Air pollution in the Czech Republic in 2021

Czech Hydrometeorological Institute

Air pollution in the Czech Republic in 2021

Air Quality Division

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Czech Hydrometeorological Institute

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I. INTRODUCTION
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II. AIR POLLUTION
M. Filipenská, A. Kassymova, P. Machálek

III. METEOROLOGICAL AND DISPERSION CONDITIONS
L. Crhová, H. Škáchová

IV. AIR QUALITY IN THE CZECH REPUBLIC
J. Díšková, M. Filipenská, A. Holubová Šmejkalová, J. Horálek, I. Hůnová, A. Kassymova, B. Krejčí, P. Machálek, J. Schovánková, M. Schreiberová, J. Sládeček, H. Škáchová, L. Vlasáková

V. AIR QUALITY IN REGIONS OF THE CZECH REPUBLIC
J. Brzezina, M. Hladík, L. Janatová, J. Komárek, B. Krejčí, P. Machálek, H. Plachá, M. Schreiberová, H. Škáchová, L. Vlasáková

VI. SMOG WARNING AND REGULATION SYSTEM
O. Vlček, F. Šopko

VII. AREAS WITH EXCEEDANCES OF LIMIT VALUES
M. Schreiberová, L. Vlasáková

VIII. EUROPEAN CONTEXT
J. Horálek, M. Klusáčková, H. Škáchová

IX. ATMOSPHERIC DEPOSITION IN THE CZECH REPUBLIC
I. Hůnová, P. Kurfürst, H. Škáchová

X. GREENHOUSE GAS EMISSIONS
M. Klusáčková

Annex I Detailed specification of the presented air pollution level maps
J. Horálek, M. Schreiberová, O. Vlček

Technical co-operation, consultants
N. Benešová, Z. Chromcová, I. Hůnová, B. Krejčí, J. Macoun, V. Novák, P. Novotný, H. Plachá, R. Seibert, J. Schovánková, J. Sládeček, R. Srněnský, E. Svobodová, O. Vlček

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Obsah

ACKNOWLEDGEMENT **5**

SUMMARY **6**

I. INTRODUCTION **11**
I.1 The political and legislative framework for ambient air quality protection **13**
I.2 Objectives of the publication **16**

II. AIR POLLUTION **21**

III. METEOROLOGICAL AND DISPERSION CONDITIONS **27**

IV. AIR QUALITY IN THE CR **32**
IV.1 Suspended particulate matter **33**
IV.1.1 Air pollution by suspended particulates in 2021 33
IV.1.2 Trends in the concentrations of suspended PM_{10} and $PM_{2.5}$ particulates 42
IV.1.3 Emissions of PM_{10} and $PM_{2.5}$ 45
IV.2 Benzo[*a*]pyrene **48**
IV.2.1 Air pollution by benzo[*a*]pyrene in 2021 48
IV.2.2 Trends in benzo[*a*]pyrene concentrations 52
IV.2.3 Emissions of benzo[*a*]pyrene 54
IV.3 Nitrogen oxides **56**
IV.3.1 Air pollution by nitrogen oxides in 2021 56
IV.3.2 Trends in nitrogen oxide concentrations 58
IV.3.3 Nitrogen oxide emissions 62
IV.4 Ground-level ozone **63**
IV.4.1 Air pollution by ground-level ozone in 2021 63
IV.4.2 Trends in ground-level ozone concentrations 67
IV.4.3 Formation of ground-level ozone 68
IV.5 Benzene **70**
IV.5.1 Air pollution by benzene in 2021 70
IV.5.2 Trends in benzene concentrations 70
IV.5.3 Benzene emissions 70
IV.6 Heavy metals **73**
IV.6.1 Air pollution by heavy metals in 2021 73
IV.6.2 Trends in heavy metal concentrations 77
IV.6.3 Emissions of heavy metals 80
IV.7 Sulphur dioxide **84**
IV.7.1 Air pollution by sulphur dioxide in 2021 84
IV.7.2 Trends in sulphur dioxide concentrations 87
IV.7.3 Sulphur oxide emissions 89
IV.8 Carbon monoxide **91**
IV.8.1 Air pollution by carbon monoxide in 2021 91
IV.8.2 Trends in carbon monoxide concentrations 91
IV.8.3 Carbon monoxide emissions 92

IV.9 Pollutants without set limit values 94
IV.9.1 Volatile organic compounds 94
IV.9.2 Measurement of the numerical size distribution of aerosol particles 98
IV.9.3 Monitoring concentrations of elemental, organic and black carbon 102

V. AIR QUALITY IN REGIONS OF THE CZECH REPUBLIC 104
V.1 Characteristics of regions 104
V.2. Air quality index in regions of the Czech Republic 112
V.3 Regional differences in air quality in the Czech Republic 116
V.3.1 Proportion of the territory and population of regions exposed to above-limit concentrations 116
V.3.2 Population-weighted PM_{10}, $PM_{2.5}$, NO_2, and O_3 concentrations 120

VI. SMOG WARNING AND REGULATION SYSTEM 123

VII. AREAS WHERE THE POLLUTION LIMIT VALUES ARE EXCEEDED 128
VII.1 Areas where the pollution limit values for the protection of human health are exceeded 128
VII.2 Areas where the pollution limit values for the protection of ecosystems and vegetation are exceeded 133

VIII. EUROPEAN CONTEXT 136

IX. ATMOSPHERIC DEPOSITION IN THE TERRITORY OF THE CR 142

X. GREENHOUSE GAS EMISSIONS 154

REFERENCES 159

LIST OF ABBREVIATIONS 165

ANNEX I Detailed specifications of the presented pollution level maps 167

ACKNOWLEDGEMENT

Dear readers,

The “Air Pollution in the Czech Republic in 2021” yearbook, you are just opening, is a result of joint efforts of a team of authors of air quality staff of CHMI, formed by experts with various specializations necessary for the successful processing of the entire publication. An important role is played by colleagues from regional offices who, in addition to their expertise, also bring knowledge of local conditions.

The yearbook has been prepared on the basis of verified data collected through the Air Quality Information System (AQIS). Primary measurements are carried out by the Czech Hydrometeorological Institute in the National Air Quality Monitoring Network. The collected air samples are analysed by air quality laboratories. Last year, new laboratories were put into operation in the Ústí nad Labem branch, which will significantly strengthen the institute's ability to measure polycyclic aromatic hydrocarbons. Another source of data for the AQIS database is information on air quality provided by cooperating institutions. These are, in particular, the Public Health Institute in Ostrava, the Public Health Institute in Ústí nad Labem, ČEZ, a. s., the Forestry and Game Management Research Institute, p. r. i., the Czech Geological Survey, the Institute of Hydrobiology, municipal authorities and other contributors. The database also includes information from the border areas of Slovakia, Germany, Poland, and Austria. Data from neighbouring states help us mainly to refine map outputs in border areas.

The emissions part of the AQIS database includes data on emissions reported through ISPOP, whose activities are ensured by the Czech Environmental Information Agency (CENIA). The Czech Statistical Office, the Transport Research Centre, p. r. i., and the Research Institute of Agricultural Technology, p. r. i., participate in the emission inventory preparation. Other data are provided by the Military Geographic and Hydrometeorology Office in Dobruška, the Road and Motorway Directorate of the Czech Republic and the Institute of Transportation Engineering of the Capital City of Prague. The operation and development of the AQIS database is provided in cooperation with the IDEA-ENVI Ltd.

The 2021 yearbook presents an overview of information on the status and development of air pollution in the area of the Czech Republic. Emphasis is placed on the interpretation of the measured data and presenting the interrelations between the level of air quality, meteorological conditions and other factors affecting the pollution burden.

I would like to thank all my colleagues who contributed to preparation of this yearbook. Thanks also go to colleagues who provided data measurement and processing. I would also like to extend my thanks to employees of cooperating organizations for their contributions. Special thanks are due to editors of the yearbook, RNDr. Leona Vlasáková, Ph.D. and Ing. Hana Škáchová, for conscientious work in coordinating preparation of the texts and graphic annexes. I am convinced that this material will be a valuable aid for your work. We greatly welcome any suggestions and recommendations for improvement of the service provision.

Prague, October 2022

RNDr. Jan Macoun, Ph.D.
Air Quality Director

SUMMARY

Concentrations of some pollutants having serious consequences for human health still exceed the pollution limit values at a number of locations in the Czech Republic. These are mainly carcinogenic benzo[*a*]pyrene, suspended PM_{10} and $PM_{2.5}$ particulates, and ground-level ozone (Tab. 1, Fig. 1). **Nevertheless, the year 2021 was good in terms of air quality.** Air pollutant concentrations in 2021 reached the second lowest values (after 2020, in which the best air quality was observed historically) within the assessment period 2011–2021[1], or the lowest values within the assessment period 2011–2021 (Fig. 2). **Concentrations of air pollutants**, except for ground-level ozone, **decrease significantly** over the evaluated period 2011–2021 (Tab. 1).

The relatively good air quality in the Czech Republic in view of pollutants except ozone in 2021 was mainly contributed by the less frequent occurrence of adverse conditions in January and November compared to the previous ten-year average 2011–2020. In the case of ozone, the significant drop in concentrations in 2021 was due to a decrease in concentrations in warmer months of the year[2]. The decrease in ozone concentrations in April, May, July and August 2021 compared to the ten-year average for the period 2011–2020 corresponds to mostly normal to strongly subnormal temperatures and normal to above-normal precipitation in these months (i.e., suppression of meteorological conditions suited for the formation of ground-level ozone). **Continuously implemented measures to improve air quality (replacement of boilers in households, measures on important sources and renewal of the vehicle fleet) contribute to the improvement of air quality in the long term.**

Areas exceeding air pollution limits excluding ground-level ozone covered 6.1 % of the territory of the CR with approximately 20 % of the population in 2021. The classification of these areas was mostly due to exceeding the annual pollution limit for benzo[*a*]pyrene. Exceeding the daily pollution limit for PM_{10} and the annual pollution limit for $PM_{2.5}$ suspended particles in 2021 contributed to the inclusion of territories to these areas in a minimal extent. Above-limit areas were the largest in the O/K/F-M agglomeration and in the Central Moravia zone. In addition, in the O/K/F-M agglomeration, the vast majority of inhabitants (96 %) are exposed to concentrations above the limit, and this is the most exposed area in the CR for a long time.

Areas exceeding air pollution limits including ground-level ozone covered 6.4 % of the territory of the CR with approximately 20 % of the population in 2021. In the year-on-year comparison of 2020/2021, there was a significant reduction (by approx. 59 %) in the area with at least one pollution limit exceeded including ozone. This resulted from relatively low concentrations of ground-level ozone measured in the last two years, 2020 and 2021, and the following reduction of the area exceeding the O_3 pollution limit in 2021 to only 0.2 % of the territory of the Czech Republic with 0.02 % of the population (the pollution limit is evaluated over a three-year period 2018–2020 or 2019–2021).

The level of air pollution depends in a given year on the amount of emissions and the prevailing meteorological and dispersion conditions. **In terms of temperature and precipitation, 2021 was normal in the CR. Compared to the 2011–2020 ten-year average, most months of 2021 could be classified as standard in view of dispersion conditions.** The exception was May with much better dispersion conditions and February with deteriorated dispersion conditions. In January and November, the months with generally the highest concentrations, poor conditions occurred less frequently compared to 2011–2020 decade values. **In the long term, pollutant emissions also decrease.** In 2021 (preliminary data) there was the lowest production of SO_x emissions and the second lowest production of TSP, NO_x, NH_3 and NMVOC emissions for the evaluated period 2011–2021[3].

In 2021, similarly to 2020, states of emergency were declared on the territory of the CR in connection with the occurrence of the SARS-CoV-2 coronavirus. From the point of view of the potential change in air quality in the CR, the most significant month was March, when even movement between districts was prohibited and thus there was a fundamental reduction in the transportation mobility of population. It can be assumed that under normal conditions without protective measures to limit the pandemic, the measured concentrations of NO_2 and NO_x in 2021 would be higher. Due to the heterogeneous composition of PM_{10} emission

1 Concerning suspended $PM_{2.5}$ particulates, the period 2012–2020 was evaluated to comply with the condition of sufficient amount data.

2 In these months, high to the highest concentrations of ground-level O_3 occur within the calendar year, in contrast to other pollutants reaching the highest concentrations in the cold part of the year.

3 For details concerning the emission situation in 2021, see the section on Emissions of pollutants.

Tab. 1 Air quality in the Czech Republic in 2021 – key facts

Pollutant	Population exposed to above-limit concentration	Area with above-limit concentration	Concentration trend for the period 2011–2021
PM_{10}	0.4 %	0.1 %	↘
$PM_{2.5}$	1.5 %	0.3 %	↘
benzo[*a*]pyrene	19.7 %	6.1 %	↘
NO_2	0 %	0 %	↘
O_3	0.02 %	0.2 %	↕
benzene	0 %	0 %	↘
As	0 %	0 %	↘
Cd	0 %	0 %	↘
Ni	0 %	0 %	↘
Pb	0 %	0 %	↘
SO_2	0 %	0 %	↘

Note:
The key data in the table are based on the following pollution characteristics:
annual average concentration for $PM_{2.5}$, NO_2, benzo[*a*]pyrene, Pb, Ni, Cd, As, and benzene; 36th highest 24-hour average concentration for PM_{10}; 26th highest maximum daily 8-hour concentration for O_3; 4th highest 24-hour average concentration for SO_2.
Trends in concentrations were analysed using the non-parametric Mann-Kendall test with a significance level of $p < 0.05$ (Mann 1945; Kendall 1955).

sources and their strong link to dispersion and meteorological conditions, no significant changes in concentrations could be expected as a result of emergency measures.

Air quality in 2021 in relation to pollution limit values for the protection of human health and for the protection of ecosystems and vegetation

The daily pollution limit value for suspended particulates PM_{10} was exceeded at 0.1 % of the territory of the CR, inhabited by approx. 0.4 % of the population. The annual pollution limit value for PM_{10} was not exceeded at any station in the Czech Republic in 2021, which occurred, since 2019, for the third time in the complete history of PM_{10} measurements starting in 1993. The annual pollution limit value for suspended particulates $PM_{2.5}$ was exceeded at 0.3 % of the national territory, inhabited by approx. 1.5 % of the population (for more see Chap. IV.1).

The annual pollution limit value for benzo[*a*]pyrene was exceeded at 6.1 % of the area of the CR, inhabited by approx. 19.7 % of the population. Estimations of annual average concentration fields of benzo[*a*]pyrene is affected by the greatest uncertainties of all the monitored substances, resulting mainly from insufficient density of measurements, especially at rural regional stations and in small settlements in the CR (for more see Chap. IV.2).

The annual pollution limit value for nitrogen dioxide (NO_2) was not exceeded at any station for the second time in the entire observation period since the 1990s. Higher NO_2 concentrations can be expected near local roads in municipalities and cities with intensive traffic, higher urban development and a dense local transport network, where traffic flow is often reduced. The hourly pollution limit value for NO_2 was not exceeded (for more see Chap. IV.3).

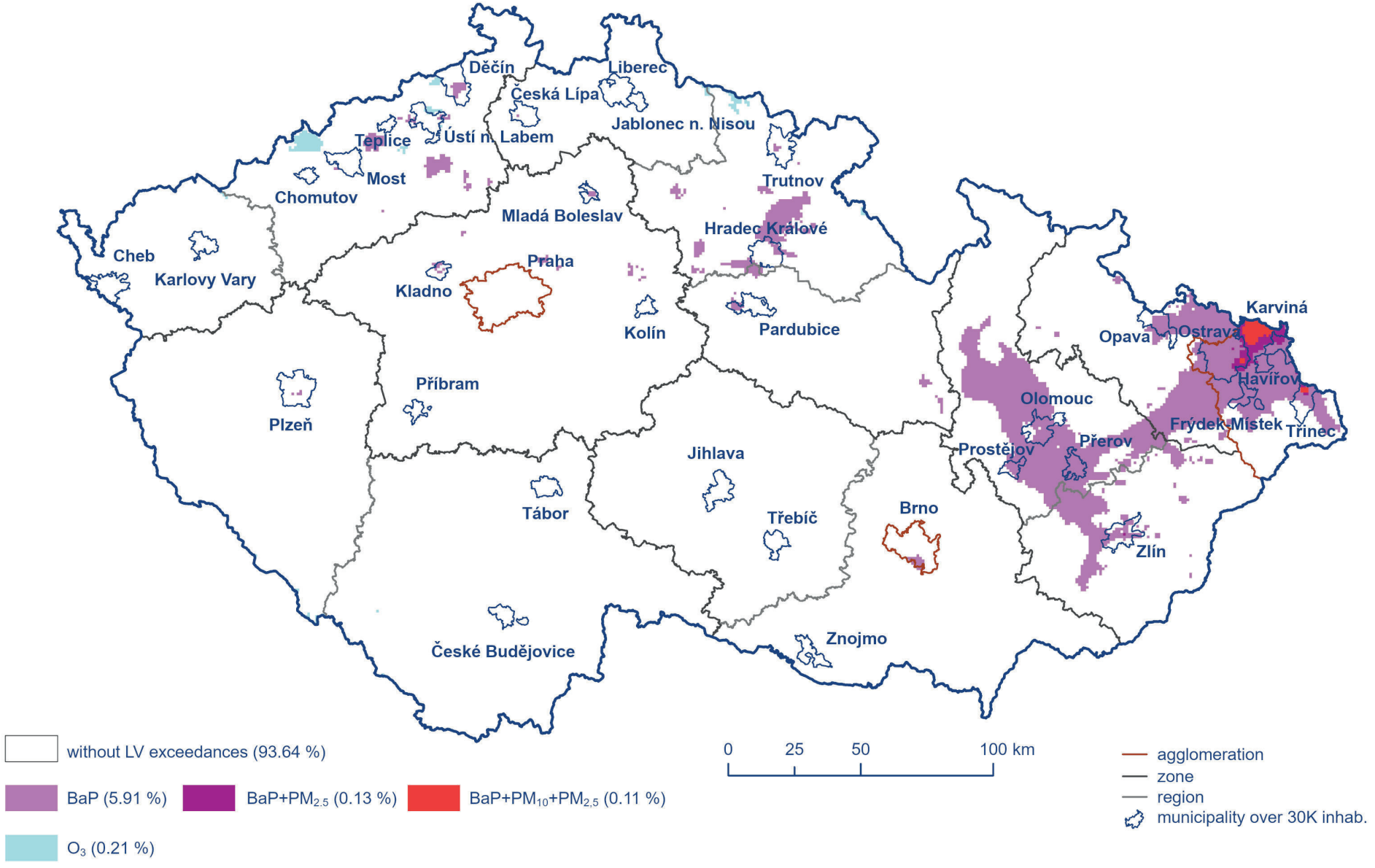


Fig. 1 Areas with exceeding of the health protection limit values for selected groups of pollutants, 2021

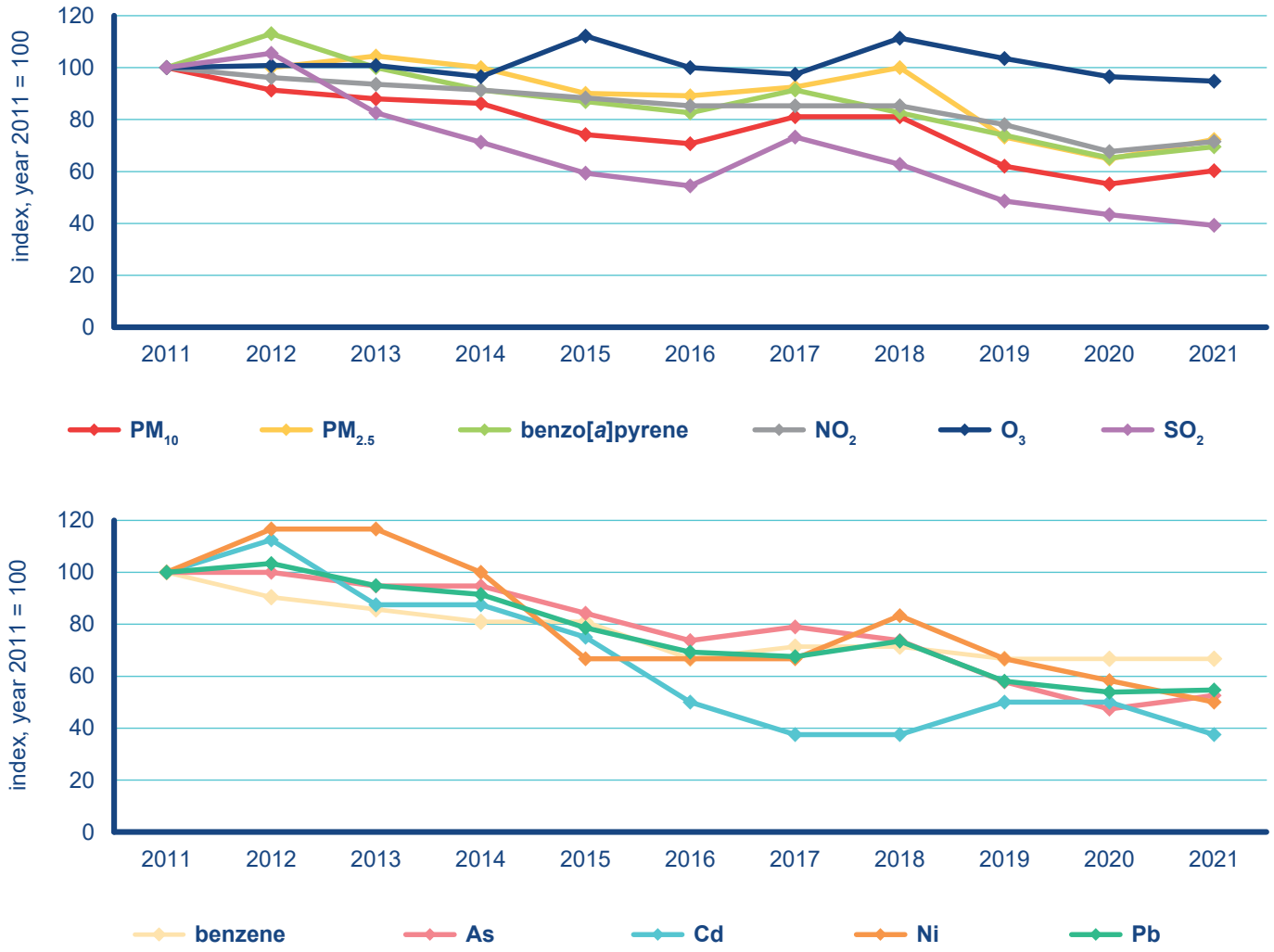


Fig. 2 Selected air pollutants characteristics, 2011–2021

Note: The graphs show the course of the following pollution characteristics:
annual average concentration for $PM_{2.5}$, NO_2, benzo[*a*]pyrene, Pb, Ni, Cd, As, and benzene; 36th highest 24-hour average concentration for PM_{10}; 26th highest maximum daily 8-hour concentration for O_3; 4th highest 24-hour average concentration for SO_2.

The pollution limit value for ground-level ozone was exceeded at 0.2 % of the territory of the CR, inhabited by approx. 0.02 % of the population (average for 2019–2021). Within the individual years in the period 2019–2021, almost 70 % of stations had the lowest number of cases exceeding the pollution limit value in 2021 (for more see Chap. IV.4).

The limit value of O_3 for the protection of vegetation (AOT40 exposure index) was exceeded at 14 stations out of a total of 39 rural and suburban stations. The pollution limit values for the protection of ecosystems and vegetation of sulphur dioxide and nitrogen oxides were not exceeded at any rural location where measurements were performed.

Regional differences in air quality

Within the CR, there are significant regional differences in air quality, that can be characterized by the population weighted concentration of pollutants. A comparison of the weighted concentration for the regions of the CR shows that inhabitants in the O/K/F-M and Brno agglomerations, and in the Olomouc, Zlín and Moravian-Silesia regions without the O/K/F-M agglomeration are exposed to the highest concentrations of suspended particulates PM_{10} and $PM_{2.5}$. In connection with intensive traffic and restrained traffic flow, the population exposed to the highest NO_2 concentrations belong to two most populous cities of the CR, i.e., Prague and Brno. In 2021, inhabitants in the O/K/F-M and Brno agglomerations and in the South Moravia without Brno, Moravian-Silesia without O/K/F-M and Central Bohemia regions were exposed to the highest weighted O_3 concentrations (26th highest maximum daily 8-hour average in 2021) (for more see Chap. V.3).

Deteriorated air quality is a problem not only in agglomerations and larger cities, but also in small settlements where local heating makes a considerable contribution to air pollution by suspended particulates and benzo[*a*]pyrene. It can be assumed that increased to above-limit concentrations may also occur in municipalities where these pollutants are not measured as indicated by, for example, campaign measurements in eight small settlements of the Czech Republic[4] or measurement of benzo[*a*]pyrene concentrations at various stations subsidized from the budget of the Moravian-Silesia region[5].

The smog warning and regulation system

In 2021, the only smog situation was announced due to high concentrations of PM_{10} in the territory of the O/K/F-M agglomeration without Třinec. Its total duration was 58 h.

Emissions of pollutants

The preliminary evaluation of emissions for 2021 shows the expected year-on-year increase of all emissions except for SO_x. The increase occurred mainly in emissions from household heating, as a result of a colder heating season (in 2021, the third lowest temperature on heating days for the period 2011–2021 was recorded). Compared to 2020, in which there was a slowdown in production, services provided and consumption of solid and automotive fuels in almost all sectors, there was a renewed increase in 2021, which was manifested by an increase in NO_x and CO emissions from the listed sources. In 2021, SO_x emissions reached the lowest level for the period 2011–2021, when the ORLEN refinery complex in Litvínov, the termination of operation of the Prunéřov I power plant on 30 June 2020, and the reduction of emissions from other important sources for the production of electricity and heat contributed the most to the reduction.

The sector Residential: Heating, water heating, cooking continued to make a significant contribution to ambient air pollution, specifically in emissions of $PM_{2.5}$ particulates (71 %), carbon monoxide (67 %), PM_{10} (55 %), TSPs (49 %), NMVOCs (37 %), cadmium (52 %), arsenic (33 %), and benzo[*a*]pyrene (96.3 %). Sector Public electricity and heat production predominated in emissions of sulphur oxides (39 %), nitrogen oxides (19 %), mercury (43 %), and nickel (33 %). Sectors of road freight transport, passenger cars, off-road vehicles and other machinery, for example in agriculture and forestry, contributed in total most in emissions of nitrogen oxide (33.5 %). These data are presented for the last completed year, i.e., 2020.

Atmospheric deposition

The year 2021 was normal in terms of precipitation in the CR. The annual precipitation amount of 683 mm represents 100 % of the 1991–2020 long-term normal.

The total deposition of sulphur in 2021 reached 30 335 tonnes, representing a decrease of less than 1 % compared to 2020 (30 577 t). Higher values were observed in the Krušné hory, Jizerské hory, Krkonoše, Orlické hory, Jeseníky, the Ostrava region, and Moravian-Silesia Beskydy. Compared to 2020, the wet component reached higher values, while the dry component lower.

The total nitrogen deposition on the area of the CR reached 55 383 tonnes in 2021. Compared to 2020 (56 396 t), this was a decrease of 2 %. Higher values occurred in the Jizerské hory, Orlické hory and Jeseníky areas. The wet deposition of reduced forms and the total wet deposition of nitrogen also reached lower values. Conversely, higher values were observed in the deposition of oxidized forms of both sub-components.

The total deposition of hydrogen ions on the area of the CR in 2021 was 2 232 tonnes (Tab. IX.2). The year 2021 is thus comparable to the year 2020, when the value was 2 224 tonnes. The partial components of hydrogen ion deposition are also comparable. The highest values were reached in the Krušné hory area, the Ostrava region, and locally in the Brno region.

Wet and dry deposition of cadmium in 2021 was comparable to 2020. Similar to previous years, the highest values occurred in the Jablonec nad Nisou district. Wet and dry deposition of lead in 2021 was comparable to 2020. The highest values were reached in mountainous areas, in the Příbram region, and in the Ostrava region.

4 The project TITSMZP704 — Measurement and Analysis of Air Pollution with Emphasis on the Evaluation of the Share of Individual Groups of Sources — funded with the state support of the Technology Agency of the Czech Republic, https://www.chmi.cz/files/portal/docs/reditel/SIS/nakladatelstvi/assets/td_000152.pdf.

5 For detailed annual evaluation see www.chmi.cz, https://air.zuova.cz/ovzdusi/article/detail/1.

I. INTRODUCTION

Polluted air has a demonstrable detrimental impact on human health. Pollutants can cause a wide range of health problems from less serious to grave diseases, and increase the burden on the immune system, which can lead to premature mortality. It also has significant economic impacts, as healthcare costs increase and productivity decreases in all sectors of the economy due to an increased incapacity for work. Pollutants adversely affect vegetation, including influencing growth and resulting in decreased yields of agricultural crops and forests. In addition, they lead to the eutrophication and acidification of soils and aquatic ecosystems, and subsequently to changes in species diversity and a reduction in the number of plant and animal species. Many pollutants cumulate in the environment, with a detrimental impact on ecosystems, and enter into the food chain. Pollutants are transported in the atmosphere and can thus affect air quality both in the immediate vicinity of the pollution source and in more distant areas. In addition, some of them directly or indirectly affect the climate system of the Earth. The damage caused by atmospheric

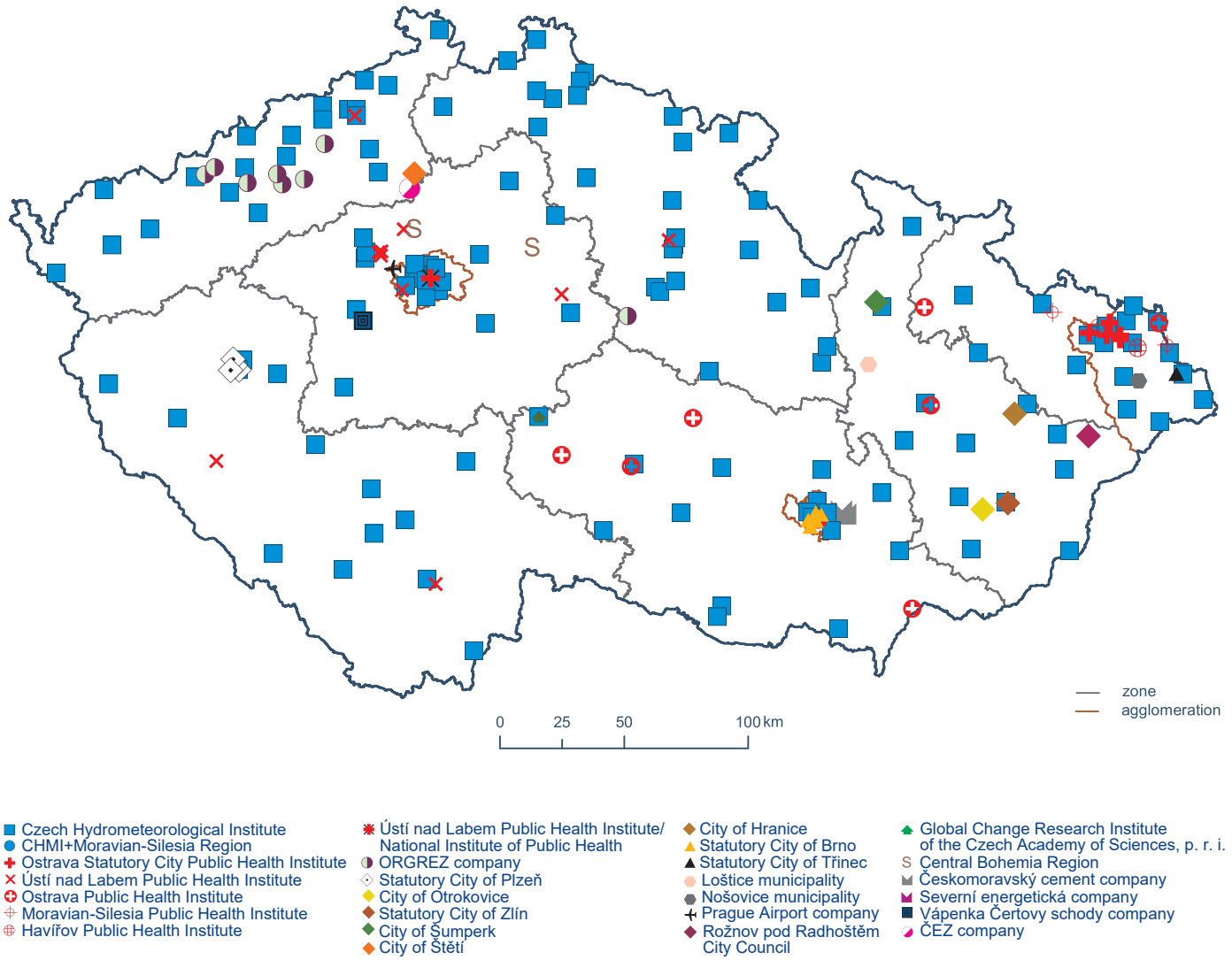


Fig. I.1 Station networks of ambient air quality monitoring in the Czech Republic, 2021

pollutants to materials and buildings, which are frequently historically important, must also be mentioned. Efforts to limit the effects of these impacts also incur economic costs related not only to the remediation of damage, but also to research focused on the quantification of pollution and related externalities.

Despite a number of measures implemented over the past years, particular sources produce emissions levels that can, in combination with meteorological and dispersion conditions, lead to exceeding the pollution limit levels for some substances. At the present time, of the monitored pollutants the greatest problems are caused by suspended particles and polycyclic aromatic hydrocarbons bound to them. In the spring and summer, pollution limit levels for ground-level ozone are exceeded at a number of locations.

However, the specific contributions of the individual sources to ambient air pollution differ in various regions depending on the composition of sources at the given location and also on the transfer of pollutants from other areas. The level of air pollution is objectively determined by means of a network of measuring stations that monitor concentrations of pollutants of the ambient air (air pollution) in the ground layer of the atmosphere (Fig. I.1). Based on a mandate from the Ministry of the Environment (MoE), the Czech Hydrometeorological Institute (CHMI) operates the State Air Quality Network in the Czech Republic, the Air Quality Information System (AQIS) of the Czech Republic, and routinely processes the measured air pollution values in the form of tabular and graphical reviews.

Tab. I.1 Limit values (LV) and permitted number of instances exceeding the limit value, upper and lower assessment thresholds according to the Act No. 201/2012 Coll. on the air protection, as amended, and Decree No. 330/2012 Coll., on the method of assessing and evaluating the level of pollution, the scope of informing the public about the level of ambient air pollution and during smog situations

Pollutant	Averaging interval	Assessment threshold [µg·m^{-3}]		Limit value [µg·m^{-3}]
		Lower assessment threshold	Upper assessment threshold	
SO_2	1 hour	—	—	**350** max. 24/year
	24 hours	**50** max. 3×/year	**75** max. 3×/year	**125** max. 3×/year
NO_2	1 hour	**100** max. 18×/year	**140** max. 18×/year	**200** max. 18×/year
	calendar year	**26**	**32**	**40**
CO	max. daily 8-hour running average	**5 000**	**7 000**	**10 000**
benzene	calendar year	**2**	**3.5**	**5**
PM_{10}	24 hours	**25** max. 35×/year	**35** max. 35×/year	**50** max. 35×/year
	calendar year	**20**	**28**	**40**
$PM_{2,5}$	calendar year	**12**	**17**	**20**[a)]
Pb	calendar year	**0.25**	**0.35**	**0.5**
As	calendar year	**0.0024**	**0.0036**	**0.006**
Cd	calendar year	**0.002**	**0.003**	**0.005**
Ni	calendar year	**0.010**	**0.014**	**0.020**
benzo[*a*]pyrene	calendar year	**0.0004**	**0.0006**	**0.001**
O_3	max. daily 8-hour running average	—	—	**120**[b)] 25× in 3-year average

a) In 2020, in the context of EU legislation, a stricter limit value of 20 µg·m^{-3} for the annual average concentration of $PM_{2.5}$ entered into force. Until 2019, the limit value of 25 µg·m^{-3} applied.

b) If the maximum permitted number of cases exceeding the limit value in a zone or agglomeration is observed, it is necessary to strive to achieve a zero number of such cases (averaging period is one year).

Pollutants monitored and evaluated for demonstrably harmful effects on population health or vegetation and ecosystems have set limit values. In evaluating the air quality, the observed concentration levels in particular are compared with the respective air pollution limit values (Tab. I.1 and I.2), or with the permissible frequencies of these limits being exceeded, which are concentration levels that should not be exceeded under applicable legislation. Brief characteristics of pollutants, an overview of their emission sources and their impacts are given in Tab. I.5.

Pollution limit levels comply with recommended values set by the World Health Organization (WHO) following a number of epidemiological studies. In the case of substances without a set limit, the levels are derived from established carcinogenic risk values (Tab. I.3 and I.4). In the interests of protecting public health, WHO recommends maintaining pollutant concentrations at levels that are even lower than those at which negative effects on human health have been documented. Nonetheless, these values stem from conclusions related to the impacts on health from ambient air pollution and do not take into account the aspects of technical and economic feasibility and further political and social factors. Consequently, pollution limit levels set by the legislation may be higher, but processes directed towards meeting the WHO guideline values must be generally supported (WHO 2013).

