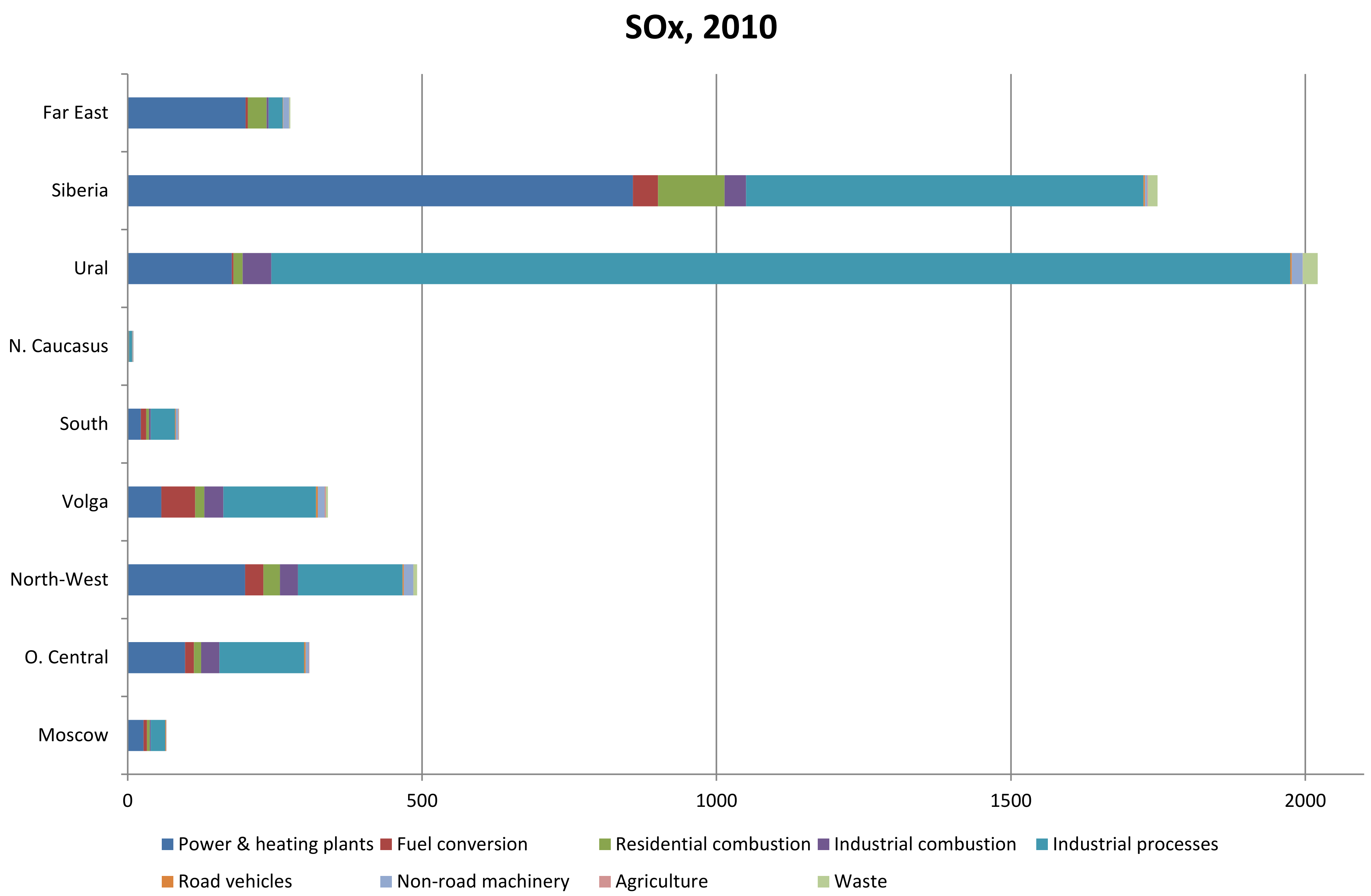
Kholod, N., Evans, M., and Kuklinski, T. 2016. Russia's black carbon emissions: focus on diesel sources. Atmos. Chem. Phys., 16, 11267–11281, doi: 10.5194/acp-16-11267-2016.

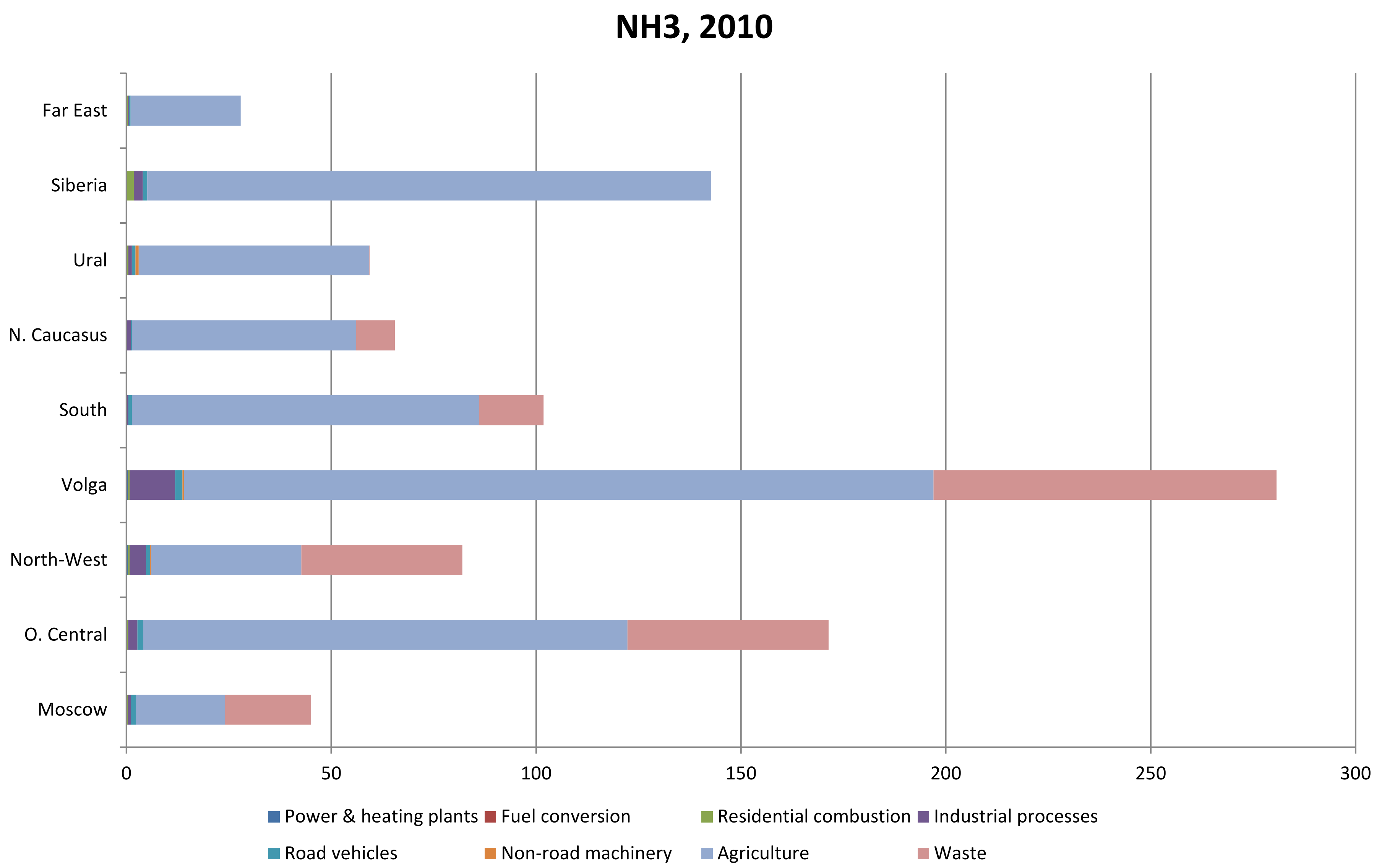
Appendix 5. Regional and sectoral structure of baseline scenario emissions in 2010 and 2030, ktonnes.




PM2.5, 2010
Far East
Siberia
Ural
N. Caucasus
South
Volga
North-West
O. Central
Moscow
0
50
100
150
200
250
300
350
400
450
Power & heating plants
Fuel conversion
Residential combustion
Industrial combustion
Industrial processes
Fuel production & distribution
Road vehicles
Non-road machinery
Agriculture
Waste


NOx, 2010
Far East
Siberia
Ural
N. Caucasus
South
Volga
North-West
O. Central
Moscow
0
100
200
300
400
500
600
700
800
900
1000
Power & heating plants
Fuel conversion
Residential combustion
Industrial combustion
Industrial processes
Road vehicles
Non-road machinery
Agriculture
Waste


SOx, 2010
Far East
Siberia
Ural
N. Caucasus
South
Volga
North-West
O. Central
Moscow
0
500
1000
1500
2000
Power & heating plants
Fuel conversion
Residential combustion
Industrial combustion
Industrial processes
Road vehicles
Non-road machinery
Agriculture
Waste


NH3, 2010
Far East
Siberia
Ural
N. Caucasus
South
Volga
North-West
O. Central
Moscow
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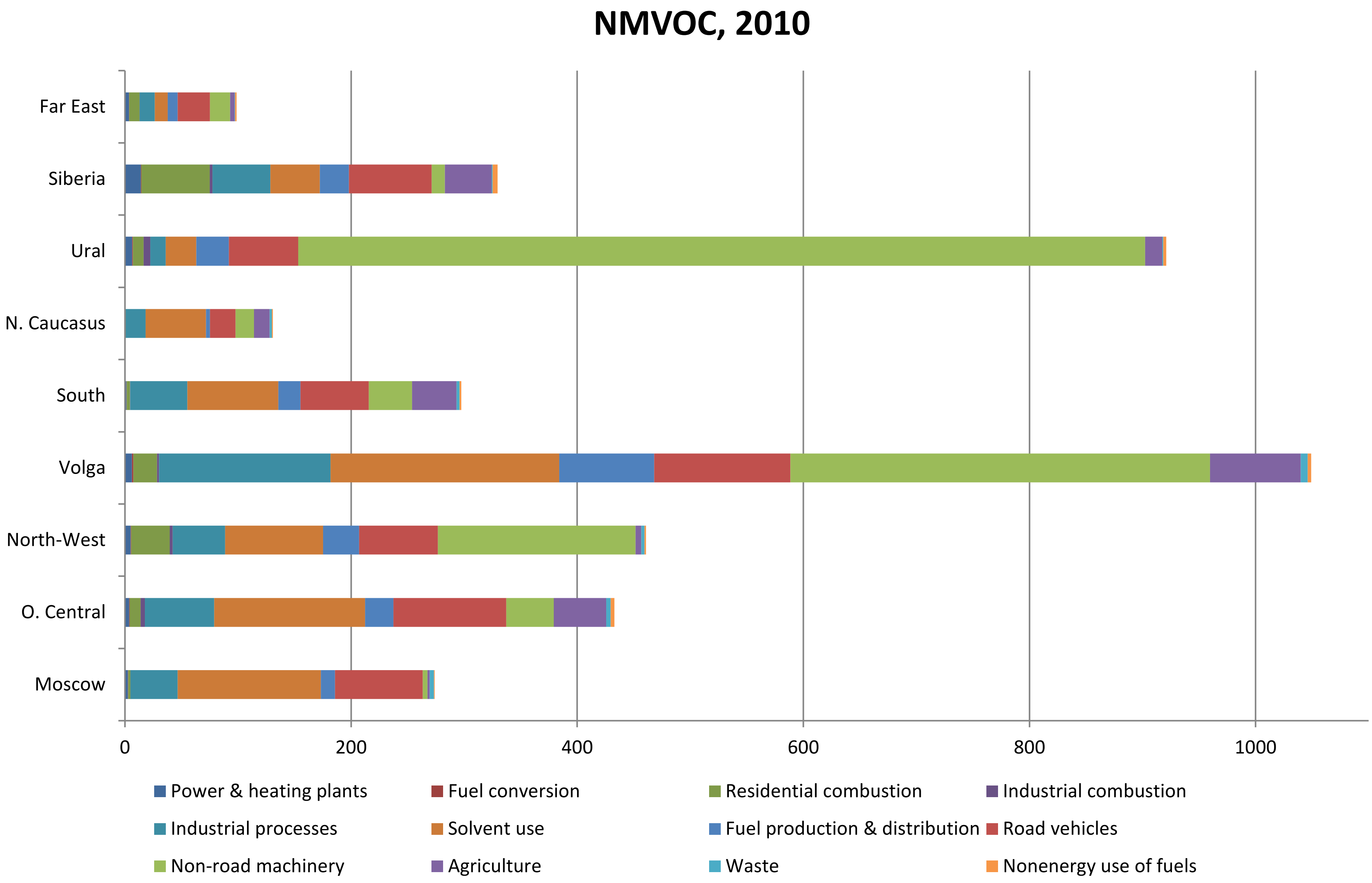
200
250
300
Power & heating plants
Fuel conversion
Residential combustion
Industrial processes
Road vehicles
Non-road machinery
Agriculture
Waste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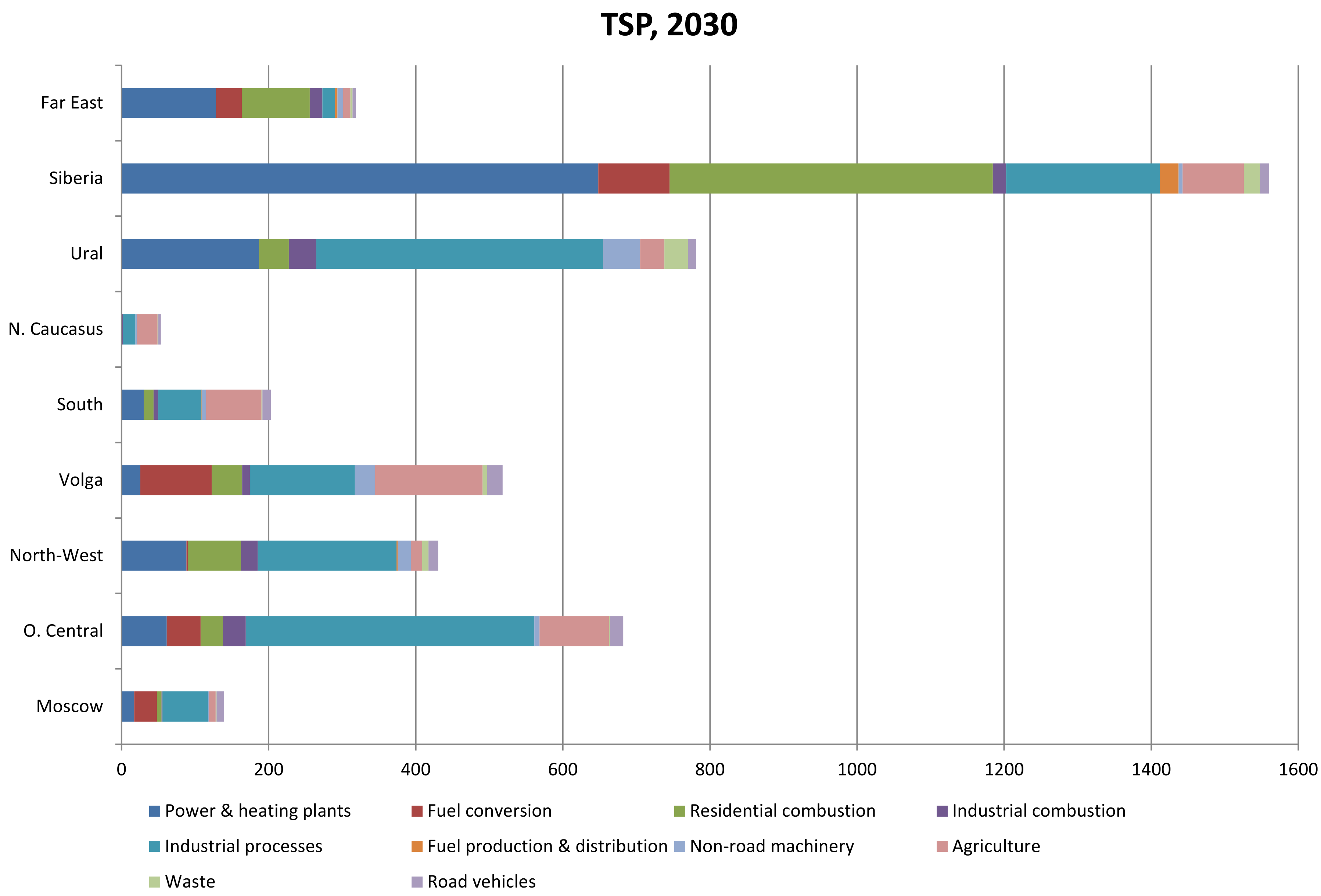
Ural
N. Caucasus
South
Volga
North-West
O. Central
Moscow
0
200
400
600
800
1000
Power & heating plants
Fuel conversion
Residential combustion
Industrial combustion
Industrial processes
Solvent use
Fuel production & distribution
Road vehicles
Non-road machinery
Agriculture
Waste
Nonenergy use of fuels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Ural
N. Caucasus
South
Volga
North-West
O. Central
Moscow
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800
1000
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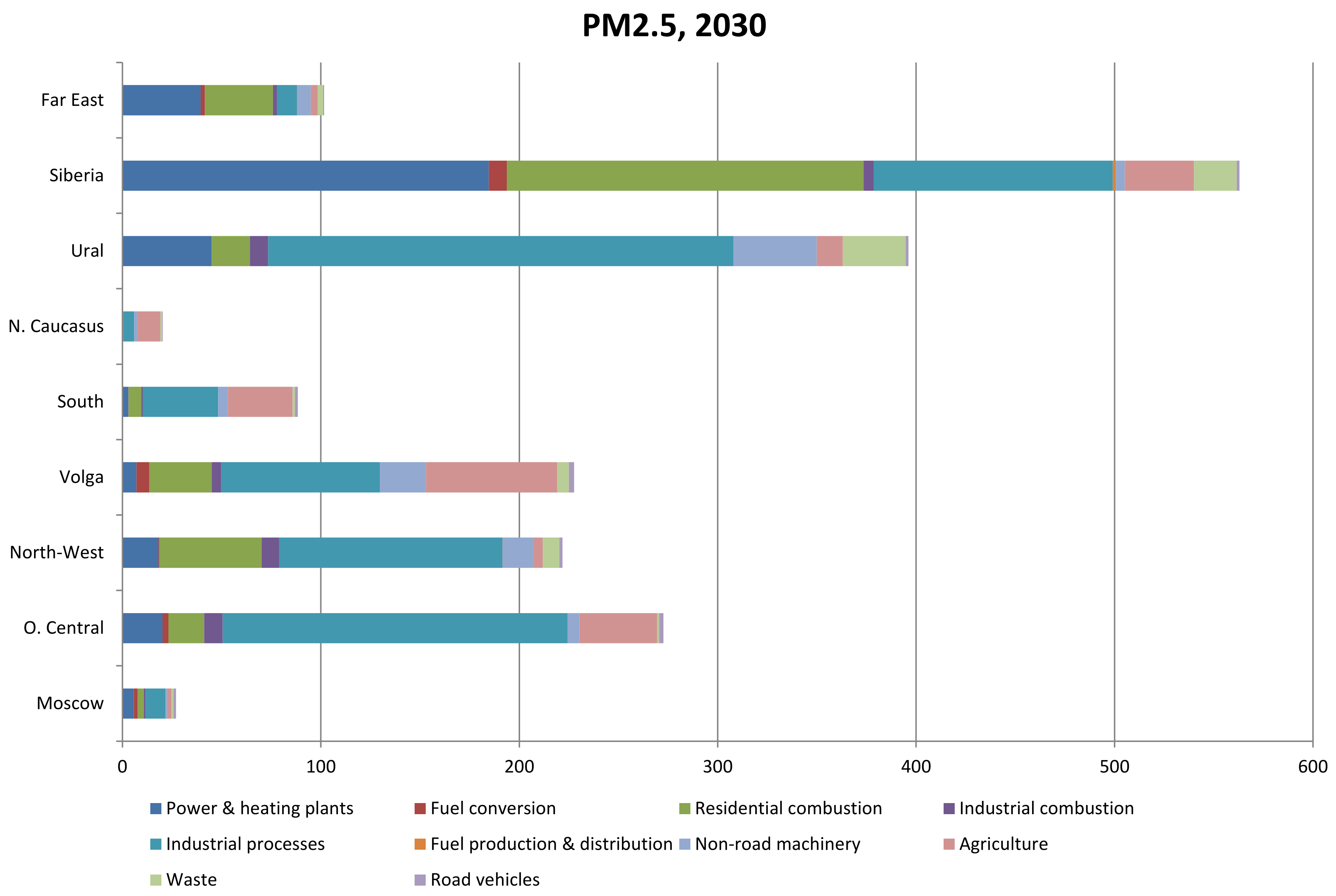
Power & heating plants
Fuel conversion
Residential combustion
Industrial combustion
Industrial processes
Fuel production & distribution
Non-road machinery
Agriculture
Waste
Road vehicles