The WHO has been issuing recommended air quality values in view of health protection on a regular basis since 1987 to help governments and civil society reduce human exposure to air pollution and its adverse effects. Other WHO recommended values for air quality were published in 2006 (WHO 2006). This global update has had a significant impact on global air pollution mitigation guidelines. More than 15 years have passed since the guidelines were issued in 2006. Since then, there has been a significant increase in the quality and amount of evidence pointing to the adverse effects of air pollution on human health. The update of WHO air quality values was launched in 2016 based on significant scientific progress and the global importance of these values. In September 2021, the WHO issued new recommended values for air quality for six pollutants (so-called classical pollutants, i.e., PM_{10}, $PM_{2.5}$, NO_2, O_3, SO_2 and CO; Tab. I.3), for which knowledge on effects on human health advanced the most (WHO 2021).

Following the European Green Deal, air quality directives are currently being revised. The aim of the revision is to align air pollution limits more closely with scientific knowledge, including the latest WHO recommendations, to improve the legislative framework for air quality and to strengthen monitoring and modelling of air quality and air quality programmes (EC 2022).

I.1 The political and legislative framework for ambient air quality protection

The Thematic Strategy on Air Pollution (hereinafter the Strategy) is the basic EU strategic document in the area of assessing and managing ambient air quality. The objective of the Strategy, in accordance with the 6th Environment Action Programme, is to achieve "a level of ambient air quality which does not give rise to risks for human health and the environment and does not have markedly negative impacts on them". On the basis of the Strategy of 2005, the European Commission carried out a comprehensive review of current EU policy in the area of air protection. This resulted in the adoption of a package of measures (Clean Air Policy Package) in December 2013. The package contains, for example, the "Clean Air for Europe" programme document, outlining new objectives in ambient air quality for the period up to 2030 (EC 2013a).

Within the framework of the EU, the main tools for ambient air quality protection and improvement are Directive 2008/50/

Tab. I.2 Limit values (LV) for the protection of ecosystems and vegetation according to the Act No. 201/2012 Coll., as amended

Pollutant	Averaging interval	Assessment threshold		Limit value [µg·m^{-3}]
		Lower assessment threshold	Upper assessment threshold	
SO_2	year and winter period (1. 10. – 31. 3.)	8	12	20
NO_x	calendar year	19.5	24	30
O_3	AOT40, calculated from 1-hour values between May and July[a)]	—	—	[µg·m^{-3}·h]
				18 000[b)] average for 5 years

a) Note: AOT40 is the sum of differences between the hourly concentration higher than 80 µg·m^{-3} (= 40 ppb) and the value 80 µg·m^{-3} in the given period by using only hourly values measured every day between 8:00 and 20:00 CET.

b) If the limit value in the zone or agglomeration of 18 000 µg·m^{-3}·h is complied with, it is necessary to strive to reach the limit value of 6 000 µg·m^{-3}·h (averaging period is one year).

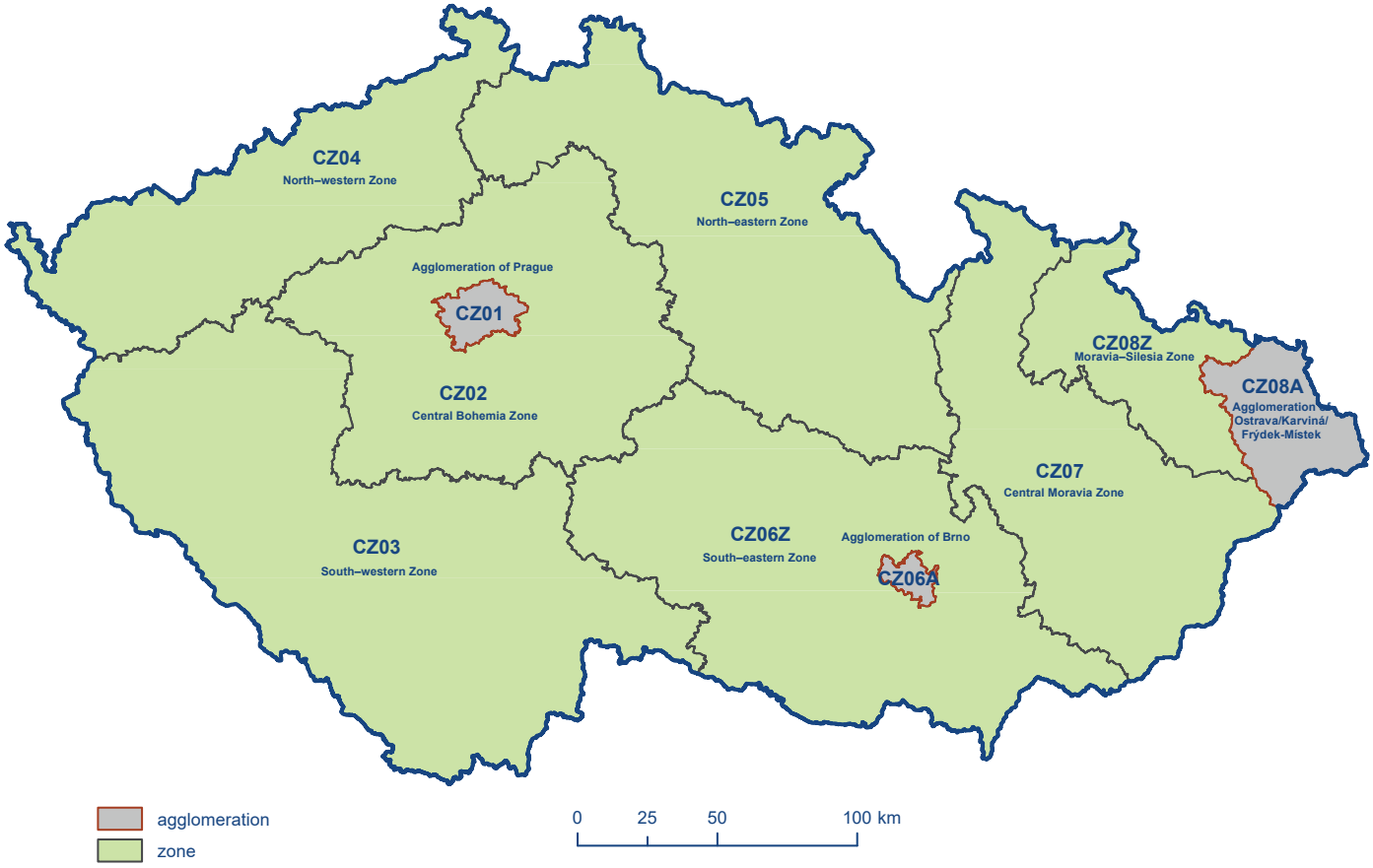


Fig. I.2 The zones and agglomerations for ambient air quality assessment and evaluation of ambient air pollution level according to the Act No. 201/2012 Col/. on Clean Air Protection, as amended

EC on ambient air quality and cleaner air for Europe, Directive 2004/107/EC relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air, Directive 2016/2284/EU on the reduction of national emissions of certain atmospheric pollutants, and European Parliament and Council Directive 2010/75/EU on industrial emissions (integrated pollution prevention and control). It is also EU Commission Decree 2015/1480 of 28 August 2015 amending several annexes to European Parliament and Council Directives 2004/107/ES and 2008/50/ES, which set the rules for reference methods, data verification and the location of sampling sites for assessing ambient air quality.

The national legislation on air quality evaluation in the Czech Republic (CR) is also based on the European legislation. The basic legislative norm in the CR is Act No. 201/2012 Coll., on air protection, as amended (hereinafter the "Air Protection Act"), defining, among other things, the zones and agglomerations for which ambient air quality is being evaluated. The zone is a territory specified by the MoE for monitoring and managing the air quality; the agglomeration is a settlement area with at least 250,000 inhabitants. The Air Protection Act sets out three agglomerations and seven zones (Fig. I.2). Details are further specified by Decree No. 330/2012 Coll., on the method of assessing and evaluating pollution levels and on the extent of informing the public on the level of pollution and in smog situations.

Based on the requirement of the European Commission to prepare a coherent approach to air quality control in the CR, a Medium-Term Strategy (up to 2020) for improving air quality in the CR had been prepared. This conceptual document was approved in December 2015, and summarizes the outputs of basic strategic documents for improving air quality – the National Emission Reduction Programme of the Czech Republic and ten programmes for improving air quality (PZKO) elaborated for designated zones and agglomerations. Among other things, it acts as a basic document for financing measures for decreasing emissions and improving air quality from EU funds via operational programmes (MŽP 2015).

At the beginning of 2020, the Ministry of the Environment published an updated National Emission Reduction Program of the Czech Republic. The CR has been updating this document continuously since 2004, and its main purpose is to ensure a reduction in the overall production of pollutants and levels of air pollution in the CR. The working group, of which CHMI was also an acti-

Tab. I.3 WHO Air Quality Guidelines for the protection of public health (WHO 2000, WHO 2005, WHO 2021)

Pollutant	Averaging time	Air quality guideline level until 2020	Air quality guideline level since 2021
PM_{10}	calendar year	20 $\mu g \cdot m^{-3}$	15 $\mu g \cdot m^{-3}$
	24 hours[c)]	50 $\mu g \cdot m^{-3}$	45 $\mu g \cdot m^{-3}$
$PM_{2.5}$	calendar year	10 $\mu g \cdot m^{-3}$	5 $\mu g \cdot m^{-3}$
	24 hours[c)]	25 $\mu g \cdot m^{-3}$	15 $\mu g \cdot m^{-3}$
benzo[*a*]pyrene[a)]		not specified	not specified
NO_2	calendar year	40 $\mu g \cdot m^{-3}$	10 $\mu g \cdot m^{-3}$
	24 hours[c)]		25 $\mu g \cdot m^{-3}$
	1 hour	200 $\mu g \cdot m^{-3}$	200 $\mu g \cdot m^{-3}$
O_3	max. daily 8-h running average[c)]	100 $\mu g \cdot m^{-3}$	100 $\mu g \cdot m^{-3}$
	peak season[d)]		60 $\mu g \cdot m^{-3}$
benzene[a)]		not specified	not specified
Pb	calendar year	0.5 $\mu g \cdot m^{-3}$	
Cd[a, b)]		not specified	not specified
As[a)]		not specified	not specified
Ni[a)]		not specified	not specified
SO_2	24 hours[c)]	20 $\mu g \cdot m^{-3}$	40 $\mu g \cdot m^{-3}$
	10 minutes	500 $\mu g \cdot m^{-3}$	500 $\mu g \cdot m^{-3}$
CO	15 minutes	100 000 $\mu g \cdot m^{-3}$	100 000 $\mu g \cdot m^{-3}$
	1 hour	30 000 $\mu g \cdot m^{-3}$	35 000 $\mu g \cdot m^{-3}$
	8 hours	10 000 $\mu g \cdot m^{-3}$	10 000 $\mu g \cdot m^{-3}$
	24 hours[c)]		4 000 $\mu g \cdot m^{-3}$

a) These are carcinogenic substances for human health. Therefore, no-effect level of the substance exposure cannot be established. The WHO recommended level is not specified. For more information on carcinogenic risks, see WHO (2000). The WHO only determines the unit risk factors for non-threshold carcinogenic substances. Unit risk factor values for 1 $\mu g \cdot m^{-3}$ lifetime risk exposure are as follows: 6×10^{-6} for benzene, 8.7×10^{-2} for benzo[*a*]pyrene, 4.9×10^{-4} for Cd, 3.8×10^{-4} for Ni, and 1.5×10^{-3} for As.

b) The recommended value for cadmium in outdoor air to prevent further accumulation of this element in agricultural soils is 0.005 $\mu g \cdot m^{-3}$.

c) Determined as 99th percentile.

d) The average of daily 8-hour O_3 maximum concentrations for six consecutive months with the highest six-month moving average O_3 concentration.

ve participant, coordinated meetings of working teams for individual sectors of interest — agriculture, transport, public energy and local household heating. In connection with the outcomes of these negotiations and analytical documents, including emission and air pollution assessments of the situation since 2008, measures were proposed to reduce the emissions of monitored pollutants. Measures according to their nature are divided into three groups, namely priority, support and cross-cutting measures. A responsible coordinator was designated for the implementation of individual measures. In the case of priority measures, in addition to the coordinator and a deadline for their fulfilment, methods of implementation and indicators for monitoring their implementation were also determined. The methods were also defined and benefits evaluated of measures to reduce emissions below the level of emission ceilings set by the requirements of Directive 2016/2284/EU (see Chapter II.).

Where a limit value is exceeded in a zone or agglomeration or if the limit value is exceeded in a zone or agglomeration multiple times and more than the permitted maximum number of instances, the Ministry of the Environment, in cooperation with the relevant regional or local authority, is obliged to develop a programme

aimed to improve air quality in the given zone or agglomeration, which it must prepare within 18 months after the end of the calendar year. The aim of the programme is to set out measures to achieve the required air quality in the shortest possible time. PZKOs set measures mainly at the regional and local level.

PZKOs 2020+ for individual zones and agglomerations were published in the Bulletin of the Ministry of the Environment (MŽP 2020, MŽP 2021). Following the amendment to the Air Protection Act of 2018 (No. 172/2018 Coll.), PZKOs 2020+ replace the previous air quality improvement programs of 2016. PZKOs 2020+ stipulate binding measures to achieve air pollution limits. These measures were determined on the basis of an analysis of the causes of air pollution and on the basis of air pollution projections of air quality developments, taking into account existing measures. In addition to these binding measures, PZKOs 2020+ also stipulate so-called Support measures. Support measures represent good practice in air quality management at all levels and in all parts of public administration.

I.2 Objectives of the publication

The "Air Pollution in the Czech Republic in 2021" yearbook, together with the published "Summary Table Survey" data yearbook (CHMI 2022e), and with the methodological material "Data collection, processing and evaluation system" (CHMI 2022d), provides a comprehensive annual overview of information on the ambient air quality in the territory of the CR for the relevant year. The evaluation of air quality is based on measured data collected within the AQIS, using additional data sources and mathematical tools. The data yearbook presents verified measured pollution data and information on the chemical composition of atmospheric precipitation from individual locations, including aggregated data, while the graphic yearbook provides a commented summary of information in the form of overview maps, graphs and tables.

The summary and introductory chapter of the yearbook contains the most important information on air quality in a given year and general information on the issue. The following chapters contain detailed elaborations of individual topics related to emissions of polluting substances, and evaluations of air quality in the CR and the situation in Europe. The publication also contains information on greenhouse gas emissions and atmospheric deposition.

Ambient air quality yearbooks are intended for authorities and organizations dealing with and managing issues related to the environment and air protection in the CR as well as to the professional and wider public. The yearbooks are publicly available on the CHMI websites www.chmi.cz and info.chmi.cz. The publication is the fundamental information document on air quality in the CR. Its aim is to evaluate the air quality in a broader context based on the available data and information.

The yearbook presents an air quality evaluation in 2021 pursuant to the requirements of the Czech legislation on air quality protection. In accordance with the Air Protection Act, the evaluation is aimed at defining areas where the limit values for the protection of health and the protection of ecosystems and vegetation are exceeded (Tab. I.1 and I.2). In 2020, in the context of EU legislation, a stricter limit value of 20 $\mu g \cdot m^{-3}$ for the annual average concentration of $PM_{2.5}$ entered into force. Until 2019, the limit value of 25 $\mu g \cdot m^{-3}$ applied.

Tab. I.4 WHO Air Quality Guidelines for the protection of vegetation (WHO 2000)

	Averaging interval	Vegetation category	Guideline value
NO_x	calendar year		30 $\mu g \cdot m^{-3}$
	24 hours		75 $\mu g \cdot m^{-3}$
SO_2	year and winter period	agricultural crops	30 $\mu g \cdot m^{-3}$
	year and winter period	forests and natural vegetation	20 $\mu g \cdot m^{-3}$
	calendar year	lichens	10 $\mu g \cdot m^{-3}$
O_3	AOT40, calculated from 1-hour values between May and July	agricultural crops	6 000 $\mu g \cdot m^{-3}$
	AOT40, calculated from 1-hour values between April and October	forests	20 000 $\mu g \cdot m^{-3}$
	AOT40, calculated from 1-hour values between May and July	semi-natural vegetation	6 000 $\mu g \cdot m^{-3}$

Tab. I.5 Brief characteristics, overview of major emission sources and major effects of ambient air pollutants

Pollutant and its sources	Health effects	Environmental effects
Suspended particles (atmospheric aerosol) Atmospheric aerosol consists of liquid or solid particles suspended in the air, originating from natural or anthropogenic processes. The natural sources include volcanic activity, wind borne dust particles and pollen, and natural fires. The largest anthropogenic source of suspended particles in the CR originates from residential combustion, road transport, farm-level agricultural operations (harvesting, tillage, etc.) and public energy and heat production. Suspended particles can be of primary or secondary origin. The primary particles are emitted directly into the air, the secondary particles are formed in the air by a gas-to-particle conversion. The main gas precursors of secondary particles are SO_2, NO_x, NH_3 and VOC (Pöschl 2011; EEA 2013). The size range of atmospheric aerosol covers five orders of magnitude – from units of nm up to hundreds of µm. Based on similar particle properties, this scale can be divided into fine mode (particles ≤ 2.5 µm) and coarse mode (particles ≥ 2.5 µm). Fine particles are mainly products of imperfect combustion, coarse particles are formed mechanically (Hinds 1999; Seinfeld, Pandis 2006). Fine particles can be further divided into nucleation, Aitken and accumulation mode particles. Particles of the nucleation mode (< 20 nm) are released into the air directly or are formed in it, if they are not removed from the atmosphere by the diffusion process they are transformed into particles of the Aitken mode. Aitken mode particles (20–100 nm) are formed during combustion processes (Finlayson-Pitts and Pitts 1999). The accumulation mode of size between 100 nm and 2.5 µm is formed by transformed particles of the previous two modes (Seinfeld and Pandis 2006). Mobile sources produce particles of 10–100 nm. Stationary sources give rise to particles in the range of 50-200 nm. Long range particle transport transfers particles of 100–1000 nm (Gu et al. 2011, Hinds 1999, Zhang et al. 2004, Zhou et al. 2005, Yue et al. 2008). Coarse mode particles consist of e.g. soil particles, sea salt, particles from industrial and agricultural activities. Their high sedimentation rate determines a short residence time in the atmosphere in the range of several hours to days. They are removed from the atmosphere by dry deposition and precipitation (Hinds 1999; Tomasi et al. 2017; Seinfeld and Pandis 2006). The legislation sets air pollution limits for the mass concentration of particles of the size fraction PM_{10} (particles with a diameter ≤ 10 micrometers) and $PM_{2.5}$ (particles with a diameter ≤ 2.5 micrometers). The mass of particles (especially ultra-fine particles < 100 nm) in the standard PM_{10} and $PM_{2.5}$ size spectrum is negligible in comparison with their numbers. Therefore, measurements of the number of particles and their size distribution are used for specific evaluations of the influence of aerosol particles (health impacts, climate impact) (Tuch et al. 1997, Stanier et al. 2004).	Suspended particles cause a broad spectrum of effects on the cardiovascular and respiratory systems. They irritate the respiratory tract, reduce defence mechanisms and facilitate the development of infection, cause an inflammatory reaction in lung tissue, contribute to oxidative stress and thus the development of atherosclerosis, affect the electrical activity of the heart and have been classified as proven human carcinogens since 2013 (IARC 2015). The effect depends on the size, shape and composition of particles. Short-term increase of daily PM_{10} concentrations contributes to increasing total morbidity and mortality due to mainly cardiovascular diseases, to the growth of the number of persons hospitalized due to respiratory diseases, increasing infant mortality and increasing the frequency of coughing and breathing problems, mainly in asthmatics (SZÚ 2015). Long-term increased concentrations can result in reduced pulmonary function, increased morbidity due to respiratory diseases and increased incidence of chronic bronchitis symptoms and decreased lifespan, especially due to increased mortality of the elderly and sick persons due to cardiovascular and respiratory diseases, including lung cancer (SZÚ 2015). A safe threshold concentration for the impact of aerosol particles in the air has not yet been determined.	They affect the Earth's radiation balance, cloud and precipitation formation, and visibility. They have a direct influence (by scattering of incoming solar radiation) and indirect influence (as condensation nuclei in the clouds affecting the reflection of radiation by the clouds). The particles reflect and / or absorb solar radiation and thus contribute to the cooling or warming of the Earth's climate system (IPCC 2013). Suspended particles affect both animals and humans, affect plant growth and ecosystem processes, and may damage and tarnish buildings (EEA 2013).

Pollutant and its sources	Health effects	Environmental effects
Benzo[*a*]pyrene Benzo[*a*]pyrene, which occurs in the air primarily bound to particles, is a suitable marker of ambient air pollution caused by PAHs. The reason is its stability and relatively constant contribution to carcinogenic activity of the mixture of PAHs bound to particles (EC 2001a). Residential heating belongs to the major sources of benzo[*a*]pyrene in the CR.	PAHs represent a group of substances of which many have toxic mutagenic or carcinogenic properties, belong among endocrine disruptors (substances damaging the function of endocrine glands) or act immunosuppressively. They affect foetal growth. Prenatal exposure to PAH is related to markedly lower birth weight (Choi et al. 2006) and probably also adversely affects the cognitive development of young children (Edwards et al. 2010). Benzo[*a*]pyrene itself is classified as a proven human carcinogen (IARC 2020).	PAHs can bioaccumulate and enter the food chain (Brookes et al. 2013, EEA 2013).
Nitrogen oxides The term "nitrogen oxides" (NO_x) refers to nitric oxide (NO) and nitrogen dioxide (NO_2). More than 90 % of anthropogenic emissions of NO_x are represented by NO emissions. The major anthropogenic sources of NO_x in the CR are road transport and public energy production.	As concerns the impact on human health, the most significant nitrogen oxide is NO_2 (WHO 2005). NO_2 can affect mainly the respiratory tract. The main effect of short-term exposure to high concentrations of NO_2 is increased reactivity of the respiratory tract and ensuing worsened symptoms in people with asthma (Samet et al. 2000). Exposure to NO_2 impairs lung functions and increases the risk of respiratory diseases in children due to reduced immunity to infections (EEA 2013, Peel et al. 2005). It is also linked to increase of the total, cardiovascular and respiratory mortality (Stieb et al. 2003, Samoli et al. 2003), however, it is difficult to separate the effects of NO_2 from other simultaneously acting substances, mainly aerosols (WHO 2005), hydrocarbons, ozone, and other substances (Brauer et al. 2002).	NO_x contribute to acidification and eutrophication of soil and water. High NO_x concentrations can lead to damage to plants. NOx act as precursors of ground-level ozone and particulate matter (EEA 2013, Brookes et al. 2013)
Ground-level ozone Ozone (O_3) is a secondary pollutant without its own emission source; it is formed as a part of photochemical smog under the influence of solar radiation during a series of reactions mainly between NO_x, VOC and oxygen. (EEA 2013). Ozone can be transported over long distances, accumulate and reach high concentrations far from its place of origin (Brookes et al. 2013)	The main effect of ozone on the human body is irritative. It irritates the conjunctiva, nasal mucosa and bronchi. Short-term studies show that O_3 concentrations can have adverse effects on lung function leading to inflammation and respiratory problems (EEA 2013). At higher concentrations, respiratory tract irritation will narrow and make it difficult to breathe. People with chronic obstructive diseases of the lungs and asthma are more sensitive to ozone. Higher ozone concentrations are associated with an increase in daily mortality (WHO 2006).	Ground-level ozone damages vegetation, impairs plant growth and decreases crop yields; it can damage forest ecosystems and reduce biodiversity (EEA 2013).
Benzene Benzene is present in the air mainly due to anthropogenic activities. Benzene emissions are released into the air by exhaust gases and evaporating from vehicle fuel systems. A significant amount of benzene emissions arises from the combustion of solid fuels in households, surface use of organic solvents, or fuel extraction.	Benzene ranks among human carcinogens (IARC 2020). At high concentrations, it can have haematotoxic, genotoxic and immunotoxic effects (SZÚ 2015).	Benzene can bioaccumulate; it can damage leaves of agricultural crops and kill plants (EEA 2013).

Pollutant and its sources	Health effects	Environmental effects
Lead Most lead present in the atmosphere is released from anthropogenic emission sources. The main sources in the CR include the production of iron and steel, road transport (tyre and brake abrasion), households, and public energy and heat production.	Long-term exposure is harmful to the biosynthesis of haem, the nervous system and blood pressure in humans. Exposure to lead also poses risks to developing foetus; it may negatively influence brain development and, consequently, mental development, (Černá et al. 2011; EEA 2013). As concerns its carcinogenic effects, lead is classified within group 2B – possibly carcinogenic to humans (IARC 2020).	Lead can accumulate in the bodies of organisms (bioaccumulation) such as fish and can enter the food chain (Brookes et al. 2013, EEA 2013).
Cadmium Cadmium is bound mainly to the particles with aerodynamic diameter of up to 2.5 µm (EC 2001b). The main sources in the CR include households (heating, water heating, cooking), public energy and heat production, iron and steel production, and glass production.	Long-term exposure to cadmium affects the function of kidneys. It can also have negative impacts on the respiratory tract; the effects of cadmium exposure also include lung cancer (WHO 2000).	Cadmium can bioaccumulate (EEA 2013).
Arsenic Arsenic occurs largely in particles with aerodynamic diameter up to 2.5 µm (EC 2001b). The main sources in the CR include households (heating, water heating, cooking), public energy and heat production, and glass production.	High concentrations affect the nervous system (SZÚ 2015a). Lung cancer is considered to be the critical effect following the long-term inhalation (EC 2001b; WHO 2000).	Arsenic can bioaccumulate; it reduces plant growth and crop yields from soils containing arsenic (EEA 2013).
Nickel Nickel is found in particles in the form of several chemical compounds with various levels of toxicity to humans and also to ecosystems. The main sources in the CR include public energy and heat production, and combustion processes in industry, construction activities and households.	Nickel can affect the respiratory and immune systems in humans (WHO 2000, EEA 2013). Nickel compounds are classified as proven human carcinogens; metallic nickel and its alloys are classified as possibly carcinogenic to humans (IARC 2020).	Nickel may cause the pollution of soil and water.
Sulphur dioxide Sulphur dioxide (SO_2) is emitted into the atmosphere during the combustion of sulphur-containing fuels. The main sources in the CR are public electricity and heat production, and residential combustion.	SO_2 causes irritation of the eyes and respiratory tract. High SO_2 concentrations can lead to respiratory problems. Inflammation of the respiratory tract causes coughing, mucus secretion, aggravation of asthma and chronic bronchitis, and makes people more prone to infections of the respiratory tract. Those suffering from asthma and chronic lung disease are the most sensitive towards SO_2 exposure (EC 1997; WHO 2014).	SO_2 contributes to acidification of the environment. It also contributes to the formation of secondary suspended particles with a proven negative impact on human health (EEA 2013).
Carbon monoxide Carbon monoxide (CO) is a gas emitted due to incomplete combustion of fossil fuels. The largest sources of CO emissions in the CR are household heating, road transport, combustion processes in industry and construction (iron and steel) and the production of iron and steel	CO binds to haemoglobin more strongly than oxygen and thus reduces the oxygen-carrying capacity of blood. The first subjective symptoms of poisoning are headaches followed by impaired coordination and reduced awareness. Those suffering from cardiovascular disease are again the most sensitive towards CO exposure (EEA 2013). Toxic effects of CO become evident in organs and tissues with high oxygen consumption such as the brain, the heart and skeletal muscles. It is also dangerous to developing foetus (WHO 2000).	CO can contribute to the formation of ground-level ozone (EEA 2013, Brookes et al. 2013).

Pollutant and its sources	Health effects	Environmental effects
Elemental carbon Elemental carbon (EC) is a product of incomplete combustion of organic materials (coal, oil, petrol, wood and biomass) (Schwarz et al. 2008). EC is emitted into the air only directly (primary particles). The term black carbon (BC) is also used in addition to the term EC. Black and elemental carbon basically designate the same component appearing in the atmosphere. While EC contains only carbon, BC can contain, apart from EC, also organic ingredients (Chow et al. 2009; Husain et al. 2007; Petzold et al. 2013). The use of terminology to denote elemental and black carbon differs in the concept of the nature of this substance. The term EC denotes volatility properties, while black carbon (BC) entails absorption properties across the spectrum of visible wavelengths (Seinfeld, Pandis 2006).	EC is a part of the fine fraction of aerosol particles ($PM_{2.5}$). It has been concluded from the evaluation of health impacts of $PM_{2.5}$ on human health that variability of epidemiologic results cannot be explained by only variance of concentrations of $PM_{2.5}$ in the environment. Causes can include just more active toxicological components of $PM_{2.5}$ (Luben et al. 2017). Compared to OC, EC (or BC) penetrates more readily into the human body and aggravates heart and lung diseases (Na, Cocker 2005). Organic particles (including organic carbon), which can contain among other components fractions of polycyclic aromatic hydrocarbon (PAHs), are studied for their carcinogenic and mutagenic effects (Seinfeld, Pandis 2006; Satsangi et al. 2012).	BC strongly absorbs solar radiation and contributes significantly to the warming of the Earth's climate system (Bachman 2009).
Organic carbon Organic (OC) carbon is formed during incomplete combustion, the production of biogenic particles (viruses, bacteria, pollen, fungal spores and all kinds of vegetation fragments) and the resuspension of transport-associated dust (Schwarz et al. 2008). OC is both primary and secondary particle, i.e. it can be formed by reactions of gaseous organic precursors.	OC is a part of the fine fraction of aerosol particles ($PM_{2.5}$). Organic particles (including organic carbon), which may contain, inter alia, polycyclic organic hydrocarbon fractions (PAHs), are being studied for their carcinogenicity and mutagenic effects (Seinfeld, Pandis 2006; Satsangi et al. 2012).	OC scatters solar radiation, which has a cooling effect on the Earth's climate system. (IPCC 2013).

II. AIR POLLUTION

Under authorization by the Ministry of the Environment, the CHMI evaluates the level of air pollution for primary pollutants of anthropogenic origin. The basic background material for this evaluation is the so-called emission inventory, which combines the direct collection of data reported by source operators with model calculations from data reported by source operators or determined in the context of statistical studies performed primarily by the Czech Statistical Office. The resulting emission inventories are presented in the form of emission balances in sectoral and territorial classifications (CHMI 2022a). The accompanying document describing the methodologies for processing emission inventories is also presented on the CHMI website (CHMI 2022b). The current report (CHMI 2022f) presents results of the emission inventory for the period 1990–2020, taking into account recommendations of the team reviewing the inventory methodology of the EU Member States. These relate mainly to a determination of ammonia emissions from applying mineral fertilizers and the inclusion of emissions of the agricultural activities sector (NMVOCs and NO_x).

Emission inventory in the Czech Republic

From the viewpoint of methods for monitoring emissions, air pollution sources are divided into individually monitored sources and collectively monitored sources. Sources listed in Annex No. 2 of the Act No. 201/2012 on air protection are monitored individually. Pursuant to Article 17(3)(c), the operators of these sources are obliged to keep operating records of permanent and variable data on stationary sources describing the source, its operation, and data on inputs and outputs from these sources. They are also obliged to annually report information on the summary operating records (SPE) through an integrated system of fulfilling reporting obligations (ISPOP). ISPOP data are then collected in the REZZO 1 and REZZO 2 databases. Data collection for the previous year takes place from January to the end of March.

Collectively monitored sources registered in REZZO 3 include emissions from unspecified combustion sources, construction and agricultural activities, the surface use of organic solvents, filling stations, coal mining, car and building fires, waste and waste-water treatment, the use of fireworks, etc. Emissions from these sources are determined using data collected by national statistical surveys and emission factors.

Data from mobile sources are also monitored collectively (REZZO 4) and include emissions from roads (including NMVOC emissions from vehicle fuel system petrol evaporation and emissions from brake, tyre and road abrasion), rail, water and air transport, and the operation of off-road machinery and equipment (agricultural, forest and construction machinery, military vehicles, greenery maintenance, etc.). Emissions from resuspension, i.e., dust swirling during vehicle operation, are not part of the emission inventory.

For the model assessment of pollution levels, to determine emissions from domestic heating, emissions factors are applied that

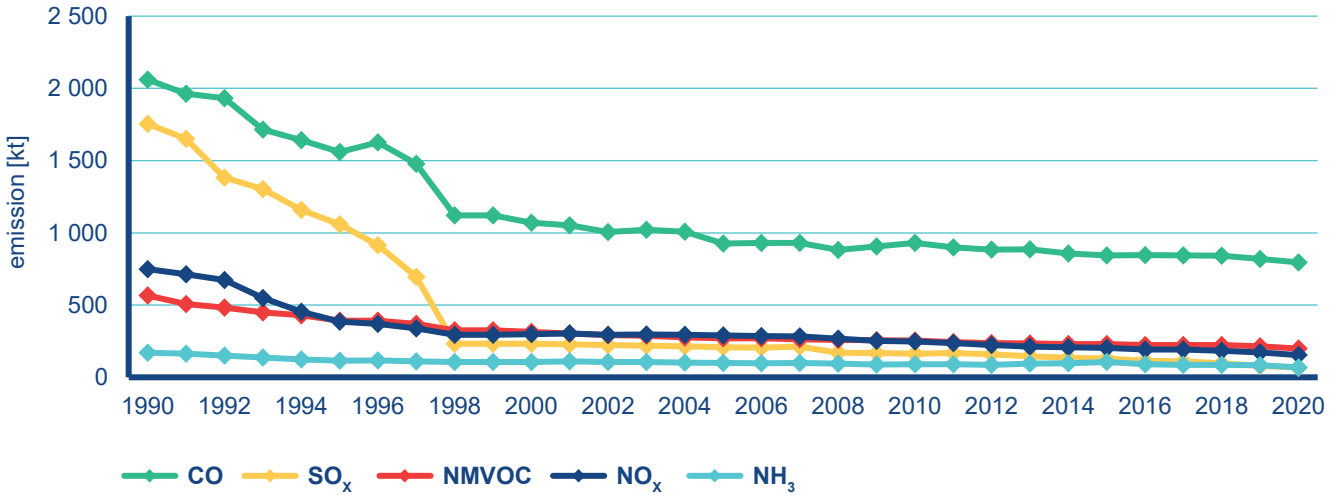


Fig. II.1 Main pollutants total emissions, 1990–2020

represent estimated conditions when boilers are operated for part of the time at reduced output, meaning imperfect combustion and increased emissions (EU 2015). Similarly, emissions from road traffic resuspension are included in the model assessment of pollution levels.