PM2.5, 2030
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Ural
N. Caucasus
South
Volga
North-West
O. Central
Moscow
0
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200
300
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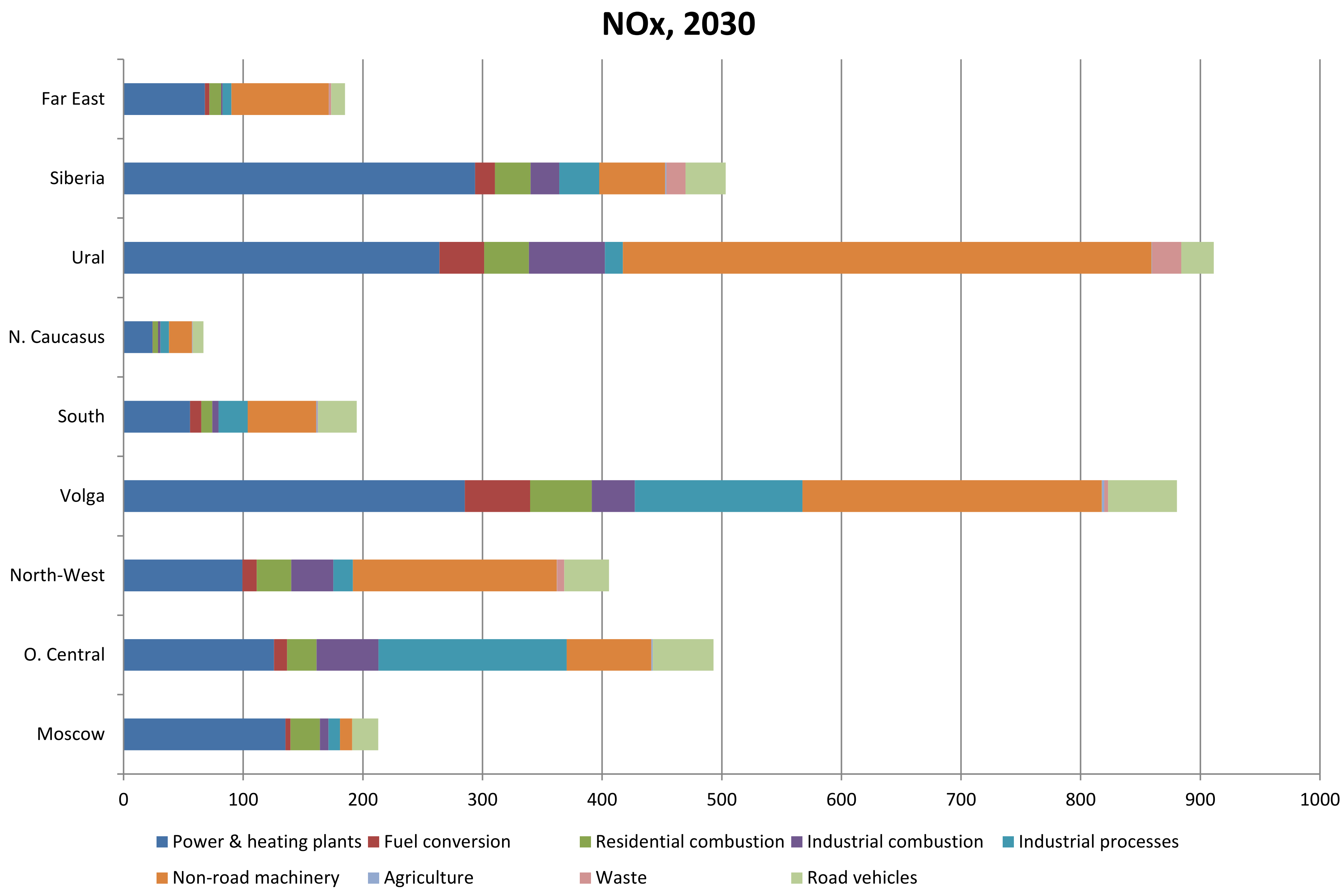
500
600
Power & heating plants
Fuel conversion
Residential combustion
Industrial combustion
Industrial processes
Fuel production & distribution
Non-road machinery
Agriculture
Waste
Road vehicles


NOx, 2030
Far East
Siberia
Ural
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South
Volga
North-West
O. Central
Moscow
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400
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700
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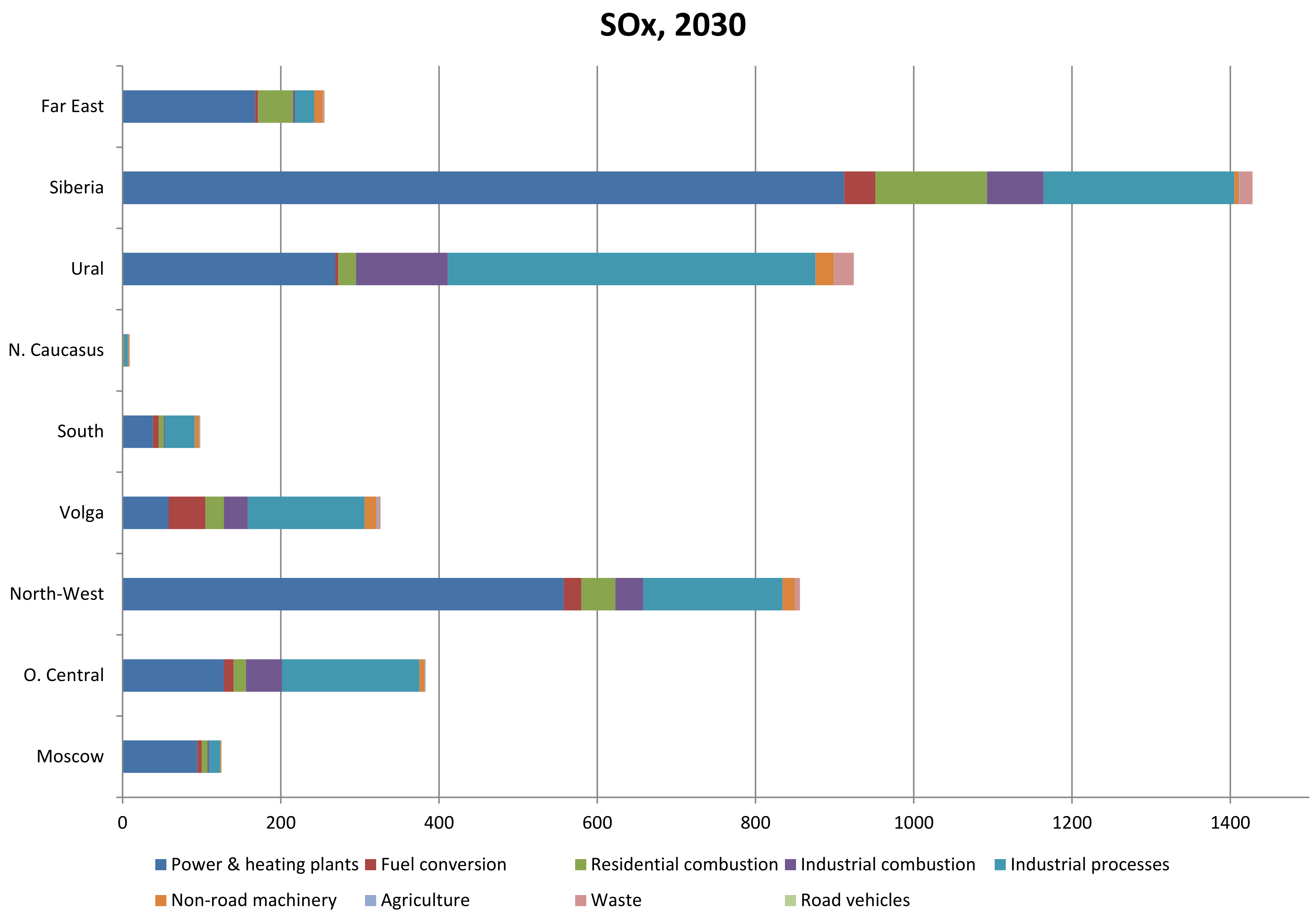
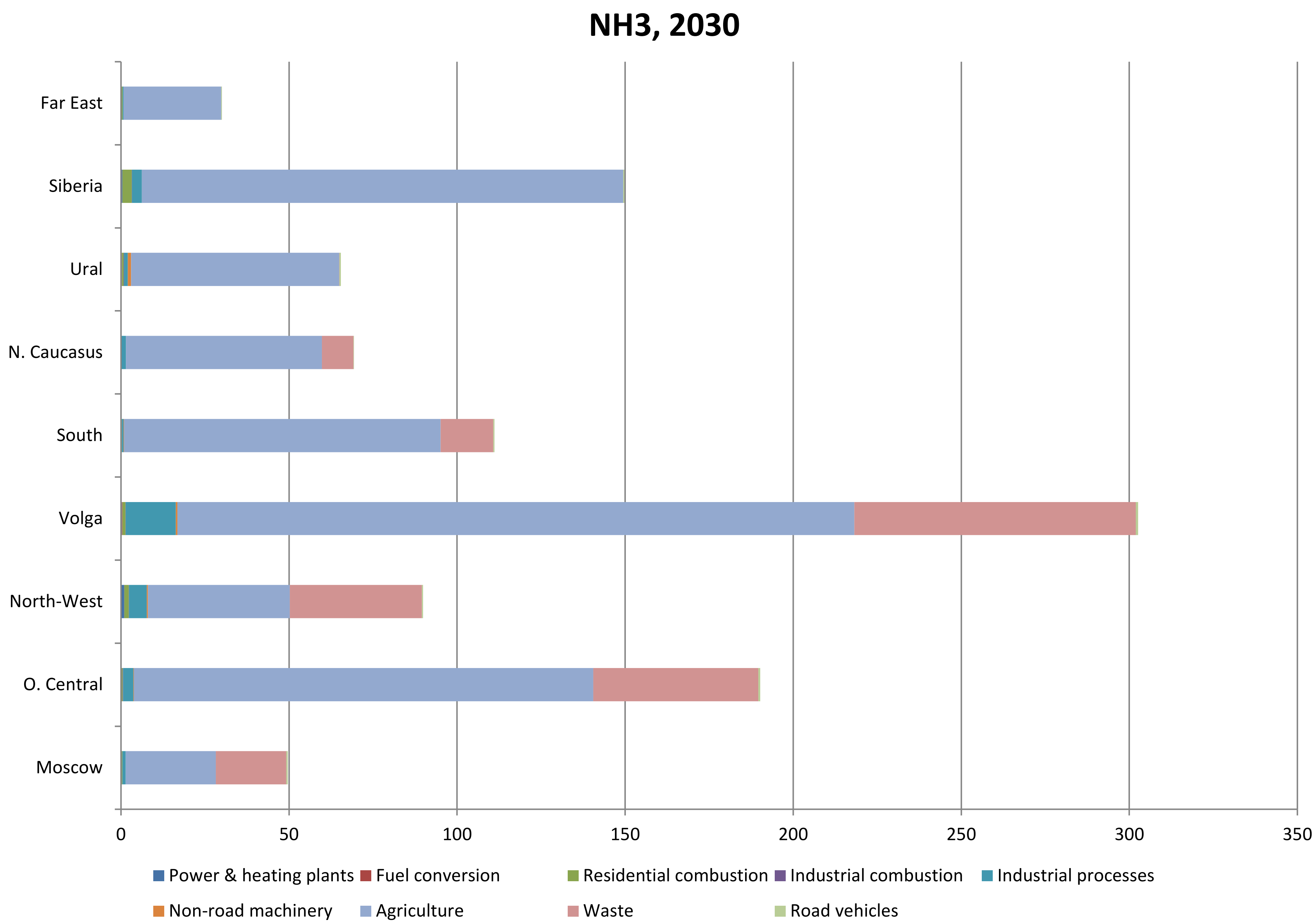
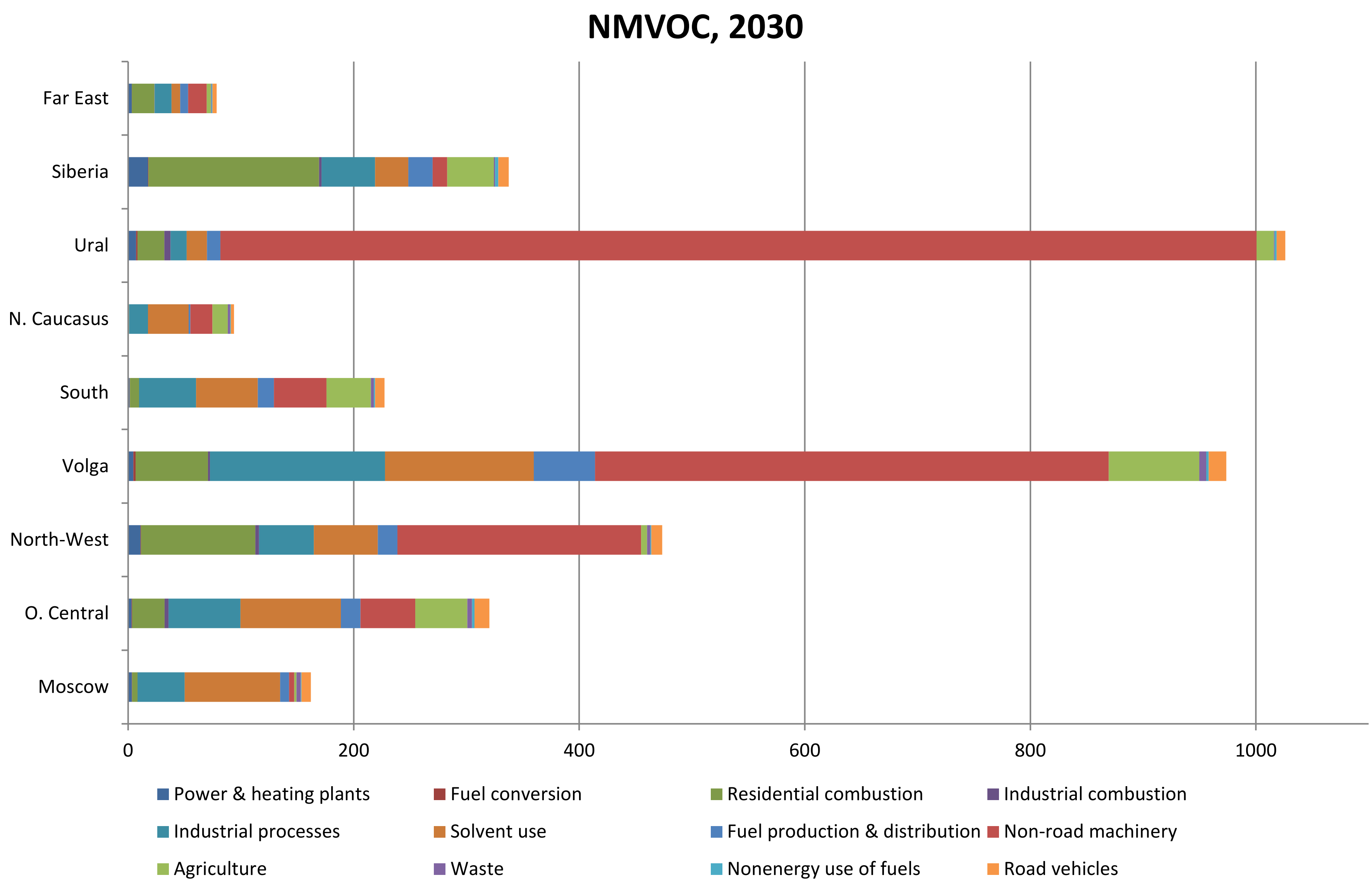
900
1000
Power & heating plants
Fuel conversion
Residential combustion
Industrial combustion
Industrial processes
Non-road machinery
Agriculture
Waste
Road vehicles


SOx, 2030
Far East
Siberia
Ural
N. Caucasus
South
Volga
North-West
O. Central
Moscow
0
200
400
600
800
1000
1200
1400
Power & heating plants
Fuel conversion
Residential combustion
Industrial combustion
Industrial processes
Non-road machinery
Agriculture
Waste
Road vehicles


NH3, 2030
Far East
Siberia
Ural
N. Caucasus
South
Volga
North-West
O. Central
Moscow
0
50
100
150
200
250
300
350
Power & heating plants
Fuel conversion
Residential combustion
Industrial combustion
Industrial processes
Non-road machinery
Agriculture
Waste
Road vehicles


NMVOC, 2030
Far East
Siberia
Ural
N. Caucasus
South
Volga
North-West
O. Central
Moscow
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200
400
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800
1000
Power & heating plants
Fuel conversion
Residential combustion
Industrial combustion
Industrial processes
Solvent use
Fuel production & distribution
Non-road machinery
Agriculture
Waste
Nonenergy use of fuels
Road vehicles

Appendix 6. PRIMES scenarios chosen for analysis.

Scenario name		TSAP_REF2050	PRIMES 2013 REF_CLE	WPE 2014 CLE
Label		PRIMES_2012	PRIMES_2014	PRIMES_2015
Scenario group		TSAP Report #1	TSAP Report #11	TSAP Report #16
Description		PRIMES_REF2050_052012 created from PRIMES_REF_Sep11 with copy of controls from PRIMES_BL2010_REF_032012 with current EU emission vector.	This is the 'Current legislation' reference Scenario for the TSAP Impact Assessment, described in TSAP Report #11. It is based on the PRIMES 2013 Reference Scenario and assumes full and timely implementation of current legislation (for 2025 and 2030 in the least-cost (COB) way).	The updated 'current legislation' (after the bilateral consultations in 2014) of the PRIMES 2013 REFERENCE activity projection (see TSAP Report #16)
Developed		2012	2014	2015
Report		TSAP #1, TSAP #6	TSAP #11	TSAP #16
Years included		2000-2030	2000-2030	2005-2030
Input data	**Emission vector**	MAY12	MARCH13	NOV14
	Control strategy	BSH09_rus_ia_052012	BSH09_russ_ia_112012	RUSS_TS_Dec13
	AGR	POLES_REFERENCE	POLES_REFERENCE	POLES_REFERENCE
	ENE-MOB	EGEO-BL	EGEO_BL_v2	EGEO_BL_v2
	PROC	POLES_PAT2_2050	POLES_PAT2_2050	POLES_PAT2_2050
	VOCP	bl_TSREV_voc_052012	bl_TSREV_voc_052012	bl_TSREV_voc_052012
Assumptions relevant for European part of the Russian Federation		Until 2020 – activity data and control measures as used for the negotiations on the revised Gothenburg Protocol (Amann et al. 2011b). Beyond 2020, the energy projections developed within the FP7 EnerGeo project (www.energeo-project.eu) that rely on scenarios developed with the POLES model[85] have been employed, together with information on the penetration of already agreed national emission control measures (TSAP #6). "Baseline" in EnerGeo: continuation of current European policies with regard to limitation of CO_2.		

References

Amann, M., Bertok, I., Borken-Kleefeld, J., Cofala, J., Heyes, C., Höglund-Isaksson, L., Klimont, Z., Rafaj, P., Schöpp, W., and Wagner, F. 2011b. An updated set of cost-effective emission reductions for the revision of the Gothenburg Protocol: Background paper for the 49th Session of the Working Group on Strategies and Review. Geneva, September 12–15, 2011, CIAM report 4/2011.

[85] https://www.enerdata.net/solutions/poles-model.html accessed in October 2019

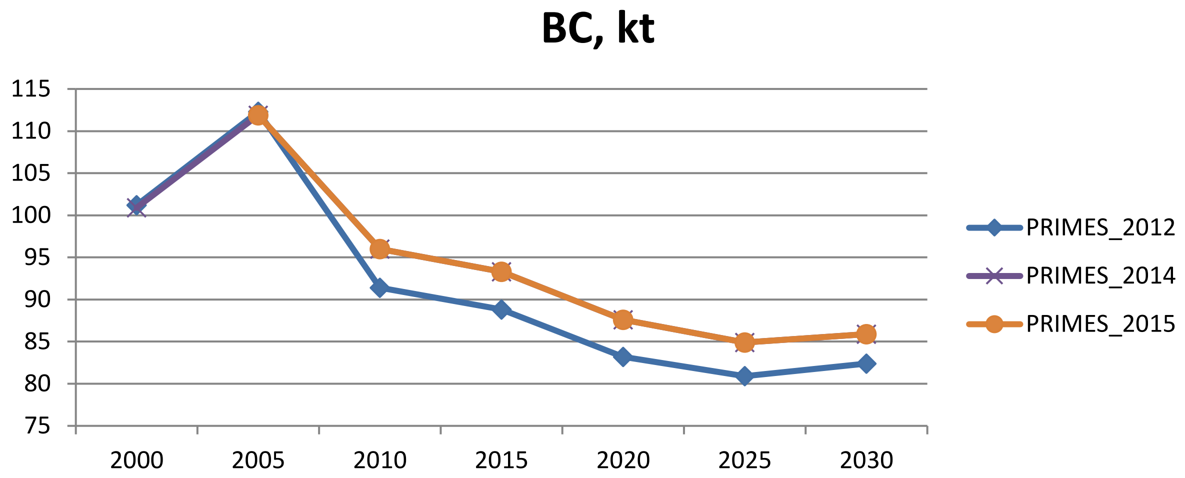
TSAP report 1. IIASA., 2012. Future Emissions of air pollutants in Europe – Current legislation baseline and the scope of further reductions. https://www.iiasa.ac.at/web/home/research/researchPrograms/air/policy/TSAP-BASELINE-20120613.pdf

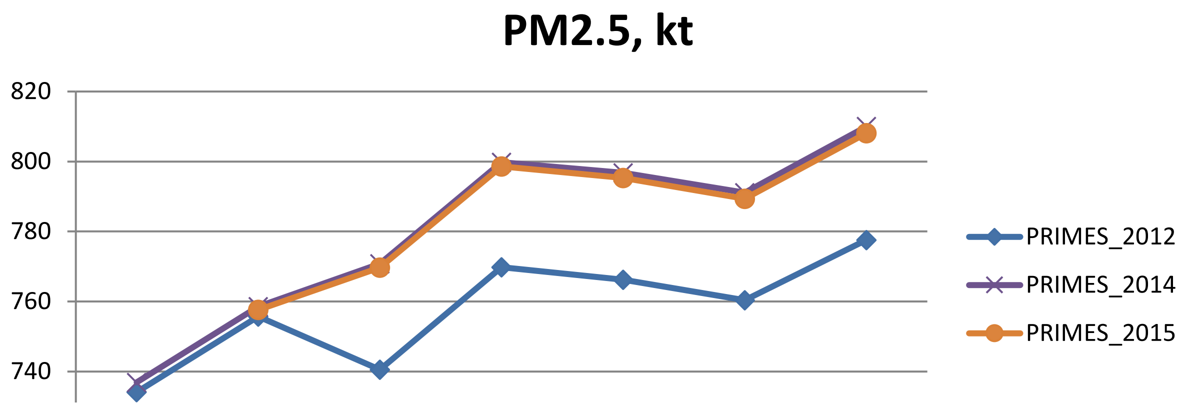
TSAP report 6. IIASA. 2012. TSAP-2012 Baseline: Health and Environmental Impacts. https://www.iiasa.ac.at/web/home/research/researchPrograms/air/policy/TSAP-_IMPACTS-20121126.pdf

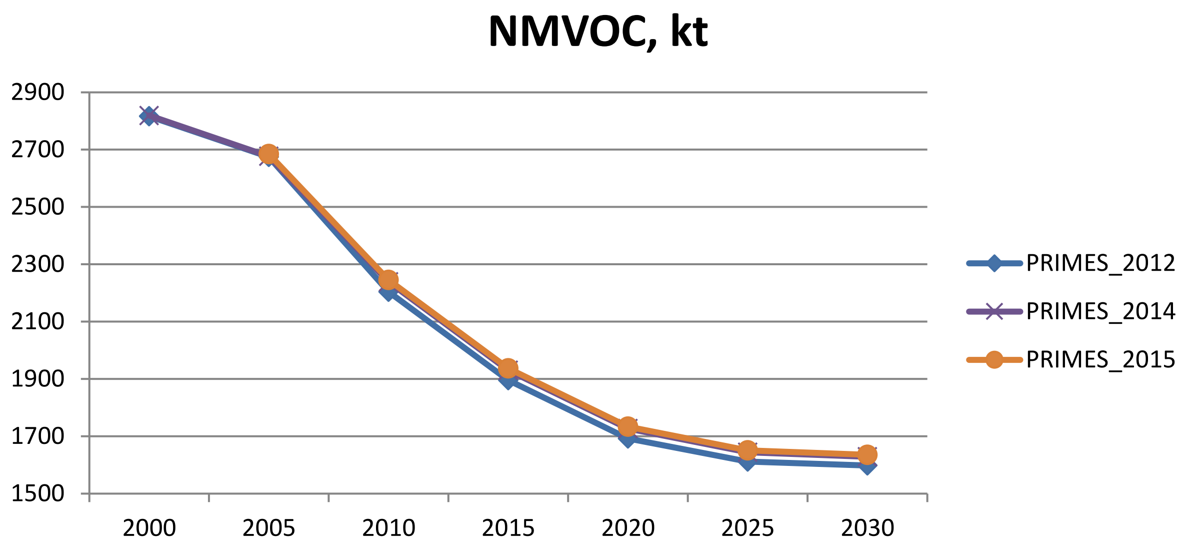
TSAP report 11. IIASA. 2014. The Final Policy Scenarios of the EU Clean Air Policy Package. https://www.iiasa.ac.at/web/home/research/researchPrograms/air/policy/TSAP_11-finalv1-1a.pdf

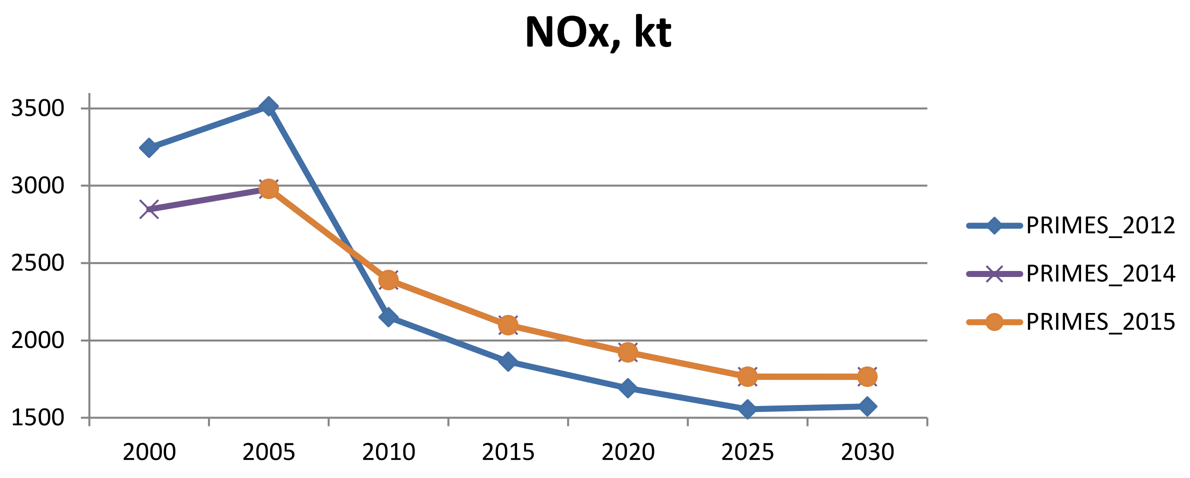
TSAP report 16. IIASA. Adjusted historic emission data, projections, and optimized emission reduction targets for 2030 – A comparison with COM data 2013. Part B> Results for Member States. https://www.iiasa.ac.at/web/home/research/researchPrograms/air/policy/TSAP_16b.pdf

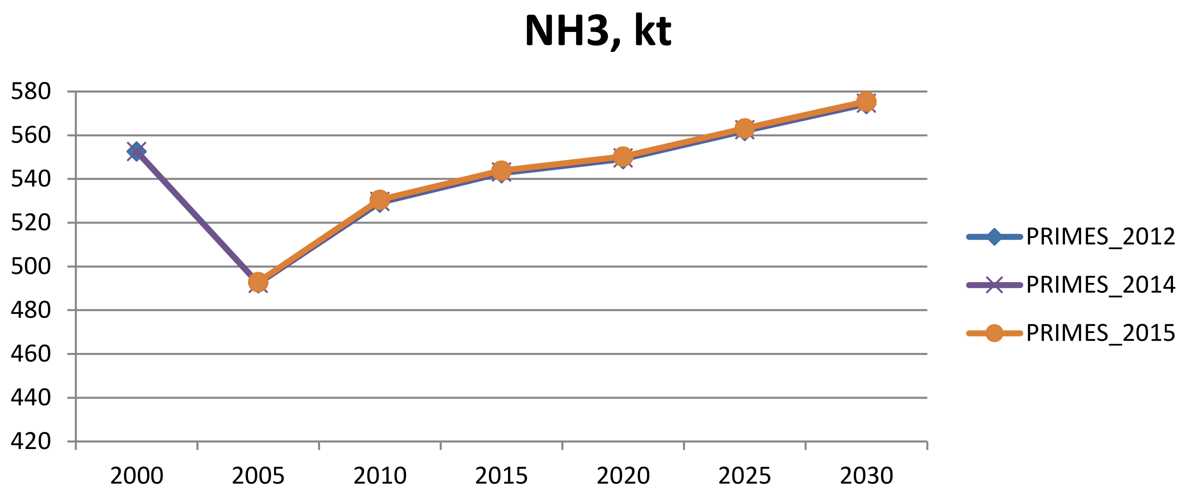
Appendix 7. Emission trends in different PRIMES scenarios.

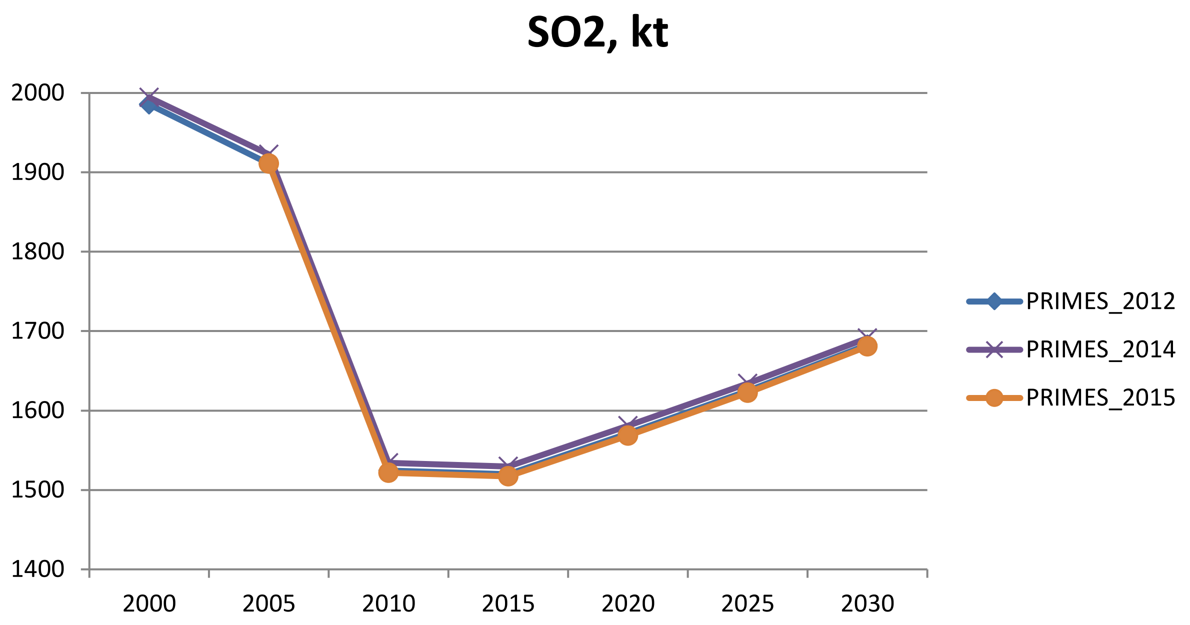






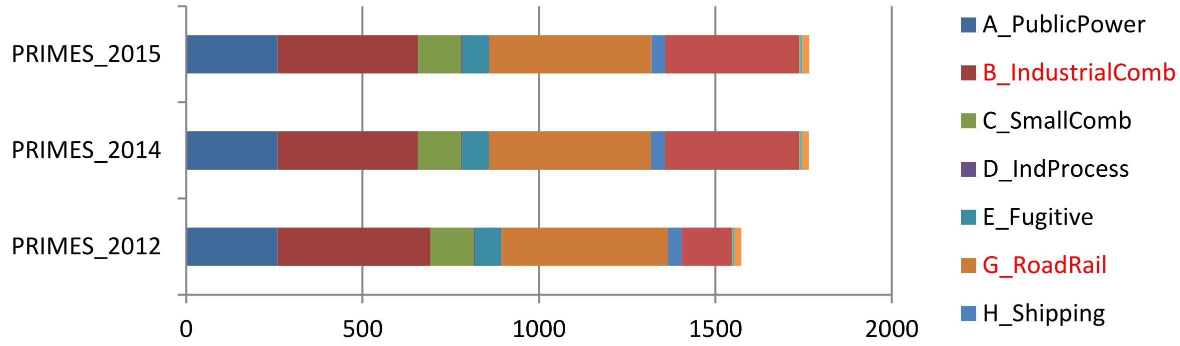

NOx, kt
3500
3000
2500
2000
1500
2000
2005
2010
2015
2020
2025
2030
PRIMES_2012
PRIMES_2014
PRIMES_2015


NH3, kt
580
560
540
520
500
480
460
440
420
2000
2005
2010
2015
2020
2025
2030
PRIMES_2012
PRIMES_2014
PRIMES_2015

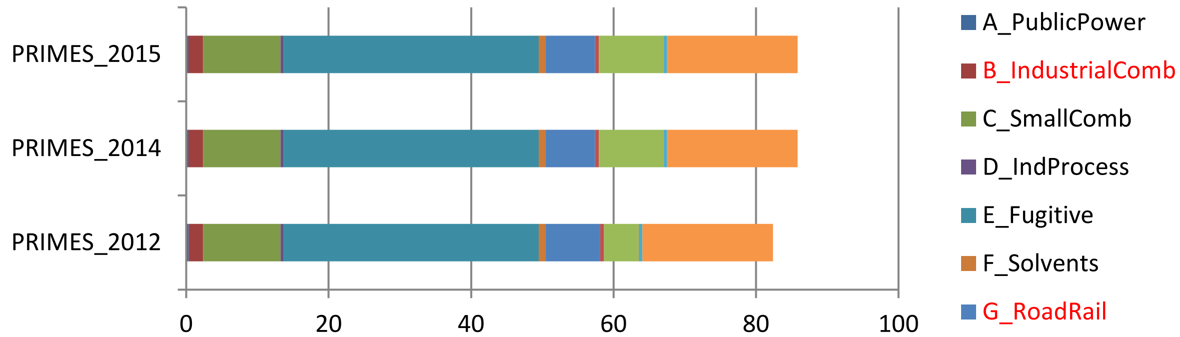

SO2, kt
2000
1900
1800
1700
1600
1500
1400
2000
2005
2010
2015
2020
2025
2030
PRIMES_2012
PRIMES_2014
PRIMES_2015

Appendix 8. Emissions by GNFR categories.

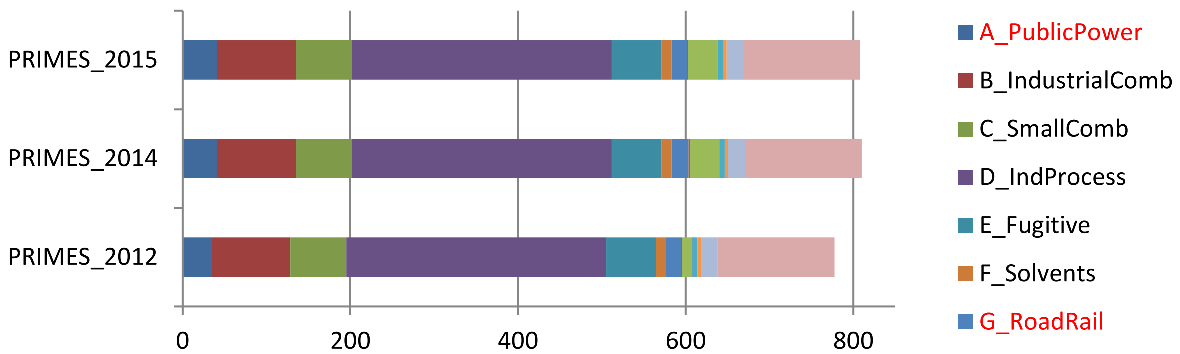
NOx emissions by GNFR categories in 2030, kt

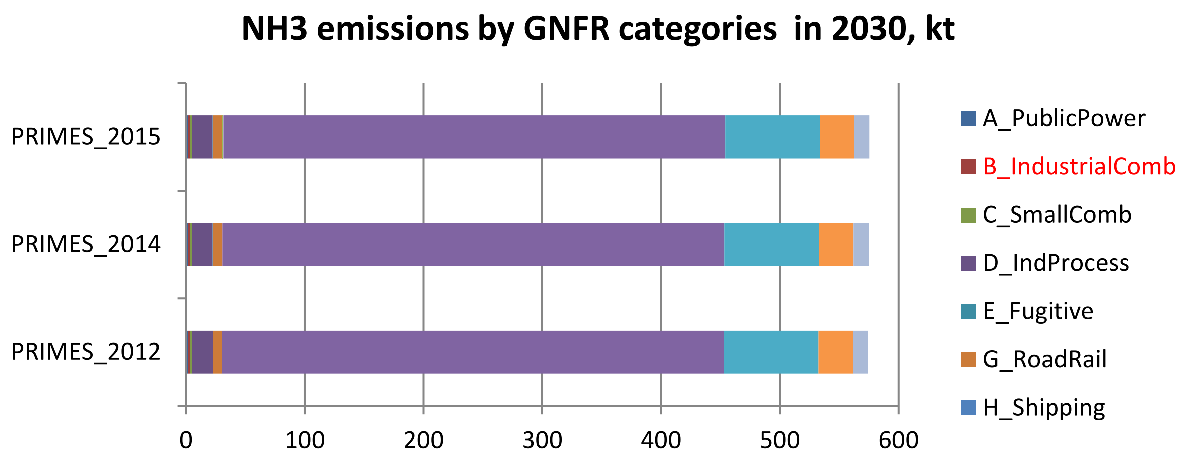


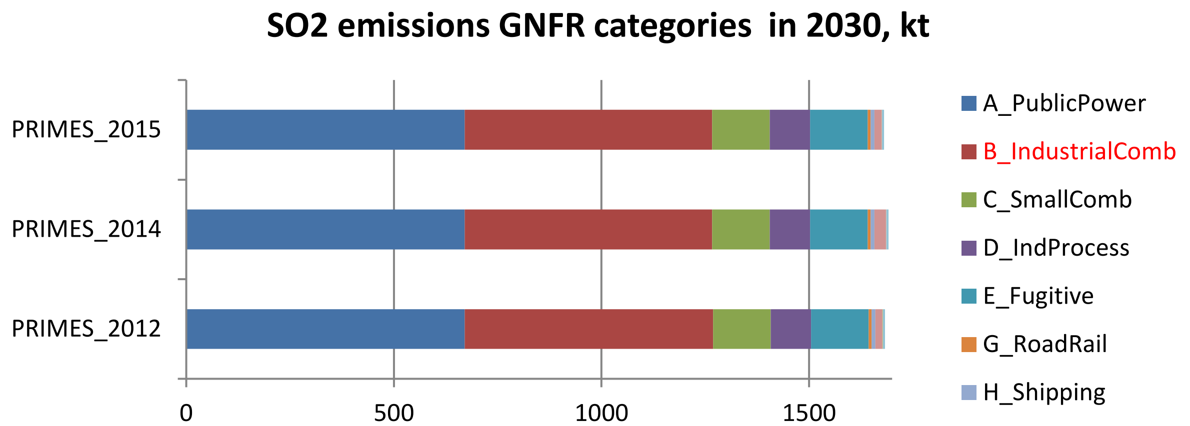
BC emissions by sectors in 2030, kt

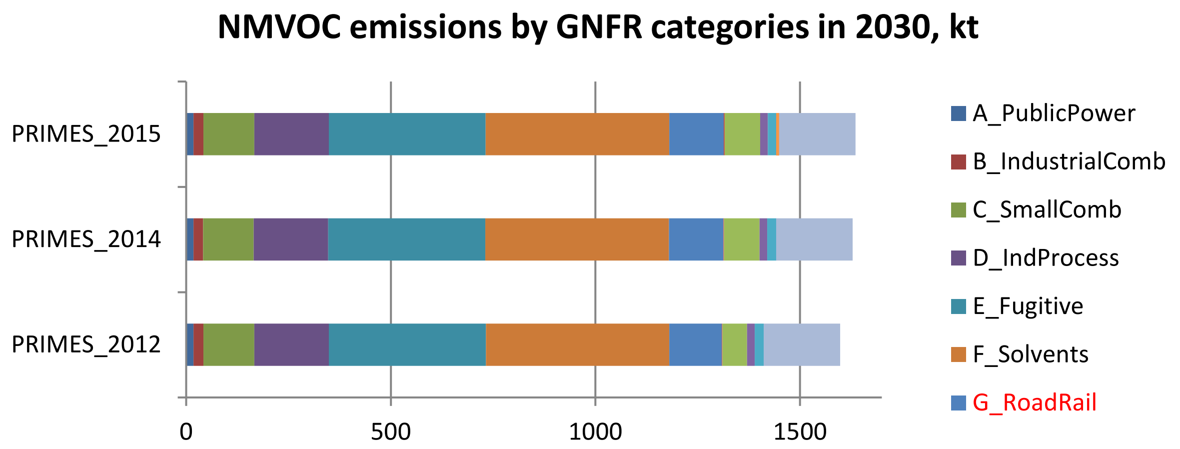


PM2.5 emissions by GNFR categories in 2030, kt




NH3 emissions by GNFR categories in 2030, kt
PRIMES_2015
PRIMES_2014
PRIMES_2012
0
100
200
300
400
500
600
A_PublicPower
B_IndustrialComb
C_SmallComb
D_IndProcess
E_Fugitive
G_RoadRail
H_Shipping


SO2 emissions GNFR categories in 2030, kt
PRIMES_2015
PRIMES_2014
PRIMES_2012
0
500
1000
1500
A_PublicPower
B_IndustrialComb
C_SmallComb
D_IndProcess
E_Fugitive
G_RoadRail
H_Shipping


NMVOC emissions by GNFR categories in 2030, kt
PRIMES_2015
PRIMES_2014
PRIMES_2012
0
500
1000
1500
A_PublicPower
B_IndustrialComb
C_SmallComb
D_IndProcess
E_Fugitive
F_Solvents
G_RoadRail

Appendix 9. Major changes in the latest PRIMES scenarios for ETR.

Important assumptions concerning 2030	PRIMES scenario			Effect on emissions, change in ktonnes					
	2012	2014	2015	NO_x	BC	$PM_{2.5}$	HN_3	SO_x	NMVOC
868 to 361 PJ gas in fuel transformation (CON_COMB)		x	x	-35.5	-0.003	-0.1	-0.1	-2.2	-1.3
From zero to non-zero EF for NO_x and NMVOC from two technological options in bricks production - Tunnel Kiln with end of pipe abatement and Vertical Shaft Brick Kiln with basic dust control			x	0.5					1.0
Lower EF for BC from coal combustion in industrial boilers		x	x		-0.002				
Higher EF for particles from biomass fuel non-boiler combustion in industries		x	x		0.018	0.3			
Road and rail transport									
Lower EF for NO_x from diesel light commercial trucks with 4-stroke engines with high stages of emission control		x	x	-12.7					
Higher EF for NMVOC from motorcycles with 4-stroke engines		x	x						5.3
Alterations in EF for road abrasion, tyre and brake wear		x			-0.7	1.9-2.8			
Non-road transport									
Plus 826 PJ gas from off-road sources with 4-stroke engines (including military sources, households and pipeline compressors)		x	x	239.6	4.2	23.1	0.6	10.5	26.4
Zero EF for gas used in off-road sources with 4-stroke engines (including military sources, households and pipeline compressors)	x		x					-10.5	
Higher EF for $PM_{2.5}$ from biofuel combustion at power plants		x	x			6.3			
From zero to non-zero EF for NMVOC and HN_3 from residential waste combustion			x				0.7		5.9

Appendix 10. Differences in costs between PRIMES scenarios.