Emission trends

Trends in air pollution levels are closely connected with economic and social-political conditions, as well as with the development of knowledge about the environment, permitting fuller and more accurate emission inventories. A time series of the 1990–2020 period, separated for the main gaseous pollutants, particulate matter, heavy metals, and POPs, are presented in Figs. II.1 to II.4. During this period, the main pollutant emissions decreased by tens of percent. After an initial decrease in the period up to 2008, benzo[*a*]pyrene emissions again started to increase, and by 2012 approached the level at 2001. Due to a higher rate of black coal consumption in households after 2010, HCB emissions also increased. In 2012, they reached levels 35 % higher than in 2000. Emissions from stationary sources in REZZO 1 and REZZO 2 decreased substantially as a result of the introduction of an air quality control system that uses many instruments (normative, economic, information, etc.) at various levels. The impacts of these instruments appeared to the greatest degree at the end of the 1990s, i.e., at a time when emission limits introduced by then new law came into force. Significant reductions in emission from the most important sources had a positive effect on air quality, especially in industrial areas of Northern Bohemia and Moravia, and there was also a significant reduction in the long-range transport of air pollutants. Despite significant reductions

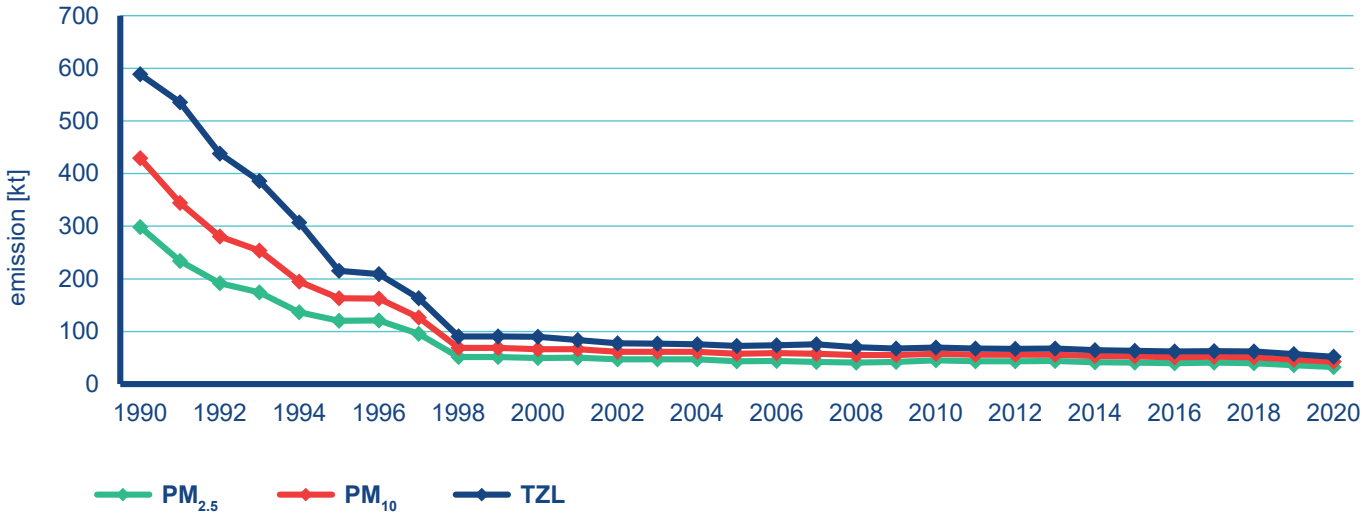


Fig. II.2 Particulate matter total emissions, 1990–2020

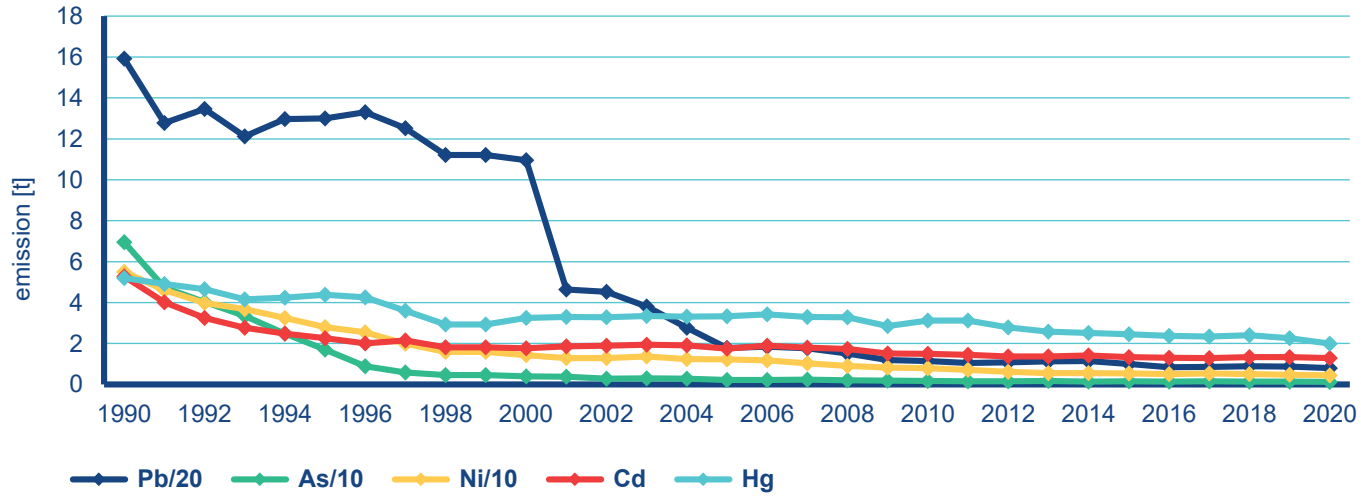


Fig. II.3 Heavy metals total emissions, 1990–2020

in emissions from energy and industrial sources, compliance problems with air quality requirements persist in many places, which is why attention has been focused in recent years on REZZO 3 and REZZO 4 categories. Although there has been a significant reduction in emissions, especially from road transport, the impact of these sources on air quality is significant mainly in municipalities, and no effective country-wide measures have yet been applied to regulate them. For these reasons, among others, revision of the Göteborg Protocol and Directive of the European Parliament and Council (EU) 2016/2284 imposed the obligation on the CR to reduce emissions by 2020 for $PM_{2.5}$ by 17 %, SO_x by 45 %, NO_x by 35 %, NMVOCs by 18 % and NH_3 by 7 % and by 2030 for $PM_{2.5}$ by 60 %, SO_x by 66 %, NO_x by 64 %, NMVOCs by 50 % and NH_3 by 22 %, compared to 2005.

In 1991, Act No. 309/1991 Coll., on air protection, came into force, supplemented by Act No. 389/1991 Coll., on state administration in air protection and fees for pollution thereof, which introduced emission limits in force from 1998 for the first time in the history of the CR. As a result of the restructuring of the economy and the modernization of resources, there has been a significant decline in production in a number of sectors since 1990 (Fig. II.5). For combustion sources with lower heat output (heating plants/boiler rooms), solid and liquid fossil fuels were gradually replaced by natural gas (Fig. II.6).

Emissions from local household heating decreased most in the 1993–1997 period as a result of conversion to gas heating in municipalities and state support for heating with electricity.

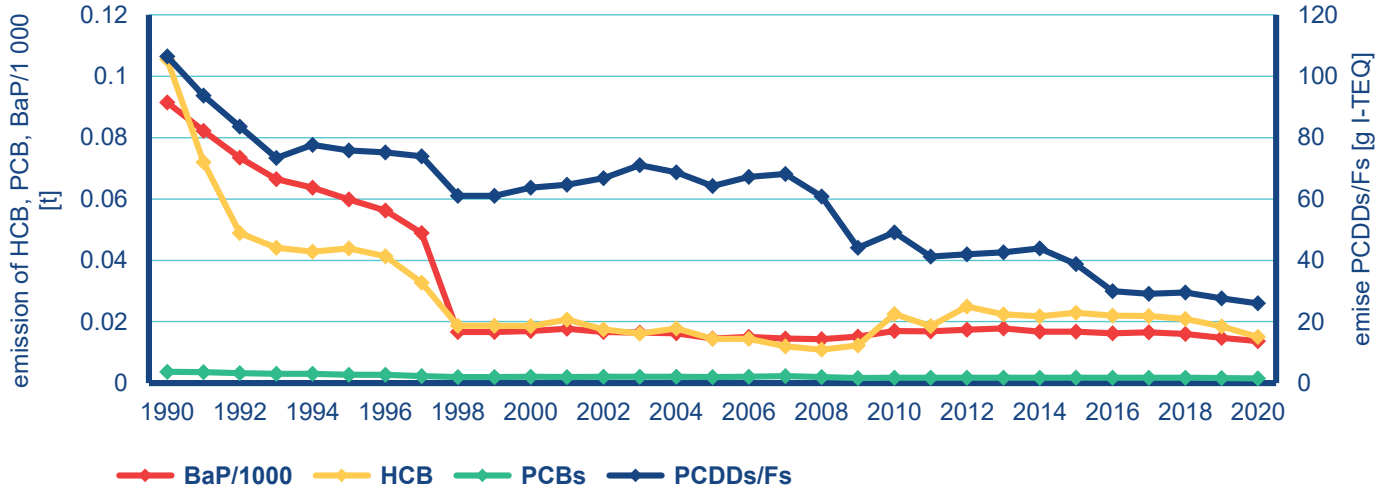


Fig. II.4 POP emissions, 1990–2020

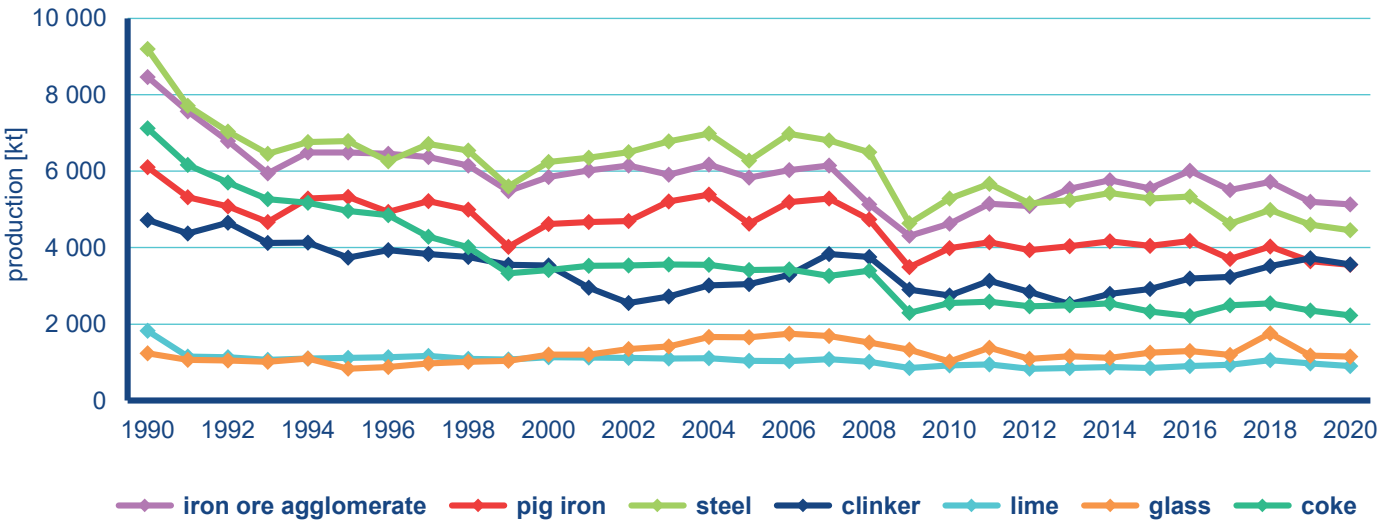


Fig. II.5 The output of basic industrial products, 1990–2020

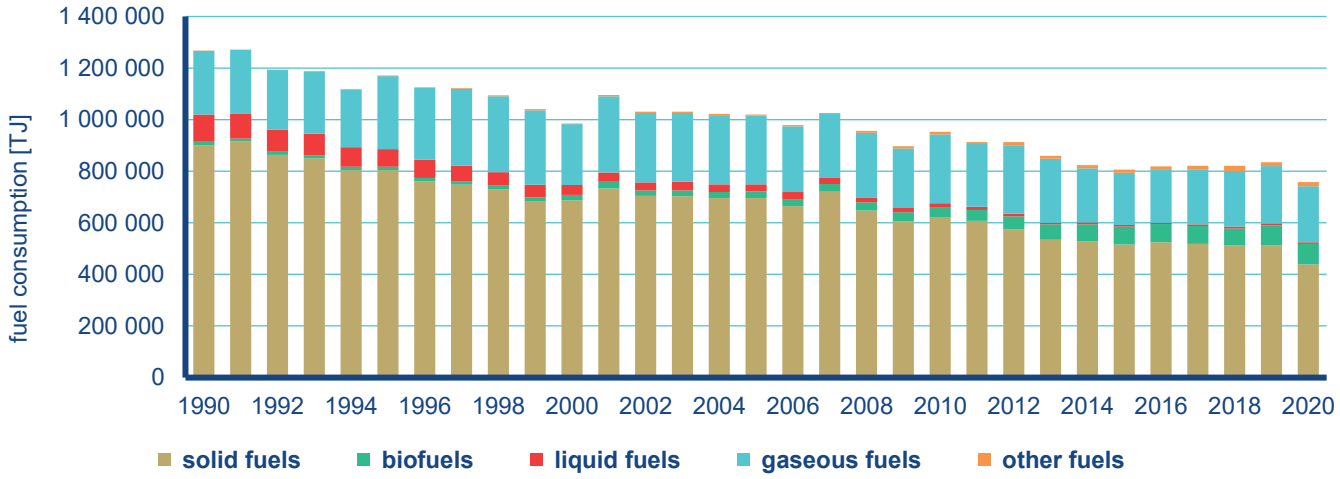


Fig. II.6 Fuel consumption in REZZO 1 and REZZO 2 sources, 1990–2020

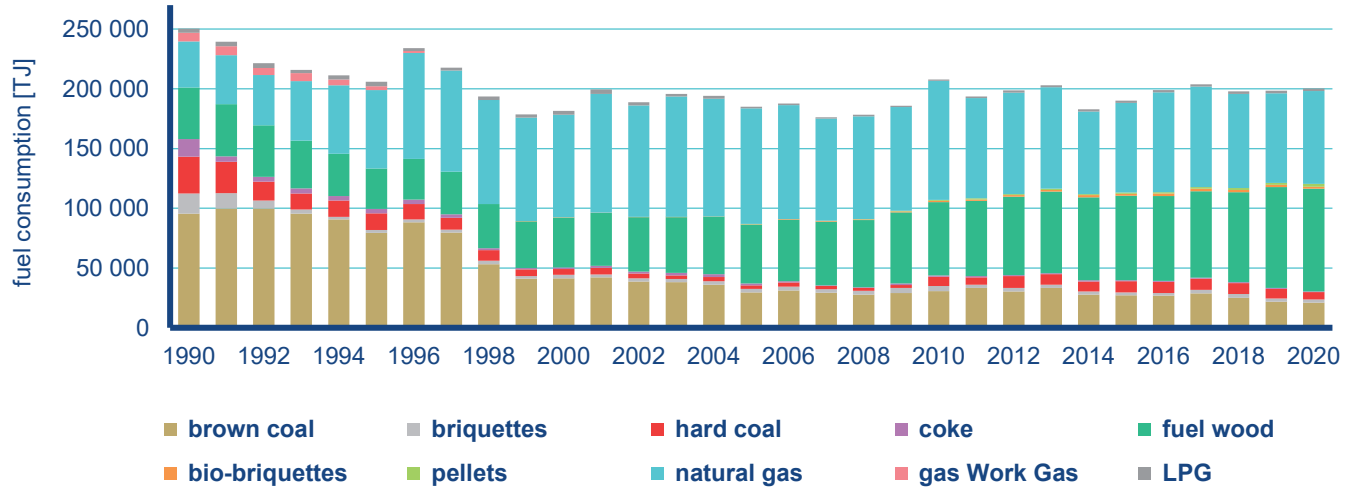


Fig. II.7 Fuel consumption in REZZO 3 sources (households), 1990–2020

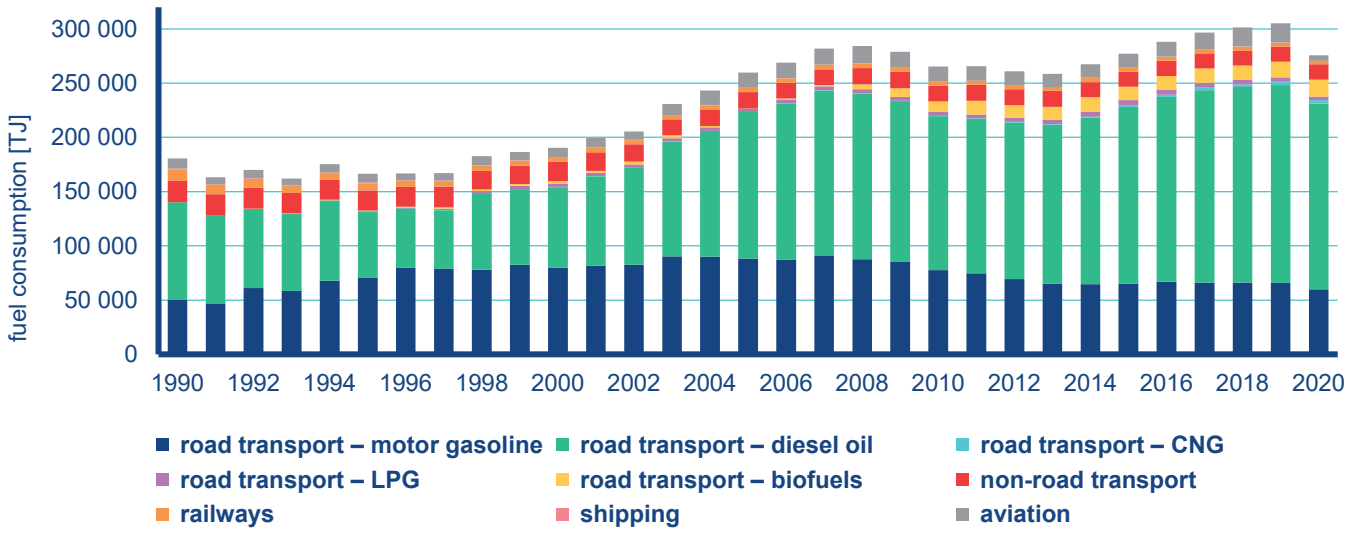


Fig. II.8 Fuel consumption in REZZO 4 sources, 1990–2020

The consumption of household fossil fuels in 2001 was 67 % lower than in 1990 (Fig. II.7). Emissions of the main pollutants from REZZO 4 sources decreased due to regular vehicle fleet renewal. Termination of the sale of leaded petrol in 2001 led to a substantial decrease in Pb emissions into the air (Fig. II.3).

The favourable trend in reducing consumption of fossil fuels in the local household heating sector did not continue after 2001, mainly because of the increasing prices of natural gas and electricity. In the 2002–2008 period, the consumption of coal slightly decreased and was replaced by increasingly popular heating with wood. After 2009 the consumption of solid fuels in households, particularly firewood, increased again (Fig. II.7). During 2009–2012, the Green Light for Savings programme helped in insulating buildings and replaced non-ecological heating with low-emission sources. Emissions of the main pollutants from REZZO 4 sources decreased due to introducing stricter emission standards for new vehicles brought to market. The impact of increased intensity of transport and consumption of diesel fuel led to an increase in emissions of heavy metals and POPs (Fig. II.8).

In 2012, the Act No. 201/2012 Coll. on air protection came into force, introducing stricter emission limits for combustion sources pursuant to Directive 2010/75/EU on industrial emissions. The most important technical measures to reduce emissions in the 2013–2020 period included the installation of sulphur-removal and nitrogen-removal equipment from combustion products (most power plants and larger heating plants) or the installation of fabric filters on existing electrostatic separators (e.g., at metallurgical plants in the Moravian-Silesia region).

The new law has also been focused on reducing emissions from the local household heating sector by introducing minimum emission parameter values for combustion sources with an overall rated thermal input of up to 300 kW for equipment brought to market since 2014 and 2018. From 1 September 2024, for these sources, it will only be possible to operate boilers complying with emission class 3, which should lead to removing of old types of boilers and replacing them with more modern equipment with lower emissions. The replacement of boilers takes place gradually and, together with reducing building energy demands, is supported by subsidy policies at national and regional levels.

The preliminary emission assessment for 2021 (Tab. II.1) shows an expected increase in all emissions except for SO_x. The increase occurred mainly in emissions from household heating, resulting from the colder heating season, leading to an increase in fuel consumption and emissions by approximately 8 %. Compared to 2020, during which there was a slowdown in industrial production, provision of services, and consumption of fuels in almost all sectors, there was another increase in 2021, which was reflected in the increase in emissions of REZZO 1 and REZZO 2 sources (NO_x by approx. 6 % and CO by about 8 %). For TSP, NMVOC and NH_3 emissions, this increase was nearly not reflected. Year-on-year, emissions decreased only for SO_x, by approx. 7 kt, while the biggest proportion in the decrease resulted from the ORLEN refinery complex operation in Litvínov (approx. 3 kt), the end of operation of the Prunéřov I power plant on 30 June 2020 (approx. 1 kt), and the reduction from other important sources for the production of electricity and heat by approx. 2.7 kt. The increase in fuel consumption by approx. 6 % of REZZO 4 category resulted in the increase in emissions of all pollutants. In total emissions, compared to previous year, a decrease only occurred in SO_x emissions by approx. 8.5 %, on the contrary, the highest increase in total emissions was for CO and NMVOCs by more than 7 %. A more detailed evaluation of the proportion of individual categories of sources in total emissions and the development of emissions of pollutants, particularly for the listed sources, can be found in the subsections of Chapter IV.

Tab. II.1 The comparasion of emissions of main pollutants, 2020–2021 (preliminary data)

Emission source category	TSP		SO_x		NO_x		CO		VOC		NH_3	
	kt·year^{-1}											
Year	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
REZZO 1-2	5.8	5.8	52.0	45.0	60.3	63.9	159.6	172.4	19.6	19.5	0.7	0.7
REZZO 3	39.7	41.9	14.4	15.6	31.5	32.6	541.9	587.1	165.6	179.1	67.0	67.5
TOTAL stationary sources	**45.5**	**47.7**	**66.4**	**60.6**	**91.8**	**96.5**	**701.5**	**759.5**	**185.2**	**198.6**	**67.7**	**68.2**
REZZO 4	6.3	6.5	0.1	0.2	62.0	62.2	94.1	97.9	13.7	15.3	0.8	0.8
TOTAL	**51.8**	**54.2**	**66.5**	**60.8**	**153.8**	**158.7**	**795.6**	**857.4**	**198.9**	**213.9**	**68.5**	**69.0**

Projections of emissions

Within the framework of reporting concerning the Czech Republic's international obligations (CLRTAP) and Directive 2016/2284/EU, the CHMI provides projections based on emission inventories, trends of socio-economic indicators, law valid for the projected time horizon and further emission reduction measures.

An emission projection for the period 2020–2030 was prepared (Fig. II.9) according to the scenario with valid measures (WEM) and with additional measures (WAM) for the purpose of updating the National Emission Reduction Programme (MŽP 2019). This projection was updated as a report preparation under international obligations in March 2021. The projections for NO_x, NMVOCs, SO_x, NH_3, and $PM_{2.5}$ particles are based primarily on expert evaluations of future emissions and activity data for significant source categories such as energy, transport, agriculture, solvent use and waste management.

By 2030, it is anticipated that emissions of all pollutants will decrease. It results from replacing heating facilities in the local household heating sector, vehicle fleet renewal including support for low-emission and zero-emission vehicles, greater support for renewable energy, tightening of obligations for the storage and application of fertilizers, and other measures.

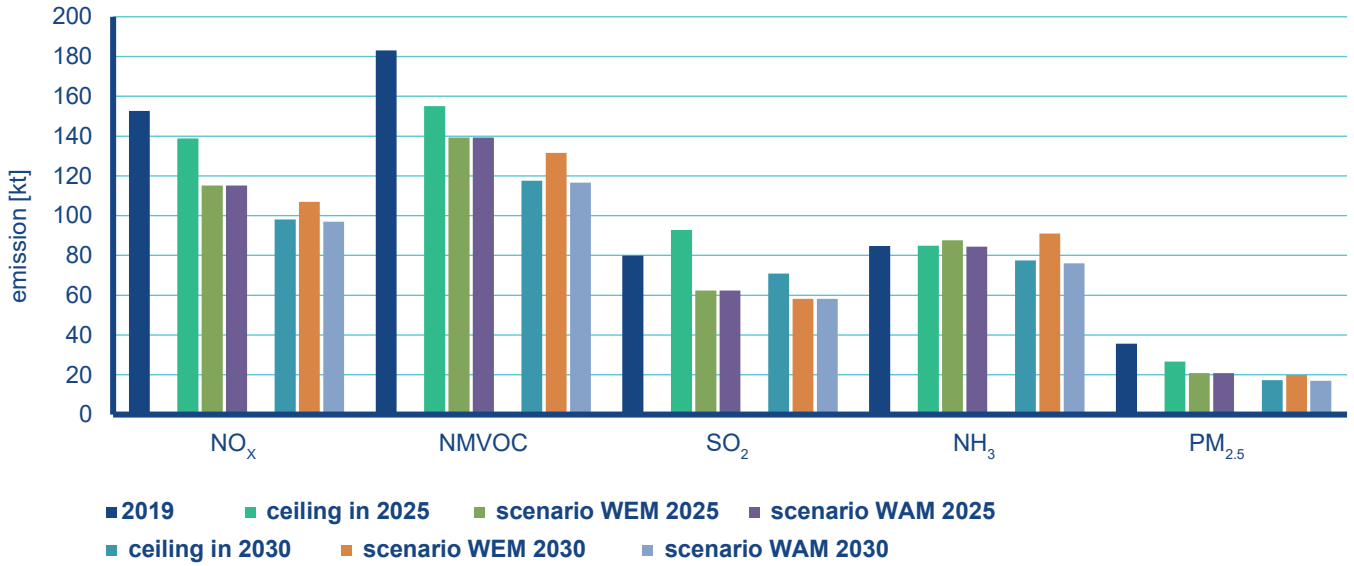


Fig. II.9 Comparison of emission limits and emission projection scenarios of basic pollutants (including subtraction of NO_x and NMVOC emissions of categories NFR 3B and NFR 3D)

III. METEOROLOGICAL AND DISPERSION CONDITIONS

Apart from emissions from respective air pollution sources, air quality is significantly affected by meteorological conditions. These conditions enable, or conversely prevent, the aerial dispersion of polluting substances, influence the amount of emissions from anthropogenic or natural sources, resuspension, and affect the formation of secondary pollutants as well as their removal rate from the air. The basic meteorological variables influencing the aerial dispersion of pollutants include air temperature, wind speed, precipitation, and vertical stability of the atmosphere. One of the ways in which dispersion conditions can be expressed numerically is in terms of the ventilation index (VI), which is defined as the product of the mixing layer depth and the average air flow velocity in it[1]. However, situations with poor dispersion conditions do not necessarily lead to the occurrence of high pollution concentrations. Important factors include the duration of the situation, the starting level of pollution, distribution of sources, and emissions to the layer under an inversion (Ferguson 2001, Škáchová 2020). The effect of meteorological conditions on anthropogenic emissions from heating is determined on the basis of a calculation of heating days and temperatures that occurred during these days. Temperature conditions in the heating season (January–May, September–December) or parts thereof are characterized in terms of degree-days, i.e., the sum of differences in reference indoor temperatures and average daily outdoor temperatures on heating days. A more detailed specification of the influence of meteorological conditions on air quality is given in (CHMI 2022d).

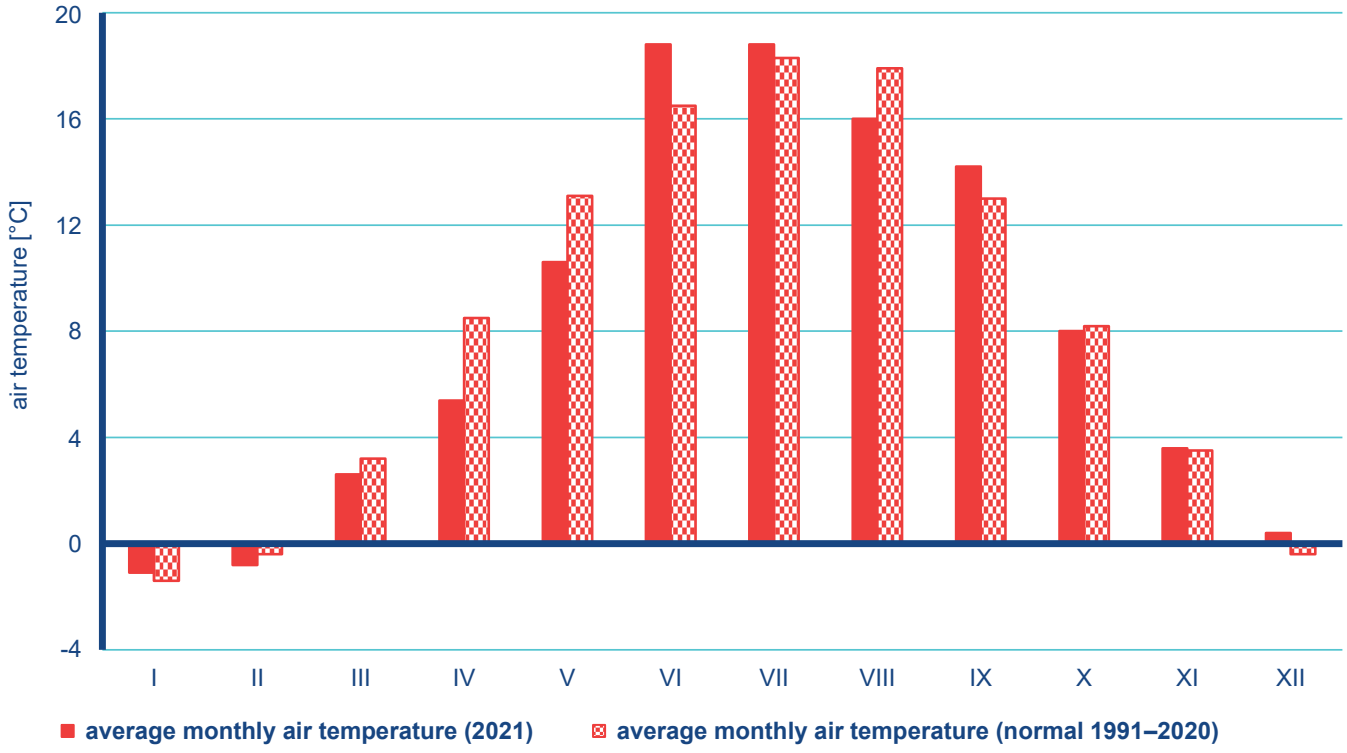


Fig. III.1 Average monthly air temperature in 2021 compared to the normal of 1991–2020

1 The mixing layer is understood as the layer of the atmosphere between the Earth's surface and the lower boundary of the lowest temperature retention layer.

Meteorological and dispersion conditions in 2021

In terms of temperature, the year 2021 was normal with the average annual temperature of 8.0 °C, being 0.3 °C below the normal of 1991–2020[2]. In the last 10 years (since 2011) only 2013 was colder with the average temperature of 7.9 °C. The previous three years were warmer by more than 1.0 °C with the average temperature of 9.1 °C (2020), 9.5 °C (2019) and 9.6 °C (2018). Majority of 2021 months were temperature normal compared to the 1991–2020 normal. However, the spring months of April and May were very cold, deviating from the normal by –3.1 °C and –2.5 °C and being rated as strongly below normal in terms of temperature. It was followed by strongly above normal June in terms of temperature (deviation +2.3 °C), which ranked as the third warmest June since 1961. August was assessed as below normal (deviation –1.9 °C) and September as above normal (deviation +1.2 °C) (Fig. III.1).

In view of precipitation over the territory of the Czech Republic (CR), the year 2021 was normal. The average total annual precipitation of 683 mm corresponds to 100 % of the normal of 1991–2020. The months of May (141 % of normal) and August (136 % of normal) were above normal. The autumn months of September and October were assessed as strongly below normal, with monthly precipitation totals being 38 % and 39 % of the normal. Other months of 2021 can be assessed as precipitation normal. However, the month of March was close to the limit of the normal and below-normal month in terms of precipitation,

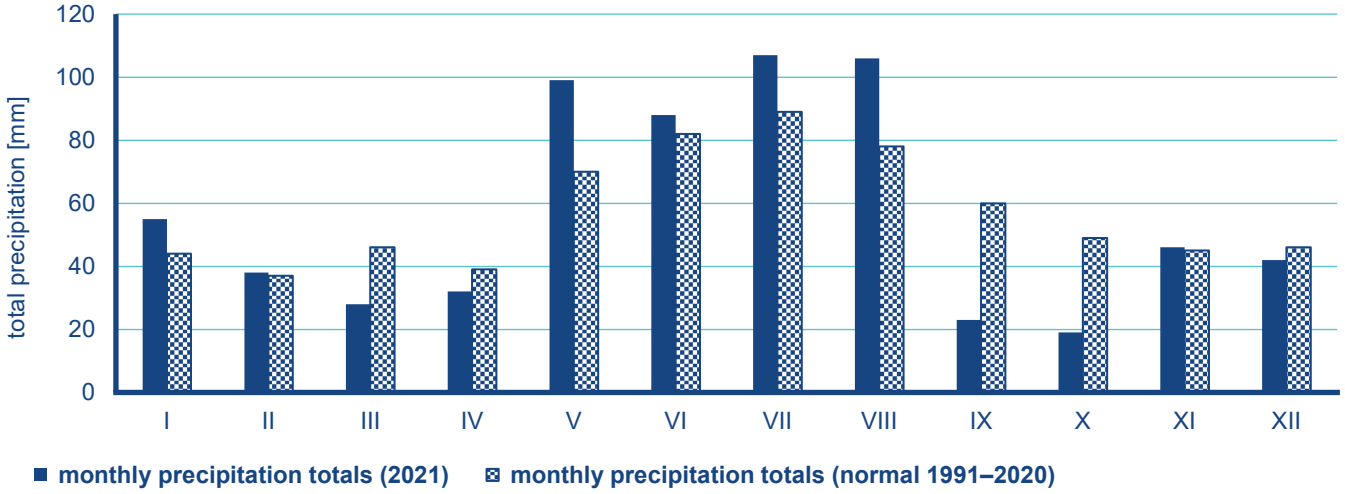


Fig. III.2 Monthly precipitation totals in 2021 compared to the normal of 1991–2020

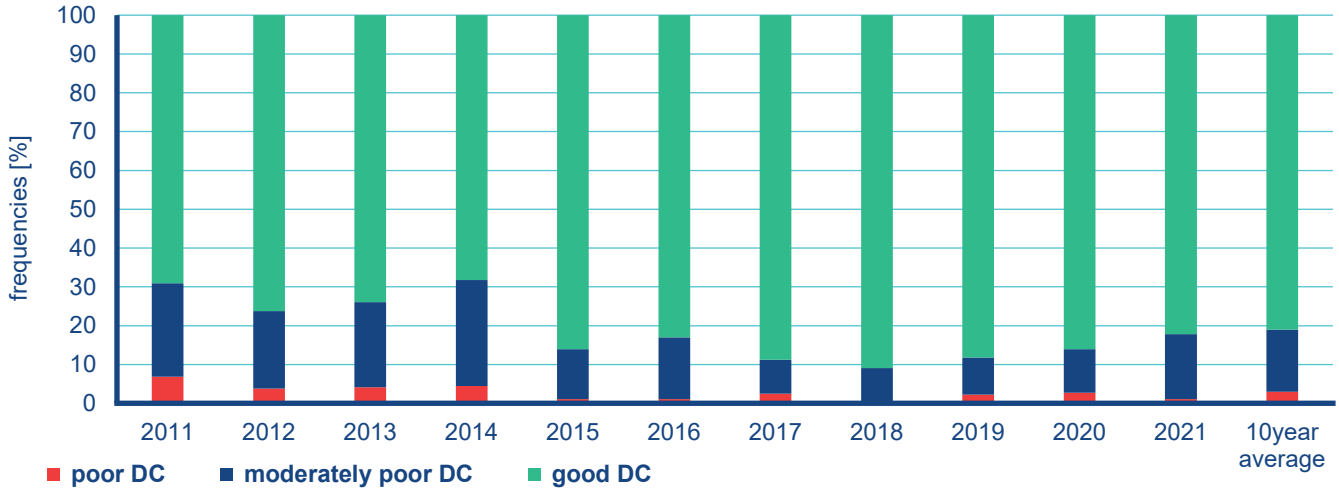


Fig. III.3 Frequency of occurrence of dispersion conditions (DC), 2011–2021

2 Based on the recommendations of the World Meteorological Organization (WMO), the CHMI has been using the most recent thirty years (1991–2020) to assess climatological characteristics since February 2022 instead of the period set for the calculation of standard climatological normals.

when 61 % of the precipitation normal covered the territory of the CR. On the contrary, January (125 % of normal) was on the limit of the normal and above-normal month in terms of precipitation (Fig. III.2).

In 2021, dispersion conditions were standard compared to the ten-year average of 2010–2020 (Fig. III.3). Good dispersion conditions, expressed by the ventilation index for the whole of the CR, were observed in 300 days (82 %) in 2021. Compared to the ten-year average (81 %), this is an improvement by 1 %. Moderately poor dispersion conditions occurred in 61 days (17 %), and poor dispersion conditions in 4 days (1 %) in 2021.

During the year, good dispersion conditions occurred the most in May (100 %), the least in February (64 %) (Fig. III.4). Poor dispersion conditions were observed in February (4 %), and January, March, and December (3 %). Compared to the ten-year average, May was assessed as a month with significantly improved dispersion conditions and February as a month with worsened dispersion conditions in 2021 (Fig. III.5). The other months (January, March, April, June, July, August, September, October, November, and December) range as standard.

The frequency distribution of dispersion conditions differs from the national average in each region (Fig. III.6). All three types of dispersion conditions were observed in all regions. The highest percentage of good dispersion conditions occurred in the Moravi-

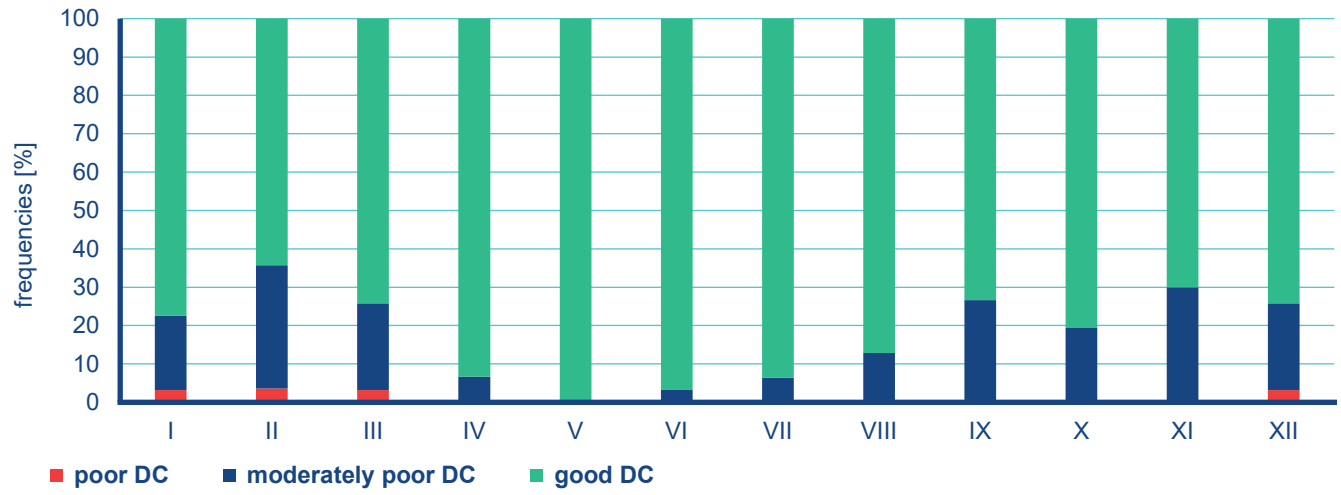


Fig. III.4 Frequency of occurrence of dispersion conditions (DC) by months, 2021

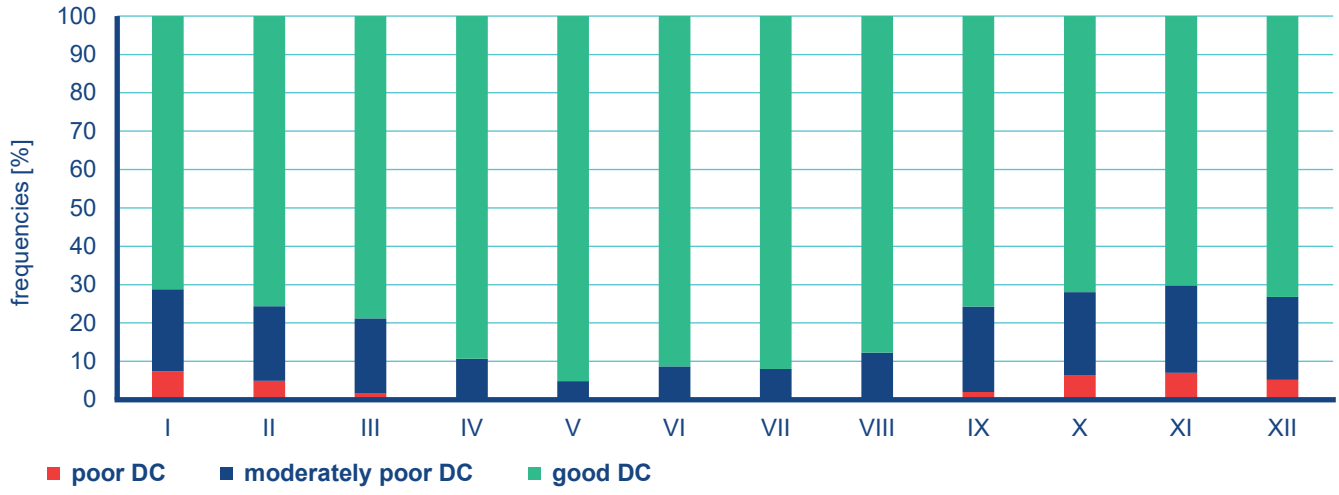


Fig. III.5 Frequency of occurrence of dispersion conditions (DC) by months, 10-year average 2011–2020

an-Silesia region without the O/K/F-M agglomeration (85 %), the lowest percentage in the Plzeň region (73 %). On the other hand, poor conditions occurred the most in the Prague agglomeration (5 %), and the least in the Moravian-Silesia region without the O/K/F-M agglomeration and the Liberec region (1 %) (Fig. III.7).