Sector	Fuel	Activity unit	Abatement technology	Activity		Unit cost, MEuro/unit		Total costs, MEuro		
				2012	2014	2012	2014	2012	2014	diff
Heavy duty trucks (I)	Diesel	10^3 vehicles	Euro V	1429	1429	1.27	1.57	1818	2249	431
Heavy duty buses (I)	Diesel	10^3 vehicles	Euro V	965	965	1.27	1.57	1228	1519	291
Passenger cars (F)	Gasoline	PJ	Euro V	595	595	0.22	0.56	132	333	201
Heavy duty trucks (F)	Diesel	PJ	Euro V	826	826	0.55	0.77	457	633	176
Heavy duty buses (F)	Diesel	PJ	Euro V	207	207	0.55	0.77	114	159	45
Fugitives from small industrial and business facilities	Non-energy	10^6 people	Good practice stage 1	48	48	4.14	4.98	198	238	40
Cement production industry	Non-energy	Mt	ESP	59	59	0.64	0.99	37	58	21
Light commercial trucks (F)	Gasoline	PJ	Euro V	55	55	0.22	0.56	12	31	19
Non-road mobile: agriculture	Diesel	PJ	Stage I	142	142	0.06	0.14	8	20	12
Passenger cars (F)	Diesel	PJ	Euro IV	135	135	0.06	0.14	8	19	11
Light commercial trucks (I)	LPG	10^3 vehicles	Euro V	125	125	0.05	0.03	7	4	-3
Light commercial trucks (I)	Gasoline	10^3 vehicles	Euro V	1377	1377	0.05	0.03	74	42	- 32
Passenger cars (I)	LPG	10^3 vehicles	Euro V	2183	2183	0.05	0.03	117	67	-50
Passenger cars (I)	Diesel	10^3 vehicles	Euro IV	4810	4810	0.07	0.05	324	253	-71
Light commercial trucks (I)	Diesel	10^3 vehicles	Euro V	2778	2778	0.10	0.07	280	204	-76
Passenger cars (I)	Gasoline	10^3 vehicles	Euro V	25184	25184	0.05	0.03	1350	769	-581

Appendix 11. Spatial distribution of BC emissions in Russia.

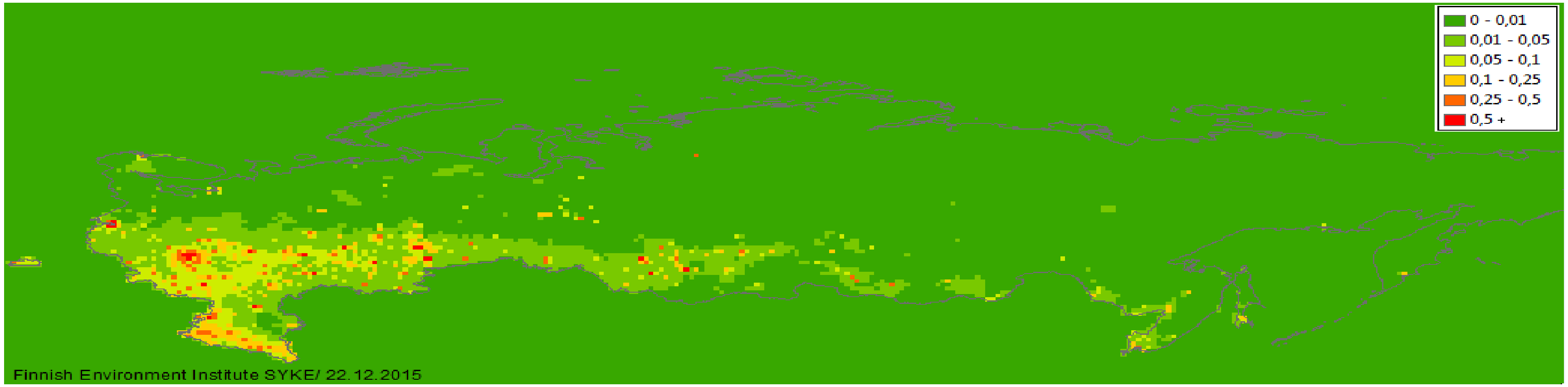


Figure 11.1. ACCMIP emissions in 2000, ktonnes/year.

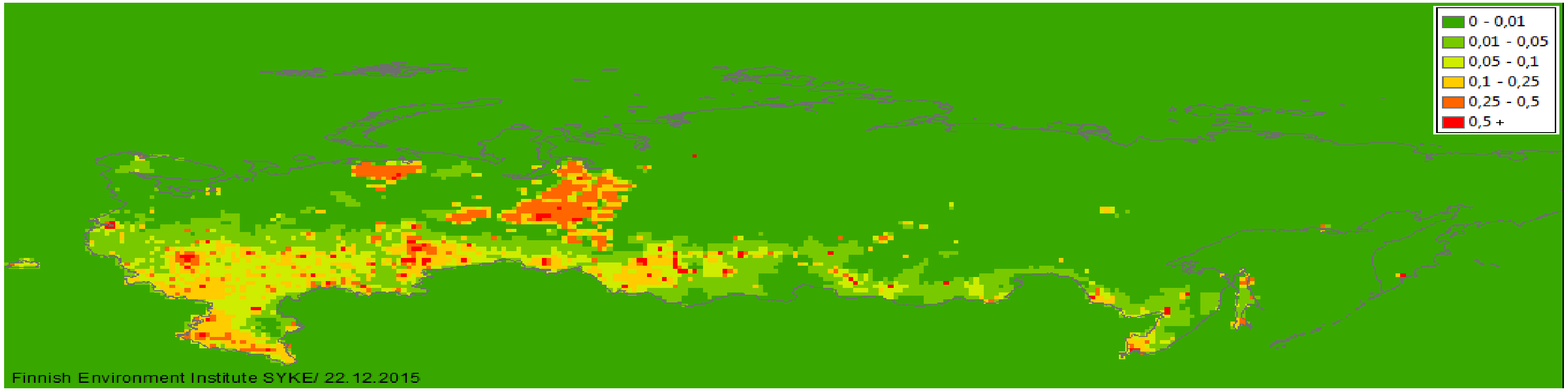


Figure 11.2. Total ECLIPSE_V5a emissions in 2000, ktonnes/year.

Appendix 12. BC emissions by source sector – Russian Federation vs ETR.

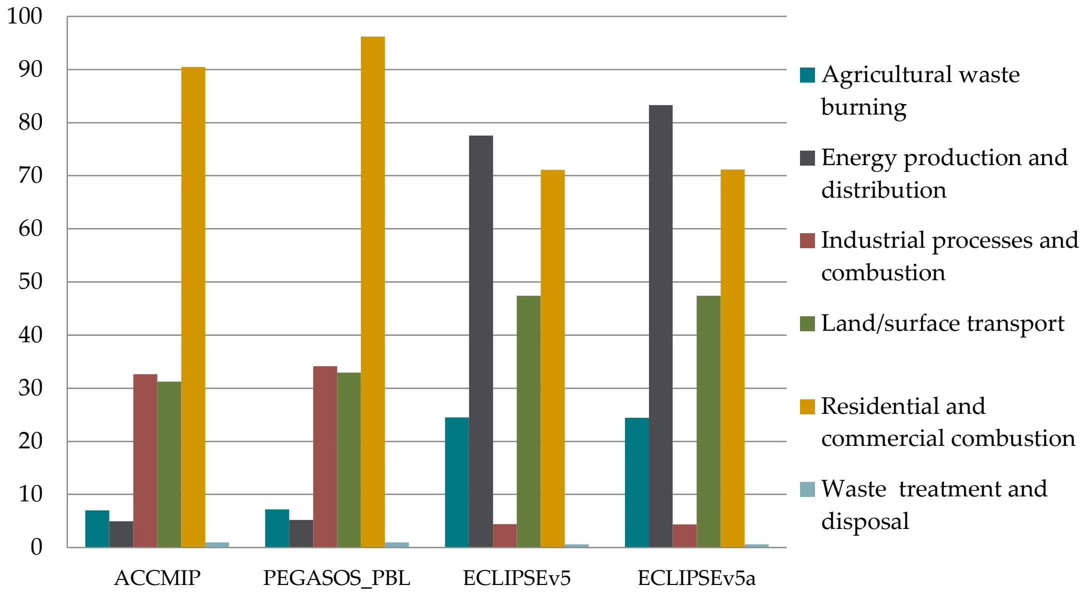


Figure 12.1. BC emissions in 2000, in the Russian Federation, by source sector, ktonnes.

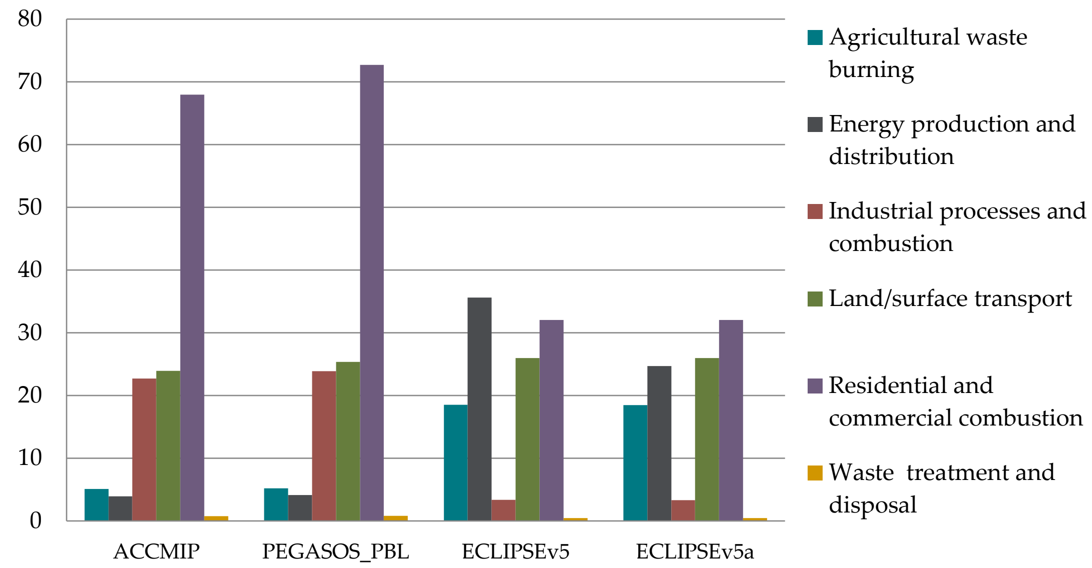


Figure 12.2. BC emissions in 2000, in the European Territory of Russia, by source sector, ktonnes.

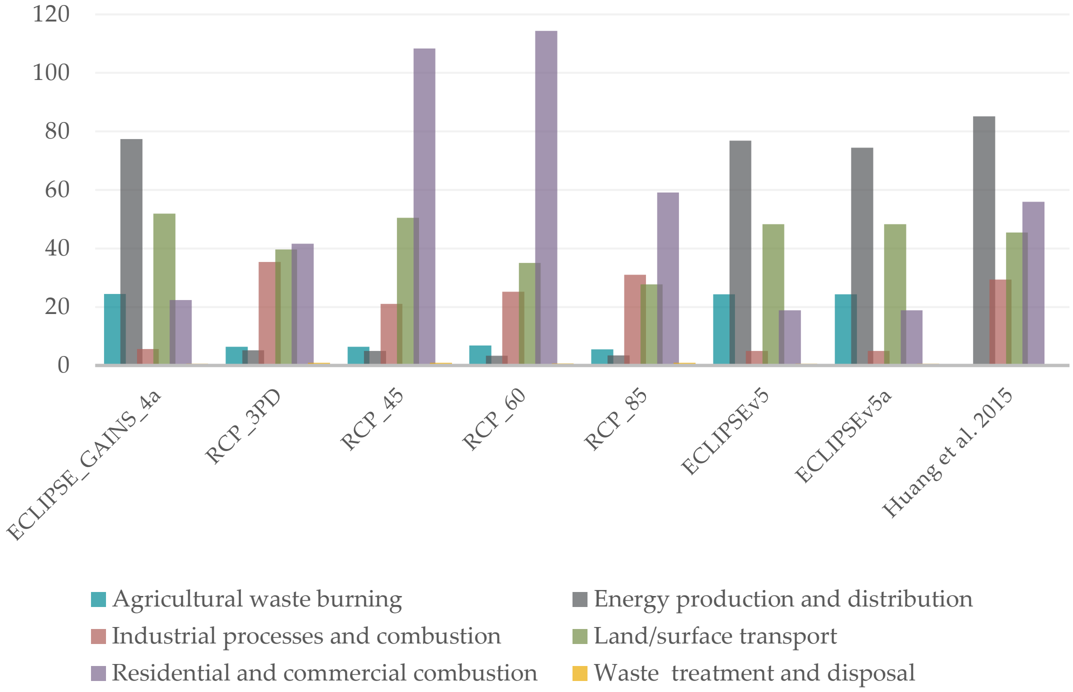


Figure 12.3. BC emissions in 2010, in the Russian Federation, by source sector, ktonnes.

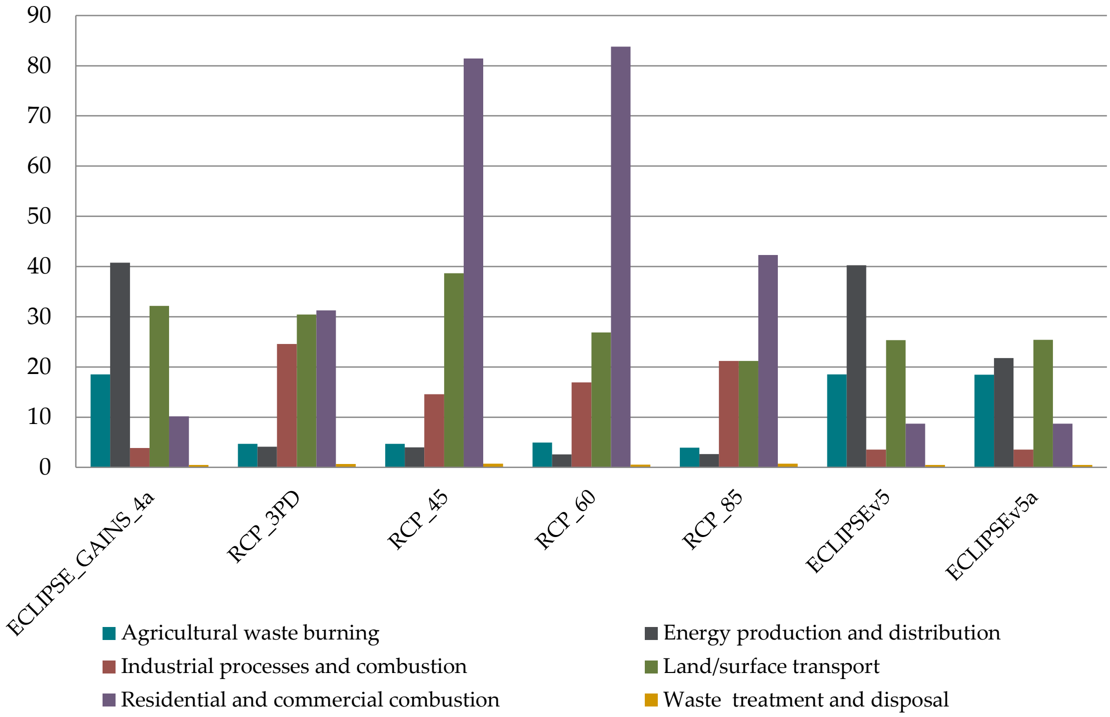


Figure 12.4. BC emissions in 2010, in the European Territory of Russia, by source sector, ktonnes.

Appendix 13. BC emissions in 2010 by GAINS Russia region.

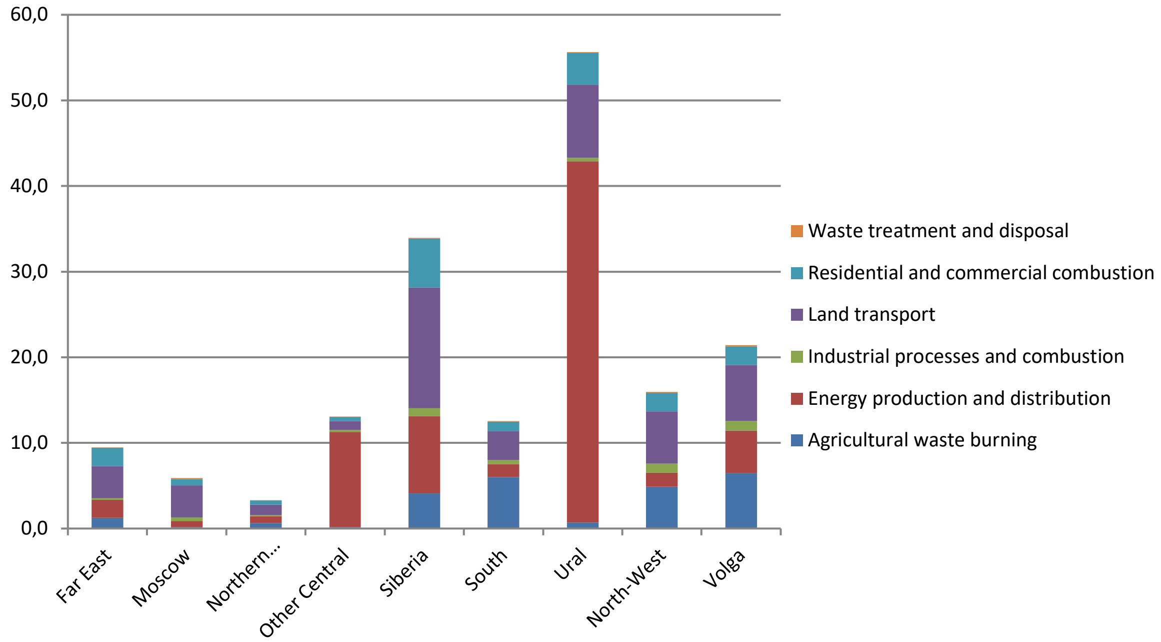


Figure 13.1. BC emissions in ECLIPSE_v5a by region and sector in 2010, ktonnes.

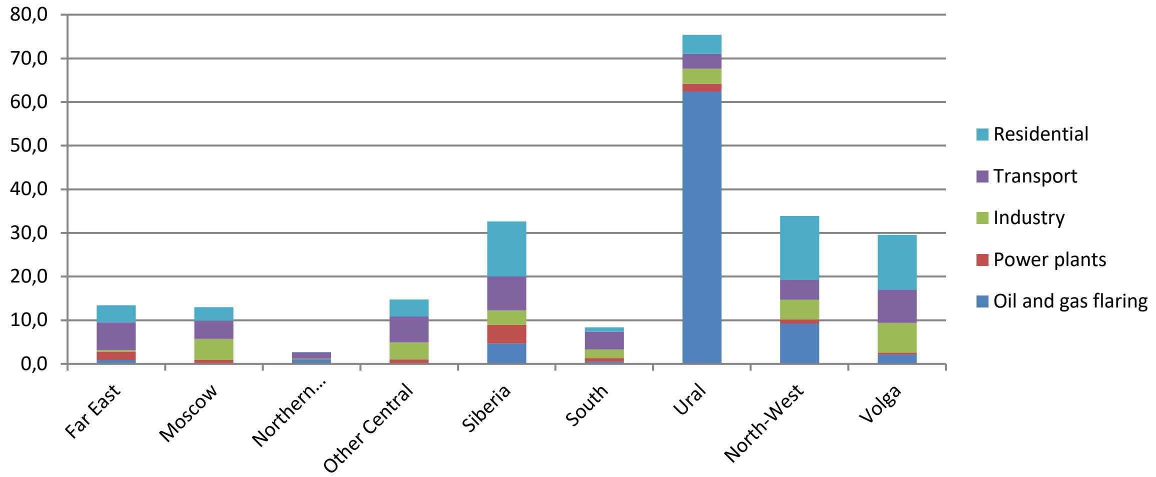


Figure 13.2. BC emissions in Huang et al. 2015 by region and sector in 2010, ktonnes.

References

Huang, K., Fu, J. S., Prikhodko, V., J. Storey, M., Romanov, A., Hodson, E.L., Cresko, J., Morozova, I., Ignatieva, Y, and Cabaniss, J. 2015. Russian anthropogenic black carbon: Emission reconstruction and Arctic black carbon simulation, J. Geophys. Res. Atmos., 120, pp. 11,306–11,333, doi: 10.1002/ 2015JD023358.

Appendix 14. BC emissions in 2015 as in ELCIPSE_v5a.

The most important emission sources are highlighted with color.

Table 14.1. Russian black carbon emissions in 2015, ktonnes.

Sector	Coal	Liquid fuels	Gaseous fuels	Biomass	Industrial processes	Other	Non-exhaust	Sum
Power & heating plants	0.1	0.8	0.0	0.0		0.0		0.9
Fuel conversion	0.0	0.2	0.0					0.2
Residential combustion	2.8	0.3	0.0	7.7				10.8
Industrial combustion	0.1	0.1	0.0	0.4		0.9		1.4
Industrial processes					6.1	0.6		6.6
Fuel production & distribution					0.0			0.0
Road vehicles		10.4	0.0				0.3	10.7
Non-road machinery		10.4	3.0					13.4
Agriculture						18.3		18.3
Waste						16.5		16.5
Sum	**3.0**	**22.0**	**3.1**	**8.1**	**6.1**	**36.3**	**0.3**	**78.8**

Table 14.2. Swedish black carbon emissions in 2015, ktonnes.

Sector	Coal	Liquid fuels	Gaseous fuels	Biomass	Industrial processes	Other	Non-exhaust	Sum
Power & heating plants	0.0	0.0	0.0	0.1				0.1
Fuel conversion		0.0	0.0					0.0
Residential combustion	0.0	0.0	0.0	1.4				1.4
Industrial combustion	0.0	0.0	0.0	0.1		0.0		0.1
Industrial processes					0.0	0.0		0.0
Fuel production & distribution					0.0			0.0
Road vehicles		0.6	0.0				0.2	0.7
Non-road machinery		0.5						0.5
Agriculture						0.0		0.0
Waste						0.1		0.1
Sum	**0.0**	**1.1**	**0.0**	**1.6**	**0.0**	**0.1**	**0.2**	**3.0**

Table 14.3. Finnish black carbon emissions in 2015, ktonnes.

Sector	Coal	Liquid fuels	Gaseous fuels	Biomass	Industrial processes	Other	Non-exhaust	Sum
Power & heating plants	0.0	0.0	0.0	0.0		0.0		0.0
Fuel conversion		0.0	0.0	0.0				0.0
Residential combustion	0.0	0.2	0.0	3.7				3.8
Industrial combustion	0.0	0.0	0.0	0.0		0.0		0.0
Industrial processes					0.0	0.0		0.0
Fuel production & distribution					0.0			0.0
Road vehicles		0.8	0.0				0.2	1.0
Non-road machinery		0.7						0.7
Agriculture						0.0		0.0
Waste						0.1		0.1
Sum	**0.0**	**1.7**	**0.0**	**3.7**	**0.0**	**0.1**	**0.2**	**5.7**

Appendix 15. BC emissions in ETR according to three recent scenarios in GAINS Europe.

Emissions from the most important sources are highlighted by color.

Table 15.1. Black carbon emissions from combustion sources in ETR in 2010, according to different scenarios, ktonnes.

Source sector	Coal			Liquid fuels			Gaseous fuels			Biomass		
	TSAP	V4a	V5a	TSAP	V4a	V5a	TSAP	V4a	V5a	TSAP	V4a	V5a
Power & heating plants	0.1	0.2	0.1	0.1	0.7	0.7	0.0	0.1	0.1	0.0	0.1	0.0
Fuel conversion	0.0	0.0	0.0	0.3	0.1	0.1	0.0	0.0	0.0	0.0		0.0
Residential combustion	3.5	2.8	2.2	0.2	0.1	0.2	0.0	0.0	0.0	4.6	**3.5**	**3.0**
Industrial combustion	0.0	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.3
Road vehicles				13.5	12.0	8.2	0.0	0.0	0.0			
Non-road machinery	0.0			8.1	9.8	6.4	5.0	4.7	4.3			
Non-energy use of fuels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Sum	**3.6**	**3.0**	**2.4**	**22.2**	**22.8**	**15.7**	**5.1**	**4.8**	**4.4**	**4.8**	**3.7**	**3.4**

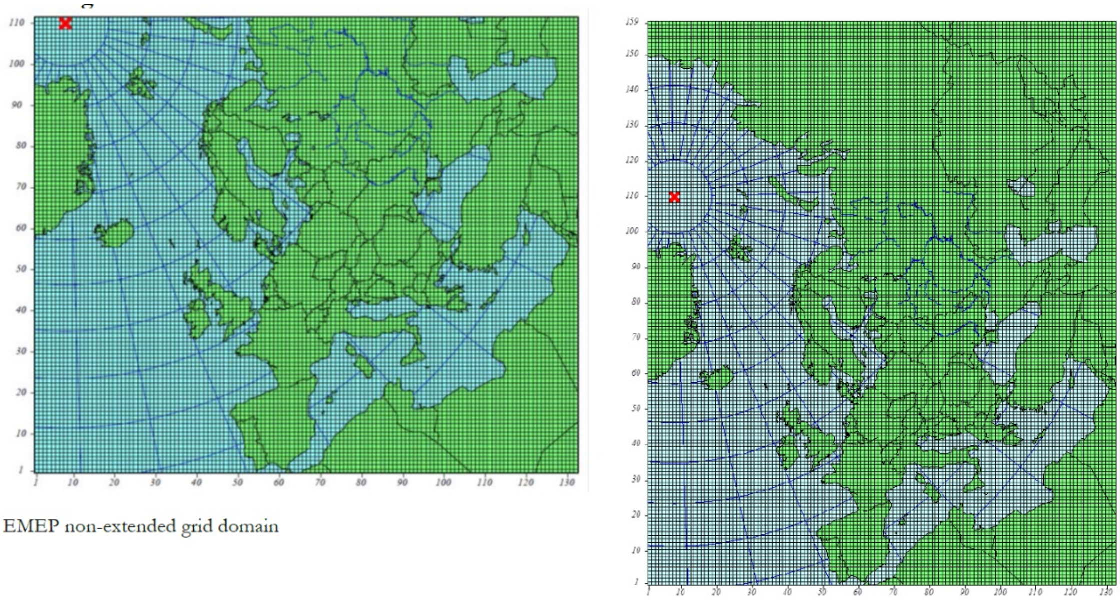
Table 15.2. Black carbon emissions from non-combustion sources in ETR in 2010, according to different scenarios, ktonnes.

Source sector	Industrial processes & production			Other			Non-exhaust		
	TSAP	V4a	V5a	TSAP	V4a	V5a	TSAP	V4a	V5a
Industrial processes	4.9	4.9	4.9	1.3	1.4	1.4			
Fuel production & distribution	0.0	0.0	0.0						
Road vehicles							0.2	0.5	0.2
Non-road machinery									
Agriculture				18.3	18.3	18.3			
Waste				35.6	35.6	16.5			
Non-energy use of fuels									
Sum	**4.9**	**4.9**	**4.9**	**55.3**	**55.4**	**36.3**	**0.2**	**0.5**	**0.2**

Appendix 16. EMEP/MSC-W model description.

The EMEP MSC-W model is a 3-dimensional Eulerian model that calculates emissions, transport, chemistry and loss processes of pollutants. The model's main purpose is to support governments in their efforts to design effective emission control strategies. The model simulates air concentrations of gaseous (including SO_2, NO_2 and ozone) and particulate pollutants, as well as acidifying and eutrophying depositions on ecosystems. Simpson et al. 2012 provides a comprehensive documentation on the version rv4.0 of the EMEP MSC-W model, which was the 3-rd Open Source release in summer 2012. The article gives a detailed description of the model's grid and domain, input data (emissions, meteorology, land-use etc.), physical (advection and turbulent dispersion, dry deposition, wet scavenging) and chemical processes.

EMEP grid domains of interest for EMEP modelling in the Russian Federation are non-extended domain and extended domain. The non-extended grid covers ETR only while the extended grid covers almost the entire area of the Russian Federation, see the maps in Figure 16.1.



EMEP non-extended grid domain

EMEP extended grid domain

Figure 16.1. EMEP MSC-W model domains: extended (newer) grid (right) vs. non-extended (elder) grid (left).

The model version used for this work – rv4.8 – is the 7-th Open Source release in 2015. A number of developments and improvements were implemented in the model between those two versions. Below, the main changes in the rv4.8 compared to rv4.0 are outlined, whereas all details on the model development can be found in the annual EMEP Status Reports (www.emep.int).

Setup and input

- Horizontal grid - improvement of grid resolution from 50x50 km² to 0.1°x0.1°;
- Vertical grid - transition from limited sigma to more flexible hybrid coordinates; improvement of the vertical resolution of surface layer (from 92 to 50 m);
- More flexible use of different meteorological input data.

Emissions

- Increased flexibility of input requirements (up to three different data sets with different resolutions and grids);
- More flexible time profiles;
- Improved emission of natural particles (sea salt and windblown dust).

Processes

- Transport - improved advection algorithm (to avoid problems with extreme divergence cases);
- Chemistry - aerosol thermo-dynamical module MARS (smoothing between different chemical regimes); uptake rates of reactive gases by aerosols (formation of coarse NO_3 on sea salt and mineral dust particles, N_2O_5 hydrolysis forming HNO).

References

Simpson et al. 2012. The EMEP MSC-W chemical transport model – technical description. Atmos. Chem. Phys., 12, 7825-7865, 2012. https://doi.org/10.5194/acp-12-7825-2012.

Appendix 17. Murmansk Oblast description.

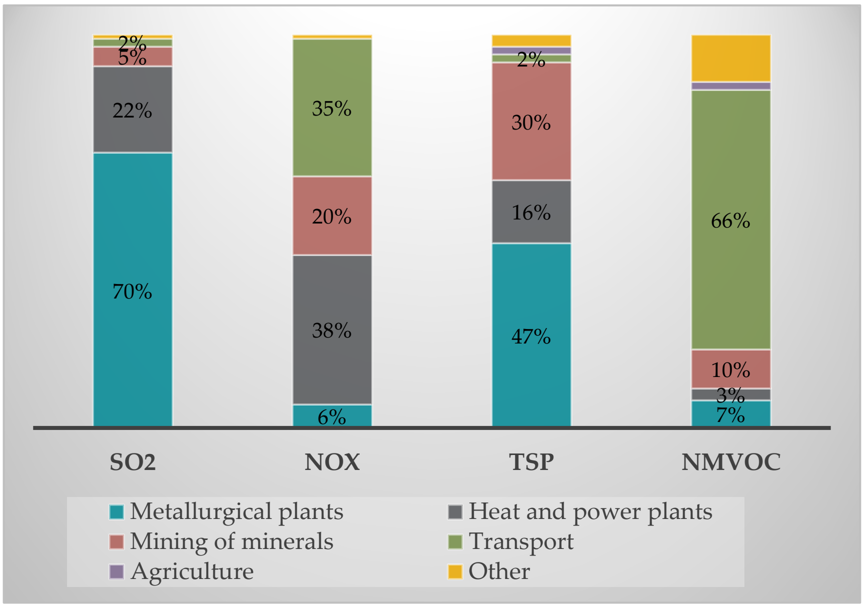
Figure 17.1. Location of Murmansk oblast on the map of the Russian Federation.

Murmansk oblast is a subject of the Russian Federation belonging to North-Western federal district. It has borders with Norway and Finland. There are many industrial enterprises in Murmansk region, located mainly in its northern and central parts.

Main industrial sector in Murmansk oblast is metallurgy – production of nickel, aluminium and iron and steel. Two major heat and power plants are located in Murmansk and Apatity. Agricultural sector is not well-developed.

Sectoral structure of four main air pollutant emissions in Murmansk oblast in 2012 is presented in Figure 17.2. Metallurgical enterprises obviously make substantial input into the total emissions of SO_2 and TSP. Transport contributes a lot to the total emissions of NO_x and NMVOC but is less significant for emissions of SO_2 and TSP.

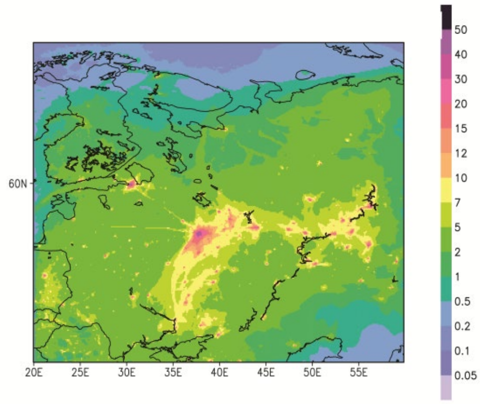
Figure 17.2. Sectoral structure of emissions of main pollutants in Murmansk oblast in 2012.



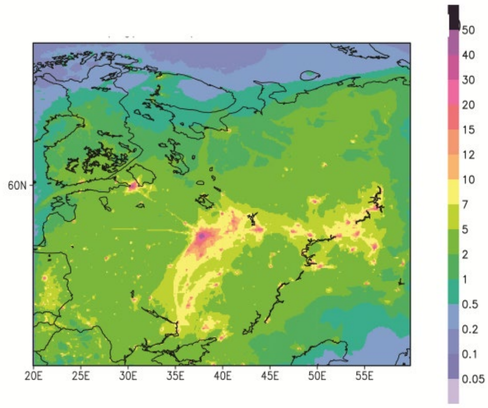
Appendix 18. EMEP/MSC-W test model runs – results.

Figure 18.1. Model test run at the resolution 0.1x0.1° : ground-level annual-average concentrations of SO_2 (a, b) and NO_2 (c, d) as modelled by SRI Atmosphere (b, d) and by MET Norway (a, c), μg/m³, their differences for SO_2 (e) and NO_2 (f), μg/m³

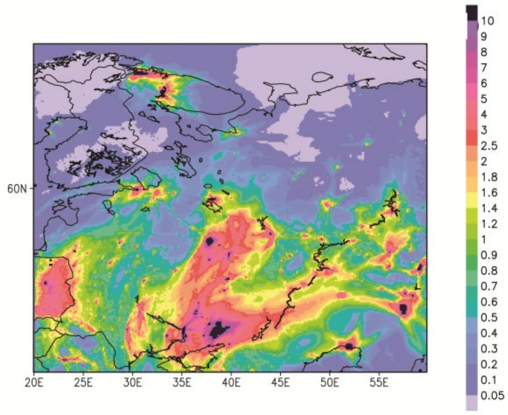
(a)



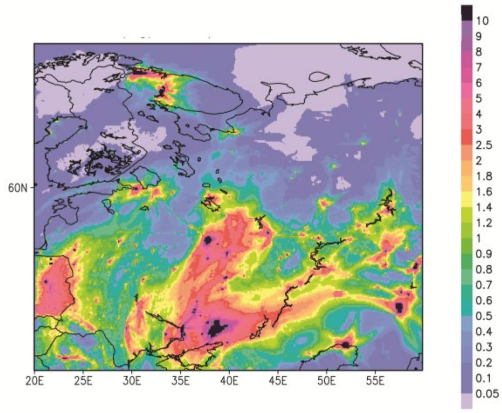
(b)



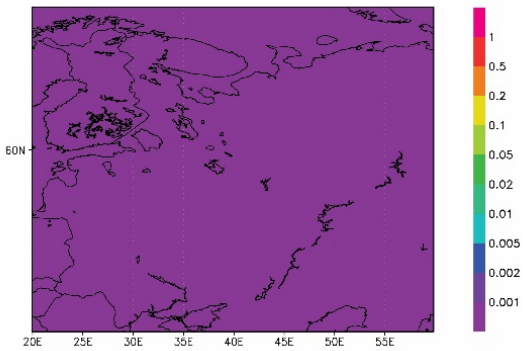
(c)



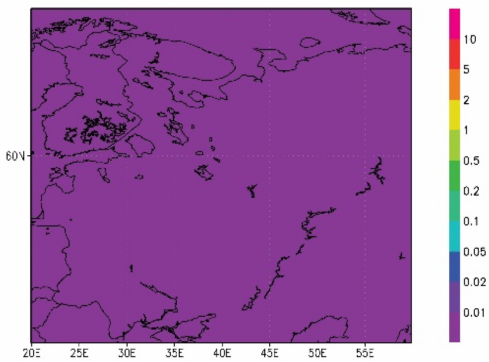
(d)



(e)



(f)



Appendix 19. SO_2 emissions by subject: CEIP vs. national data, 2012.

EMEP code	Subject of the Russian Federation (ETR)	SO_2, tonnes		
		National data[86]	CEIP	Difference
501	Republic of Adygea	963	5413	-4450
502	Republic of Bashkortostan	42324	96457	-54133
505	Republic of Dagestan	3783	12779	-8996
506	Republic of Inhushetia	179	2123	-1944
507	Kabardino-Balkar Republic	623	3605	-2982
508	Republic of Kalmykia	320	1450	-1130
509	Karachay-Cherkess Republic	481	1779	-1298
510	Republic of Karelia	64047	6873	57174
511	Komi Republic	106107	12299	93808
512	Mari El Republic	1815	10451	-8636
513	Republic of Mordovia	1013	5685	-4672
515	Republic of North Ossetia-Alania	945	2783	-1838
516	Republic of Tatarstan	28169	47961	-19792
518	Udmurt Republic	4932	12811	-7879
520	Chechen Republic	1120	20739	-19619
521	Chuvash Republic	1301	7692	-6391
523	Krasnodar Krai	8493	34677	-26184
526	Stavropol Krai	6402	28113	-21711
529	Arkhangelsk Oblast	81500	23383	58117
530	Astrahan Oblast	48892	5444	43448
531	Belgorod Oblast	16810	38678	-21868
532	Bryansk Oblast	1953	6994	-5041
533	Vladimir Oblast	4183	11787	-7604
534	Volgograd Oblast	9630	35613	-25983
535	Vologda Oblast	54455	29457	24998
536	Voronezh Oblast	4639	11358	-6719
537	Ivanovo Oblast	2993	10956	-7963
539	Kaliningrad Oblast	5500	7888	-2388
540	Kaluga Oblast	1172	4090	-2918

[86] Based on statistics by the National Statistical Committee; in these numbers, emissions from certain sectors are excluded since they only are calculated on the ETR level (see Chapter 5.3.3.1). The total number reported to EMEP in 2014 (1200900 tonnes) is therefore higher than the sum of emissions from all subjects.

EMEP code	Subject of the Russian Federation (ETR)	SO_2, tonnes		
		National data[86]	CEIP	Difference
543	Kirov Oblast	16037	23913	-7876
544	Kostroma Oblast	4491	16479	-11988
546	Kursk Oblast	2408	12059	-9651
547	Leningrad Oblast	27596	61607	-34011
548	Lipetsk Oblast	20362	14285	6077
550	Moscow Oblast	19263	88537	-69274
551	Murmansk Oblast	194885	13081	181804
552	Nizhny Novgorod Oblast	19505	53601	-34096
553	Novgorod Oblast	2424	6810	-4386
556	Orenburg Oblast	118200	31134	87066
557	Oryol Oblast	760	6598	-5838
558	Penza Oblast	2436	9141	-6705
559	Perm Krai	12517	46981	-34464
560	Pskov Oblast	3079	3364	-285
561	Rostov Oblast	67677	67471	206
562	Ryazan Oblast	25437	37449	-12012
563	Samara Oblast	34831	80155	-45324
564	Saratov Oblast	10492	38375	-27883
567	Smolensk Oblast	1772	9861	-8089
568	Tambov Oblast	1930	14833	-12903
569	Tver Oblast	3097	14879	-11782
571	Tula Oblast	17921	65107	-47186
573	Ulyanovsk Oblast	2337	13754	-11417
576	Yaroslavl Oblast	15780	23811	-8031
577	Moscow City	20101	24891	-4790
578	St. Petersburg City	7866	20850	-12984
583	Nenets Autonomous Okrug	10146	363	9783
Total ETR		**1168094 (1200900)**	**1298727**	**-130633 (-97827)**

Appendix 20. SO_2 emissions by EMEP grid cell: CEIP vs. national data, 2012.

Xmod	Ymod	Xoff	Yoff	Emissions, CEIP, t	Emissions, _Rosstat, t	Recommendations to CEIP regarding data corrections
81	101	46	90	3946	104779	Recommended corrected value – as in Rosstat
93	121	58	110	201.45	70070	Recommended corrected value – as in Rosstat
127	122	92	111	6642	65545	**Orsk City is probably not considered in the CEIP data** Recommended corrected value – as in Rosstat
91	96	56	85	61	42051	Recommended corrected value – as in Rosstat
85	101	50	90	155	33878	Recommended corrected value – as in Rosstat
83	102	48	91	728	21256	Recommended corrected value – as in Rosstat
95	105	60	94	185	20383	Recommended corrected value – as in Rosstat
118	118	83	107	1353	19288	**Large point source should be moved from cell 83_108 to cell 83_107. Value in cell 83_108 should be increased to 19 288 tonnes**
118	119	83	108	30803	192	
119	118	84	107	7532	24	**Only backgroud emissions** Recommended corrected value – as in Rosstat
94	104	59	93	11562	33096	Recommended corrected value – as in Rosstat
122	110	87	99	25389	3240	Recommended corrected value – as in Rosstat
121	110	86	99	27784	8489	Recommended corrected value – as in Rosstat
121	108	86	97	545	6984	Recommended corrected value – as in Rosstat
130	100	95	89	23831	2996	Recommended corrected value – as in Rosstat
123	89	88	78	32785	111	**These emissions seem to origin in Kharkov (Ukraine)** Recommended corrected value – as in Rosstat
113	104	78	93	6530	14060	Recommended corrected value – as in Rosstat
113	103	78	92	39437	438	Recommended corrected value – as in Rosstat
101	93	66	82	43233	17577	Recommended corrected value – as in Rosstat
112	95	77	84	46814	21584	Recommended corrected value – as in Rosstat
105	98	70	87	23332	31345	Recommended corrected value – as in Rosstat
130	101	95	90	1020	3311	Recommended corrected value – as in Rosstat
131	92	96	81	46006	59469	Recommended corrected value – as in Rosstat

Appendix 21. EMEP/MSC-W model runs with updated input emissions.

50x50 km² resolution

Figure 21.1. Nitrogen oxides: Ground-level annual-average concentrations (upper panel) and corresponding emissions (middle panel), as modelled based on the national emission data (left) and based on the data prepared by CEIP (right). Lower panel: left – differences in the concentrations between the two model runs; right – differences in the corresponding emissions. Unit for concentrations – μg/m³, unit for emissions – mg/m² per year.