The number of degree-days during 2021 in the CR was above normal compared to the long-term average 1991–2020. The highest number of degree-days was recorded in 1996 (4 787), when the lowest average temperature on heating days was observed (2.4 °C). On the contrary, the lowest number of degree-days (3 611) was recorded in 2014, when the highest average daily temperature (5.8 °C) was reached on heating days (Fig. III.8). In five months (February, March, April, May, and October), the number of degree-days was above the long-term average, and in three months below the average (January, September, and December). The number of degree-days in November corresponded to the long-term average (Fig. III.9). The largest decrease in the number of degree-days compared to the long-term average was recorded in September, which is climatologically assessed as above normal in terms of temperature and positively affects the estimated emissions from domestic heating. On the contrary, the highest increase in the number of degree-days was recorded in April and May, which are rated as strongly below normal in terms of temperature.

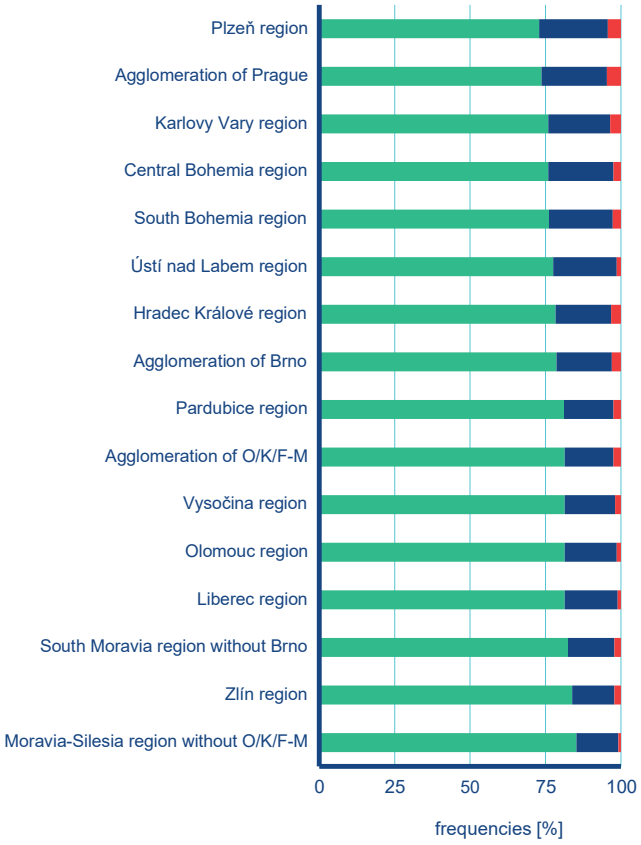


Fig. III.7 Frequency of occurrence of dispersion conditions in regions, 2021

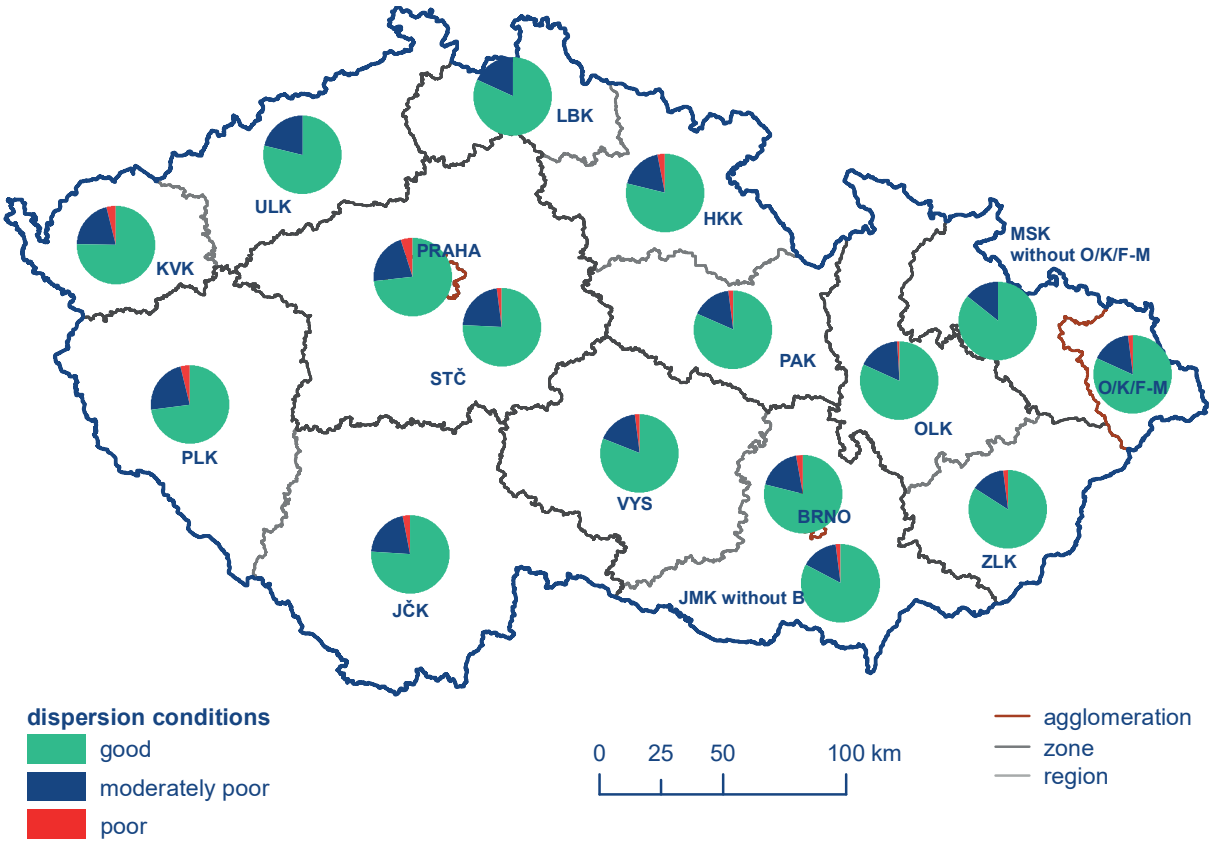


Fig. III.6 Composition of dispersion conditions in regions, 2021

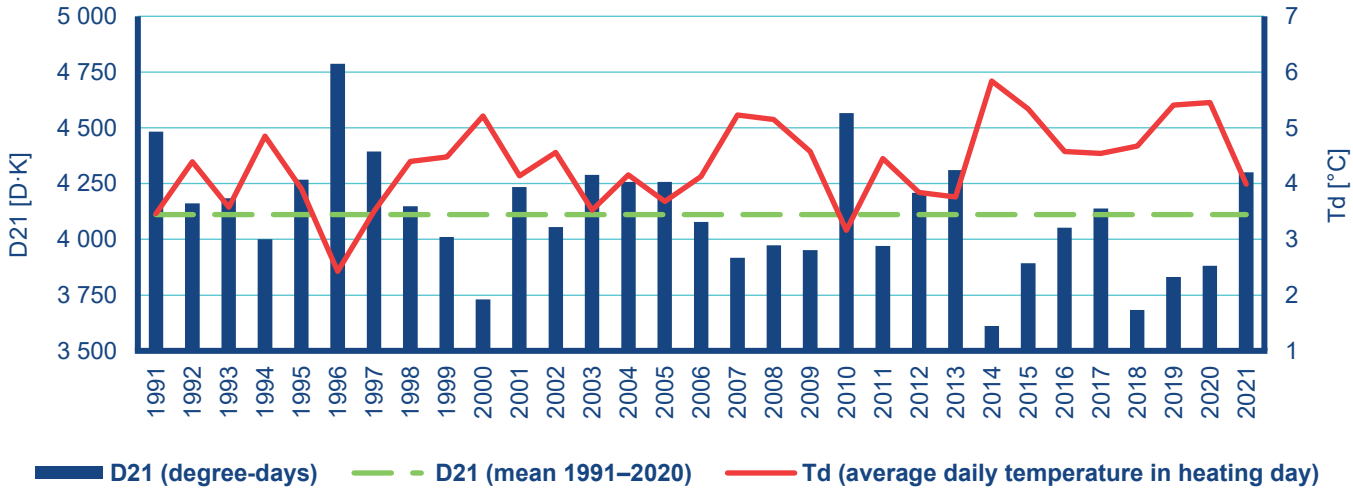


Fig. III.8 Annual heating seasons in the CR expressed as degree-days (D21) in 2021 and their average for the 1991–2020 period

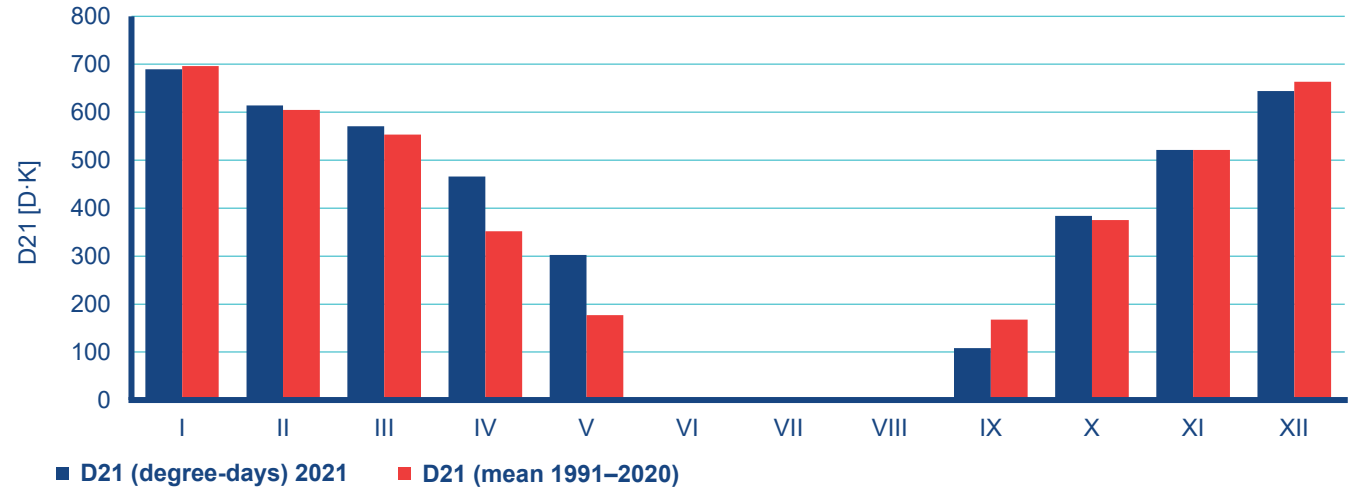


Fig. III.9 Annual variation of degree-days in the territory of the CR in the heating season 2021 (I–V, IX–XII)

IV. AIR QUALITY IN THE CR

The evaluation of air quality set forth in this yearbook covers the entire territory of the CR. Documentation of compliance with legal requirements including areas where none of the pollution limit values are exceeded is one of the fundamental principles of Directive 2008/50/ES. Where the targets for ambient air quality stipulated in this Directive are not met the member states are obliged to take measures towards compliance with the pollution limit values and long-term air pollution targets. Air quality assessment is carried out with regard to the protection of population health and the protection of ecosystems and vegetation.

The air quality was evaluated for this yearbook employing the calculation criteria in Annex I of Directive 2008/50/ES and Annex IV of Directive 2004/107/ES. These annexes set the data quality targets for ambient air quality assessment. According to Annex I of Directive 2008/50/ES and Annex IV of Directive 2004/107/ES, air quality may be evaluated only using data from monitoring stations at which the requirement of minimum data collection of 90 % was met, not including losses of data as a consequence of regular calibration or normal maintenance of the instrumental technology. Without prejudice to Annex I of Directive 2008/50/ES, data collection and calculation of statistical parameters are based on the criteria set forth in Annex XI of this Directive. As a consequence of these changes, some of the data presented in earlier yearbooks may differ slightly from the data presented in this yearbook.

The concentrations measured at the monitoring stations form the basis for evaluation of the air quality. The monitoring network is densest in areas with the highest pollution concentrations but nonetheless covers the entire CR. In 2021, measured data from a total of 198 locations were supplied to the AQIS database. The National Air Quality Monitoring Network (NAQMN), operated by CHMI, forms the backbone of monitoring stations. It includes both stations with an automated measuring program and a manual measuring program, from which samples are analysed in the CHMI laboratories. At many locations, the air pollution is monitored simultaneously by both automatic and manual methods. The national pollution monitoring network is supplemented by the monitoring stations of other organizations and their measurements are also employed in evaluating the air quality. The AQIS also includes information from the border areas of Germany, Poland, Austria and Slovakia obtained as part of the reciprocal exchange of data.

Map interpretation is an essential starting point for indication of areas where the pollution limit levels are exceeded from the viewpoint of protection of human health, for which the legislation requires preparation of programmes to improve the air quality or regulatory rules. A uniform colour scale has been introduced to improve orientation in the area maps of pollutants where a specific colour corresponds to a particular level of the air pollution (Tab. IV.1). Exceeding the pollution limit is indicated in red, the other basic distinctions between the categories consist of the WHO recommended values and the lower and upper assessment thresholds (Tab. I.1-I.3, Chap. Introduction). The upper and lower assessment thresholds for evaluating the level of pollution and the permitted number of cases exceeding the limit are set out in Annex No. 4 of Decree No. 330/2012 Coll., on the method of assessing and evaluating the level of pollution, the scope of informing the public about the level of pollution and during smog situations. In places where the pollution level reaches or exceeds the upper assessment threshold for evaluating the pollution level, the assessment of the pollution level is carried out by measurements made in accordance with the data quality objectives according to Part I of Annex No. 1 to this Decree. In places where the pollution level does not exceed the lower assessment threshold for evaluating the pollution level, the assessment of the pollution level is carried out by calculation through the model. In places where the pollution level is lower than the upper assessment threshold, the evaluation of the level of pollution is carried out by a combination of site measurement and orientation measurement. The diagram maps clearly depict the trends in pollution level characteristics in the period 2011–2021.

The graphs showing a course of pollution characteristics of selected pollutants in agglomerations and in the whole territory of the CR (if data are available) present variations of air pollution levels in the last 11 years, comparison of the situation in the currently evaluated year with the average for the previous ten-year period, variations of pollution levels during the current year, and pollutant concentrations at individual monitoring stations. A uniform colour scale has been introduced to improve orientation in the graphs where a specific colour corresponds to a particular type of station (Tab. IV.2). This is a simplified classification, which is based on the official EoI classification, including subcategories (for more explicit explanation and details see CHMI 2022d). The "Summary Table Survey" data yearbook (CHMI 2022e) provides overviews of measured concentrations of pollutants in outdoor air in the CR at individual measuring stations in 2021. The values are arranged in descending order and the grey background indicates exceeding the pollution limit level.

Tab. IV.1 Colour scale in the legend of the areal maps of polluting substances for classification of areas by assessment thresholds and areas above the pollution limit

	≤ WHO air quality guideline
	≤ lower assessment threshold
	lower assessment threshold – upper assessment threshold
	upper assessment threshold – limit value
	> limit value
	> limit value (heavily polluted areas)

Tab. IV.2 Colour scale in the legend of the graphs for classification of monitoring stations by a type of station (x – any letter in the classification)

	Simplified classification	EoI locality classifi-cationl
	rural regional stations (REG)	B/R/xxx-REG
	rural near city stations (R)	B/R/xxx-NCI
	suburban background stations (SUB)	B/S/xxx
	urban background stations (UB)	B/U/xxx
	traffic stations (T)	T/x/xxx
	industrial stations (I)	I/x/xxx

IV.1 Suspended particulate matter

Air pollution from suspended particulate matter of PM_{10} and $PM_{2.5}$ fractions remains one of the main problems to be resolved in ensuring air quality in the CR. Exceeding pollution limit levels for PM_{10} and $PM_{2.5}$ continues to contribute to the extent of areas with above-limit air pollution.

IV.1.1 Air pollution by suspended particulates in 2021

Suspended PM_{10} particulate matter

The 24-hour pollution limit level for PM_{10} (the average 24-hour concentration of 50 $\mu g \cdot m^{-3}$ is possible to exceed 35 times a year) was exceeded in 2021 at less than 3 % of stations (4 stations of a total number of 152 with a sufficient amount of data for evaluation; Fig. IV.1.1, and Fig. IV.1.2). This concerned two industrial stations – Ostrava-Radvanice-ZÚ (57 cases exceeding the limit) and Karviná (51 cases), the rural station Věřňovice (56 cases), and the urban background station Rychvald (42 cases). All stations exceeding the emission limit are located on the territory of the O/K/F-M[1] agglomeration.

The Ostrava-Radvanice-ZÚ, Věřňovice, Karviná and Rychvald stations, similarly to other stations in the O/K/F-M agglomeration, are long-term affected by long-range transport of pollution from Poland. The Ostrava-Radvanice-ZÚ station is also affected by industrial emissions and Karviná by emissions from construction activities. At the Věřňovice station, there is a combination of the impact of air pollution from southern Poland and rural development on the Czech side of the border, together with specific meteorological conditions in the Olše River valley. The representativeness of the Věřňovice station for the Czech countryside is therefore limited and the measurement results from this station are not included in other statistical characteristics (annual trend of monthly concentrations and concentration trends).

The pollution limit level for the average 24-hour concentration of PM_{10} was exceeded in 2021 in only 0.1 % of the territory of the CR, with approx. 0.4 % of the population (Fig. IV.1.3). Compared to previous years (0.001 % of the territory in 2020, 0.3 % in

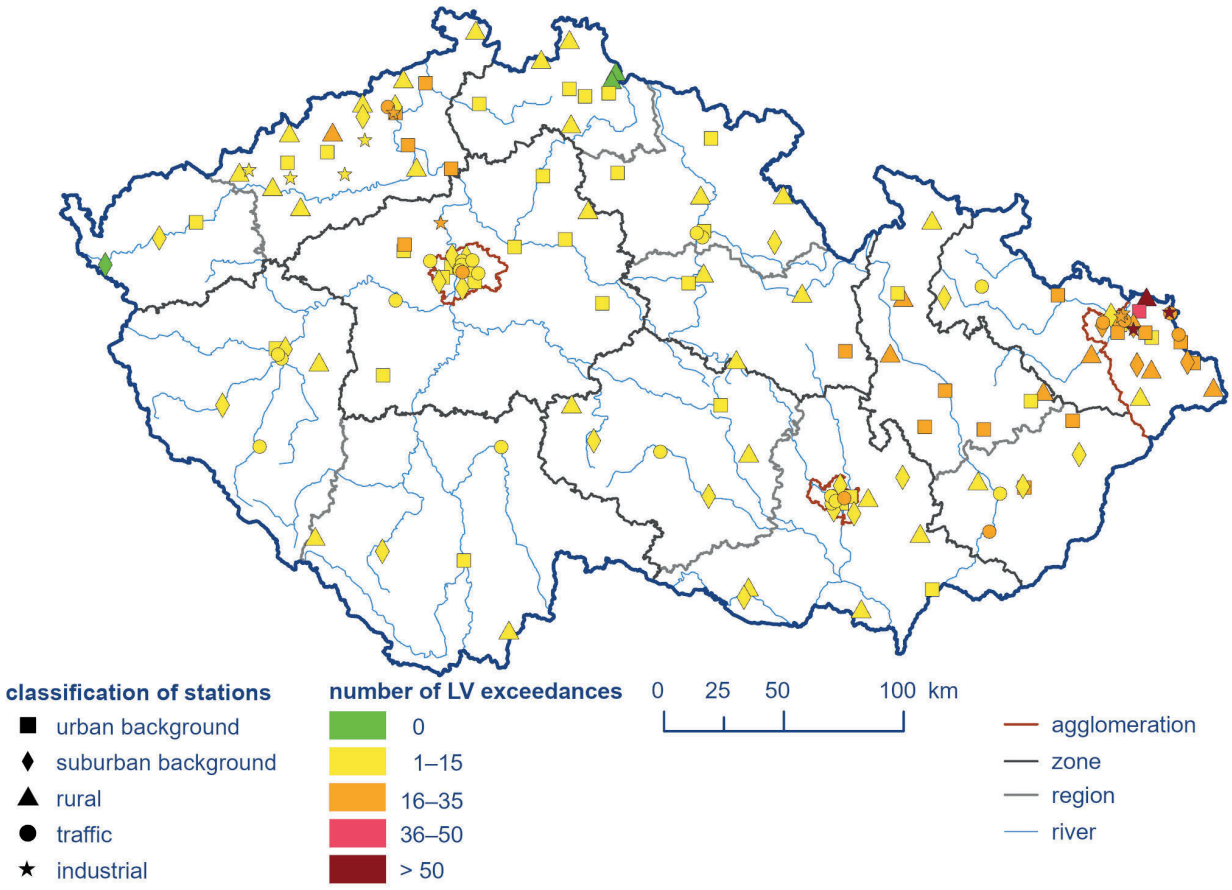


Fig. IV.1.1 Number of cases exceeding the pollution limit value of 24-hour average PM_{10} concentrations at air quality monitoring stations, 2021

1 At the Brno-Zvonařka industrial station, which is significantly affected by construction activities, the value of the 24-hour pollution limit was exceeded 36 times in 2021. However, the station did not have sufficient data for evaluation according to Annex 1 to Decree No. 330/2012 Coll., and thus cannot be included in the overall statistics.

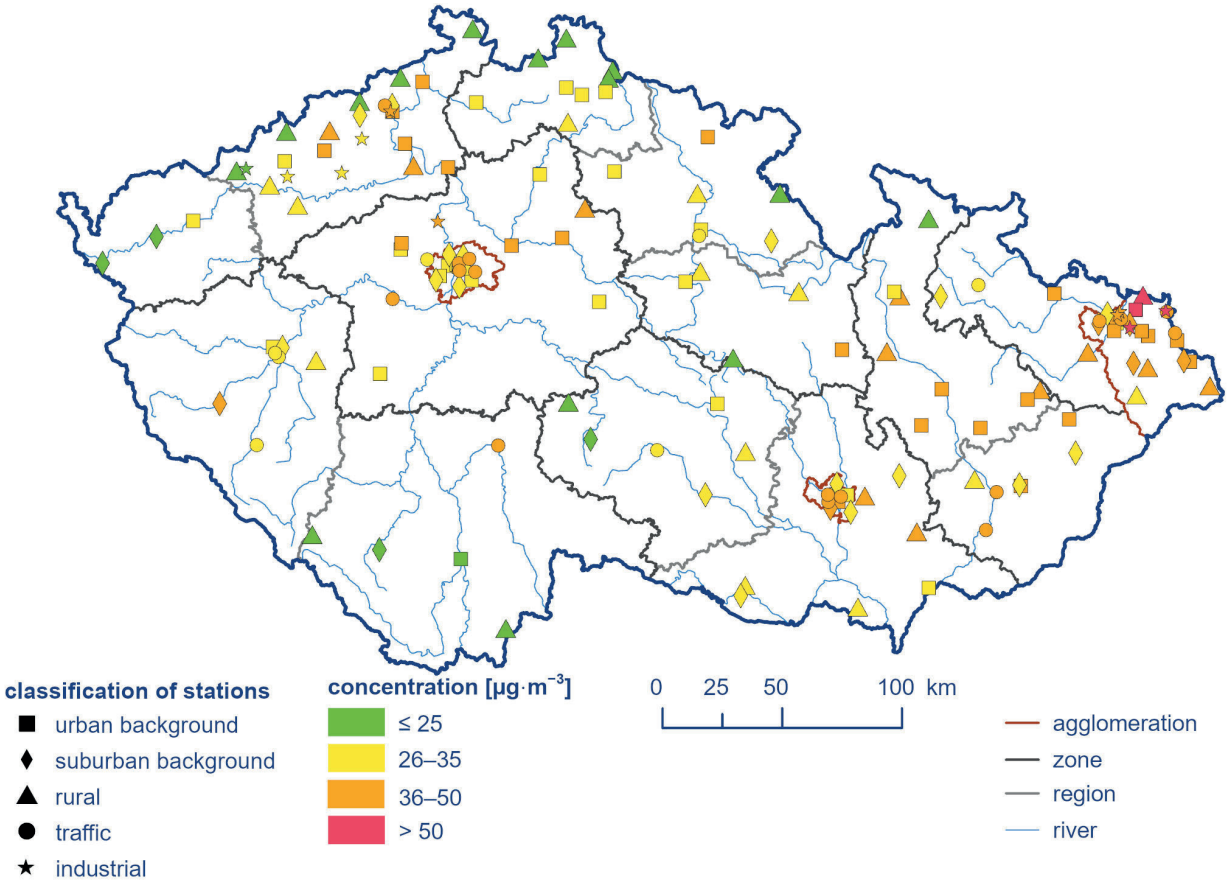


Fig. IV.1.2 The 36th highest 24-hour PM_{10} concentrations at air quality monitoring stations, 2021

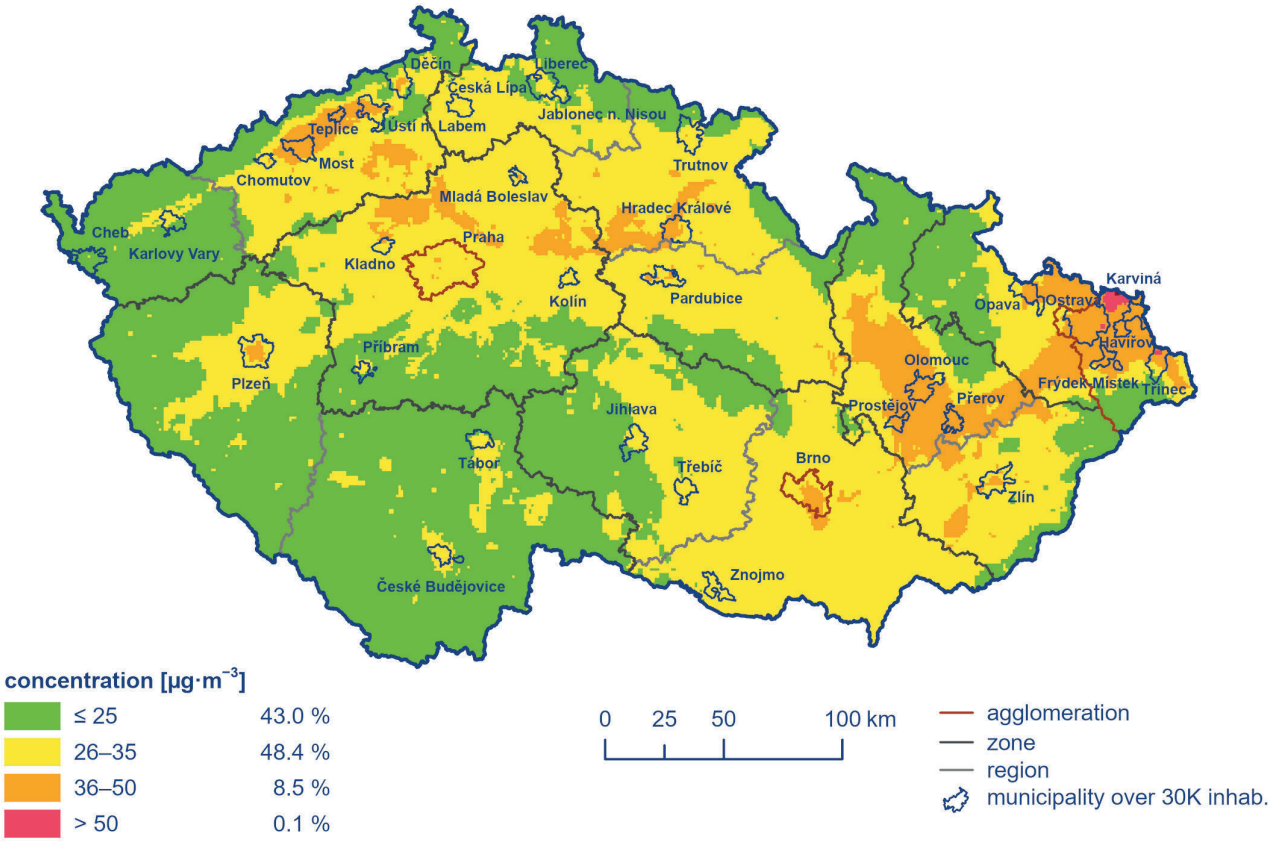


Fig. IV.1.3 Field of the 36th highest 24-hour PM_{10} concentration, 2021

Fig. IV.1.4 The 36th highest 24-hour and annual average PM_{10} concentrations at selected stations of UB, SUB, I, and T classification, 2011–2021

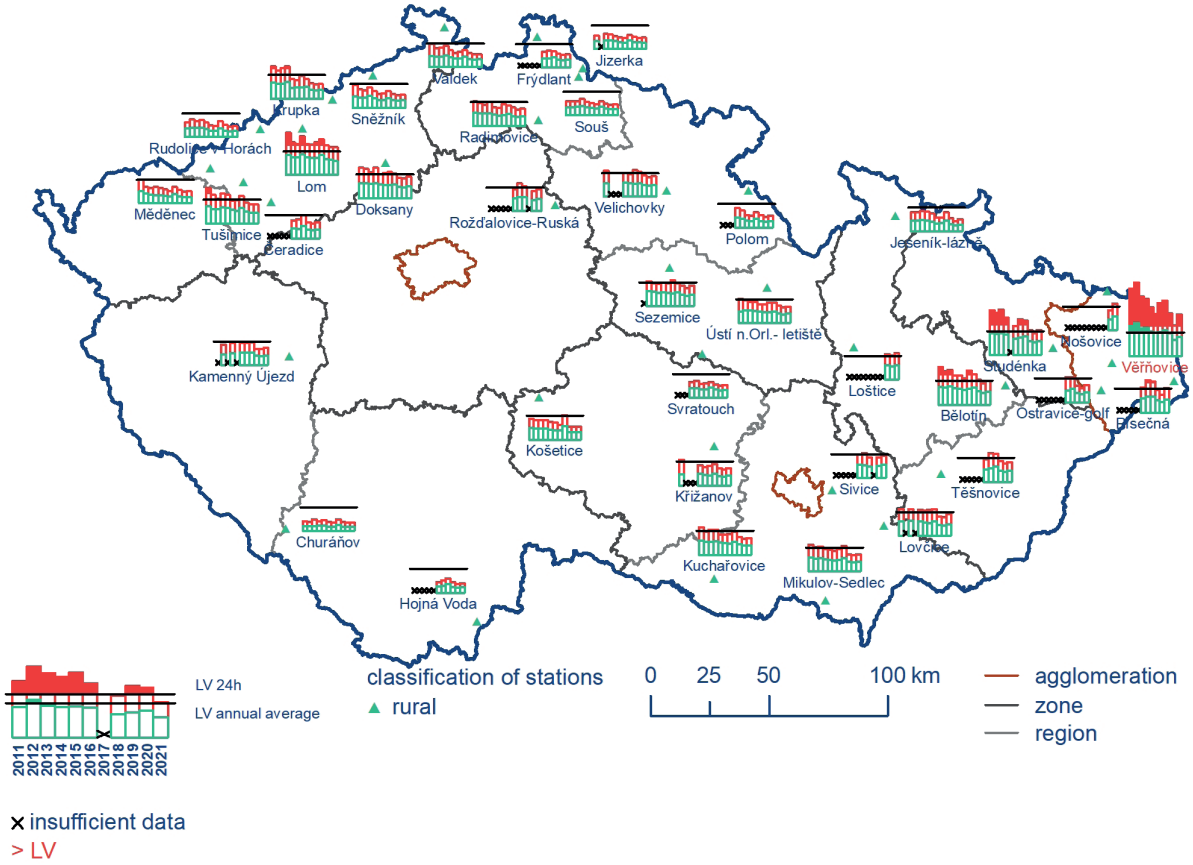


Fig. IV.1.5 The 36th highest 24-hour and annual average PM_{10} concentrations at selected rural (R) stations, 2011–2021

2019, 3.2 % in 2018, and 8.3 % in 2017), the year 2021 ranks among the years with a smaller area of the CR exposed to above-limit concentration of PM_{10}, which corresponds to a low number of cases exceeding the pollution limit at measuring stations. A large part of the territory of the CR (87 %) was exposed to a concentration up to 35 $\mu g \cdot m^{-3}$ in 2021, that is to concentrations below the upper assessment limit set by Decree No. 330/2012 Coll., on the method of assessment and evaluation of ambient air pollution levels and on the extent of informing the public on the level of ambient air pollution and during smog situations[2].