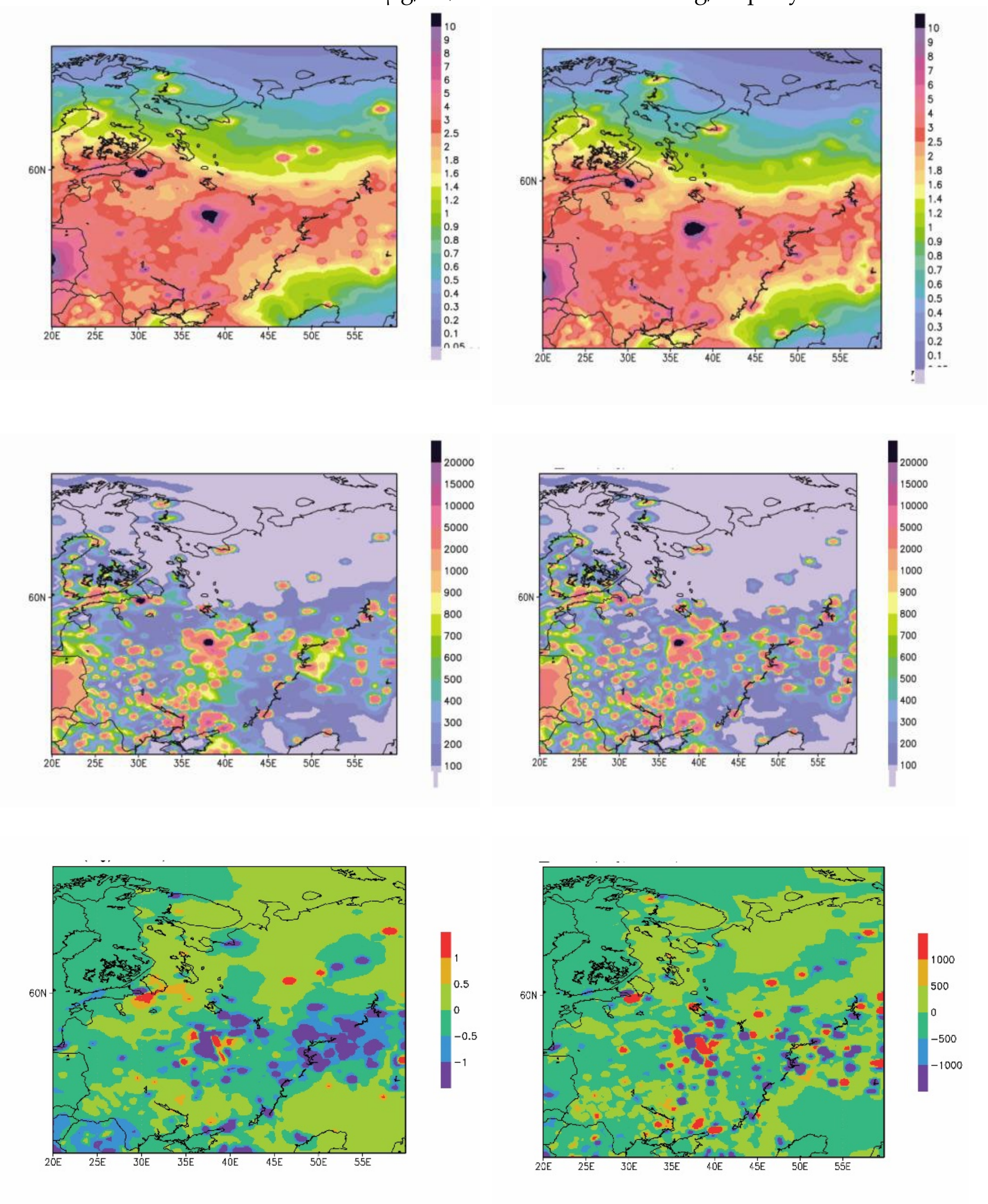
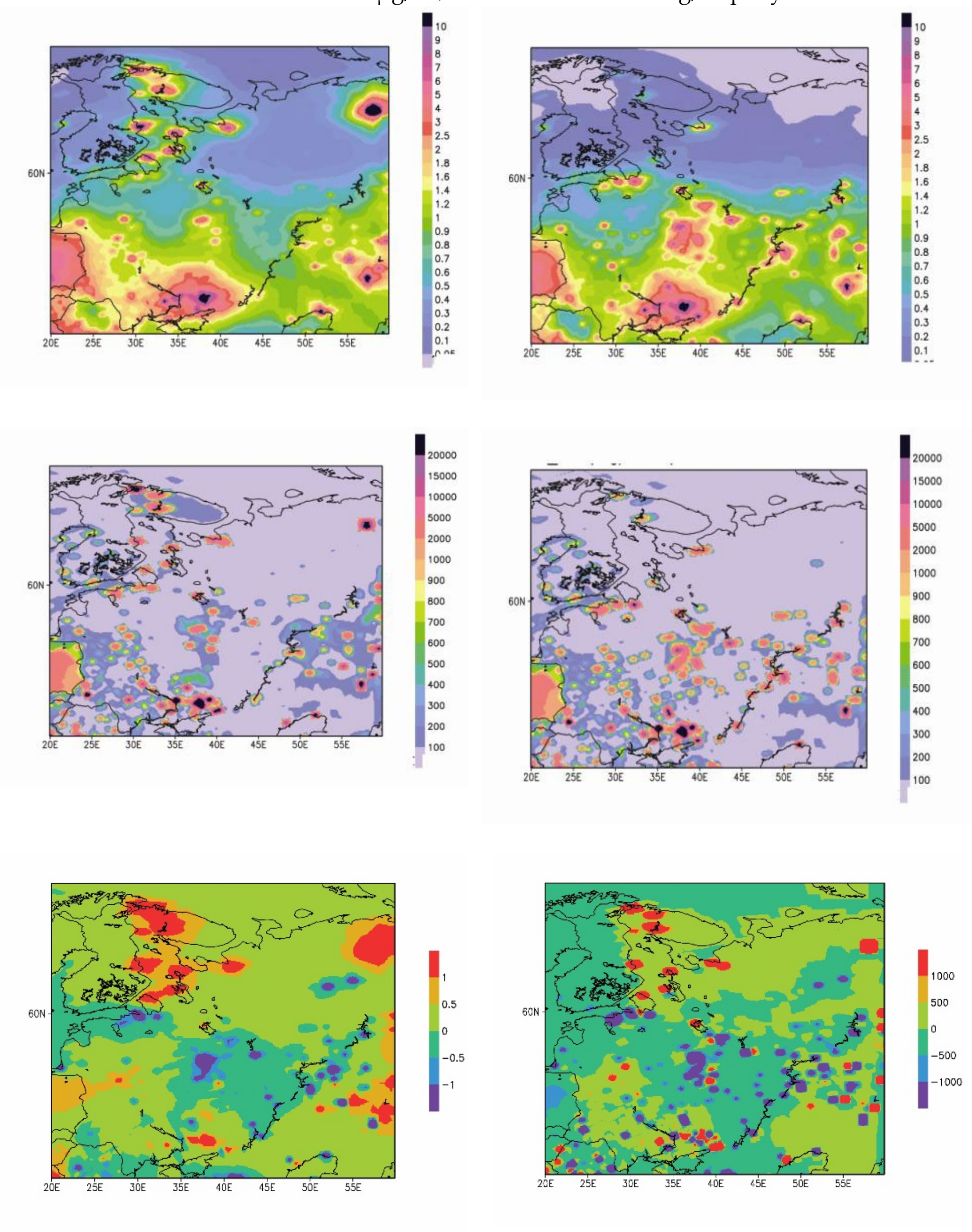


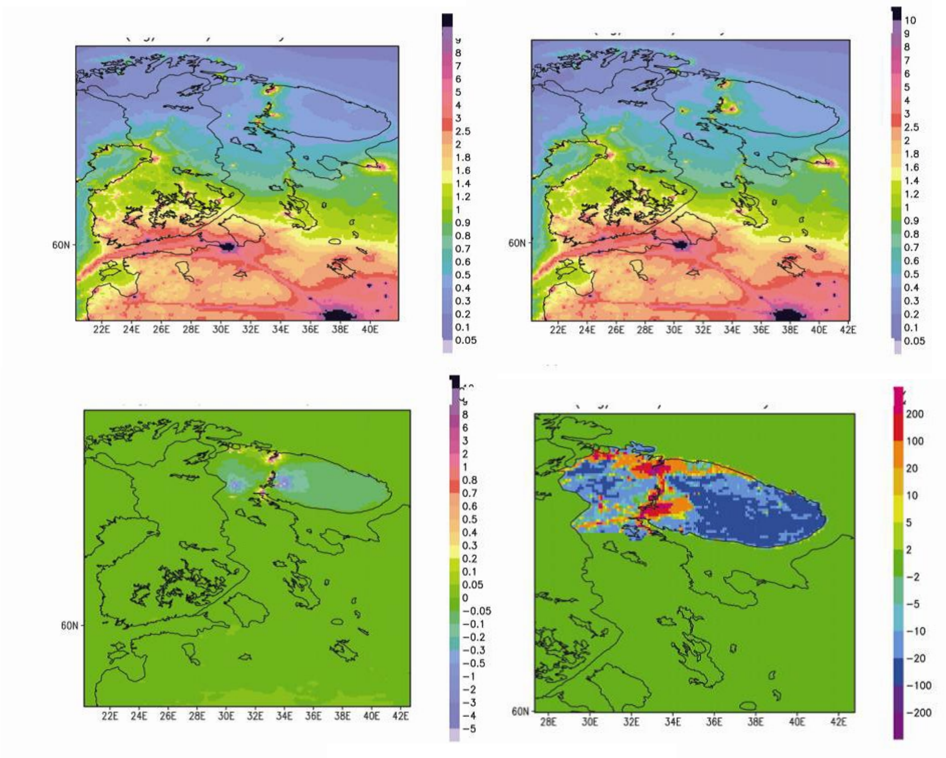
Figure 21.2. Sulphur oxides: Ground-level annual-average concentrations (upper panel) and corresponding emissions (middle), as modelled based on the national emission data (left) and based on the data prepared by CEIP (right). Lower panel: left – differences in the concentrations between the two model runs; right – differences in the corresponding emissions. Unit for concentrations – µg/m³, unit for emissions – mg/m² per year.



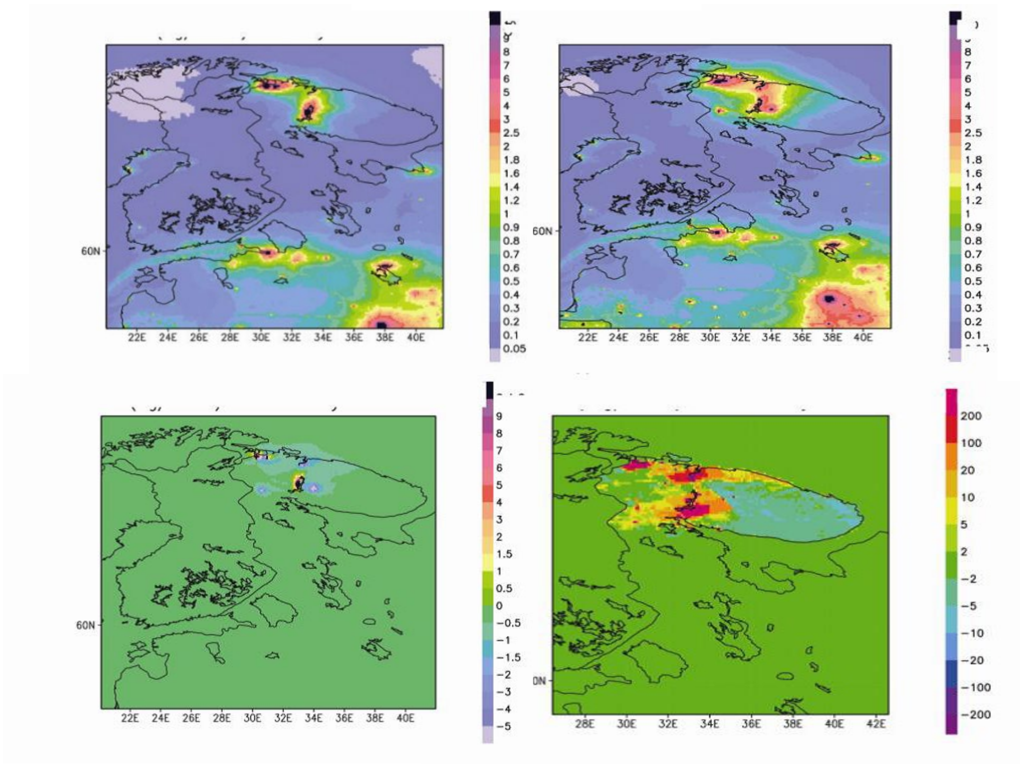
0.1x0.1° resolution

Figure 21.3. Upper panel: ground-level annual-average concentrations as modelled based on the initial TNO-INERIS emission data (left) and based on the "updated TNO" (right). Lower panel: left – differences in the concentrations between the two model runs; right – differences in the emissions corresponding emissions. Unit for concentrations – μg/m^3, unit for emissions – mg/m^2 per year.

Nitrogen oxides



Sulphur oxides



Appendix 22. Effects of horizontal resolution on the EMEP/MSC-W model performance.

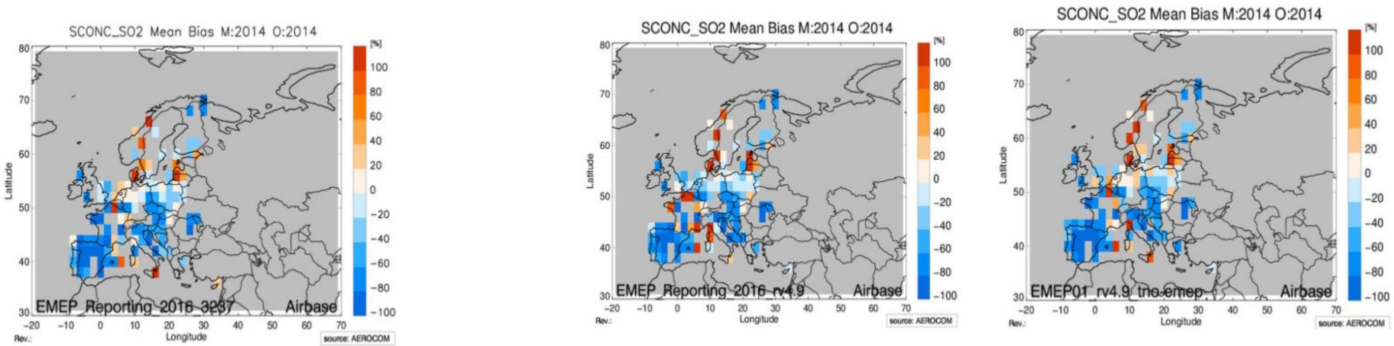


Figure 1a. Bias maps calculated vs. observed SO_2 at regional background sites: EMEP 50x50 km² (left) and EMEP 0.1x0.1°: with CEIP emissions (middle), EMEP/TNO emissions (right).

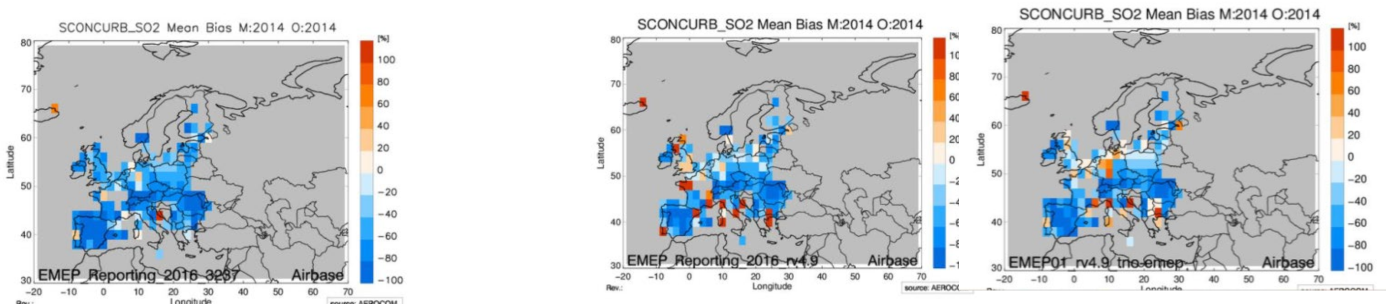


Figure 1b. Same as 1a but at sub-urban/urban sites.

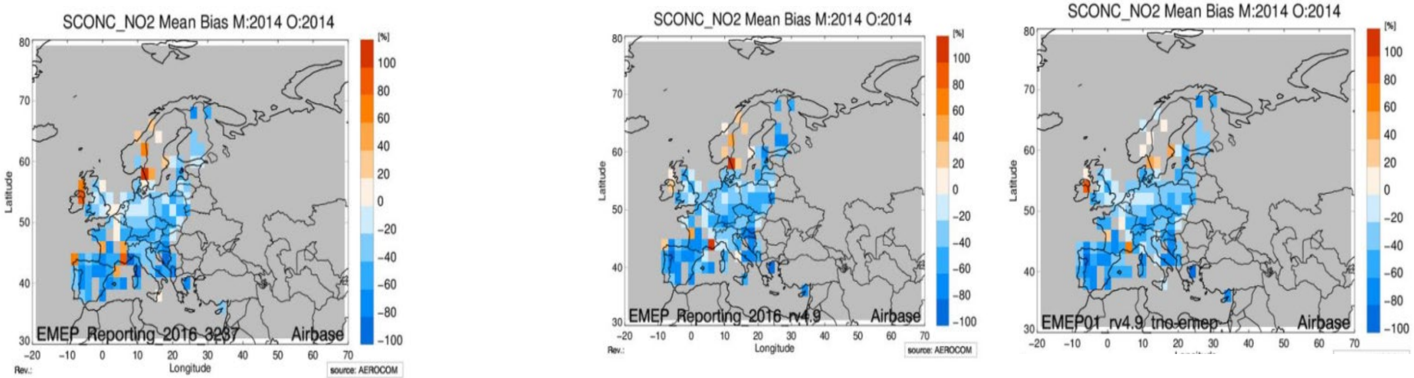


Figure 2a. Bias maps calculated vs. observed NO_2 at regional background sites: EMEP 50x50 km² (left) and EMEP 0.1x0.1°: with CEIP emissions (middle), EMEP/TNO emissions (right).

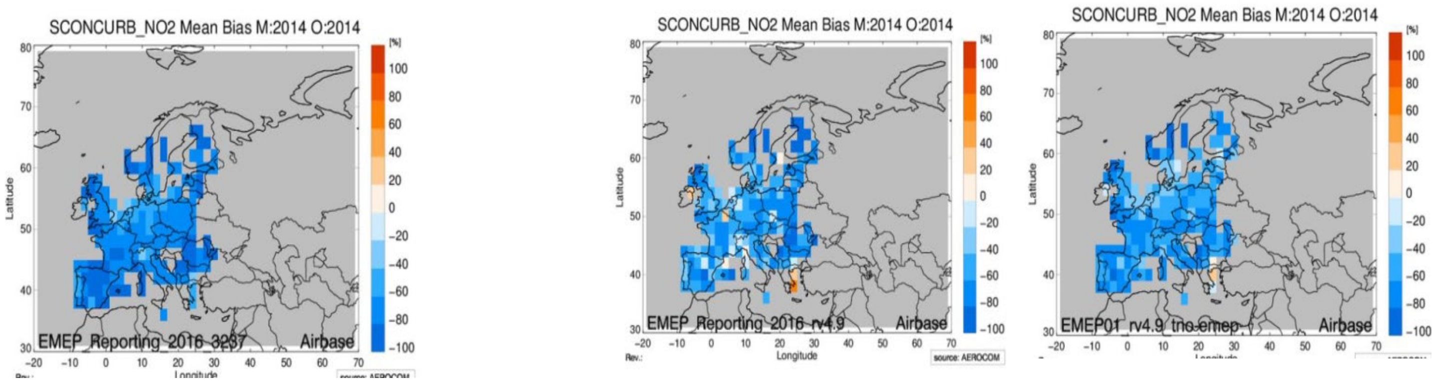


Figure 2b. Same as 2a but at sub-urban/urban sites.

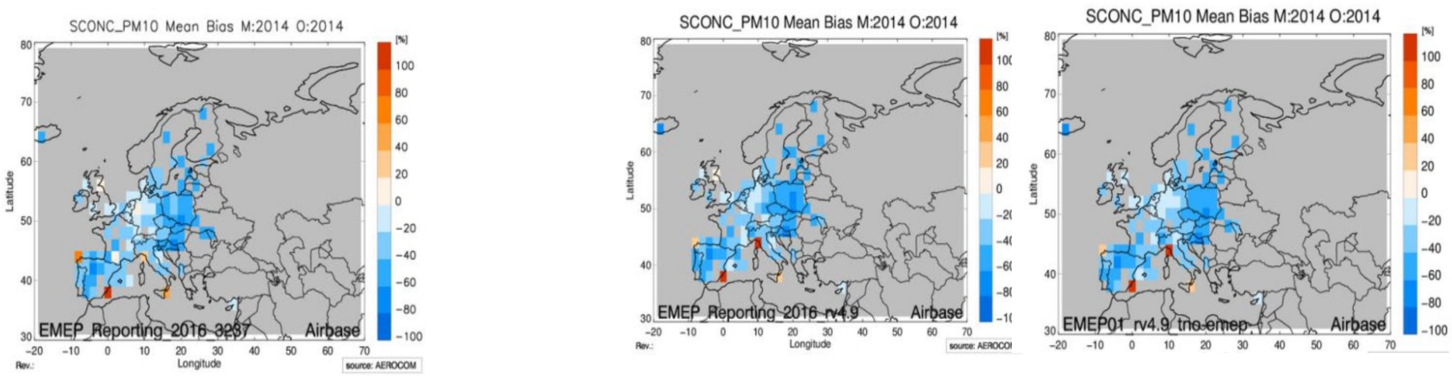


Figure 3a. Bias maps calculated vs. observed PM_{10} at regional background sites: EMEP 50x50 km² (left) and EMEP 0.1x0.1°: with CEIP emissions (middle), EMEP/TNO emissions (right).

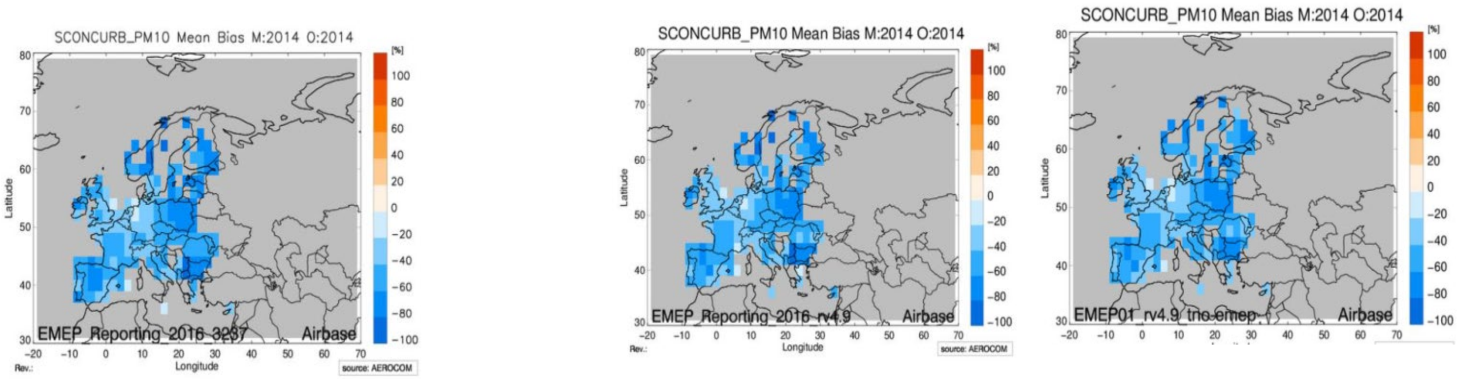


Figure 3b. Same as 3a but at sub-urban/urban sites.

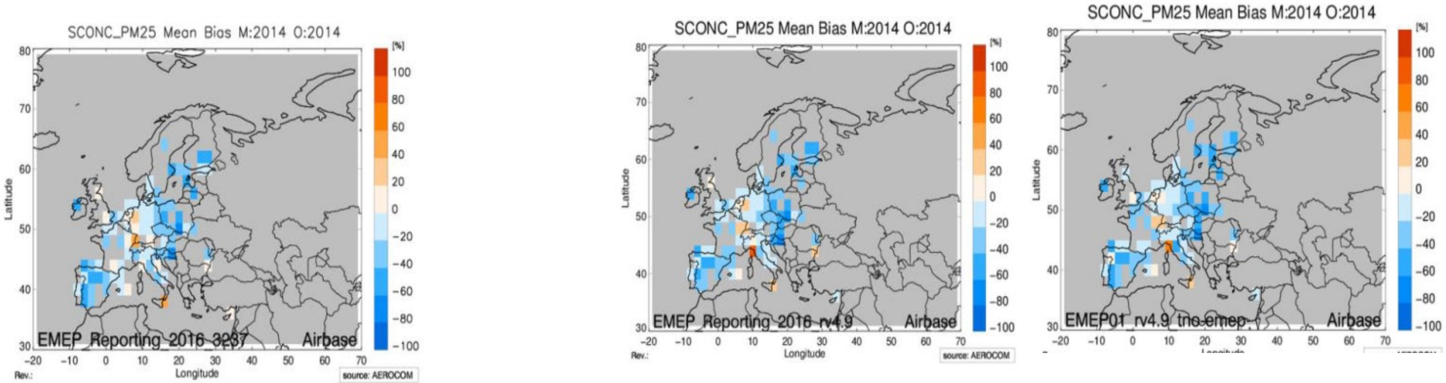


Figure 4a. Bias maps calculated vs. observed PM10 at regional background sites: EMEP 50x50 km² **(left) and EMEP 0.1x0.1°: with CEIP emissions (middle). EMEP/TNO emissions (right).**

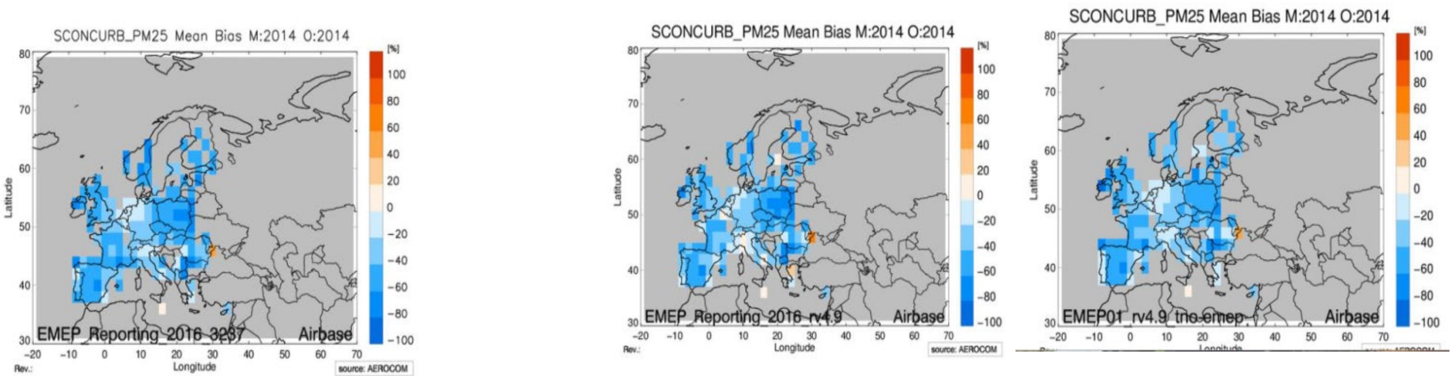


Figure 4b. Same as 4a. but at sub-urban/urban sites.

Scatter-plots model vs. Airbase for Rural – Background sites

EMEP 50x50km[2] (left), and EMEP 0.1x0.1° with CEIP emissions (middle), with EMEP/TNO emissions (right).

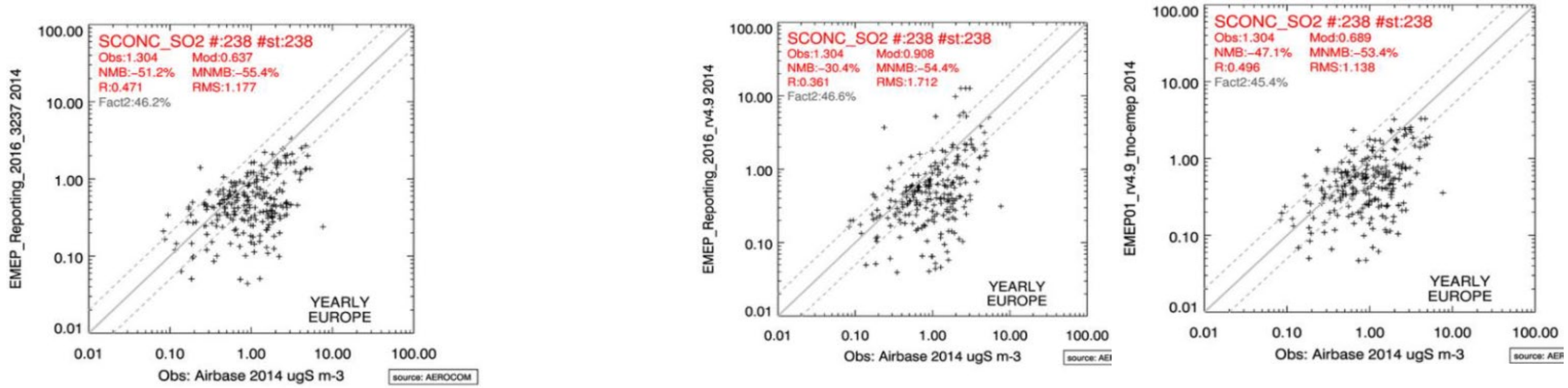


Figure 5a: SO_2

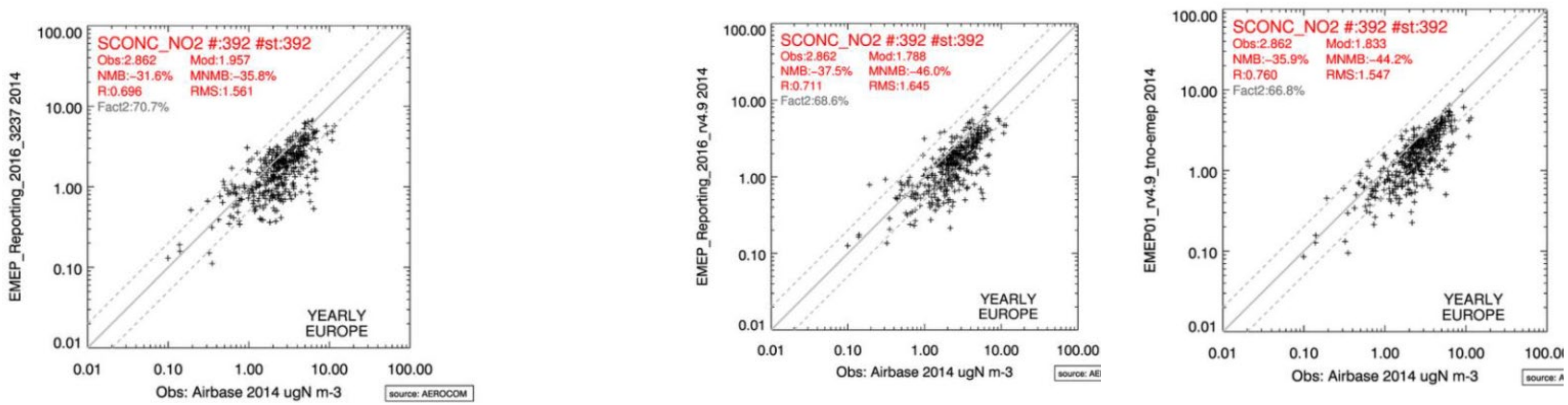


Figure 5b: NO_2

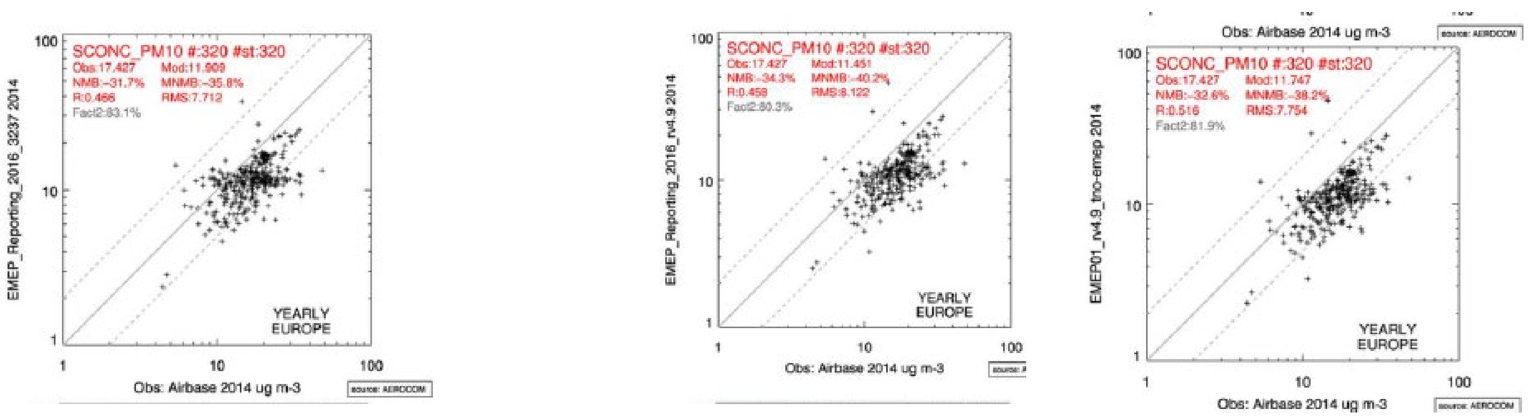


Figure 5c: PM_{10}

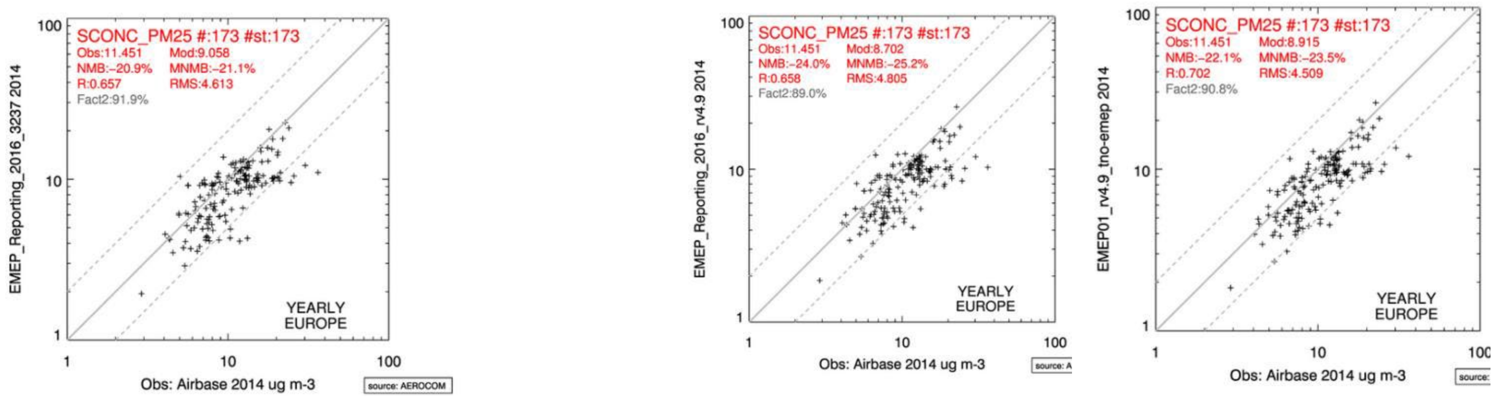


Figure 5d: $PM_{2.5}$

Scatter-plots model vs. Airbase for Urban – sub-urban sites

EMEP 50x50km[2] (left), and EMEP 0.1x0.1° with CEIP emissions (middle), with EMEP/TNO emissions (right).

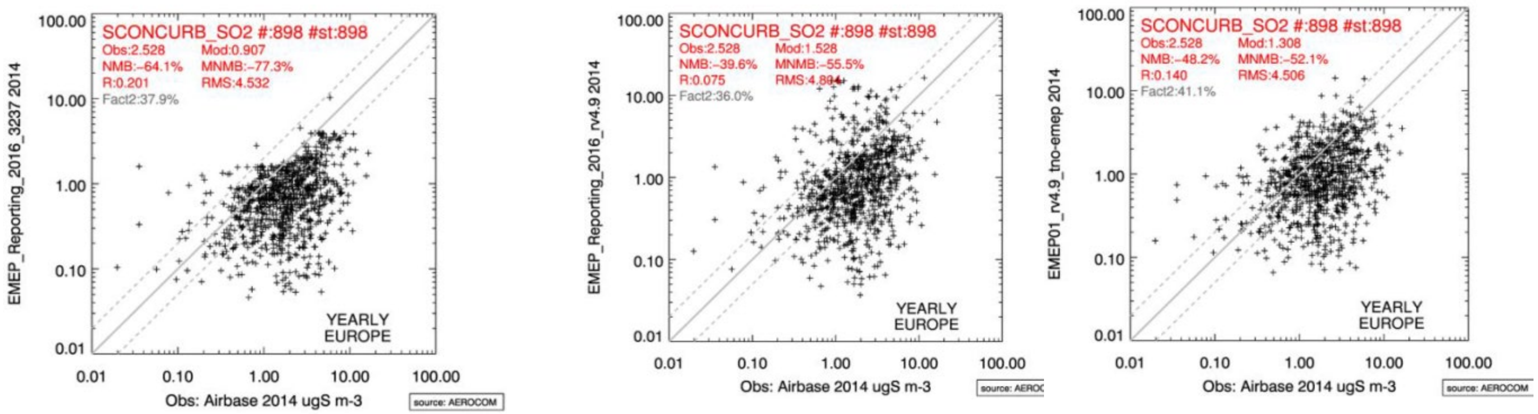


Figure 6a: SO_2

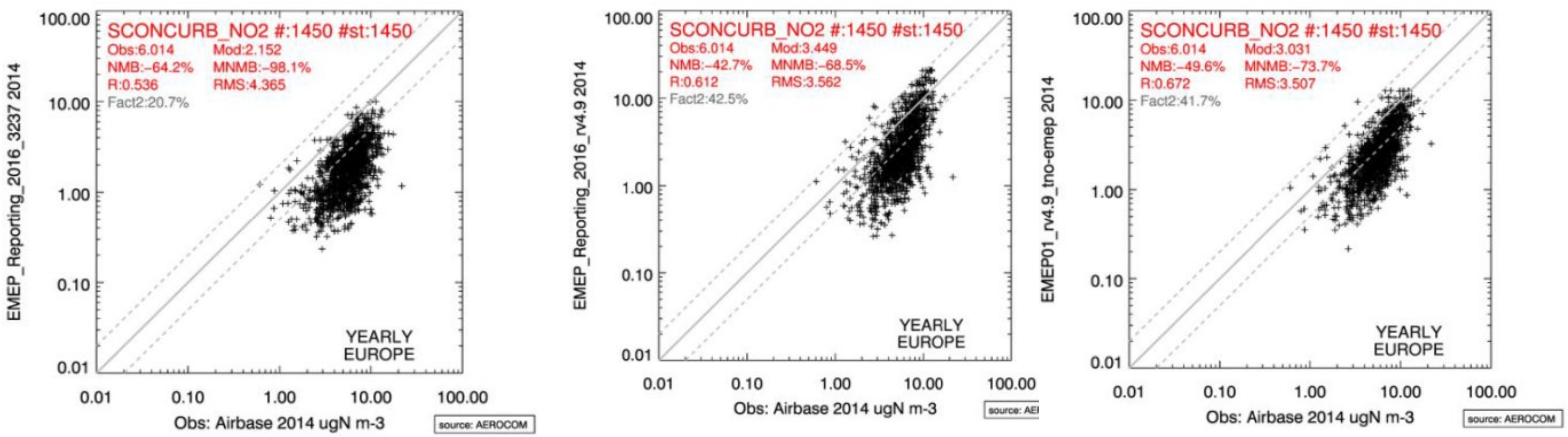
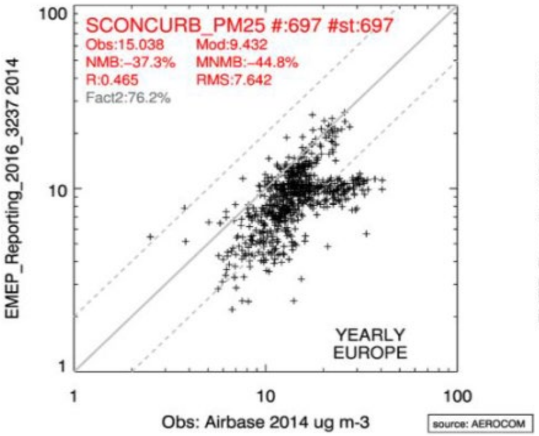
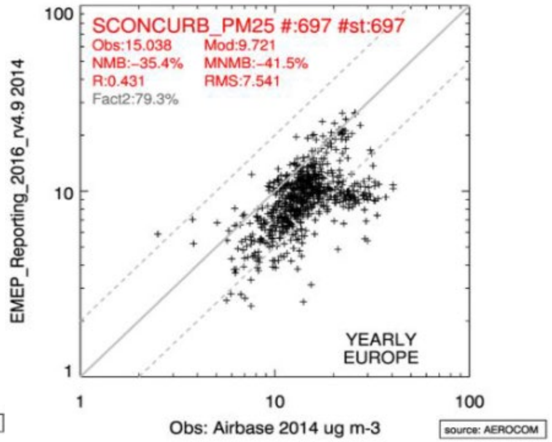


Figure 6b: NO_2





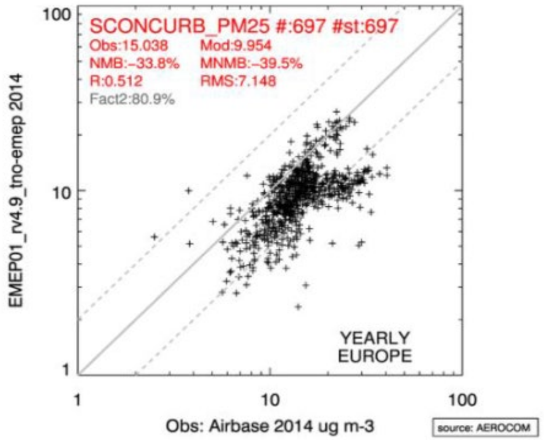
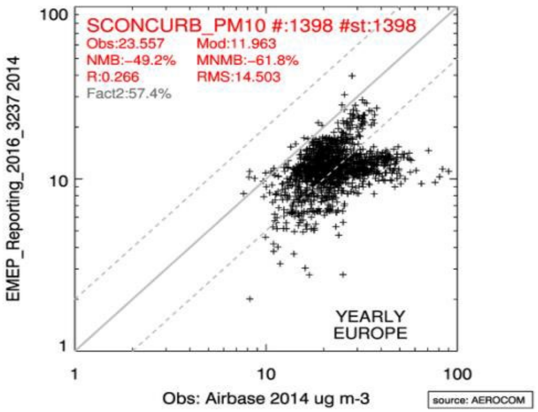
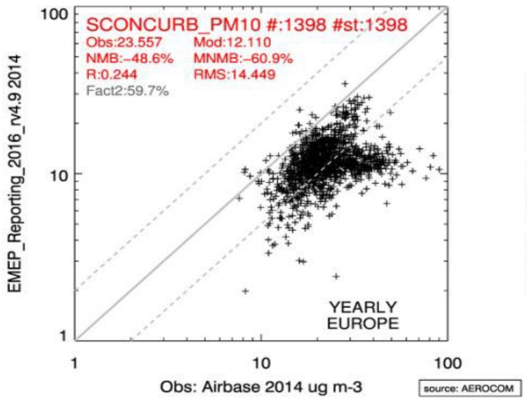


Figure 6c: $PM_{2,5}$





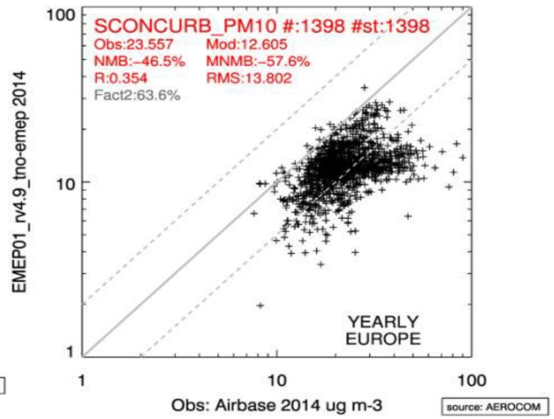


Figure 6d: PM_{10}

Appendix 23. Comparisons of modelling results with observations.