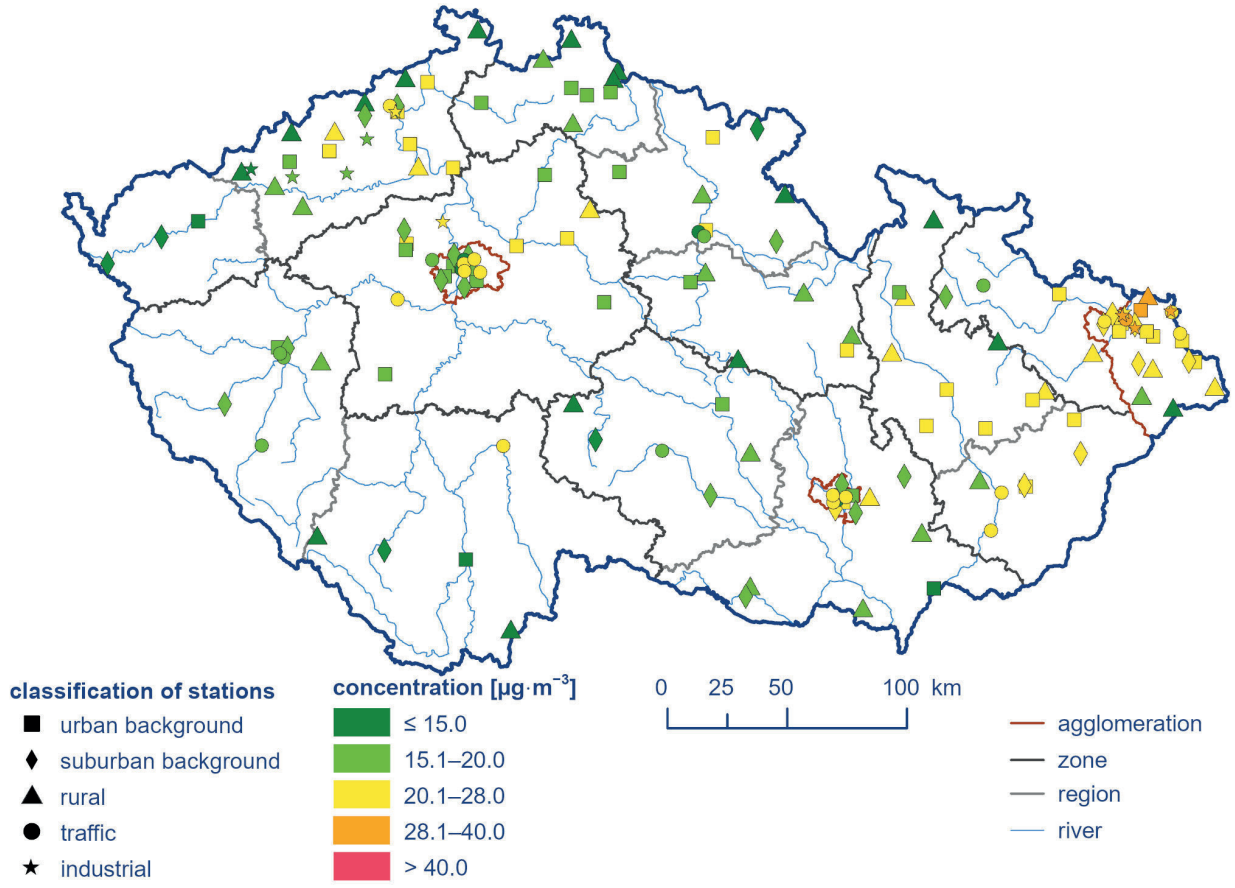


Fig. IV.1.6 Annual average PM_{10} concentrations at air quality monitoring stations, 2021

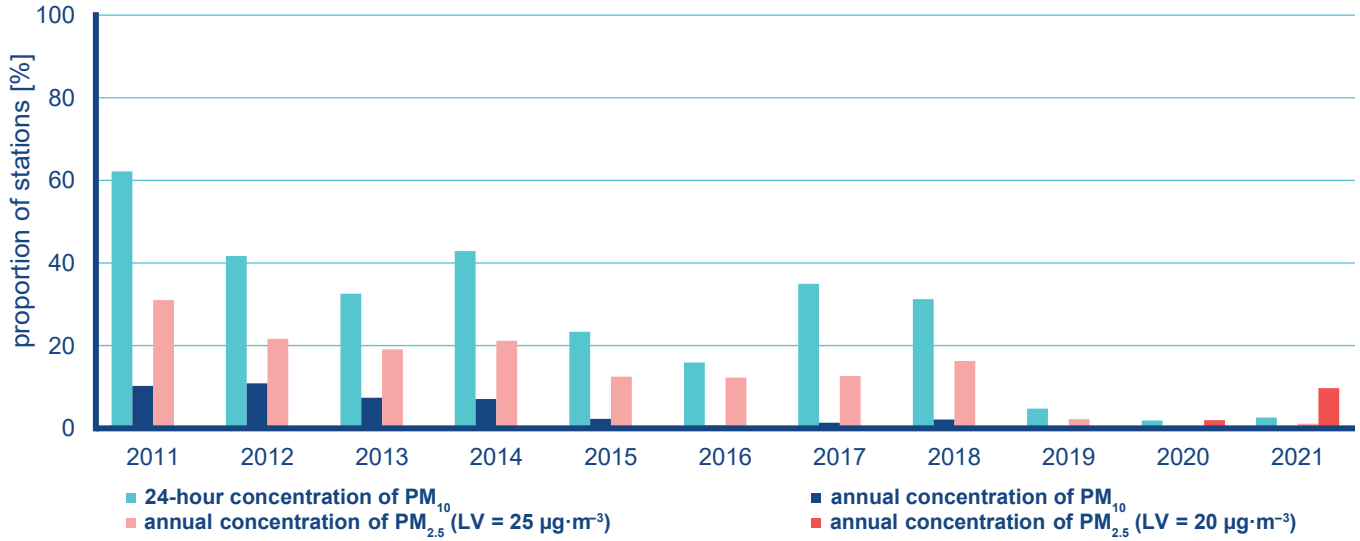


Fig. IV.1.7 Ratio of stations where the pollution limit level of 24-hour average PM_{10} concentration and of annual average PM_{10} and $PM_{2.5}$ concentration was exceeded, 2011–2021

2 The upper and lower assessment thresholds for assessing the level of pollution and the permitted number of cases exceeding the limit are set out in Annex 4 to this Decree. For more, see the introduction to Ch. IV.

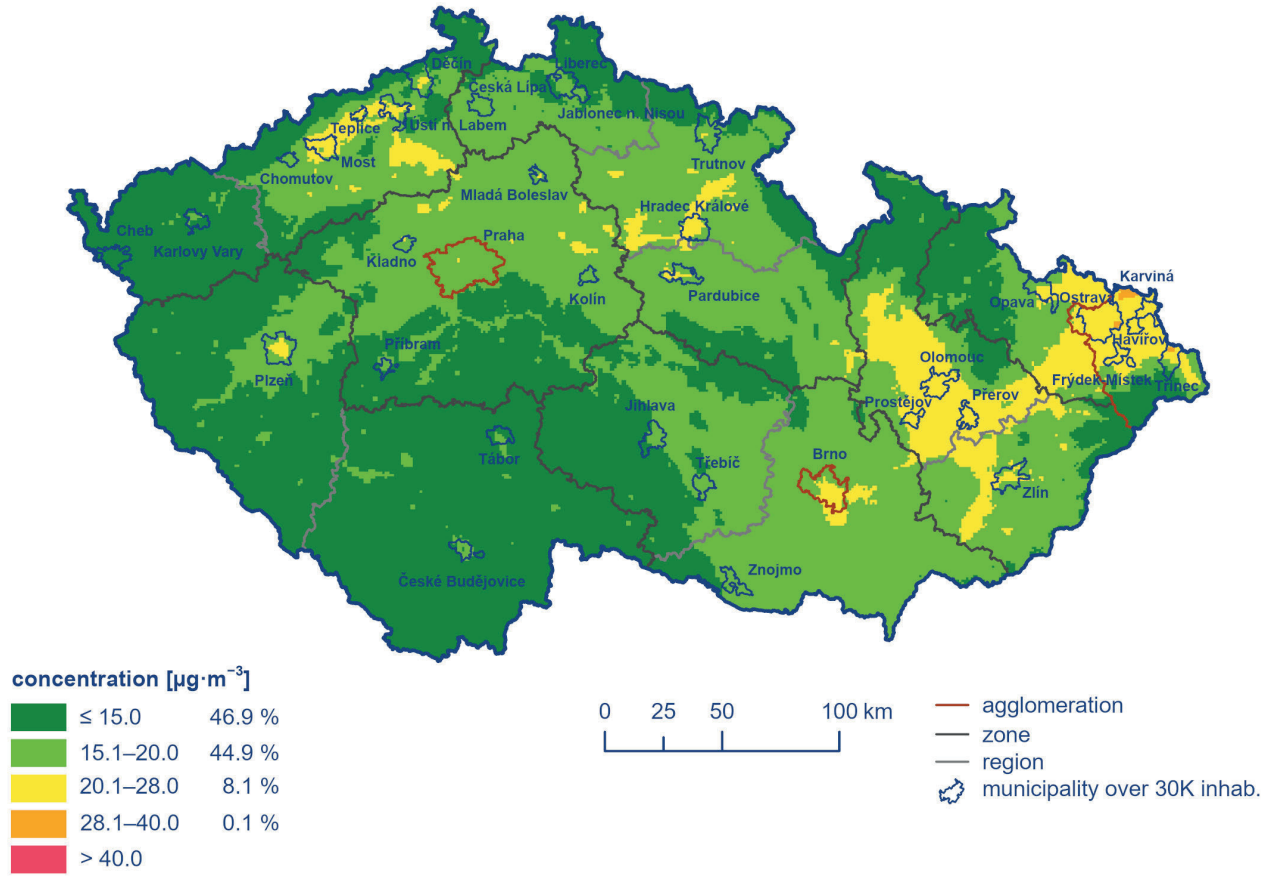


Fig. IV.1.8 Field of annual average PM_{10} concentration, 2021

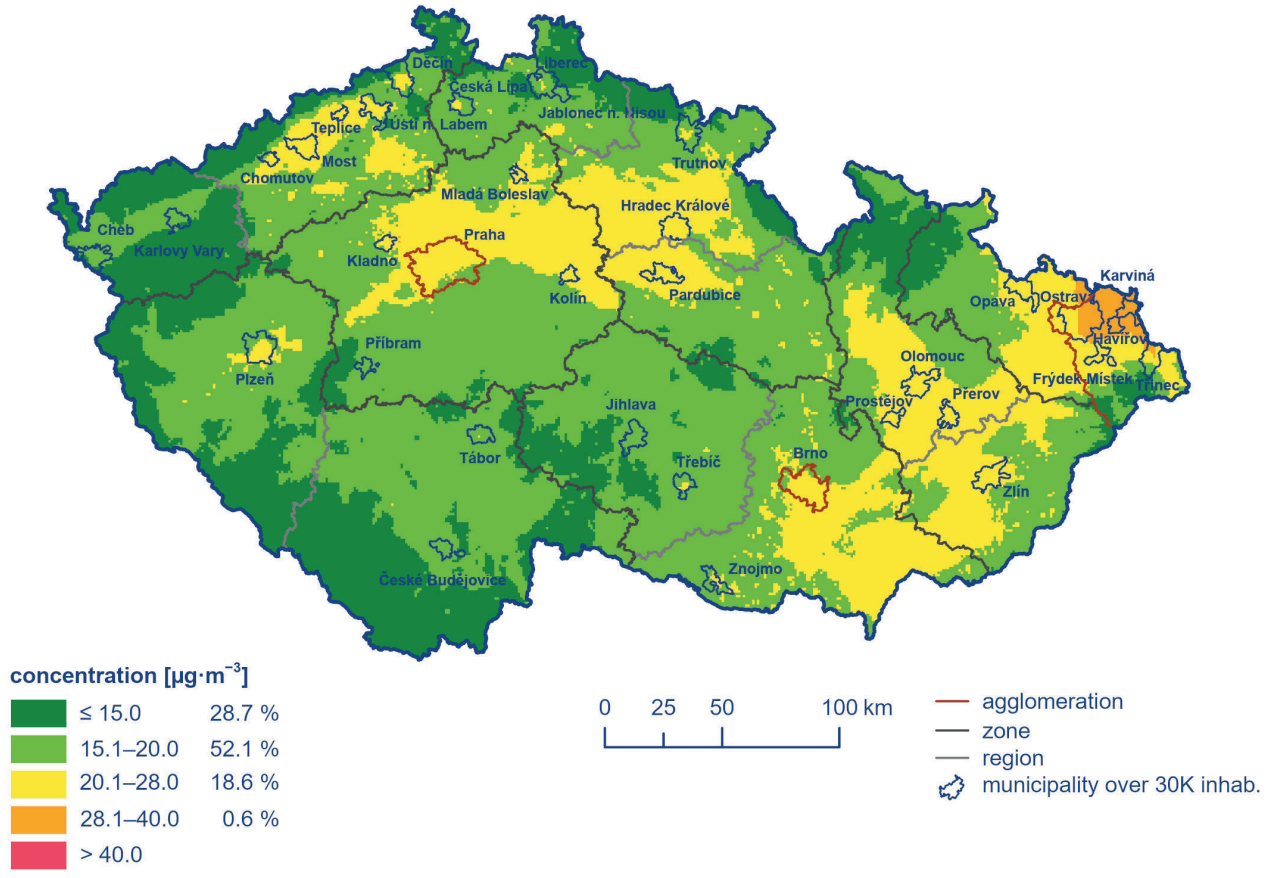


Fig. IV.1.9 Five-year average of annual average PM_{10} concentrations, 2017–2021

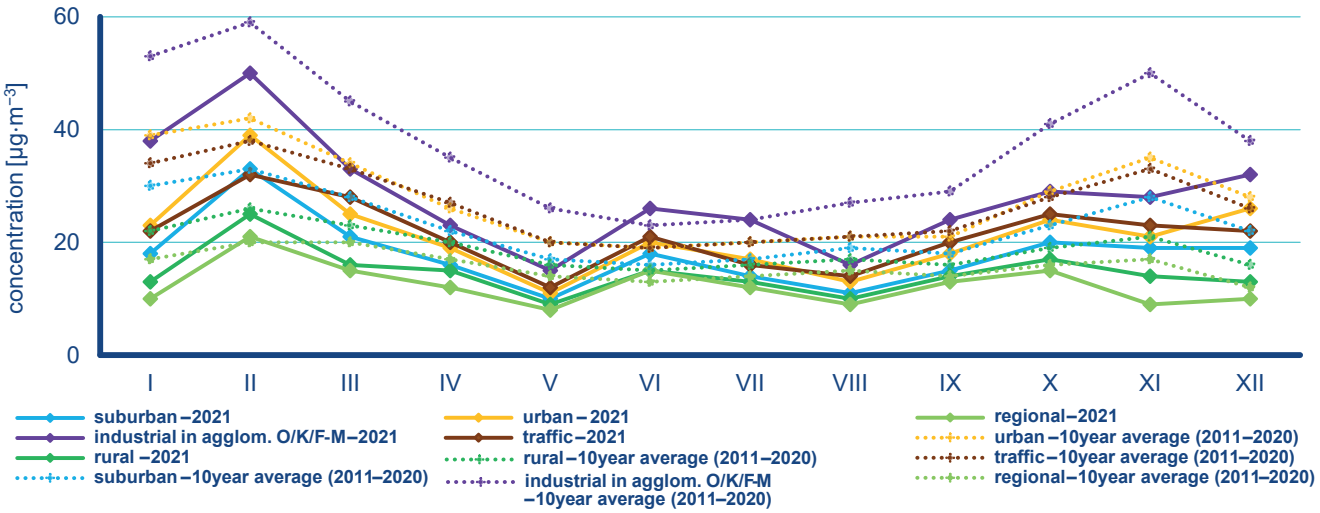


Fig. IV.1.10 Annual course of average monthly PM_{10} concentrations (averages for a given type of station), 2021

As in previous years, the O/K/F-M agglomeration was the most polluted continuous area (Fig. IV.1.4 and IV.1.5).

The pollution limit for the average annual concentration of PM_{10} (40 µg·m^{-3}) was not exceeded at any station in the CR in 2021, which occurred, together with 2019 and 2020, for the third time for the entire history of PM_{10} observation since 1993. The highest annual average concentrations were measured at stations of the O/K/F-M agglomeration (Fig. IV.1.6). Similar to previous years, the highest annual average concentrations were measured at the Ostrava-Radvanice ZÚ industrial station (34.3 µg·m^{-3}), at the Věřňovice rural station (32.4 µg·m^{-3}), and at the Karviná industrial station (31.5 µg·m^{-3}).

Similar to 2019 and 2020, no territory of the CR had an above-limit annual average concentration of PM_{10} at a spatial resolution of 1×1 km (Fig. IV.1.8). However, in previous years the annual average concentration of PM_{10} was exceeded on only small part of the territory of the CR (0.1 % in 2018, and 0.02 % in 2017). In terms of the five-year average of annual average concentrations, the most polluted area is the O/K/F-M agglomeration (Fig. IV.1.9).

PM_{10} concentrations exhibit a clear annual variation, with the highest values in the cold months of the year (Fig. IV.1.10), when the 24-hour pollution limit is most often exceeded (more than 85 % of cases exceeding the limit occur in January, March, and December). Higher air PM_{10} concentrations during the colder season relate both to greater emissions of particulates from seasonally operated heating sources and also to more frequent occurrence of poorer dispersion conditions this part of the year.

The annual variation of PM_{10} concentrations in 2021 had a less distinct trend compared to the ten-year average showing a clearer dominance of autumn and winter months. In 2021, the highest PM_{10} concentrations were measured in February, when moderately poor to poor dispersion conditions occurred. In February, increased concentrations of PM_{10} were observed on several days throughout the CR, also in connection with the transfer of sand particles from the Sahara. In the remaining months of the cold season of the year, i.e., in January, March and in the last three months of the year, the concentrations were at a similar level (Fig. IV.1.10).

Average monthly PM_{10} concentrations in 2021 compared to the ten-year average (2011–2020) were lower in all months of the year, except for June. The decrease in PM_{10} concentrations at stations was especially significant in January (a decrease by almost 13 µg·m^{-3}, i.e., by 40 %) and in November (a decrease by almost 11 µg·m^{-3}, i.e., by 36 %). At the beginning of 2021 (January–March), standard dispersion conditions prevailed, with the exception of February (deteriorated dispersion conditions), the months were characterized as normal in terms of temperature and normal to subnormal in terms of precipitation. The conditions determining fuel consumption (emission intensity), self-cleaning of the atmosphere and dispersion of pollutants in January-March 2021 were therefore mostly average to slightly below the average. Nevertheless, the average monthly concentrations of suspended particles decreased compared to the ten-year average 2011–2020, although due to conditions mentioned above, it would be possible to assume their increase to the levels or above the levels of the average ten-year concentrations. This decrease in concentrations points to decreasing emissions of suspended particles due to the gradual modernization of emission sources (large sources following the application of BAT, exchange of boilers heating households with solid fuels, renewal of the vehicle fleet). Lower average monthly concentrations of PM_{10}, compared to the ten-year average 2011–2020, were also observed in April, which was subnormal in terms of temperature and precipitation, when a partial impact of emissions from local heating can still be assumed.

The end of the year (October–December) was normal in terms of temperature and precipitation, with only October assessed as below normal in terms of precipitation. Dispersion conditions, compared to the ten-year average 2011–2020, were characterized as standard, however, adverse conditions with low frequency occurred in January compared to ten-year period, while adverse conditions did not occur in October neither in November 2021 (Fig. III.3 and III .4). Relatively good dispersion conditions also

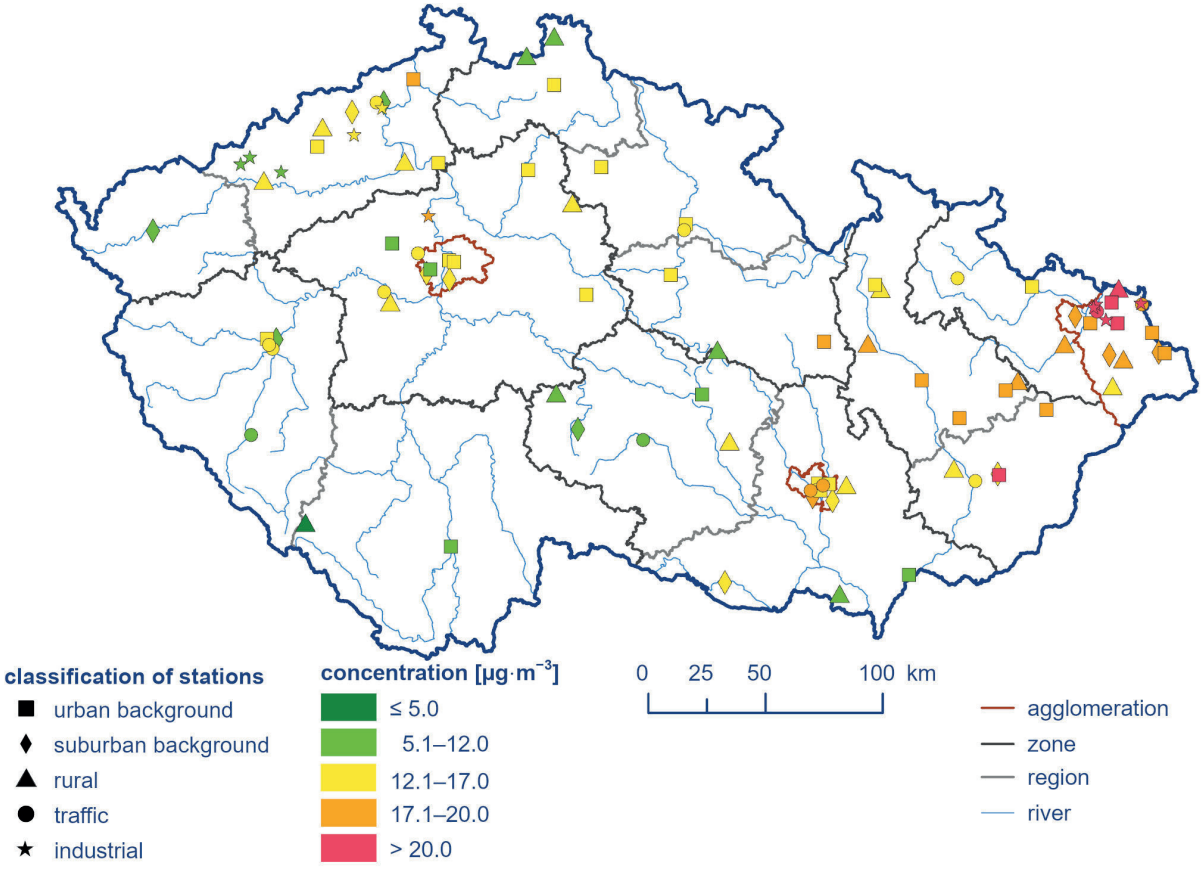


Fig. IV.1.11 Annual average $PM_{2.5}$ concentrations at air quality monitoring stations, 2021

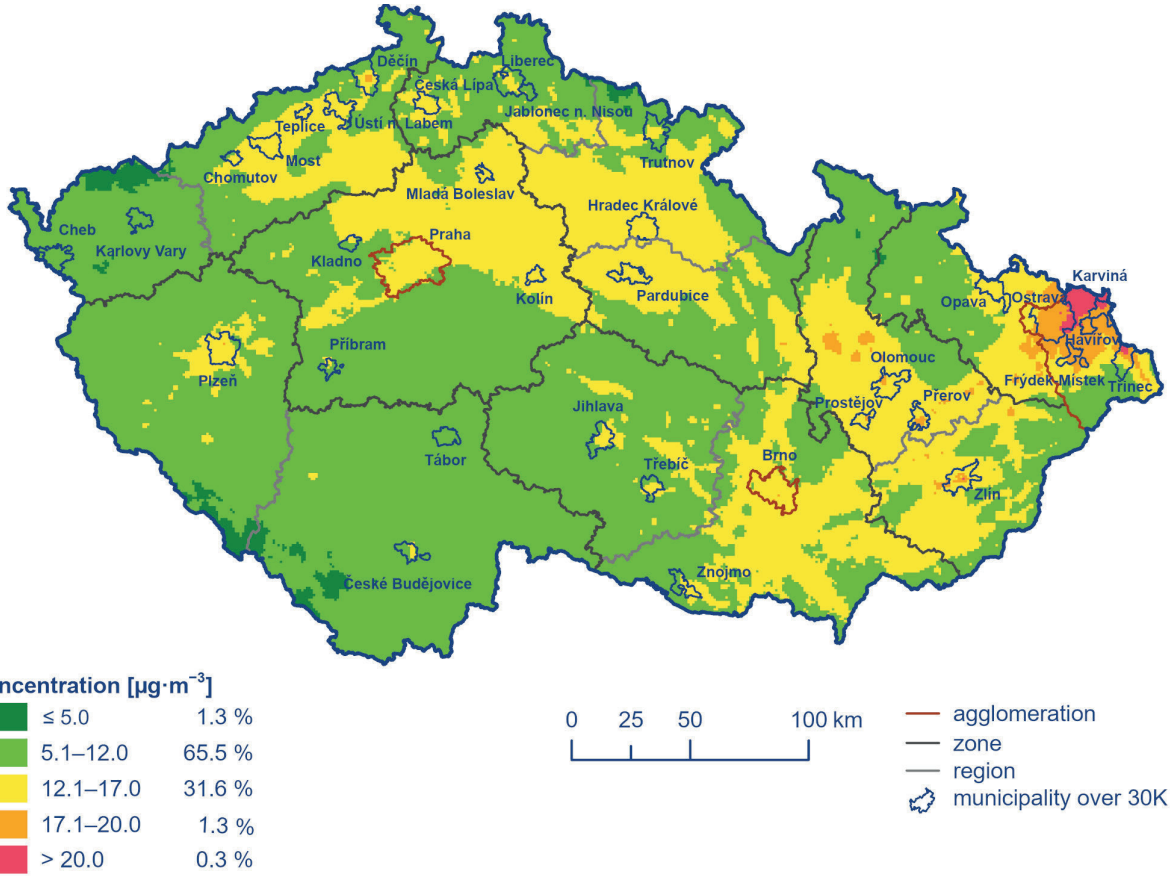


Fig. IV.1.12 Field of annual average $PM_{2.5}$ concentration, 2021

Fig. IV.1.13 Annual average $PM_{2.5}$ concentrations at selected stations, 2011–2021

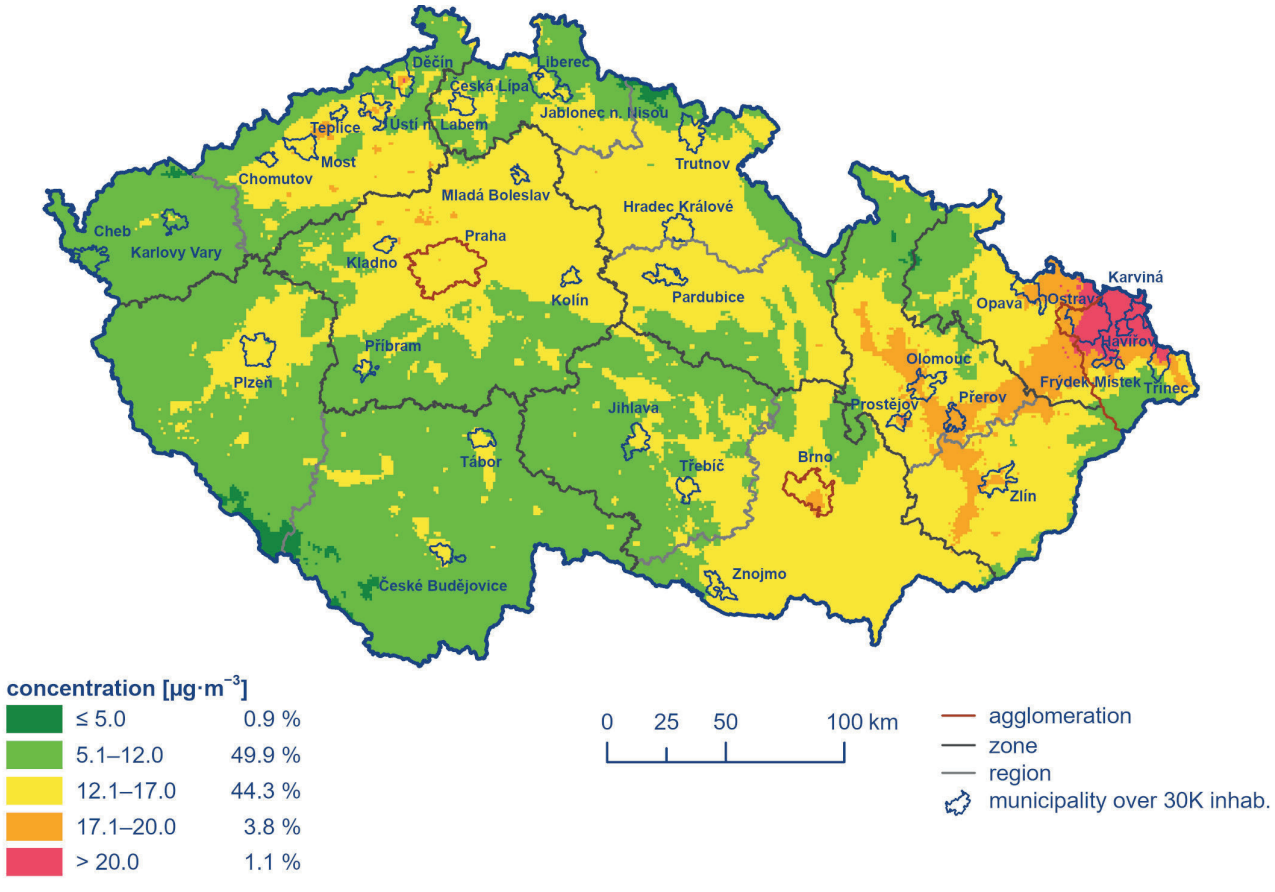


Fig. IV.1.14 Five-year average of annual average $PM_{2.5}$ concentrations, 2017–2021

contributed to the decrease in monthly concentrations in these months. In December, poor dispersion conditions occurred and PM_{10} concentrations increased above the pollution limit value, as a result of which a smog situation was announced for the territory of the O/K/F-M agglomeration without Třinec between 27 and 29 December 2021 (see Chapter VI).

Concentrations at a lower level are typical for the summer period of the year (April–September), when seasonal sources attenuate. Concentrations are strongly affected by the occurrence of drought, which leads to dustiness and a subsequent increase in the concentration of suspended particles in the air. The lowest average monthly concentration in 2021 was measured in May and August. In addition, significantly good dispersal conditions prevailed in May. On the contrary, the increase in concentrations in June was probably related to the low amount of precipitation in the first two thirds of the month and the strongly above-normal temperature.

In 2021, similarly to 2020, states of emergency were declared on the territory of the CR in connection with the occurrence of the SARS-CoV-2 coronavirus. From the point of view of the potential change in air quality in the CR, the most significant month was March, when even movement between districts was prohibited. Due to the heterogeneous composition of PM_{10} emission sources and their strong relationship with dispersion and meteorological conditions, no significant changes in concentrations can be expected as a result of emergency measures. On the one hand, there was a decrease in emissions of suspended particles and nitrogen oxides (precursors of secondary suspended particles) from transport, on the other hand, the likely higher intensity of heating due to the population remaining in the home environment led to higher emissions of particles from local heating (CHMI 2020). A more detailed evaluation of the effect of the state of emergency to the change in air quality in the CR can be referred to in CHMI (2021).

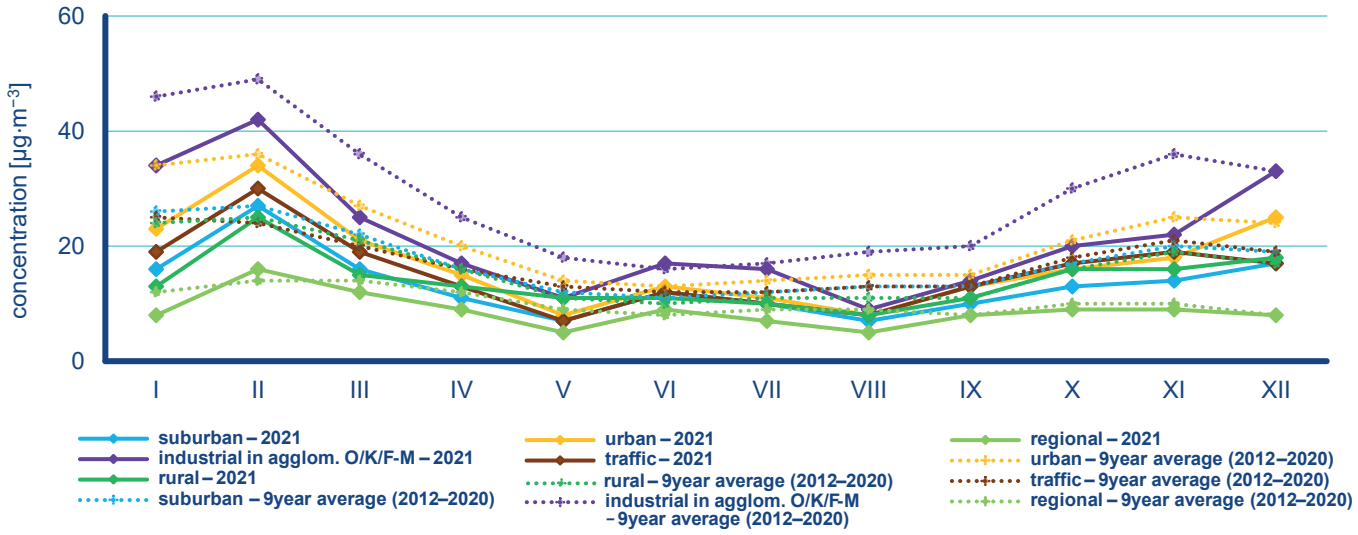


Fig. IV.1.15 Annual course of average monthly $PM_{2.5}$ concentrations (averages for a given type of station), 2021

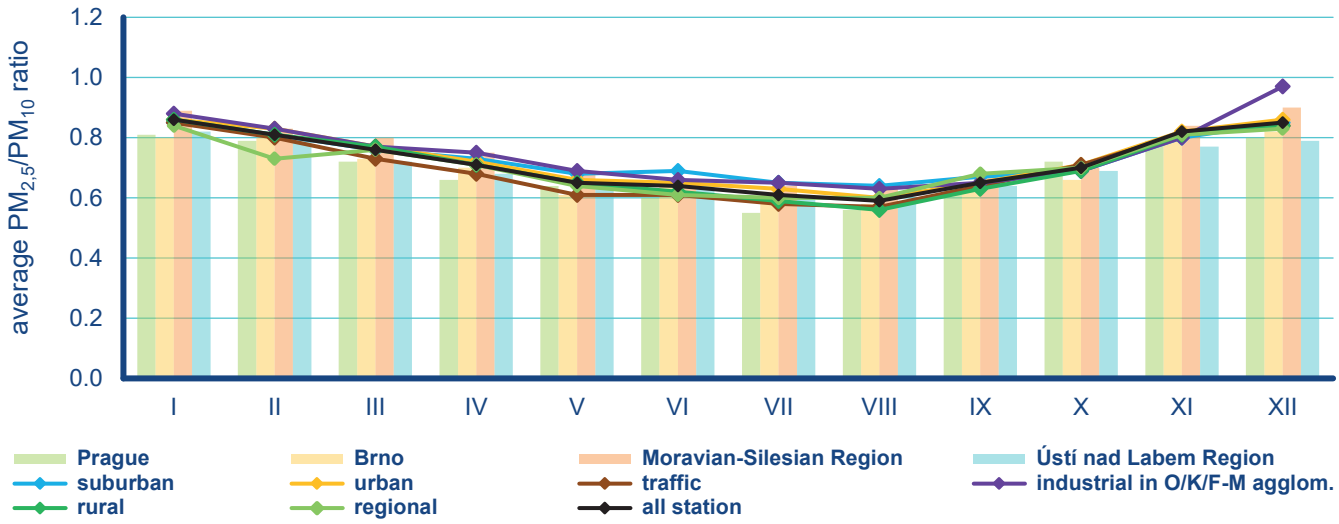


Fig. IV.1.16 Monthly average ratios of $PM_{2.5}/PM_{10}$, 2021

Suspended $PM_{2.5}$ particulate matter

In 2021, the pollution limit level for the average annual concentration of $PM_{2.5}$ (20 $\mu g \cdot m^{-3}$)[3] was exceeded at 9 stations (9.7 %) of a total of 93 stations. All stations where the average annual concentration of $PM_{2.5}$ was exceeded in 2021 (except for the Zlín-ZŠ Kvítkova city background station) were located in the territory of the O/K/F-M agglomeration (Fig. IV.1.11). For comparison with previous years, it can be stated that in terms of the limit value valid until 2019 (25 $\mu g \cdot m^{-3}$), the limit was exceeded in 2021 at the Ostrava-Radvanice ZÚ station only, where the annual average concentration of 23.3 $\mu g \cdot m^{-3}$ was measured. The second highest concentration was measured at the Věřňovice station (24.3 $\mu g \cdot m^{-3}$).

The pollution limit level for the average annual concentration of $PM_{2.5}$ was exceeded in 2021 over 0.3 % of the territory of the CR with approx. 1.5 % of the population (Fig. IV.1.12). In 2020, this concerned 0.04 % of the CR territory with approx. 0.2 % of the population.

In the evaluated period 2011–2021, above-limit annual average concentrations of $PM_{2.5}$ were observed mainly on the territory of the O/K/F-M agglomeration (Fig. IV.1.13). In terms of the five-year average of annual average concentrations of $PM_{2.5}$, the most polluted area is the O/K/F-M agglomeration (Fig. IV.1.14).

Monthly $PM_{2.5}$ concentrations show annual variation very similar to that of PM_{10}, including a significant decrease in average monthly concentrations compared to their ten-year average. The highest concentrations were measured in February. Average monthly $PM_{2.5}$ concentrations in 2021 compared to the ten-year average (2011–2020) were lower, except for June, in all other months of the year. The decrease in PM_{10} concentrations at the stations was especially significant in January (decrease by 10 $\mu g \cdot m^{-3}$, i.e., by 38 %), March (decrease by 6 $\mu g \cdot m^{-3}$, i.e., by 25 %), August (decrease by 6 $\mu g \cdot m^{-3}$, i.e., by 45 %), and in November (decrease by almost 5 $\mu g \cdot m^{-3}$, i.e., by 27 %).

Ratio of the $PM_{2.5}$ and PM_{10} suspended particle fractions

The ratio of the $PM_{2.5}$ and PM_{10} fractions is not constant but exhibits seasonal variations and is also dependent on the character of the location (Fig. IV.1.16). In 2021, an average value of 68 stations in the CR where $PM_{2.5}$ and PM_{10} are measured simultaneously and have a sufficient number of measurements for evaluation ranged from 0.59 (July) to 0.86 (January). In Prague and Brno, where annual variations are affected by the high proportion of traffic locations, this ratio ranged from 0.55 (July) to 0.81 (February), and from 0.58 (August) to 0.82 (December), respectively. In the Moravian-Silesia region, the ratio ranged from 0.63 (August) to 0.90 (December) and in the Ústí nad Labem region from 0.59 (August) to 0.82 (January). When the ratio of $PM_{2.5}$ and PM_{10} fractions is compared by location type, the ratio at rural locations ranges from 0.56 (August) to 0.86 (January), at urban backgrounds from 0.60 (August) to 0.86 (January, December), at suburban backgrounds from 0.64 (August) to 0.85 (January, December), at traffic locations from 0.57 (August) to 0.85 (January), and at industrial locations from 0.63 (August) to 0.97 (December).