1 - Run 1 (EMEP-CEIP 50x50 km²) **2 – Run 2 (SRI for ETR 50x50 km²)** **3 – Run 4 ("updated TNO" 0.1x0.1°)**

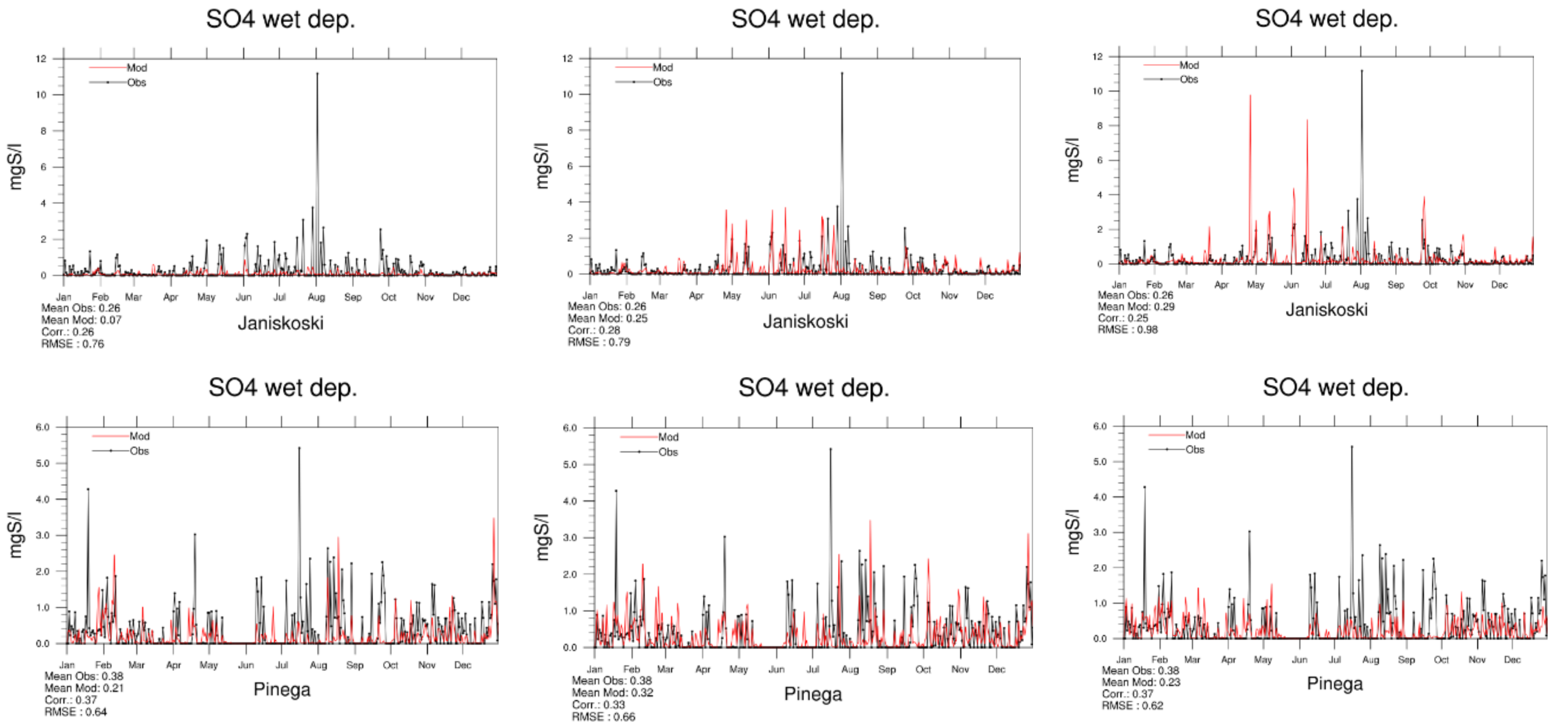


Figure 23.1. Timeseries of daily sulphate concentrations in precipitation in Janiskoski (upper) and Pinega (lower): observed (black) and model calculated (red) from Run 1 (left), Run 2 (middle) and Run 4 (right).

1 - Run 1 (EMEP-CEIP 50x50 km²) | **2 – Run 2 (SRI for ETR 50x50 km²)** | **3 – Run 4 (“updated TNO” 0.1x0.1°)**

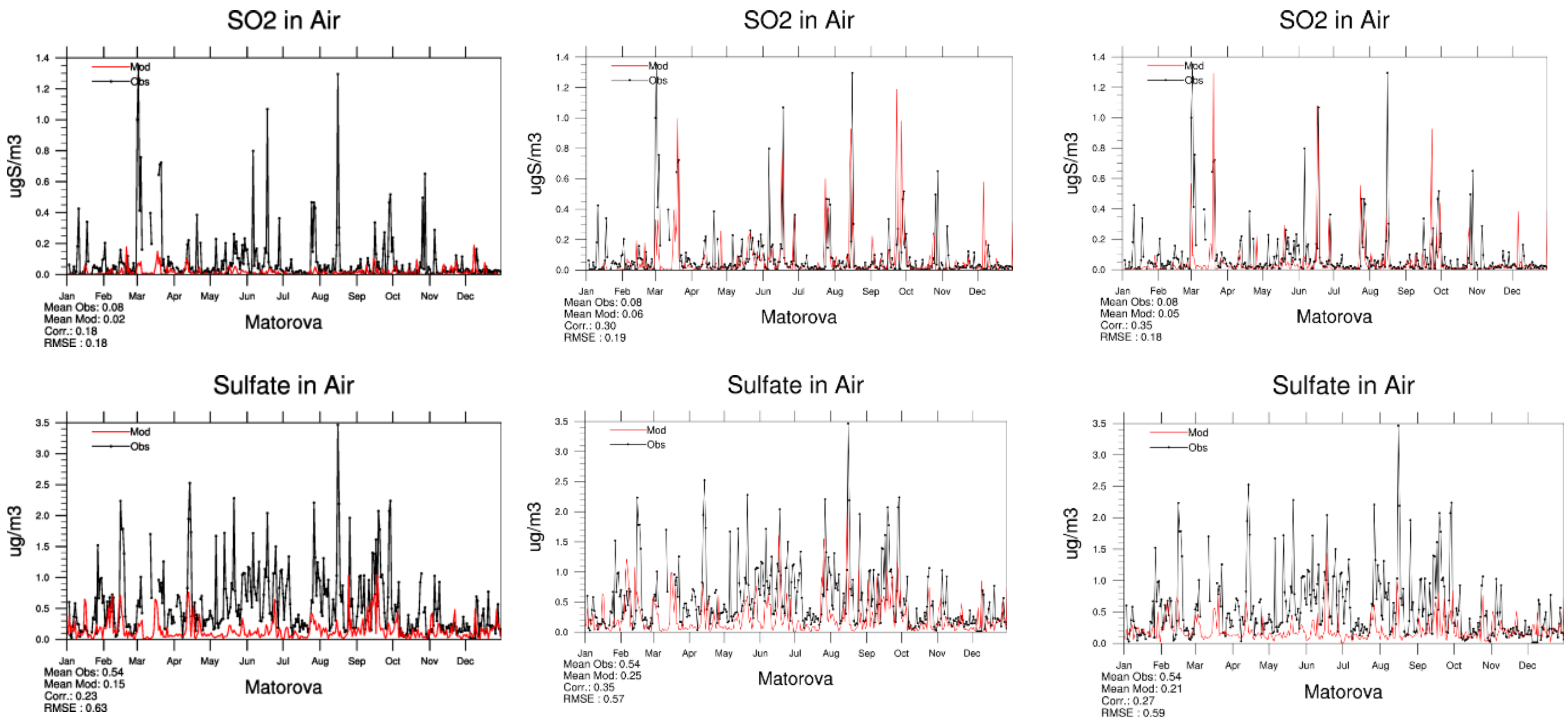


Figure 23.2 Timeseries of daily sulphate concentrations in precipitation in Janiskoski (upper) and Pinega (lower): observed (black) and model calculated (red) from Run 1 (left), Run 2 (middle) and Run 4 (right).

Appendix 24. Murmansk region and transboundary pollution in ETR.

Table 24.1. SR run at 0.1x0.1°.

0.1x0.1°		Deposition, mg S/N/m²			Concentration, ng/m³	
Receivers from Murmansk region		SO_x	NO_x	NH_3	PM_{10}	$PM_{2.5}$
AL	Albania	0.005	0.001	0.001	0.039	0.039
AM	Armenia	0.007	0.001	0.001	0.069	0.067
AT	Austria	0.054	0.002	0.010	0.076	0.075
AZ	Azerbaijan	0.027	0.004	0.000	0.176	0.171
BA	Bosnia and Herzegovina	0.009	0.001	0.002	0.052	0.051
BE	Belgium	0.043	0.006	0.000	0.482	0.472
BG	Bulgaria	0.050	0.007	0.007	0.208	0.204
BY	Belarus	1.782	0.199	-0.097	2.882	2.837
CH	Switzerland	0.010	0.000	0.003	0.036	0.035
CY	Cyprus	0.001	0.000	0.000	0.052	0.049
CZ	Czech Republic	0.106	0.011	0.009	0.317	0.312
DE	Germany	0.599	0.057	-0.004	0.607	0.597
DK	Denmark	0.159	0.019	-0.031	1.420	1.392
EE	Estonia	0.808	0.117	-0.029	4.570	4.474
ES	Spain	0.060	0.008	0.013	0.042	0.040
FI	Finland	39.953	2.691	-0.282	17.256	16.796
FR	France	0.219	0.021	0.018	0.143	0.139
GB	United Kingdom	0.206	0.038	0.003	0.236	0.226
GE	Georgia	0.066	0.006	0.011	0.111	0.109
GL	Greenland	0.156	0.013	0.002	0.023	0.022
GR	Greece	0.021	0.003	0.004	0.093	0.091
HR	Croatia	0.022	0.001	0.004	0.071	0.070
HU	Hungary	0.100	0.005	0.010	0.281	0.276
IE	Ireland	0.033	0.005	0.003	0.118	0.110
IS	Iceland	0.317	0.034	0.002	0.461	0.447
IT	Italy	0.021	0.003	0.008	0.015	0.014
KZT	Kazakhstan	1.029	0.231	-0.036	0.672	0.649
LT	Lithuania	0.634	0.077	-0.050	2.968	2.918
LU	Luxemburg	0.002	0.000	0.000	0.317	0.312
LV	Latvia	0.728	0.112	-0.040	3.484	3.417
MD	Republic of Moldova	0.074	0.008	-0.005	0.791	0.777
MK	The FYR of Macedonia	0.006	0.001	0.001	0.069	0.067
MT	Malta	0.000	0.000	0.000	0.011	0.007
NL	Netherlands	0.055	0.006	-0.012	0.763	0.748
NO	Norway	24.042	0.670	0.047	6.691	6.505

0.1x0.1°		Deposition, mg S/N/m²			Concentration, ng/m³	
Receivers from Murmansk region		SO_x	NO_x	NH_3	PM_{10}	$PM_{2.5}$
PL	Poland	1.059	0.114	-0.012	1.390	1.366
PT	Portugal	0.012	0.003	0.000	0.055	0.053
RO	Romania	0.323	0.029	0.026	0.458	0.450
RUCFD	Russia: Central FD	5.738	0.916	-0.204	3.501	3.428
RUMFD	Russia: Murmansk region	166.206	6.811	1.033	99.697	92.401
RUNCFD	Russia: Northern Caucasus FD	0.240	0.033	0.029	0.284	0.275
RUNWD	Russia: North-Western FD	96.126	8.073	0.439	11.628	11.348
RUSFD	Russia: Southern FD	0.824	0.173	0.030	0.767	0.745
RUVFD	Russia: Volga FD	10.175	1.196	-0.256	2.466	2.417
SE	Sweden	13.589	1.010	-0.003	5.515	5.414
SI	Slovenia	0.009	0.000	0.002	0.063	0.062
SK	Slovakia	0.051	0.004	0.002	0.320	0.314
TMT	Turkmenistan	0.032	0.007	0.000	0.170	0.160
TR	Turkey	0.126	0.008	0.008	0.080	0.079
UA	Ukraine	1.845	0.223	0.015	1.049	1.030
UZT	Uzbekistan	0.032	0.009	0.001	0.400	0.379
BLS	Black Sea	0.880	0.079	0.035	0.368	0.360

Table 24.2. SR run at 50x50 km².

50x50 km²		Deposition, mg S/N/m²			Concentration, ng/m³	
Receivers from Murmansk region		SO_x	NO_x	NH_3	PM_{10}	$PM_{2.5}$
AL	Albania	0.006	0.001	0.002	0.032	0.032
AM	Armenia	0.014	0.001	0.001	0.106	0.103
AT	Austria	0.052	0.002	0.010	0.072	0.071
AZ	Azerbaijan	0.037	0.008	0.000	0.258	0.248
BA	Bosnia and Herzegovina	0.009	0.001	0.002	0.045	0.043
BE	Belgium	0.043	0.007	-0.001	0.466	0.455
BG	Bulgaria	0.060	0.010	0.008	0.211	0.207
BY	Belarus	1.791	0.202	-0.077	2.783	2.741
CH	Switzerland	0.010	-0.001	0.003	0.033	0.033
CY	Cyprus	0.001	0.000	0.000	0.064	0.063
CZ	Czech Republic	0.107	0.011	0.010	0.309	0.304
DE	Germany	0.605	0.057	0.006	0.586	0.577
DK	Denmark	0.158	0.021	-0.036	1.447	1.420
EE	Estonia	0.847	0.119	-0.035	4.860	4.767
ES	Spain	0.053	0.011	0.012	0.039	0.038
FI	Finland	41.229	2.630	-0.269	19.864	19.395
FR	France	0.209	0.023	0.021	0.134	0.130
GB	United Kingdom	0.208	0.046	0.004	0.240	0.229
GE	Georgia	0.083	0.007	0.010	0.138	0.135
GL	Greenland	0.697	0.068	0.006	0.071	0.070
GR	Greece	0.024	0.004	0.004	0.098	0.095

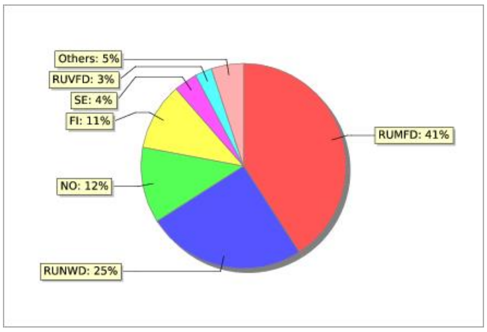
50x50 km^2		Deposition, mg S/N/m^2			Concentration, ng/m^3	
Receivers from Murmansk region		**SO_x**	**NO_x**	**NH_3**	**PM_{10}**	**$PM_{2.5}$**
HR	Croatia	0.019	0.001	0.004	0.064	0.062
HU	Hungary	0.091	0.005	0.010	0.239	0.234
IE	Ireland	0.036	0.008	0.003	0.122	0.113
IS	Iceland	0.328	0.036	0.005	0.452	0.438
IT	Italy	0.024	0.006	0.008	0.015	0.014
KZT	Kazakhstan	1.153	0.277	-0.046	0.832	0.799
LT	Lithuania	0.663	0.076	-0.046	2.931	2.886
LU	Luxemburg	0.002	0.000	0.000	0.309	0.309
LV	Latvia	0.732	0.109	-0.044	3.492	3.430
MD	Republic of Moldova	0.072	0.008	-0.003	0.759	0.745
MK	The FYR of Macedonia	0.007	0.001	0.002	0.065	0.062
MT	Malta	0.000	0.000	0.000	0.001	0.001
NL	Netherlands	0.055	0.007	-0.014	0.745	0.731
NO	Norway	46.517	0.859	0.088	9.186	8.912
PL	Poland	1.123	0.123	0.000	1.381	1.359
PT	Portugal	0.012	0.005	0.000	0.049	0.046
RO	Romania	0.327	0.033	0.031	0.430	0.423
RUCFD	Russia: Central FD	5.524	0.953	-0.110	3.495	3.425
RUMFD	Russia: Murmansk region	158.752	6.860	1.050	110.816	103.254
RUNCFD	Russia: Northern Caucasus FD	0.306	0.042	0.033	0.366	0.353
RUNWD	Russia: North-Western FD	97.476	8.162	0.480	12.196	11.916
RUSFD	Russia: Southern FD	0.948	0.198	0.027	0.862	0.837
RUVFD	Russia: Volga FD	10.368	1.334	-0.244	2.692	2.641
SE	Sweden	14.418	1.046	-0.015	6.238	6.141
SI	Slovenia	0.009	0.000	0.002	0.068	0.067
SK	Slovakia	0.048	0.005	0.003	0.296	0.291
TMT	Turkmenistan	0.107	0.037	0.003	0.310	0.286
TR	Turkey	0.152	0.015	0.018	0.080	0.078
UA	Ukraine	1.912	0.241	0.033	1.035	1.016
UZT	Uzbekistan	0.155	0.045	0.014	0.356	0.328
BLS	Black Sea	0.820	0.080	0.045	0.354	0.345

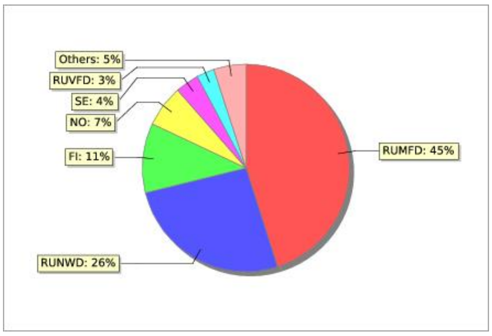
Appendix 25. Deposition of SO_x, NO_x and NH_y from emissions in Murmansk region.

Relative contribution from Murmansk region to deposition of oxidized sulphur (SO_x), oxidized nitrogen (NO_x) and reduced nitrogen (NH_y) in the studied receptor-regions calculated with 50x50 km² (left) and 0.1x0.1° (right) grid resolution.

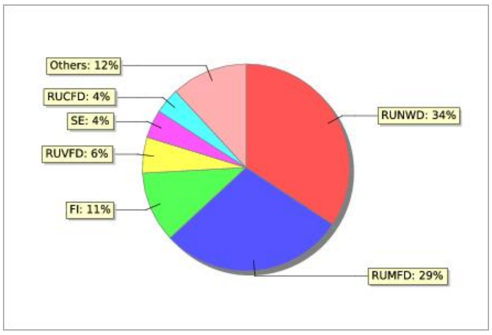
RUMFD – Murmansk region, RUNWD – remaining Nonwestern FD, RUVFD – Volga FD, RUCFD – Central FD, RUNCFD – Northern Caucasus FD, SFD – South FD, FI – Finland, NO – Norway, SE – Sweden, BLS – Black Sea, UA – Ukraine, Others – other EMEP regions.

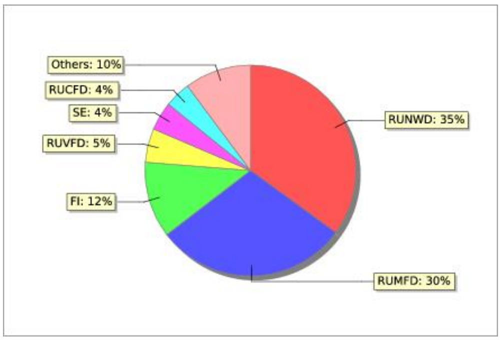
SO_x



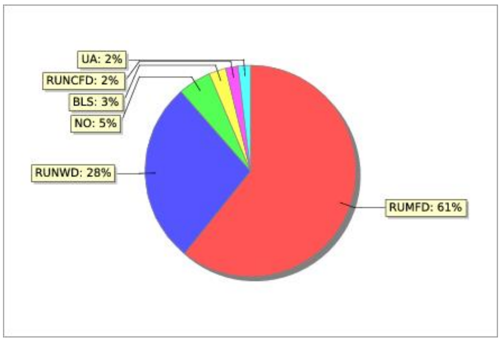


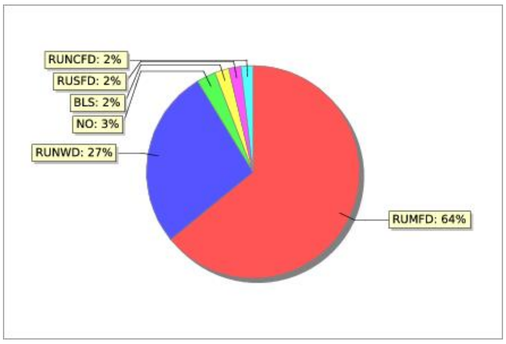
NO_x





NH_y

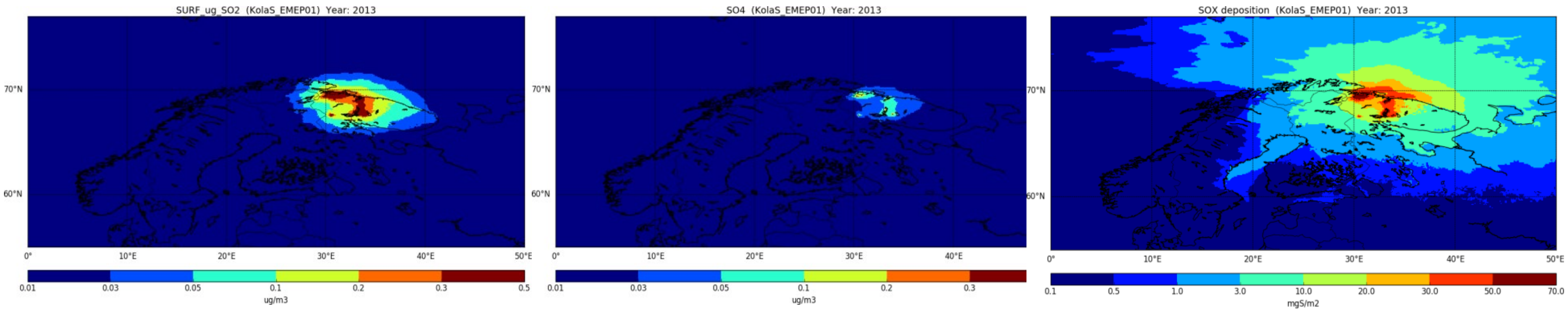




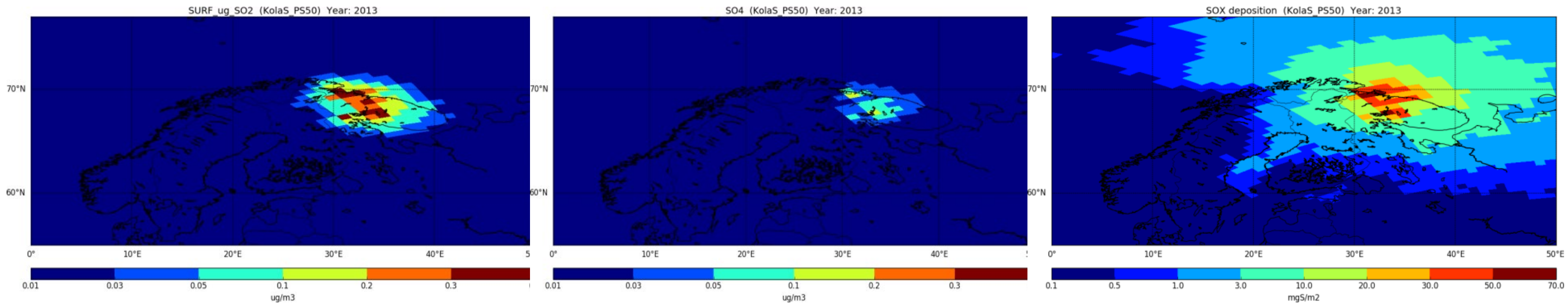
Appendix 26. Murmansk region – emissions and deposition of oxidized sulphur at different resolutions.

Concentrations of SO_2, SO_4 and depositions of oxidized sulphur due to 15% emission from Murmansk region in 2013

Resolution 0.1x0.1°



Resolution 50x50 km²



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