The annual variation in the ratio of the $PM_{2.5}$ and PM_{10} fractions is related to a seasonal character of certain emission sources. Emissions from combustion sources exhibit a greater content of the $PM_{2.5}$ fraction than, e.g., emissions from agricultural activities and resuspension during dry and windy weather. Heating in winter can thus lead to a greater content of the $PM_{2.5}$ fraction compared to the PM_{10} fraction. The highest $PM_{2.5}/PM_{10}$ ratio in 2021 was identified in February, regardless of the location type. The occurrence of highly above-normal amount of precipitation in February had a role in this aspect (Chapter III). $PM_{2.5}/PM_{10}$ ratios are generally higher in wet months due to a smaller contribution of resuspension to PM_{10} concentration (Akinlade et al. 2015). Decreases during the spring and beginning of the summer have also been explained by some studies as being a result of the amount of larger biogenic particulates, e.g. pollen (Gehrig, Buchmann 2003).

The $PM_{2.5}$ to PM_{10} ratio is the lowest at traffic locations. When fuel is combusted in traffic, the particulates are mainly in the $PM_{2.5}$ fraction and the ratio should therefore be higher at traffic locations. The fact that this is not the case emphasises the importance of emissions of the largest particulates swirling from the road surface, as well as emissions from the abrasion of tyres, brake linings and roads. The proportion of the larger fraction at traffic stations is also increased as a consequence of resuspension of particulates from the application of grit to roads during winter. Increases in PM_{10} concentrations can also occur as a result of greater road surface abrasion by this grit and the subsequent resuspension of abraded material (EC 2011). On the contrary, a higher ratio of $PM_{2.5}$ to PM_{10} fractions resulting from emissions from combustion processes is observed at industrial stations.

IV.1.2 Trends in the concentrations of suspended PM_{10} and $PM_{2.5}$ particulates

The trend in concentrations of suspended PM_{10} particles at particular types of stations is evaluated for the last 11 years, i.e. 2011–2021.

36th highest 24-hour PM_{10} concentration (on average from all stations with measurements available for the entire evaluated period) ranged from about 32 to 58 $\mu g \cdot m^{-3}$ in the period 2011–2021 (Fig. IV.1.17). Minimum concentrations during the evaluated period were recorded in 2020, the maximum in 2011. 36th highest 24-hour PM_{10} concentrations decreased gradually in 2011–2016, an increase was observed in 2017 and 2018, and a gradual decre-

3 In 2020, in connection with EU legislation, a stricter limit value of 20 $\mu g \cdot m^{-3}$ for the annual average $PM_{2.5}$ concentration entered into force. Until and including 2019, the limit value of 25 $\mu g \cdot m^{-3}$ applied.

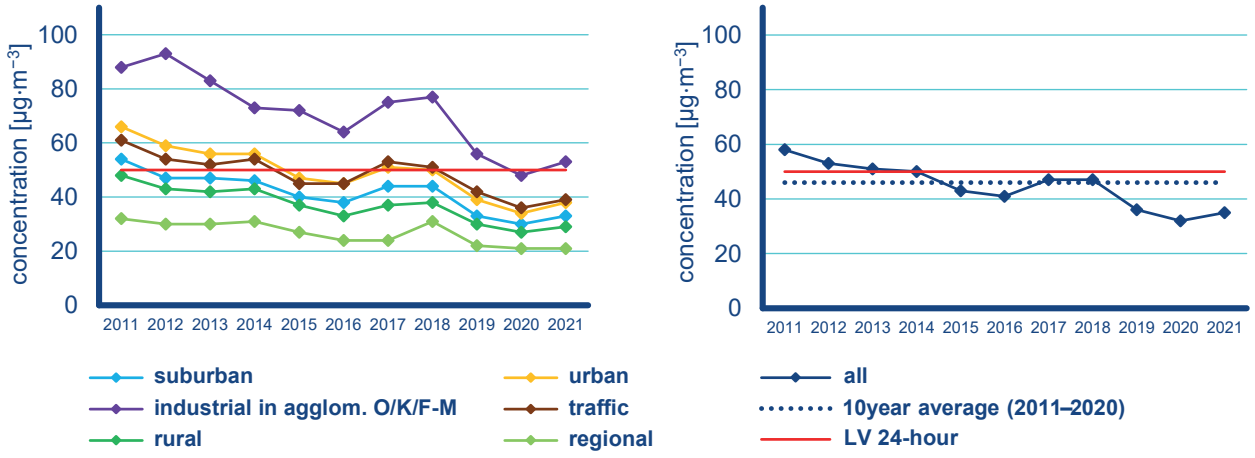


Fig. IV.1.17 The 36th highest 24-hour PM_{10} concentrations at particular types of stations, 2011–2021

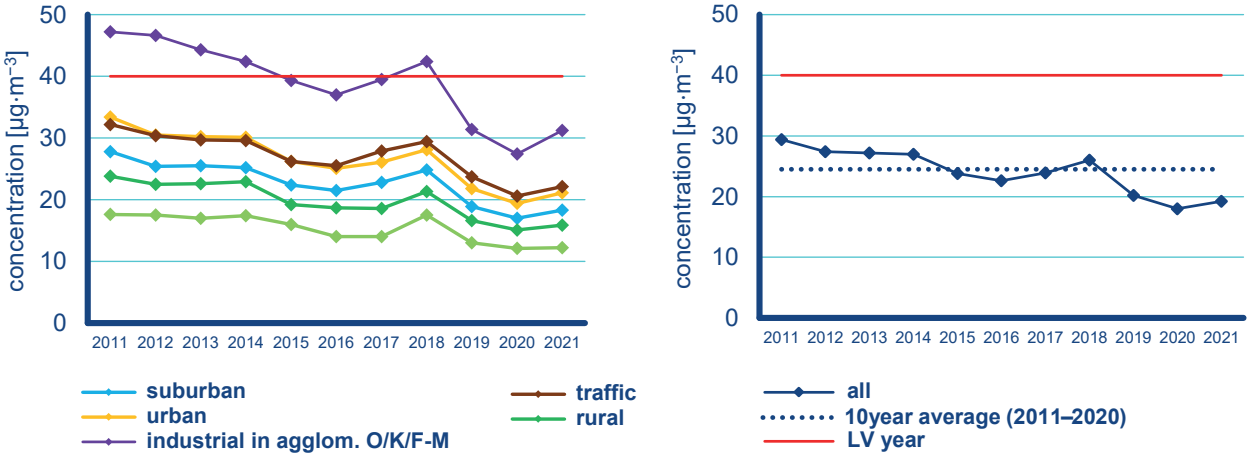


Fig. IV.1.18 Annual average PM_{10} concentrations at particular types of stations, 2011–2021

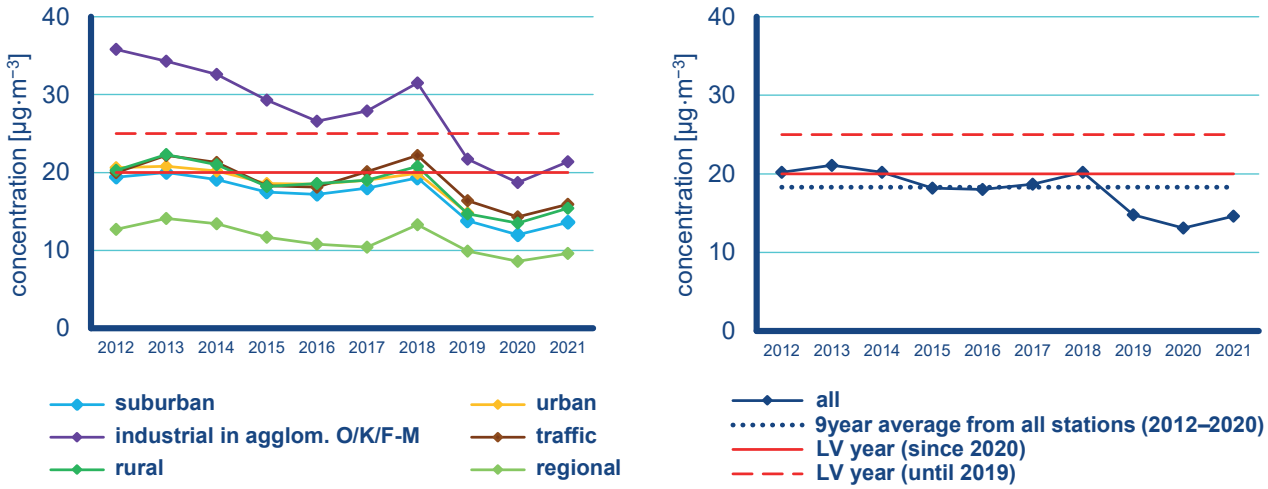


Fig. IV.1.19 Annual average $PM_{2.5}$ concentrations at particular types of stations, 2012–2021

ase again in 2019 and 2020, with a more pronounced decrease recorded in particular between 2018 and 2019. Concentrations in 2021 were at the second lowest level in this period after 2020, which was extremely good in terms of air quality. Compared to the ten-year average of concentrations from all stations (46 $\mu g \cdot m^{-3}$), the annual average PM_{10} concentrations in 2021 (35 $\mu g \cdot m^{-3}$) decreased by almost 24 %.

Annual average PM_{10} concentrations (on average from all stations with measurements available for the entire evaluated period) ranged from approximately 18.0 to 29.4 $\mu g \cdot m^{-3}$ in the period 2011–2021 (Fig. IV.1.18). During the evaluated period, the minimum concentrations were recorded in 2020, the maximum in 2011. The trend of annual average concentrations is similar to the trend of 36th highest 24-hour PM_{10} concentrations. Concentrations in 2021 were at the second lowest level for this period after 2020, which was exceptionally good in terms of air quality. Compared to the ten-year average of concentrations from all stations (24.5 $\mu g \cdot m^{-3}$ for the period 2011–2020), the annual average concentration of PM_{10} in 2021 (19.2 $\mu g \cdot m^{-3}$) decreased by almost 22 %.

The longer-term trend of annual average concentrations of $PM_{2.5}$ can be assessed over the last nine years (in view of data availability and continuous time series at observing stations). Annual average concentrations of $PM_{2.5}$ ranged from approx. 13.1 to 20.0 $\mu g \cdot m^{-3}$ in the period 2012–2021 (Fig. IV.1.19). During the evaluated period, the minimum concentrations were recorded in 2020, the maximum in 2012 and 2018. Compared to the nine-year average of concentrations from all stations (18.3 $\mu g \cdot m^{-3}$ for the period 2012–2020), the annual average concentration of $PM_{2.5}$ decreased in 2020 (14.6 $\mu g \cdot m^{-3}$) by 20 %.

The continuing decrease in concentrations of suspended PM_{10} and $PM_{2.5}$ particulates can be attributed to a combination of factors, both to good meteorological and dispersion conditions in some months of the year and to continued emission reductions due to measures already implemented to improve air quality (replacement of boilers, the ongoing renewal of the vehicle fleet and measures implemented at large sources). The effect of measures associated with states of emergency declared on the territory of the CR in connection with the occurrence of the SARS-CoV-2 coronavirus in relation to changes in the concentration of suspended particulates is inconclusive.

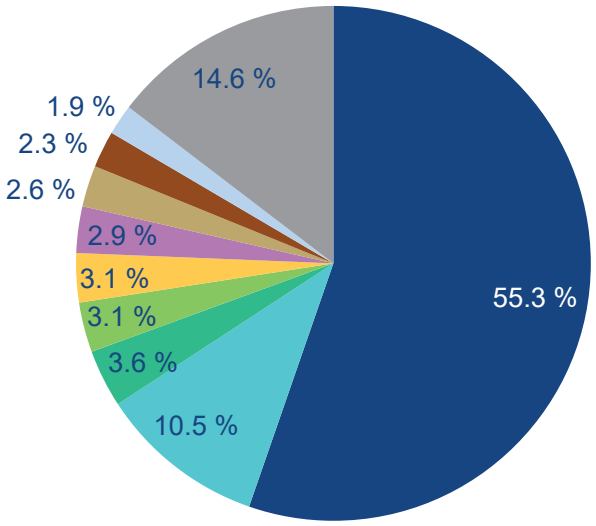


Fig. IV.1.20 Share of NFR sectors in total PM_{10} emissions, 2020

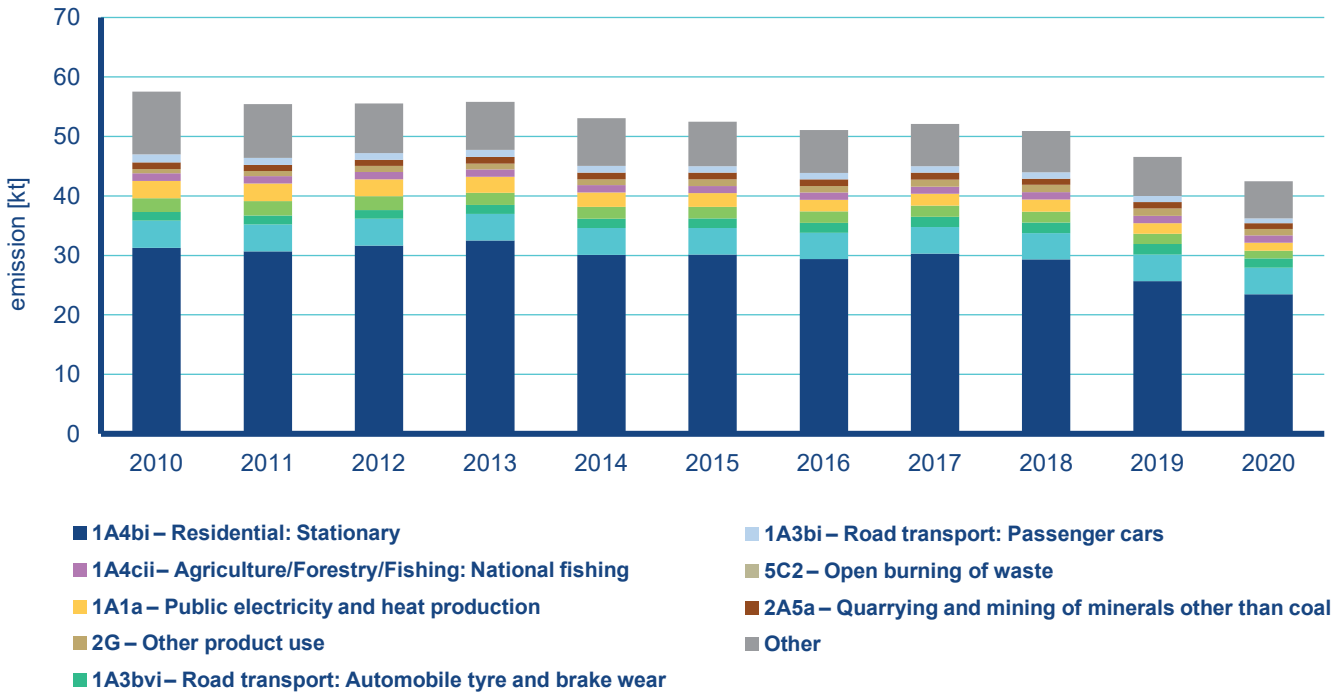


Fig. IV.1.21 Total PM_{10} emissions, 2010–2020

IV.1.3 Emissions of PM_{10} and $PM_{2.5}$

Aerosols originating from fuel combustion and other industrial activities can exist in the form of solid, liquid or mixed suspended matter. Taken together, these aerosols are termed Total Suspended Particulates (TSP) (solid pollutants (SP) in the Czech legislation). TSP emissions have varying size and chemical composition resulting from the characteristics of the source and the mode of formation. They can contain heavy metals and act as carriers for VOCs and PAHs. The PM_{10} and $PM_{2.5}$ size fractions are most frequently distinguished in emission inventories in relation to pollution limit levels.

Emission inventories of PM_{10} and $PM_{2.5}$ prepared according to current regulations include only the primary emissions of these substances. However, a considerable contribution to airborne concentrations of PM_{10} and $PM_{2.5}$ comes from secondary suspended particulates formed directly in the air from gaseous precursors through physical-chemical reactions. The fraction of secondary suspended inorganic particulates in total $PM_{2.5}$ concentrations in urban environments can vary between 20 and 40 % (Vlček, Corbet 2011). According to the model estimate, the contribution of secondary suspended organic particulates of biogenic origin under European conditions can equal 2–4 $\mu g \cdot m^{-3}$ of $PM_{2.5}$ (Fuzzi et al. 2015).

Compared to emissions of other pollutants, particulate matter emissions in the air originate from a great many significant source types. In addition to sources from which these substances are emitted through controlled chimneys or stacks (industrial production, household heating, transport exhaust emissions), significant amounts of TSP emissions originate from fugitive sources (quarries, dumping of dusty materials, manipulations involving dusty materials, etc.). Relevant sources include also emissions from abrasion of tyres, brake linings and abrasion of roads calculated from traffic intensity. The air quality is also affected by the resuspension of particles, which is not included in the standard emission inventories.

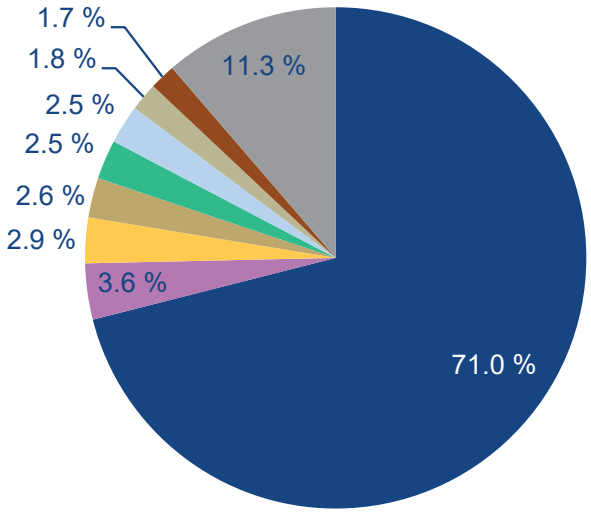


Fig. IV.1.22 Share of NFR sectors in total $PM_{2.5}$ emissions, 2020

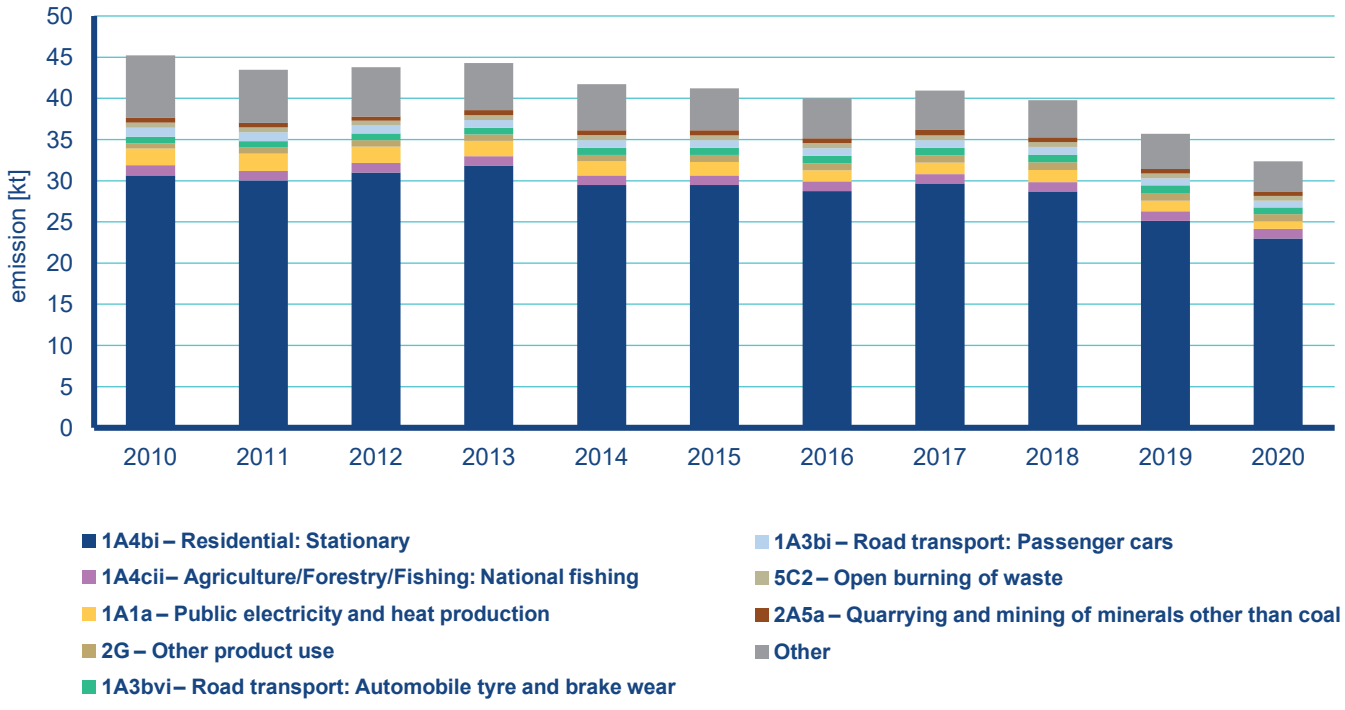


Fig. IV.1.23 Total $PM_{2.5}$ emissions, 2010–2020

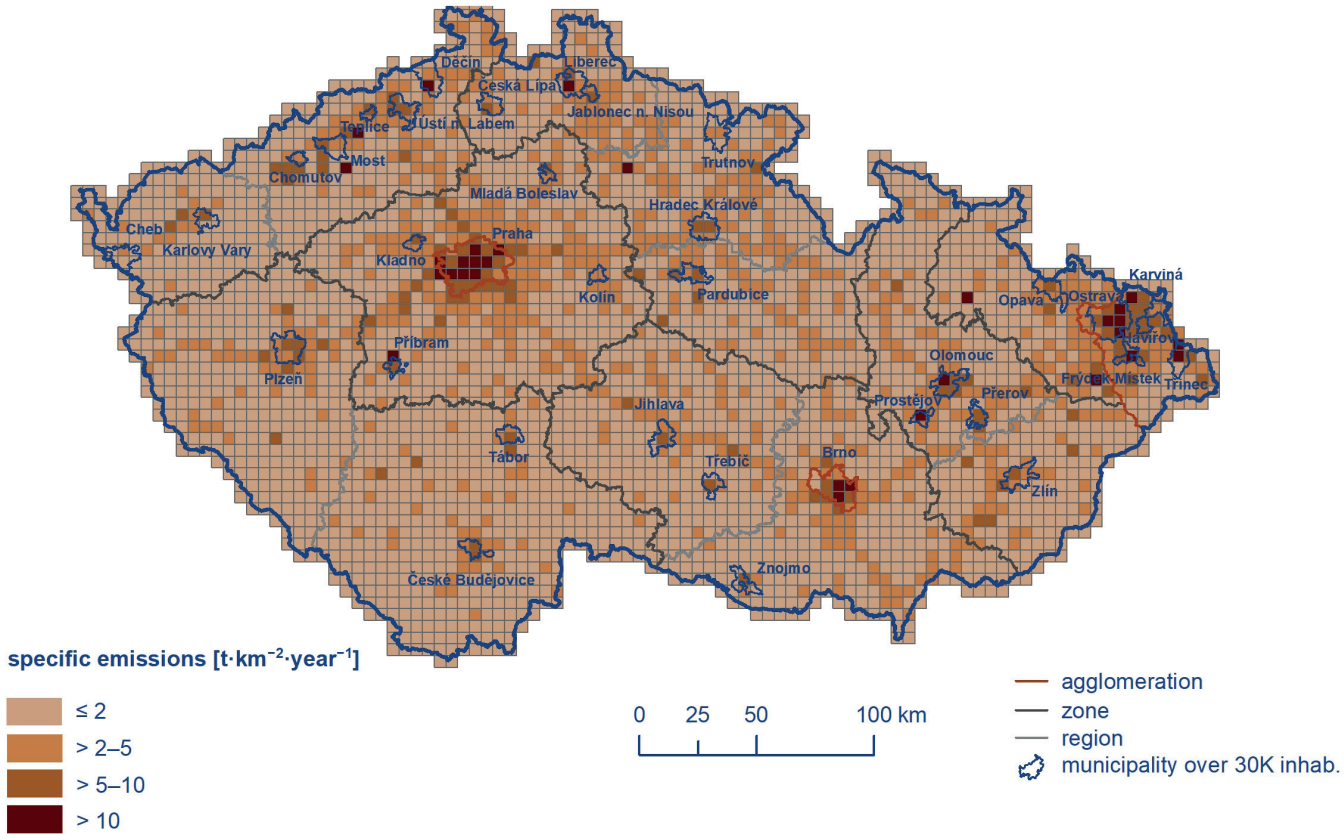


Fig. IV.1.24 Total PM_{10} emissions in 5×5 km spatial resolution squares, 2020

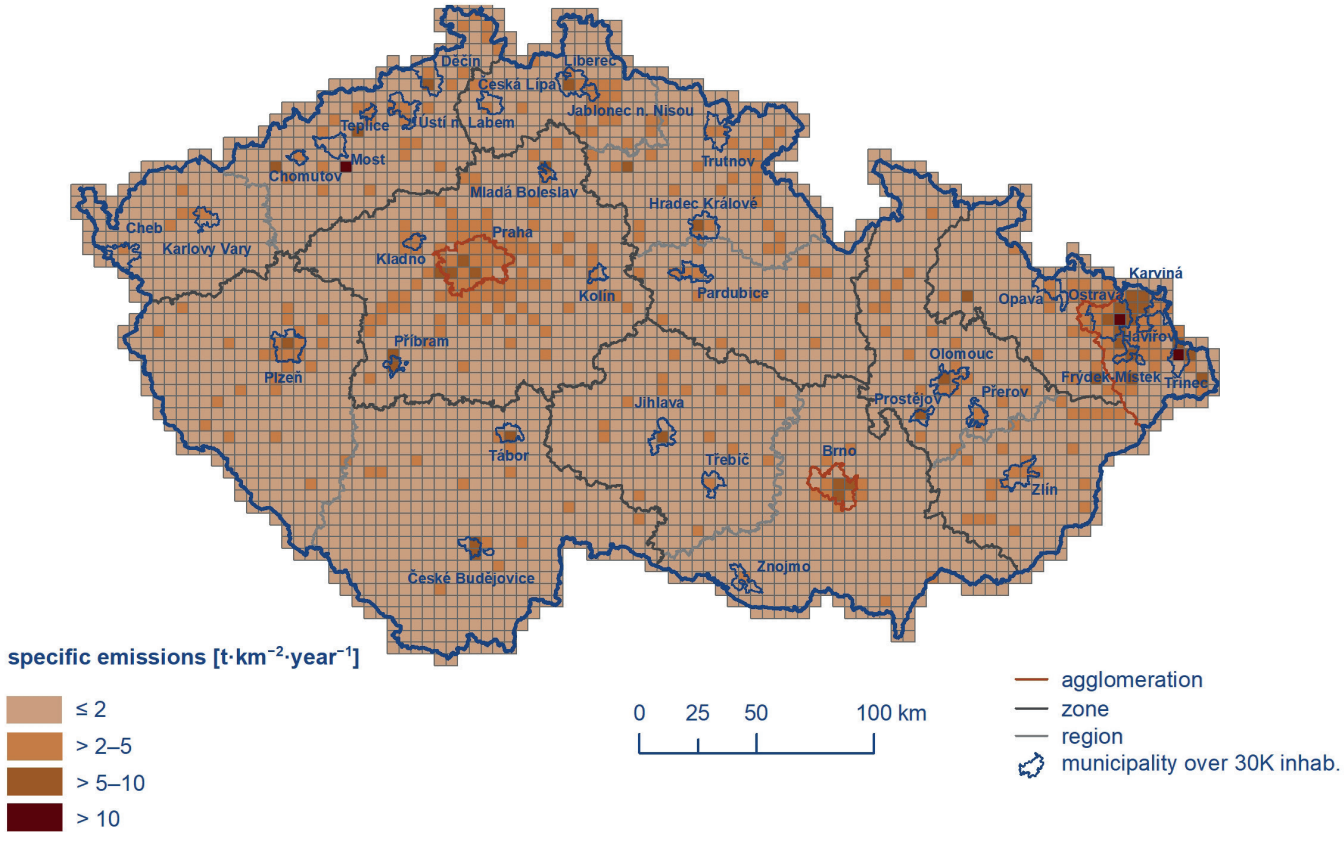


Fig. IV.1.25 Total $PM_{2.5}$ emissions in 5×5 km spatial resolution squares, 2020

The main sources of particulate matter emissions in 2020 (Fig. IV.1.20 and Fig. IV.1.22) included sector 1A4bi — Residential: Heating, water heating, cooking, which contributed 55.3 % of PM_{10} substances and 71 % of $PM_{2.5}$ substances to air pollution on a country-wide scale. Further important sources of PM_{10} emissions included sector 3Dc — Farm-level agricultural operations including storage, handling and transport of agricultural products, with emissions formed during tillage of the soil, harvesting and cleaning of agricultural crops. This sector represented 10.5 % of PM_{10} emissions. A substantial risk to human health is caused by particulates coming from transport, especially from fuel combustion in diesel engines that produce particles with sizes up to hundreds of nanometres (Vojtíšek 2010). Mobile sources (CHMI 2022d) contributed 11.7 % to PM_{10} emissions and 11.8 % to $PM_{2.5}$ emissions in 2020.

Solid fuel consumption in households, affecting significantly emission levels, can be characterized by a growing trend in the period 2010–2020, possibly related to the economic situation. Nevertheless, the resulting effect has been compensated by natural renewal of the vehicle fleet, a decrease in agricultural production, and in particular the use of the best available techniques for reducing TSP emissions (fabric filters) in the energy and industry sectors. Total PM_{10} and $PM_{2.5}$ emissions in nearly the entire period 2010–2020 therefore show a declining trend (Fig. IV.1.21 and Fig. IV.1.23).

In individual regions of the CR, the contribution by sectors varies depending on the composition of sources in a given area. Since the main source of PM_{10} and $PM_{2.5}$ emissions is from local heating, the production of these substances is also distributed throughout the territory of the CR along with residential buildings. In the territory of the CR, areas with higher emissions correspond to sites where lignite mining takes place and important energy sources using solid fossil fuels or large industrial complexes are located (the Ústí nad Labem and Moravian-Silesia regions). The fraction of suspended particle emissions from transport is greater primarily in large cities (Fig. IV.1.24 and Fig. IV.1.25).

IV.2 Benzo[*a*]pyrene

IV.2.1 Air pollution by benzo[*a*]pyrene in 2021

Air pollution by benzo[*a*]pyrene is one of the main air quality problems in the CR. In 2021, the annual average concentration of benzo[*a*]pyrene exceeded the pollution limit value (1 ng·m^{-3}) at 40 % of stations, i.e., 19 of a total of 49 stations with a sufficient number of measurements for evaluation (Fig. IV.2.1). In 2021, the area with above-limit concentrations of benzo[*a*]pyrene covered 6.1 % of the area of the CR inhabited by approx. 20 % of the CR population (Fig. IV.2.2). The area with above-limit concentrations in 2021 was the second lowest in the last five years. The largest year-on-year increase in the area with above-limit concentrations of benzo[*a*]pyrene occurred in the Zlín and Olomouc regions. The regions with the highest concentrations of benzo[*a*]pyrene in the long term remain the Moravian-Silesia, Zlín and Olomouc regions (Fig. IV.2.3). However, exceeding the annual benzo[*a*]pyrene pollution limit in connection with local heating also occurs in a number of cities and municipalities outside the most heavily burdened regions.

The highest annual average concentrations of benzo[*a*]pyrene have long been recorded at all types of stations in the whole area of the O/K/F-M agglomeration (Fig. IV.2.4). High above-limit concentrations of benzo[*a*]pyrene occur there in connection with the highest emission load within the CR (from various types of sources), including the impact of cross-border transfer from Poland. As in previous years, also in 2021 the highest annual average concentration of benzo[*a*]pyrene (8.9 ng·m^{-3}) was recorded at the Ostrava-Radvanice ZÚ industrial station, where the annual benzo[*a*]pyrene pollution limit was exceeded almost ninefold. The results of the identification of air pollution sources and the evaluation of causes of air pollution in the eastern part of Ostrava within the ARAMIS project – Integrated system of research, evaluation and control of air quality (co-funded with the state support of the Technology Agency of the CR under the Environment for Life program) show that at this station, with limited representativeness of hundreds of meters from the station (corresponding to classification and purpose of the station), pollution by benzo[*a*]pyrene originates mainly from the site of the Liberty Ostrava a. s. metallurgical company (about two-thirds in the cold part of the year) and almost the entire remaining part involves household heating (Seibert et al. 2022). The second highest value of the annual average concentration of benzo[*a*]pyrene was identified at the Věřňovice border rural station (6.8 ng·m^{-3}) within the subsidized extension of monitoring by the Moravian-Silesia region (Hladký et al. 2022). In this locality, a combination of the impact of air pollution from southern Poland and the specific composition of small settlements on the Czech side of the border, together with the often poor dispersion conditions in the valley

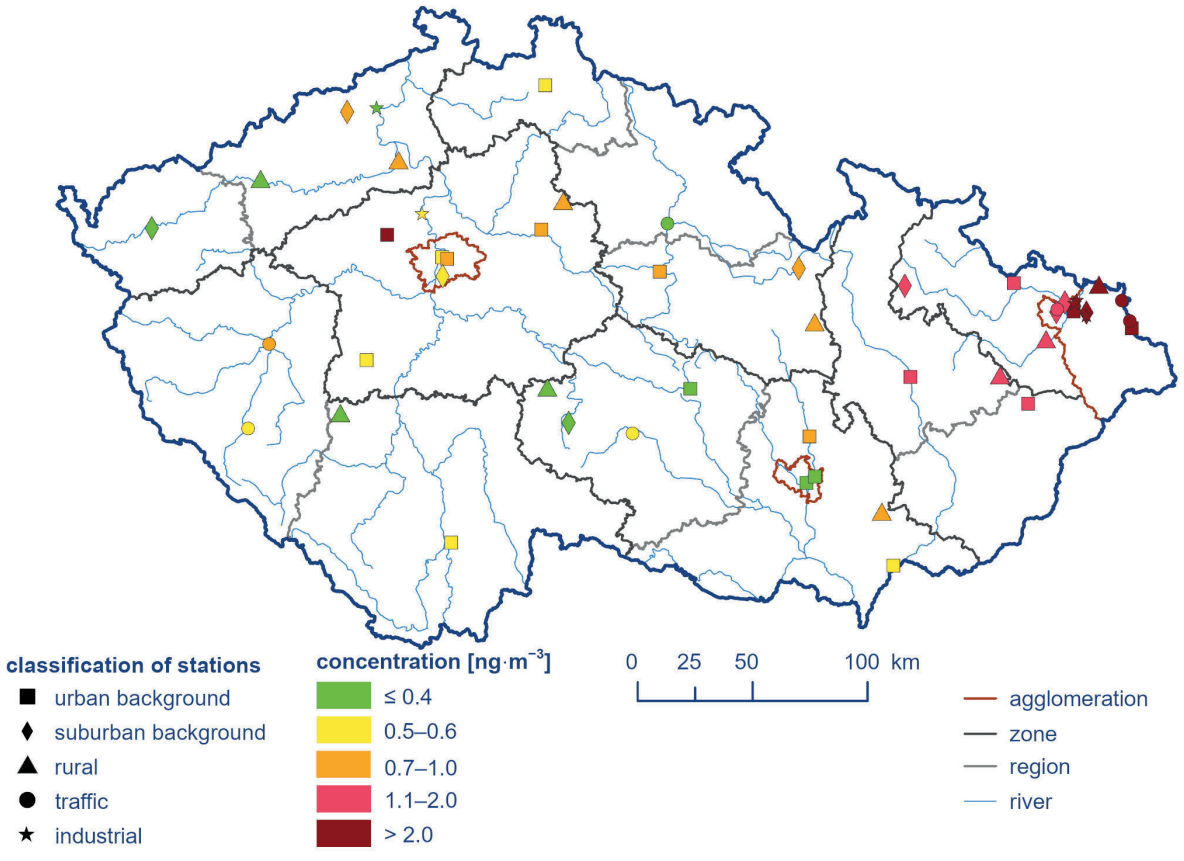


Fig. IV.2.1 Annual average concentrations of benzo[*a*]pyrene at air quality monitoring stations, 2021

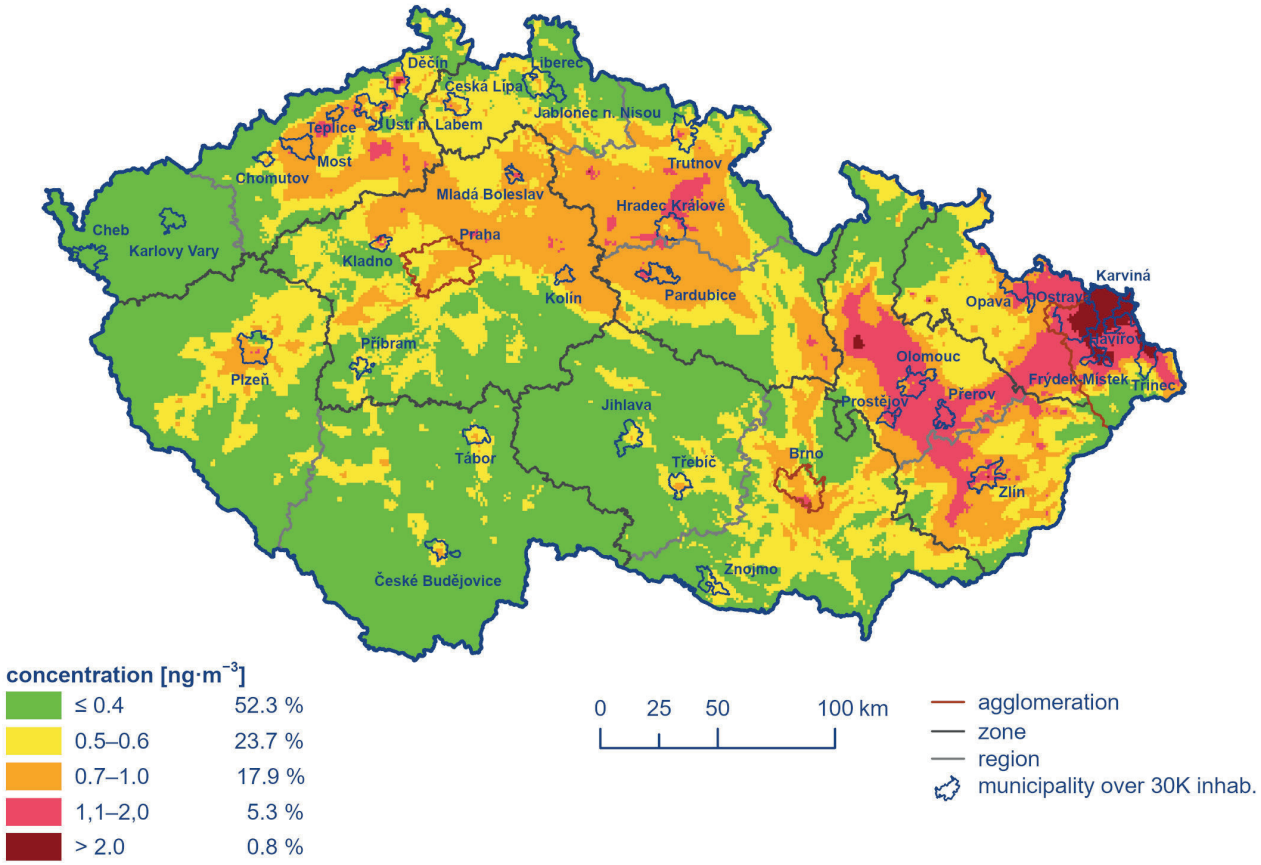


Fig. IV.2.2 Field of annual average concentration of benzo[*a*]pyrene, 2021

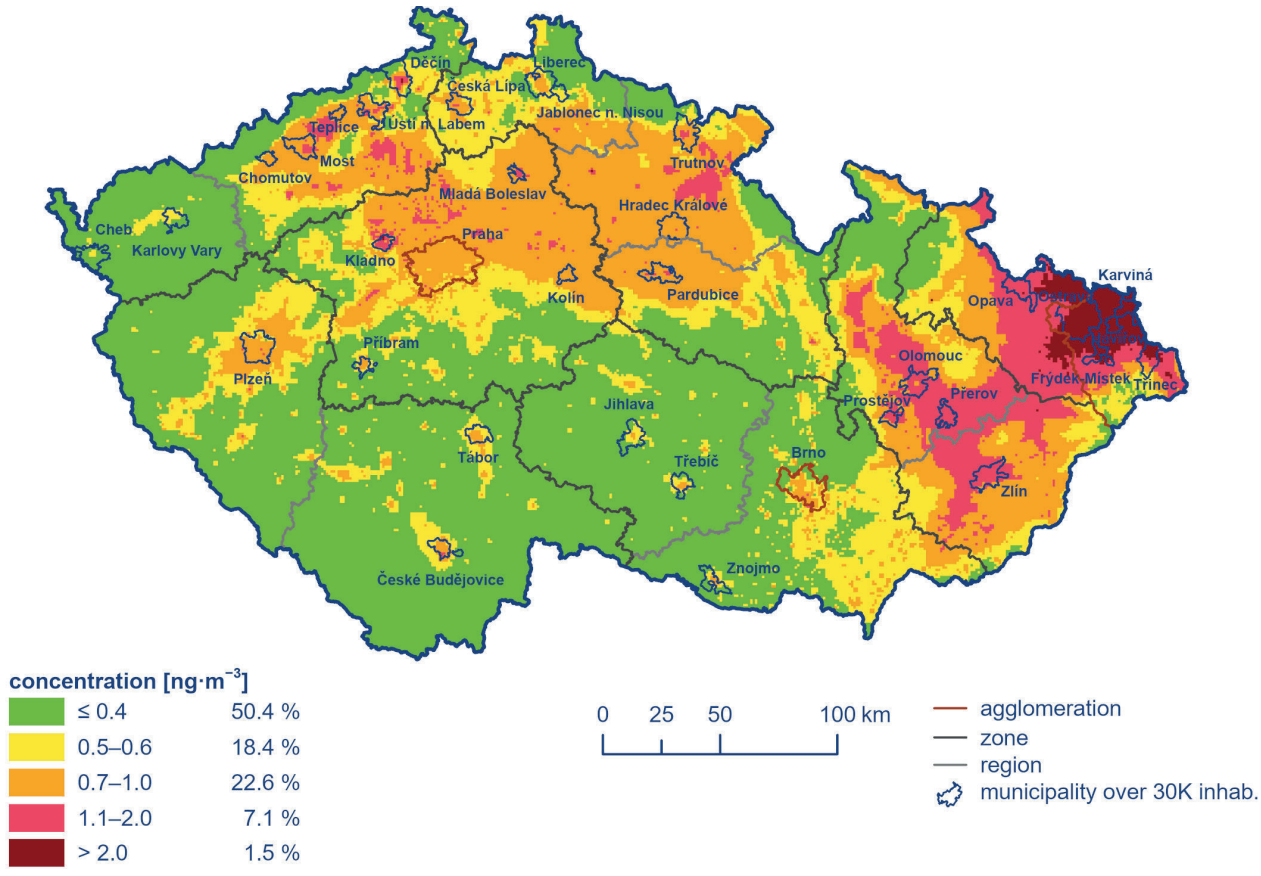


Fig. IV.2.3 Five-year average of annual average concentrations of benzo[*a*]pyrene, 2017–2021

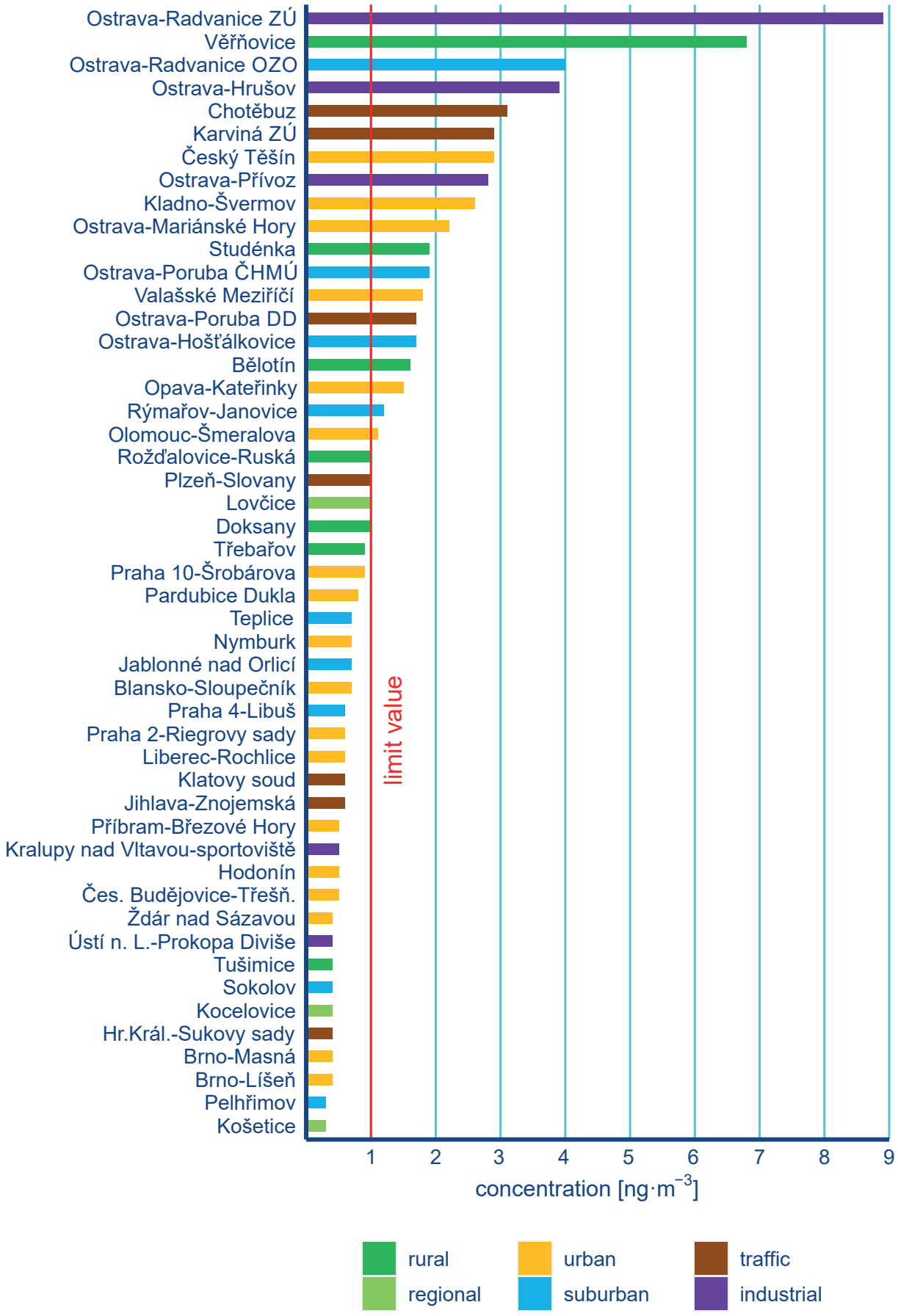


Fig. IV.2.4 Annual average concentrations of benzo[*a*]pyrene at monitoring stations, 2021

of the Olše River, is manifested. Benzo[*a*]pyrene-air pollution here comes from local household heating with coal (two-thirds to three-quarters of the average annual concentration) and biomass (less than 20 % of the average annual concentration). Above-limit values of benzo[*a*]pyrene were also measured at stations with the lowest concentrations of benzo[*a*]pyrene in the O/K/F-M agglomeration (Ostrava-Hošťálkovice and Ostrava-Poruba DD with 1.7 and 1.6 ng·m^{-3}, respectively). Benzo[*a*]pyrene concentrations exceeding the pollution limit were measured at all stations monitoring benzo[*a*]pyrene in the Moravian-Silesia, Olomouc and Zlín regions. Apart from the most burdened area in Moravia, higher concentrations of benzo[*a*]pyrene are recorded every year in the Kladno area (Kladno-Švermov station with 2.6 ng·m^{-3}), in connection with the dense development of family houses with local heating in the vicinity of the measuring station. Above-limit values can also be expected in other municipalities with a higher proportion of household heating with solid fuels where benzo[*a*]pyrene is not routinely measured. On the contrary, low annual average concentrations of benzo[*a*]pyrene were observed in the South Moravia and Vysočina regions. Conversely, low annual average concentrations of benzo[*a*]pyrene were found in the Brno agglomeration and in the South Bohemia, Karlovy Vary, and Vysočina regions. Below-limit values of benzo[*a*]pyrene concentrations are also observed in large cities (Prague, Brno, Plzeň), i.e., in cities with a high proportion of remote central heating. The lowest average annual concentration of benzo[*a*]pyrene (0.3 ng·m^{-3}) was observed at the Košetice regional station, which monitors background concentrations of polluting substances in the CR. Regional localities are not directly affected by local emission sources, but are only affected by the long-range transport

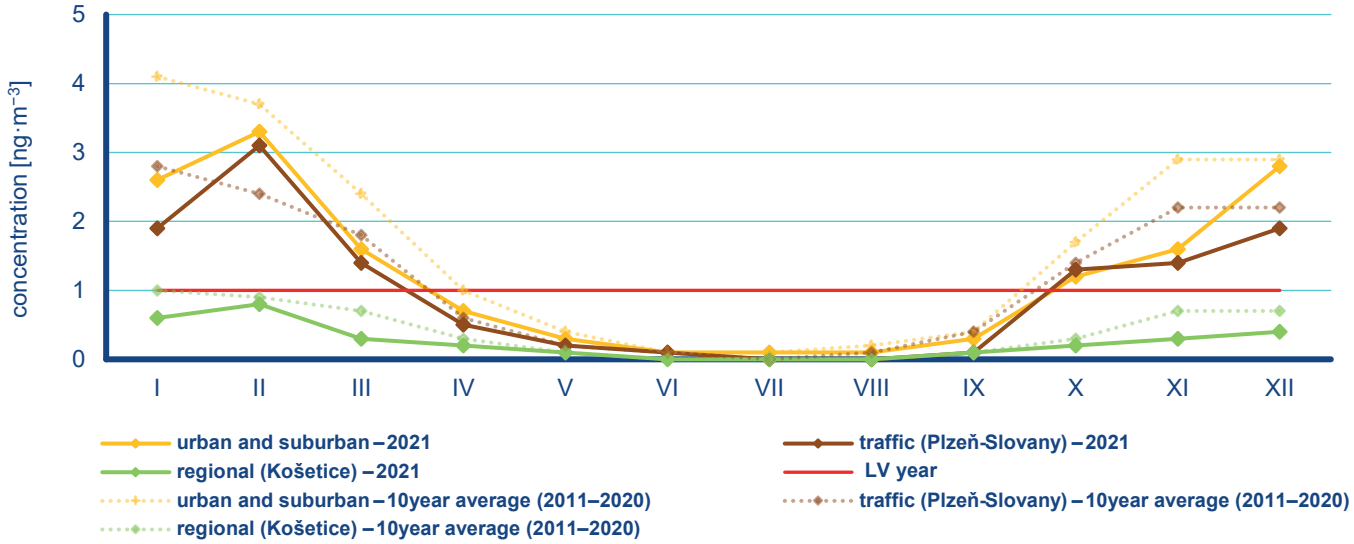


Fig. IV.2.5 Annual course of average monthly concentrations of benzo[*a*]pyrene (averages for a given type of station), 2021

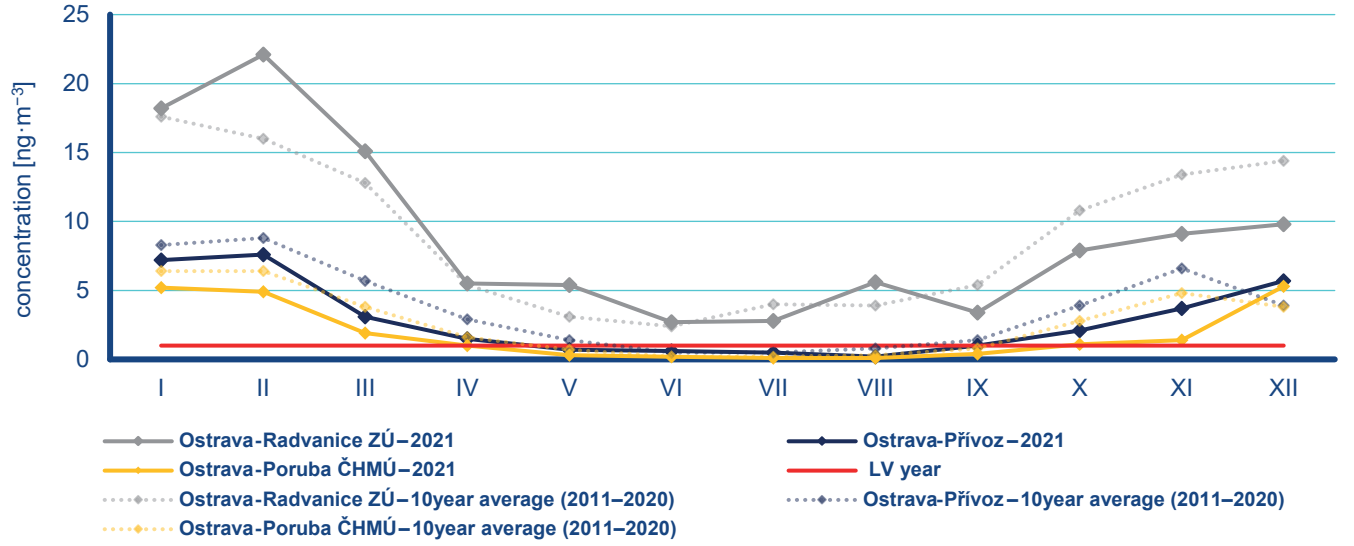


Fig. IV.2.6 Annual course of average monthly concentrations of benzo[*a*]pyrene at Ostrava-Radvanice, Ostrava-Přívoz and Ostrava-Poruba CHMI

of pollutants in combination with meteorological and dispersion conditions. Low concentrations of benzo[*a*]pyrene can therefore be expected also in places away from the direct impact of emission sources and in well-ventilated localities (e.g., natural mountain areas).

Benzo[*a*]pyrene concentrations exhibit a distinct annual variation with maxima in winter (Fig. IV.2.5, Fig. IV.2.6). The reason for the high concentrations of benzo[*a*]pyrene in the cold part of the year are emissions from seasonal anthropogenic sources — local heating units, additionally worsened by adverse meteorological conditions in this period. The annual variation of monthly benzo[*a*]pyrene concentrations clearly reflects the effect of emissions from local heating, with a rate (or intensity) influenced by the number of heating days during the heating season, which determines fuel consumption. In summer, concentrations decrease due to improved dispersion conditions, increased chemical and photochemical decomposition of PAHs at higher levels of solar radiation and high temperatures, and naturally mainly due to rapid decrease of emissions from anthropogenic sources (Li et al. 2009; Ludykar et al. 1999; Teixeira et al. 2012). In 2021, the highest monthly average benzo[*a*]pyrene concentrations at urban and suburban sites were recorded in connection with worsened dispersion conditions in February and December, when, in addition, the values were close to those of the ten-year average (2011–2020), and at some stations with a long series of measurements, they were even higher. On the contrary, significantly lower concentrations of benzo[*a*]pyrene compared to the ten-year average 2011–2020 at urban and suburban background stations were found in January and November (almost by 1.6 ng·m^{-3}, i.e., by 38 % and 1.3 ng·m^{-3}, i.e., by 44 %). The annual variation of monthly benzo[*a*]pyrene concentrations at the Košetice regional station is similar to that at suburban and urban stations, but with significantly lower values of benzo[*a*]pyrene concentrations.

Fig. IV.2.6 shows the annual variation at the Ostrava-Přívoz and Ostrava-Radvanice ZÚ industrial stations, where in addition to the cross-border transmission of pollution typical for the entire Ostrava-Karviná area, there is an enormous emission load from a combination of sources from local heating and industry. For comparison, the graph also shows data from the Ostrava-Poruba CHMI background urban station, which monitors the level of background concentrations in the city of Ostrava. At the Ostrava-Přívoz station, the monthly concentrations of benzo[*a*]pyrene were lower in all months, except for June and December, compared to the long-term average of 2011–2020. Compared to the CHMI city background station Ostrava-Poruba, the values at the Ostrava-Přívoz station are slightly higher, however, the annual variation is similar for both stations. Monthly concentrations of benzo[*a*]pyrene at the Ostrava-Radvanice ZÚ industrial station are several times higher than at the Ostrava-Přívoz and Ostrava-Poruba CHMI stations, with a slightly different annual variation. Compared to the long-term average 2011–2020, the concentrations of benzo[*a*]pyrene at the Ostrava-Radvanice ZÚ station fluctuate. The largest decrease in benzo[*a*]pyrene concentrations compared to the long-term average 2011–2020 at the Ostrava-Radvanice ZÚ station was recorded in December (4.6 ng·m^{-3}, 32 % lower) and in November (4.2 ng·m^{-3}, 32 % lower). On the contrary, the largest increase in concentrations was recorded in February (by 6.1 ng·m^{-3}, 38 % higher) and in May (by 2.3 ng·m^{-3}, 73 % higher). Concentrations above 1 ng·m^{-3} occur at industrial stations in the O/K/F-M agglomeration throughout the year, including the summer months, which demonstrates the year-round impact of emissions from industry in the localities. In December, as in the previous year, higher average concentrations of benzo[*a*]pyrene were recorded at the Ostrava-Poruba and Ostrava-Přívoz stations in comparison to the long-term average 2011–2020. Worsened dispersion and meteorological conditions at the end of the year contributed to the increased concentrations of benzo[*a*]pyrene in December, when the only smog situation was announced in 2021.

It must be borne in mind that the estimates of annual average benzo[*a*]pyrene concentrations (Fig. IV.2.2) is accompanied by considerably greater uncertainties than for the other evaluated substances. The uncertainty in the map is due in part to the limited number of measurements at rural regional stations and the absence of more extensive measurements in smaller settlements in the CR, where the effect of local heating units on air pollution by benzo[*a*]pyrene would be demonstrated. The CHMI is therefore using the so-called system of rotating stations, which makes it possible to monitor more locations over a period of several years. The assessment of the year-on-year change in the extent of the territory affected and population exposed to above-limit concentrations of benzo[*a*]pyrene is also accompanied by greater uncertainty. The number of stations with measurements of benzo[*a*]pyrene is limited particularly by the high costs of laboratory analyses and the capacity of laboratories for processing benzo[*a*]pyrene samples. The uncertainties in the maps are described in detail in Annex I.

IV.2.2 Trends in benzo[*a*]pyrene concentrations

Benzo[*a*]pyrene concentrations at individual types of stations and on average for all stations is evaluated for the period of the last 11 years, i.e., 2011–2021 (Fig. IV.2.7). The value of the annual average concentration of benzo[*a*]pyrene with a set pollution limit is significantly affected at all stations, except for the industrial stations in the O/K/F-M agglomeration, by the concentration levels during months of the cold season in the year, since in summer months, the concentrations of benzo[*a*]pyrene are minimal. In the evaluated period, the highest annual concentrations of benzo[*a*]pyrene were recorded in 2012, associated with the repeated occurrence of poor meteorological and dispersion conditions in the cold season of the year. From 2012 to 2016, it is possible to observe a gradual decrease or stagnation of benzo[*a*]pyrene concentrations. The slight increase in benzo[*a*]pyrene concentrations in 2017 was associated with poor dispersion conditions in the cold part of the year. Between 2018 and 2020, benzo[*a*]pyrene concentrations decreased again. After an excellent year 2020 from the point of view of air quality, BaP concentrations were slightly higher in 2021, however, BaP concentrations in 2021 were about 20 % lower on average (0.4 ng·m^{-3}), compared to the ten-year average 2011–2020. The annual concentration of benzo[*a*]pyrene

averaged over all stations in 2021 was the second lowest in the evaluated period.

The average annual concentrations of benzo[*a*]pyrene at stations have been fluctuating during the evaluated period, with a decline seen in areas of the highest air pollution load (the O/K/F-M agglomeration and the Kladno area) (Fig. IV.2.8). Inter-annual variability is mainly affected by meteorological conditions in the cold part of the year. In the year-on-year comparison of 2020/2021, benzo[*a*]pyrene concentrations increased at more than half of the stations (i.e., at 28 of the total 38 stations) with data available for both years compared. The most significant decrease was recorded at the Ostrava Radvanice ZÚ industrial station, namely by 1 ng·m^{-3} (13 %). However, concentrations of benzo[*a*]pyrene

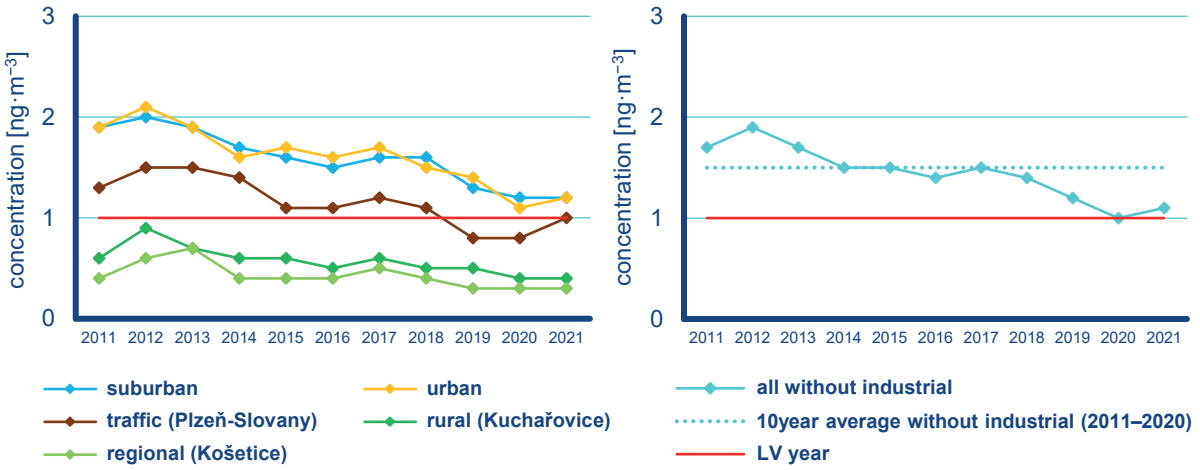


Fig. IV.2.7 Annual average concentration of benzo[*a*]pyrene at particular types of stations, 2011–2021

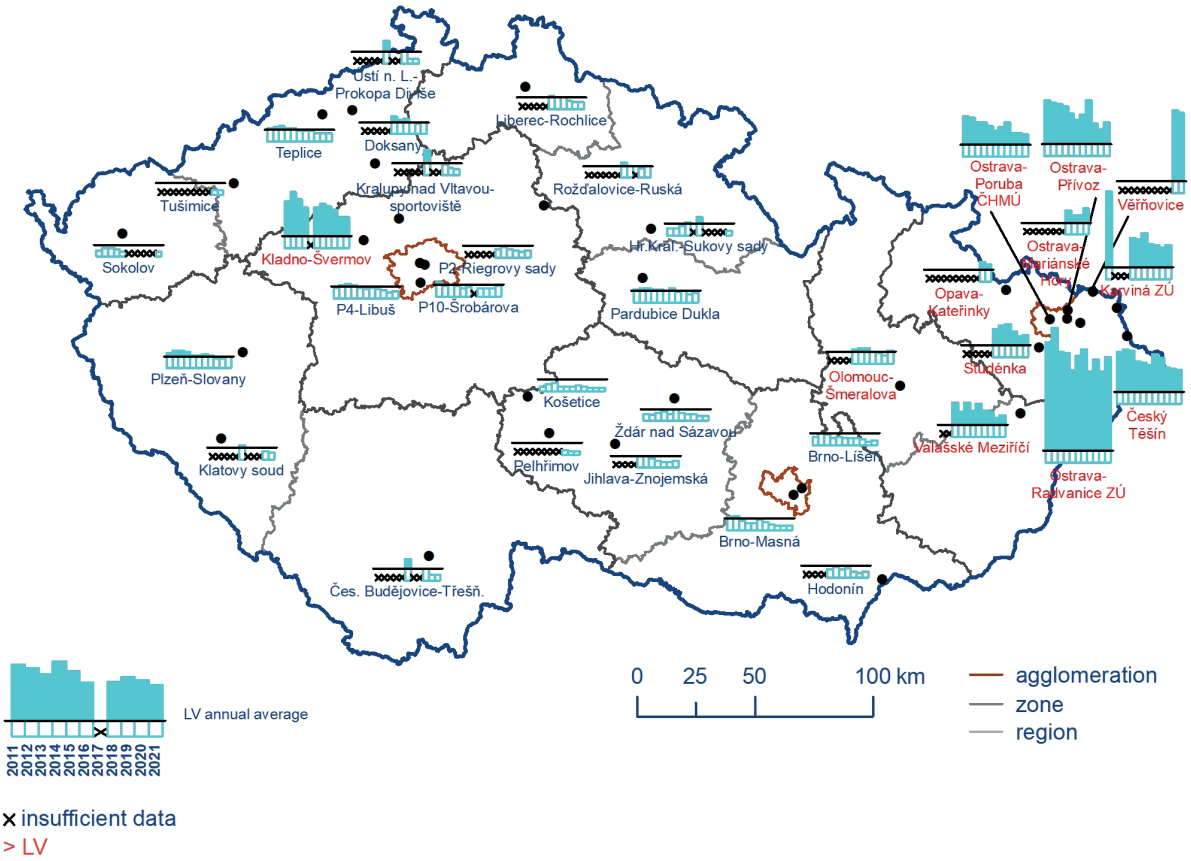


Fig. IV.2.8 Annual average concentration of benzo[*a*]pyrene at selected stations, 2011–2021

there still exceed the limit value by almost seven times. There was no increase in the annual average concentration of benzo[*a*]pyrene at any station in 2020. The highest year-on-year increase was recorded at the stations of Ostrava-Radvanice ZÚ (by 1.2 ng·m^{-3}) and Ostrava-Hrušov (by 1.1 ng·m^{-3}), both downwind of industrial sources of benzo[*a*]pyrene pollution in Ostrava.

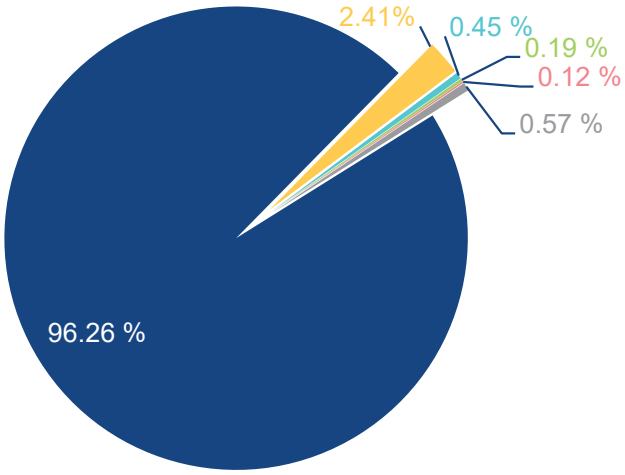


Fig. IV.2.9 Share of NFR sectors in total benzo[*a*]pyrene emissions, 2020

In assessing benzo[*a*]pyrene, there was a slight year-on-year increase in the annual average concentrations and the annual pollution limit was exceeded in many areas of the CR. In a number of cities and municipalities, in connection with local heating, benzo[*a*]pyrene concentrations above the limit are still found. However, compared to the long-term ten-year average 2011–2020, the measured concentrations of benzo[*a*]pyrene in 2021 were lower. In particular, less frequent occurrence of adverse conditions in January and November compared to ten-year values, as well as decreasing fuel consumption due to rising temperatures in the winter months in recent years, contributed to the improvement. Measures implemented to improve air quality, especially the renovation of boilers in households, have also contributed to the decrease in benzo[*a*]pyrene concentrations (Novák and Plachá eds. 2021).

IV.2.3 Emissions of benzo[*a*]pyrene

PAH emissions, of which benzo[*a*]pyrene in particular is monitored in view of air quality, are produced almost exclusively by combustion processes during which the organic combustible substances present are not sufficiently oxidised. Benzo[*a*]pyrene is a product of incomplete combustion at temperatures of 300 to 600 °C. Thus, one of its most important sources is the combustion of solid fuels in low-capacity boilers, particularly household heating units (sector 1A4bi – Residential: Heating, water heating, cooking, Fig. IV.2.9). The next significant source is the burning of plant waste (NFR 5C2), which accounts for 2.4 % of total emissions in 2020. The influence of traffic is mainly observed along

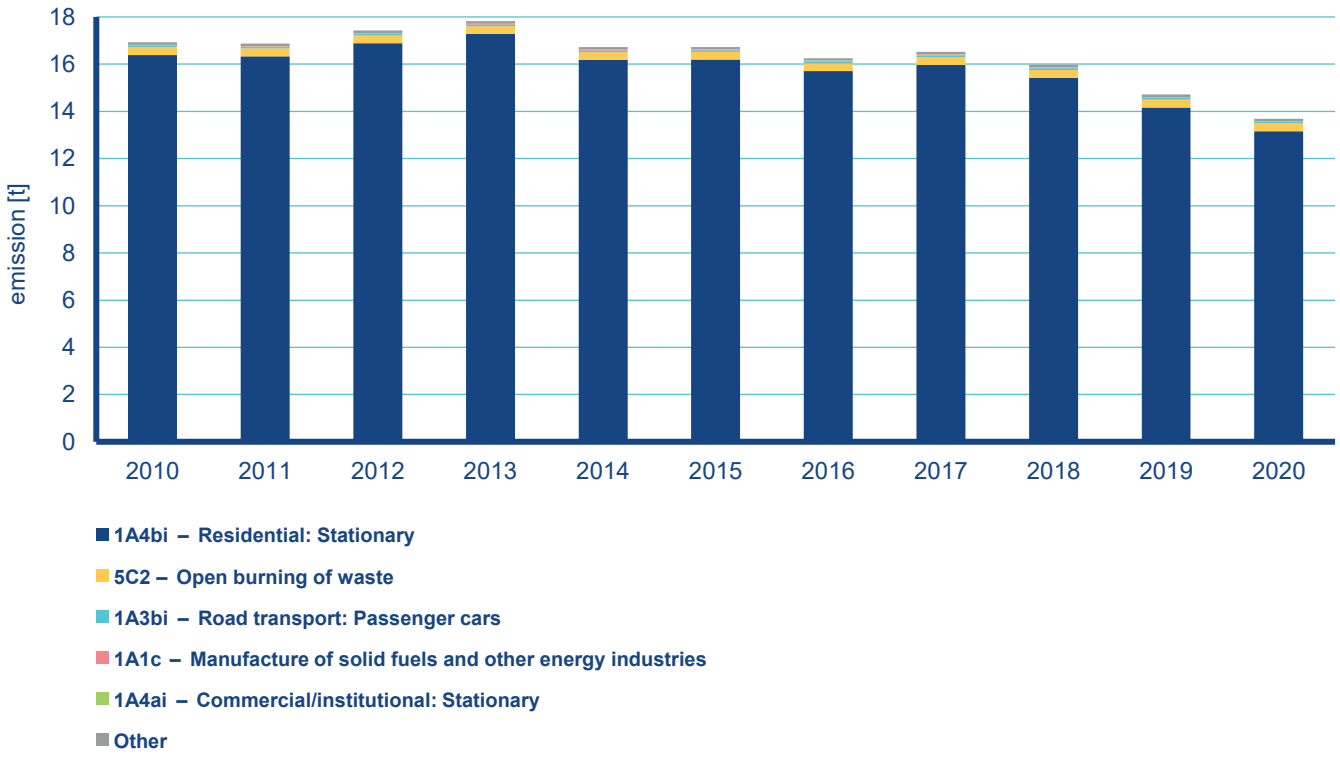


Fig. IV.2.10 Benzo[*a*]pyrene total emissions, 2010–2020

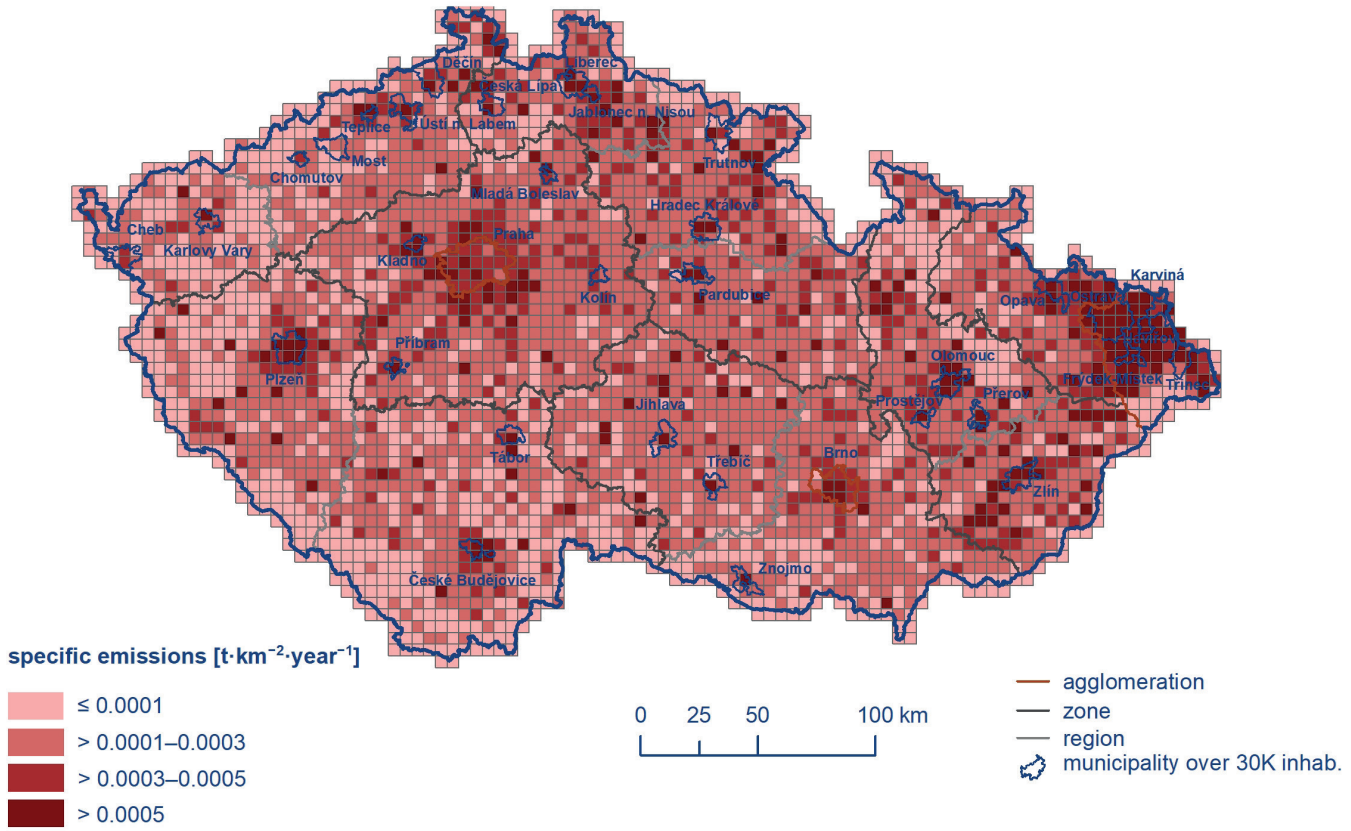


Fig. IV.2.11 Total benzo[*a*]pyrene emissions in 5×5 km spatial resolution squares, 2020

motorways, roads with intensive traffic and in the territory of large urban units. Benzo[*a*]pyrene emissions from industrial sources, especially from coal coke production, do not represent a significant proportion in total emissions, but on a local scale, even with regard to year-round operation, they can fundamentally affect air quality. The trend in total emissions in the period 2010–2020 (Fig. IV.2.10) is mainly related to the consumption of solid fuels in households, which depends on specific temperature conditions. The replacement of older boilers, the transition to natural gas or to non-emission sources, especially heat pumps, have also contributed to the reduction of emissions in recent years.

In view of predominant contribution of the sector 1A4bi, emissions of benzo[*a*]pyrene are distributed over the territory of residential buildings throughout the CR (Fig. IV.2.11). The O/K/F-M agglomeration is burdened most with emissions of benzo[*a*]pyrene. The reason is primarily the high population density, the higher proportion of coal burning in households in combustion-type boilers, as well as the metallurgical industry and coke production in the CR.

IV.3 Nitrogen oxides

IV.3.1 Air pollution by nitrogen oxides in 2021

In monitoring and evaluating the quality of ambient air, the term nitrogen oxides (NO_x) is understood to refer to a mixture of nitrogen oxide (NO) and nitrogen dioxide (NO_2). A pollution limit level for the protection of human health has been set for NO_2, while a limit level for the protection of ecosystems and vegetation has been set for NO_x.

Air pollution by nitrogen dioxide in 2021 in relation to pollution limit levels for the protection of human health

The limit value for the annual average nitrogen dioxide (NO_2) concentration (40 µg·m^{-3}) was not exceeded at any station in the CR in 2021, which happened, along with 2020, for only the second time in the entire history of the measurement (i.e., since the 1990s) (Fig. IV.3.1). Due to a measurement failure following a technical defect at the Prague 2-Legerova station (hot spot) during the year, it was not possible to include this most pollution loaded station in the evaluation. At this station, the highest values of NO_2 concentrations have been measured for a long time in connection with the high traffic intensity in the immediate vicinity of the station and its location in the street canyon, where the possibility of ventilation is significantly reduced. In the case of year-round measurement without a technical defect, the possibility of exceeding the annual NO_2 pollution limit cannot be ruled out. The highest annual average NO_2 concentration values were traditionally recorded at transport stations in big cities, especially in Prague and Brno. Higher concentrations of NO_2 can also be expected in the vicinity of busy roads in municipalities and cities with intense traffic, where traffic flow is often reduced. The lowest NO_2 concentrations are measured at regional stations (Churáňov, Košetice, Polom), i.e., in areas far from the influence of emission sources.

The limit value for an hourly NO_2 concentration (200 µg·m^{-3} with a maximum permitted number of 18 cases exceeding the limit per year) was not exceeded at any station in 2021. The hourly NO_2 limit value was once exceeded at one station (Ostrava-Poruba DD).

The modelled annual average concentration of NO_2 did not exceed 26 µg·m^{-3}, i.e., the value of the lower assessment threshold, in almost the entire territory of the CR, except for the centres of large cities (Fig. IV.3.2). However, it is important to note that NO_2 concentration maps are prepared in a resolution of 1×1 km, and therefore the effect of higher concentrations measured at transport stations with a low radius of representativeness (up to 100 m) are not

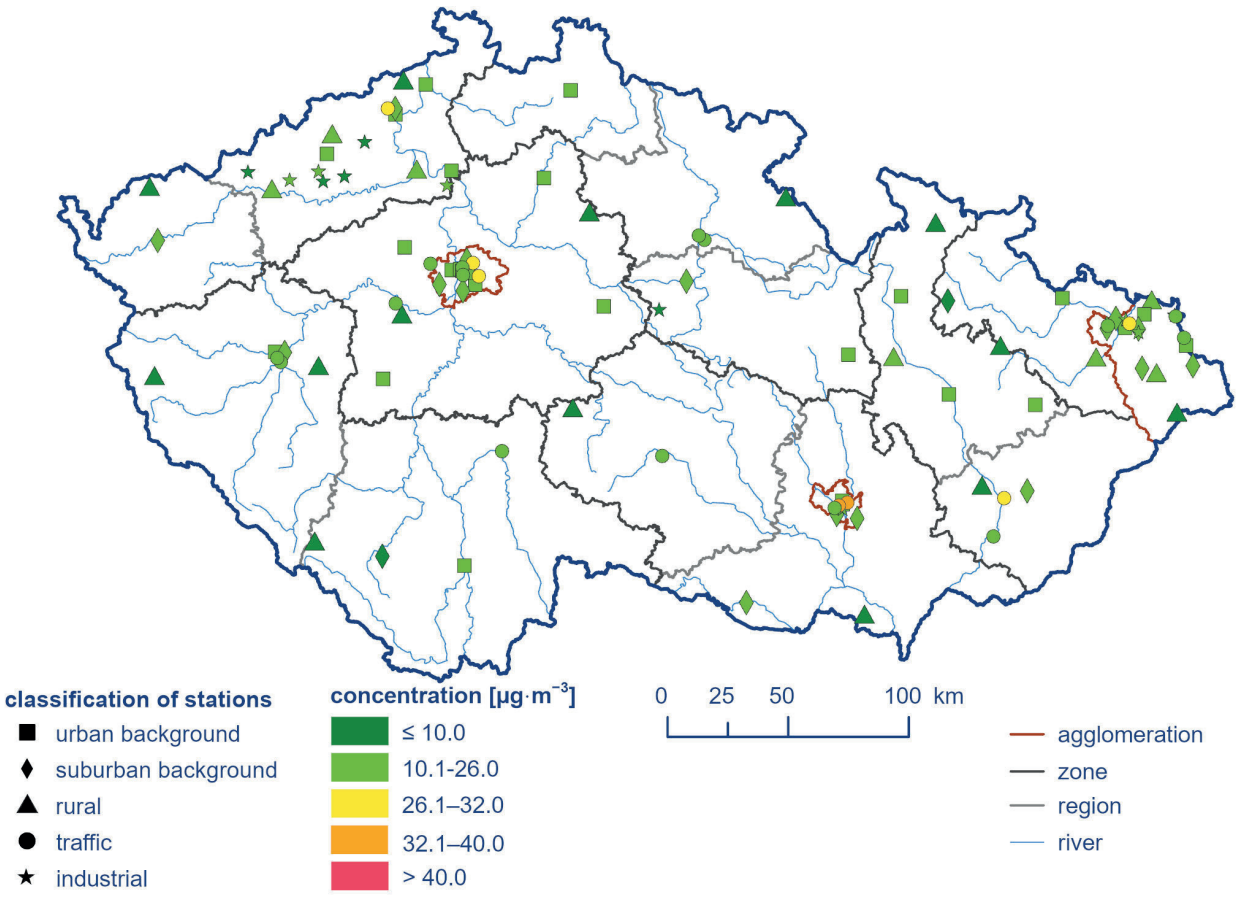


Fig. IV.3.1 Annual average NO_2 concentrations at air quality monitoring stations, 2021

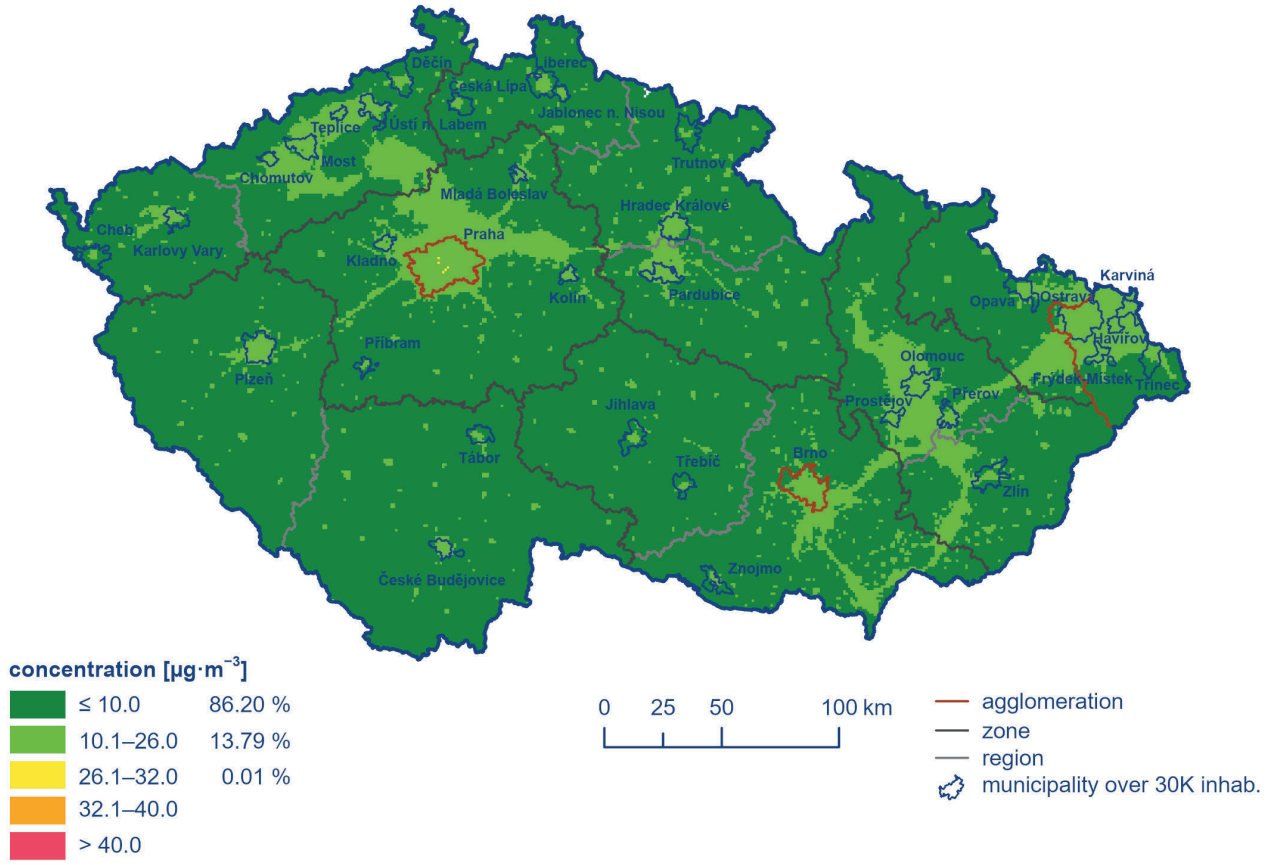


Fig. IV.3.2 Field of annual average NO_2 concentrations, 2021

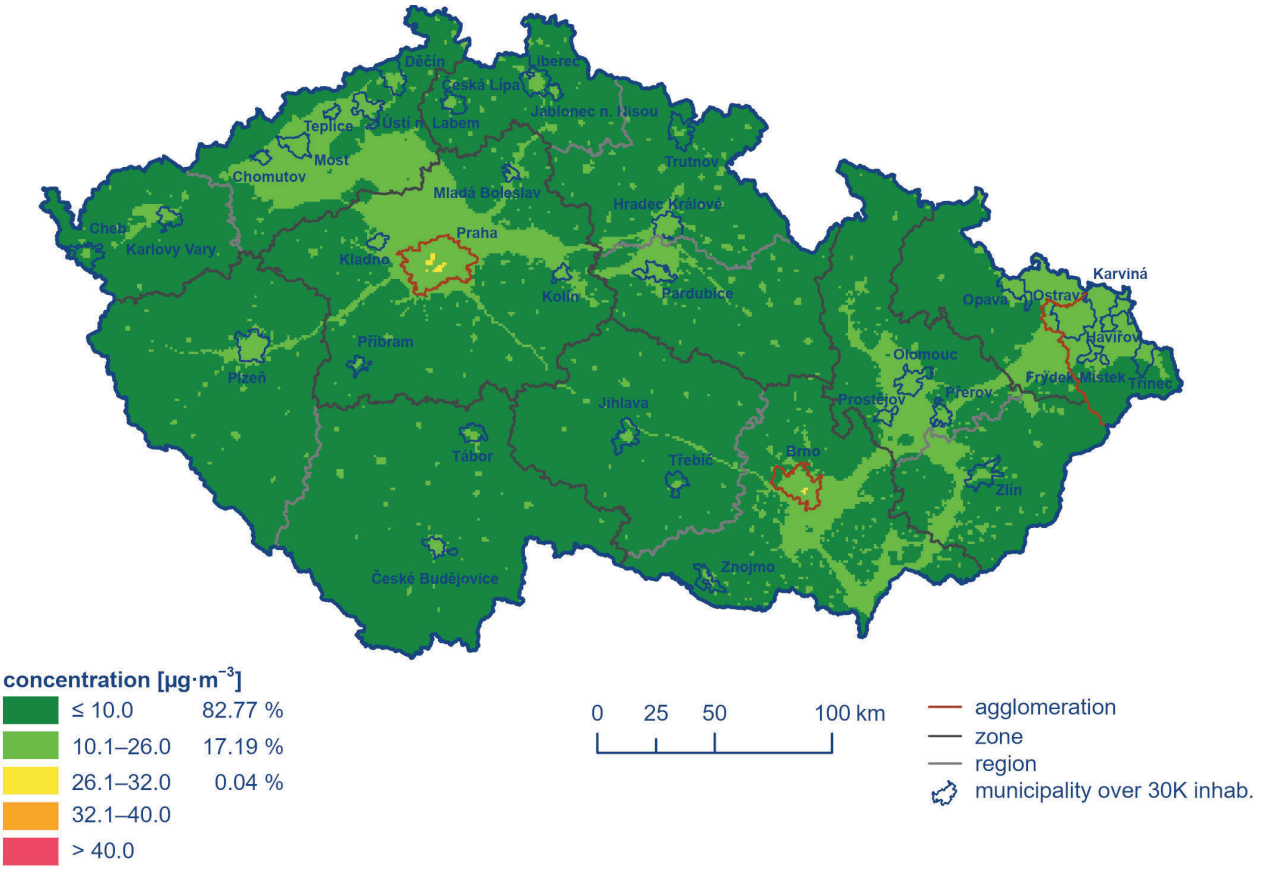


Fig. IV.3.3 Five-year average of annual average NO_2 concentrations, 2017–2021

reflected in the final image. The low radius of representativeness of transport stations is related to a sharp decrease in NO_2 concentrations with increasing distance from roads. From a long-term perspective (Fig. IV.3.3), higher concentrations are expected in centres of large cities with high traffic intensities (Prague and Brno).

The annual variation of monthly average concentrations is similar for all types of stations. The highest values of NO_2 concentrations are observed at transport stations in connection with strong influence from a nearby emission source – transport (Fig. IV.3.4.). As transport is the main source of NO_2, which operates throughout the year, the variation of concentrations during the year is affected by meteorological and dispersion conditions. In addition, peaks in the colder period of the year occur due to increased emissions from domestic heating and car cold ignition. On the contrary, in the period April-September, there is generally a decrease in NO_2 concentrations. The reason for this decrease is higher intensity of solar radiation in this season, which results in decomposition of NO_2 and its participation in photochemical reactions forming ground-level ozone. During the summer holiday months, there is also a reduction in traffic intensity in large cities, which improves the flow of traffic and thus reduces NO_2 emissions. The average monthly NO_2 concentrations are the lowest and well below the lower assessment threshold at regional rural localities remote from direct exposure to emission sources, showing thus less distinct annual variation. The highest monthly average NO_2 concentrations in 2021 were measured in February and were close to or even exceeded the 10-year average concentrations. The higher consumption of natural gas for heating houses and flats, including water heating, contributed to the increased NO_2 concentrations in February, whether at a centralized or local level in connection with the occurrence of low temperatures in combination with moderately poor to poor dispersion conditions. Conversely, the lowest monthly NO_2 concentrations were recorded in July. In 2021, all monthly average NO_2 concentrations, except February, were lower compared to the ten-year average 2011–2020. Significantly lower monthly average concentrations of NO_2 compared to the ten-year average 2011–2020 were in August, by about 30 %.

Air pollution by nitrogen oxides in 2021 in relation to pollution limit levels for the protection of ecosystems and vegetation

The pollution limit level for the protection of ecosystems and vegetation for the average annual NO_x concentration (30 $\mu g \cdot m^{-3}$) was not exceeded in 2021 at any of 21 rural stations with a sufficient amount of data for evaluation. The concentration map of annual average NO_x concentrations was prepared using combined data from all stations measuring NO_x and a dispersion model. Higher NO_x concentrations are measured in the vicinity of busy roads in municipalities. On the map, point symbols designate only rural stations because average annual NO_x concentrations are evaluated only at these locations, following the Czech legislation in force in relation to the pollution limit level for the protection of ecosystems and vegetation (Fig. IV.3.5).

IV.3.2 Trends in nitrogen oxide concentrations

The trends in NO_2 and NO_x concentrations at stations are evaluated over the last 11 years, i.e., 2011–2021 (Fig. IV.3.6, Fig. IV.3.7, Fig IV.3.8, and Fig. IV.3.9). The long-term decrease in NO_x emissions related to the gradual modernization of emission sources (large sources, renewal of the vehicle fleet) is manifested by a decrease in both NO_2 and NO_x concentrations in the air. However, the level of inter-annual concentrations of NO_2 and NO_x, as well as other pollutants, is significantly influenced by meteorological and dispersion conditions in individual years. During the evaluated period, the highest NO_2 and NO_x annual concentrations were recorded in 2011, in association with the recurrence of poor meteorological and dispersion conditions in the cold period of the year. Since 2011 until 2016, it is possible to observe a gradual decrease or stagnation in all monitored nitrogen oxide characteristics.

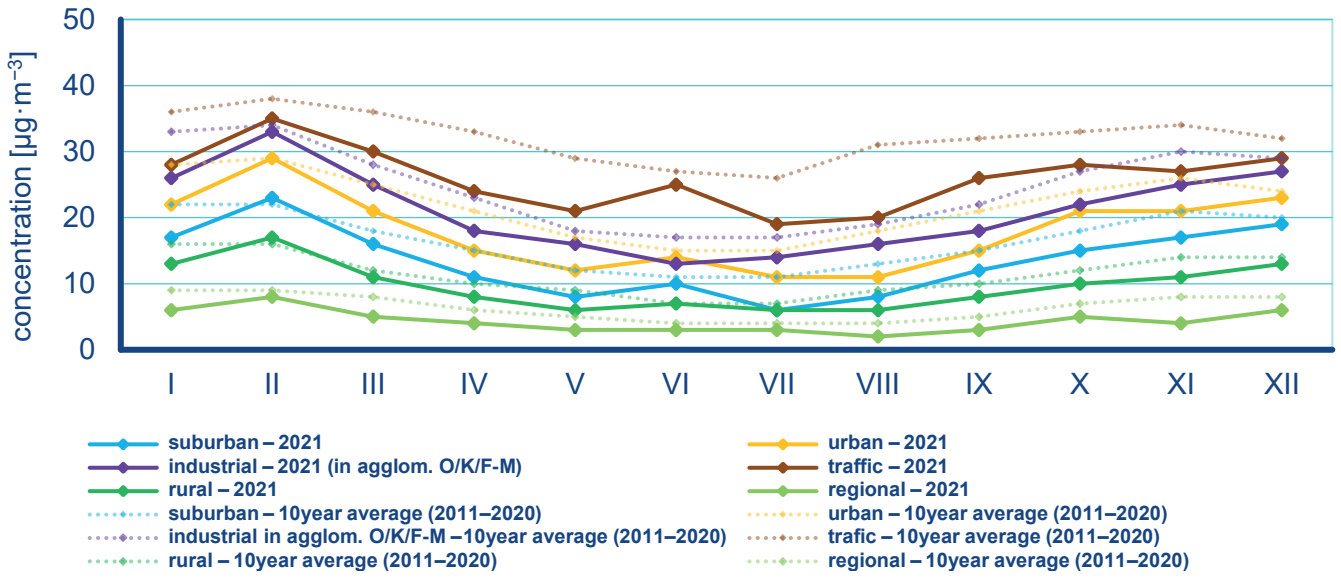


Fig. IV.3.4 Annual course of average monthly concentrations of NO_2 (averages for a given type of station), 2021

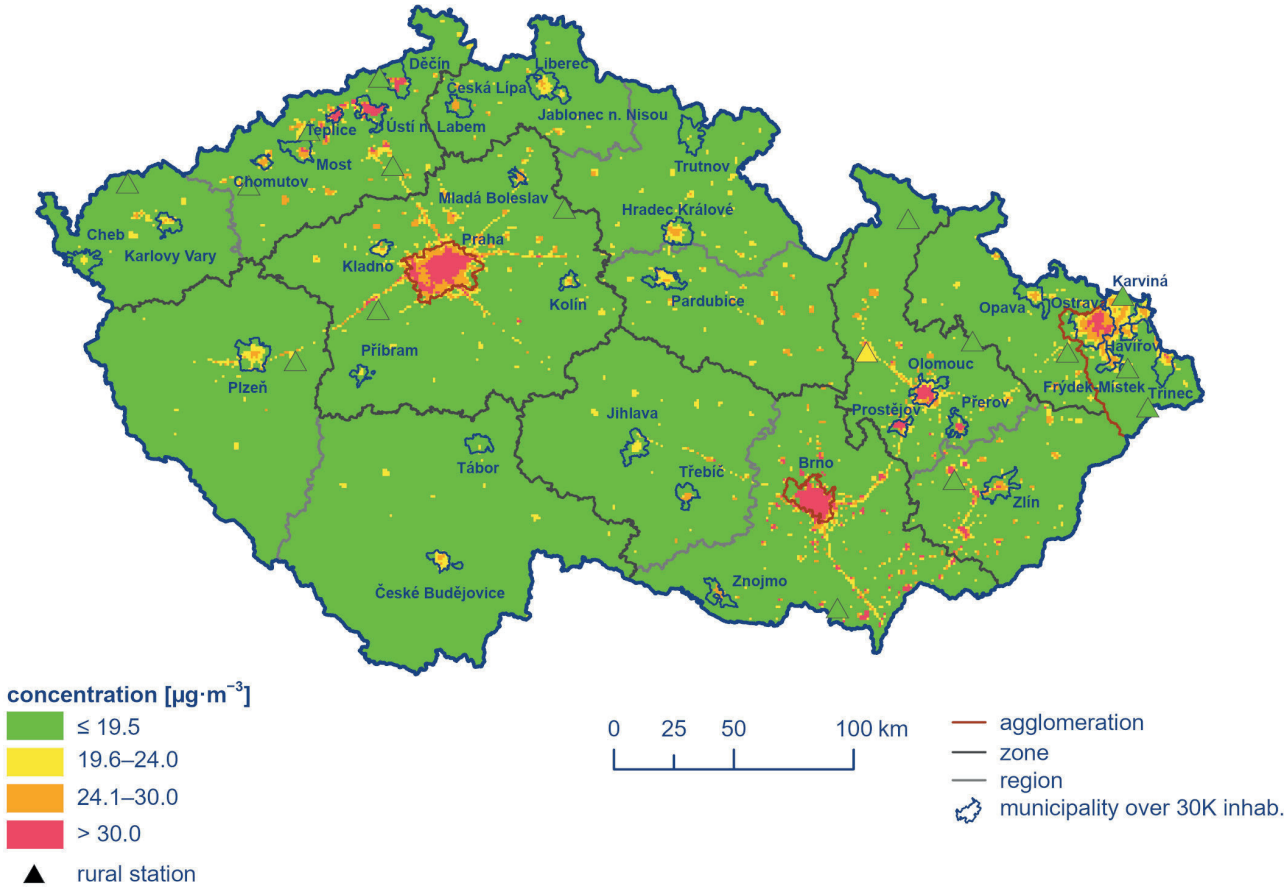


Fig. IV.3.5 Field of annual average NO_x concentration, 2021

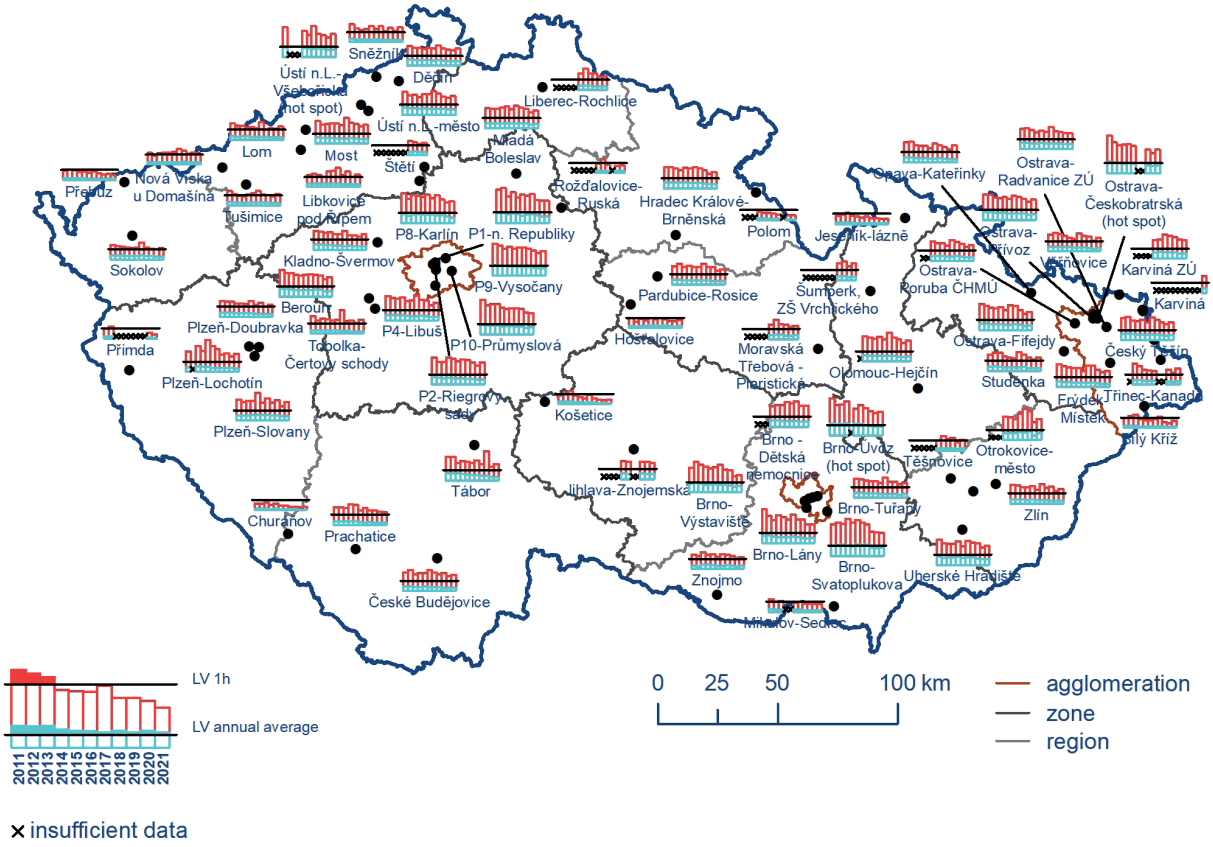


Fig. IV.3.6 The 19th highest hourly and annual average NO_2 concentrations at selected stations, 2011–2021

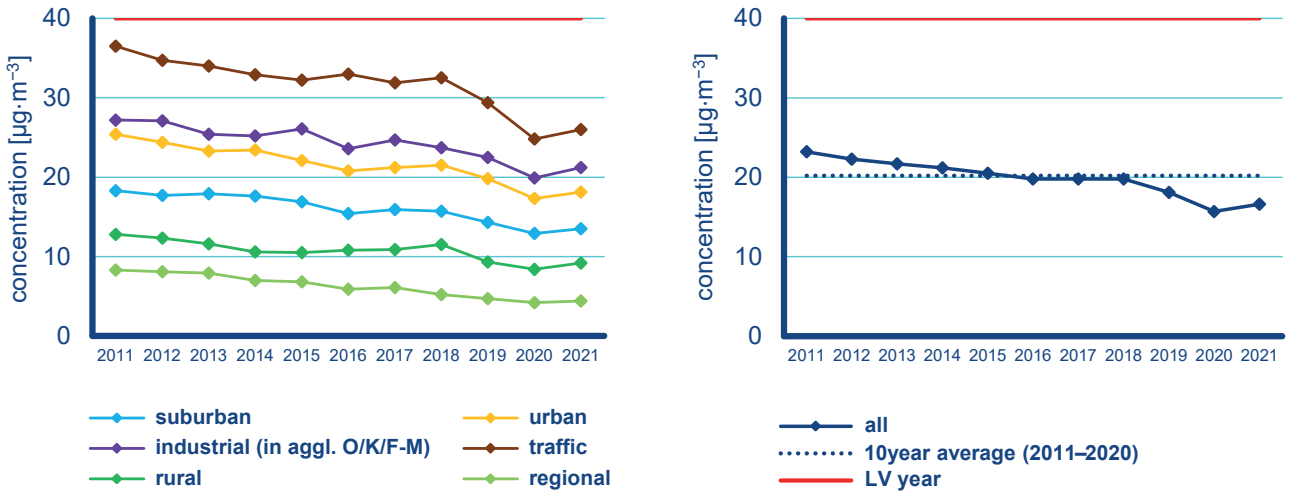


Fig. IV.3.7 Annual average NO_2 concentrations at particular types of stations, 2011–2021

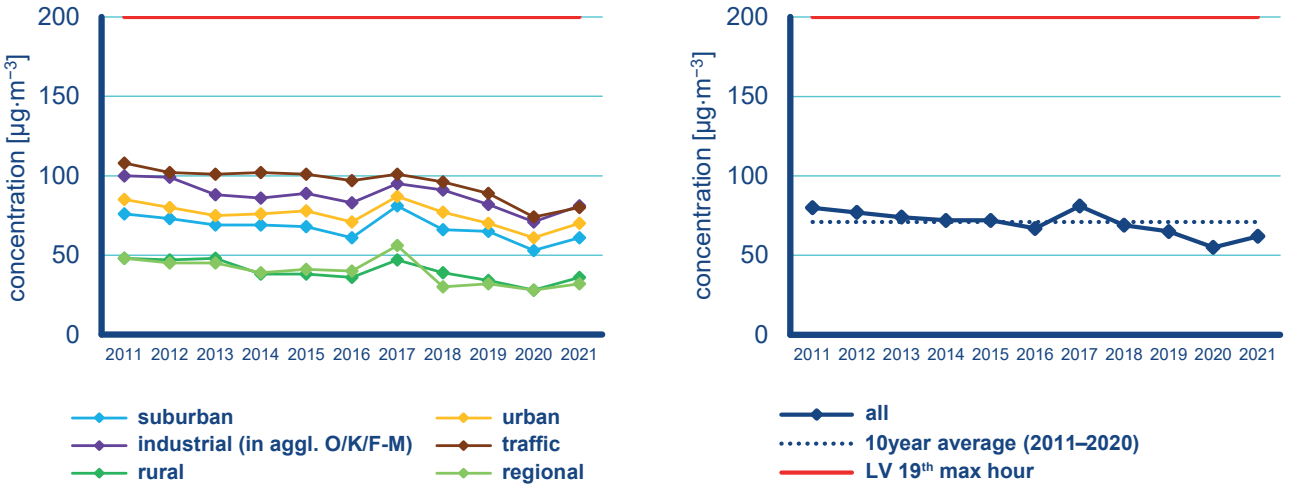


Fig. IV.3.8 The 19th highest hourly NO_2 concentrations at particular types of stations, 2011–2021

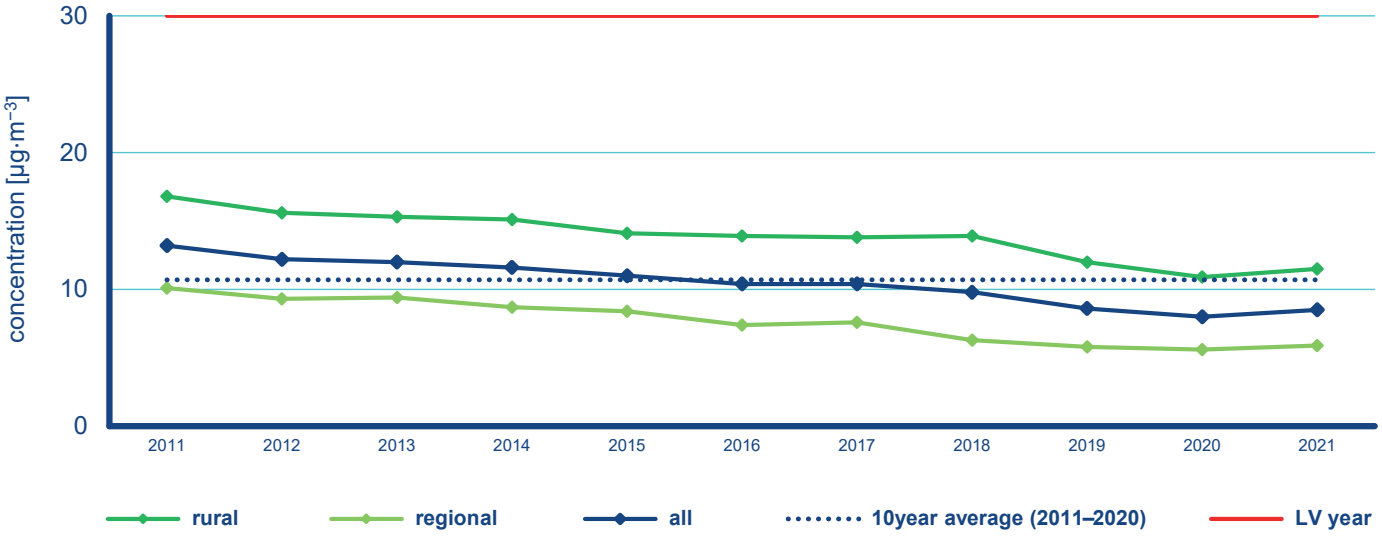


Fig. IV.3.9 Annual average NO_x concentrations at particular types of stations, 2011–2021

The slight increase in NO_2 and NO_X concentrations in 2017 was associated with poor dispersion conditions in the cold part of the year. During 2019 and 2020, NO_2 and NO_X concentrations decreased significantly. After the excellent year 2020, there was a slight increase in the average annual concentration of NO_2 and NO_X, in year-on-year comparison 2020/21, and the concentration values returned to the level of 2019. Compared to the ten-year average of concentrations (2011–2020) from all stations (20.2 $\mu g \cdot m^{-3}$), the annual average NO_2 concentration (16.6 $\mu g \cdot m^{-3}$) in 2021 was almost 18 % lower. The most significant differences in measured NO_2 concentrations compared to the ten-year average (2011–2020) were recorded at transport stations (by 6 $\mu g \cdot m^{-3}$, approx. 19 % lower), which was also positively reflected by lower regional background concentrations in clean areas of the CR, being about more than a third lower. In the case of the 19th maximum average hourly NO_2 concentration in 2021 compared to the ten-year average (2011–2020) from all stations, the values were lower by 13 %. A decrease also occurred in NO_X concentrations, and compared to the ten-year average (2011–2020), annual average NO_X concentrations from all rural background stations were 21 % lower.

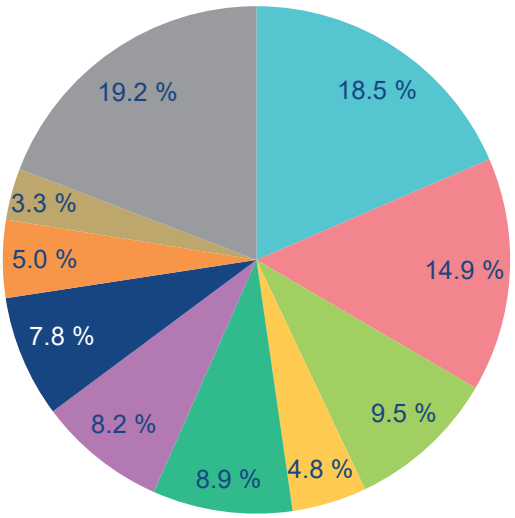


Fig. IV.3.10 Share of NFR sectors in total NO_x emissions, 2020

The concentrations of NO_2 and NO_X in 2021 can be evaluated as very good, despite the slight year-on-year increase, because, just like in the previous year 2020, the pollution limits established for the protection of human health and for the protection of vegetation were not exceeded. Meteorological and dispersion conditions have a great influence on the inter-annual variability of NO_2 and NO_X concentrations, as well as other pollutants. In 2021, both NO_2 and NO_X concentrations were quite well affected by meteorological conditions in May and August, which were above normal in terms of precipitation with better dispersion conditions compared to the ten-year average during autumn. In addition, in 2021, similar to 2020, a state of emergency was declared on the territory of the CR in connection with the ongoing SARS-CoV-2 coronavirus pandemic. From the point of view of the influence on the level of NO_2 and NO_X concentrations in the ambient air, the protective measures taken in the first quarter of 2021 were essential, when schools were closed, and especially in March, when movement between districts was prohibited and thus the mobility of residents was fundamentally reduced. The restriction of the movement of the population manifested itself in a decrease in the

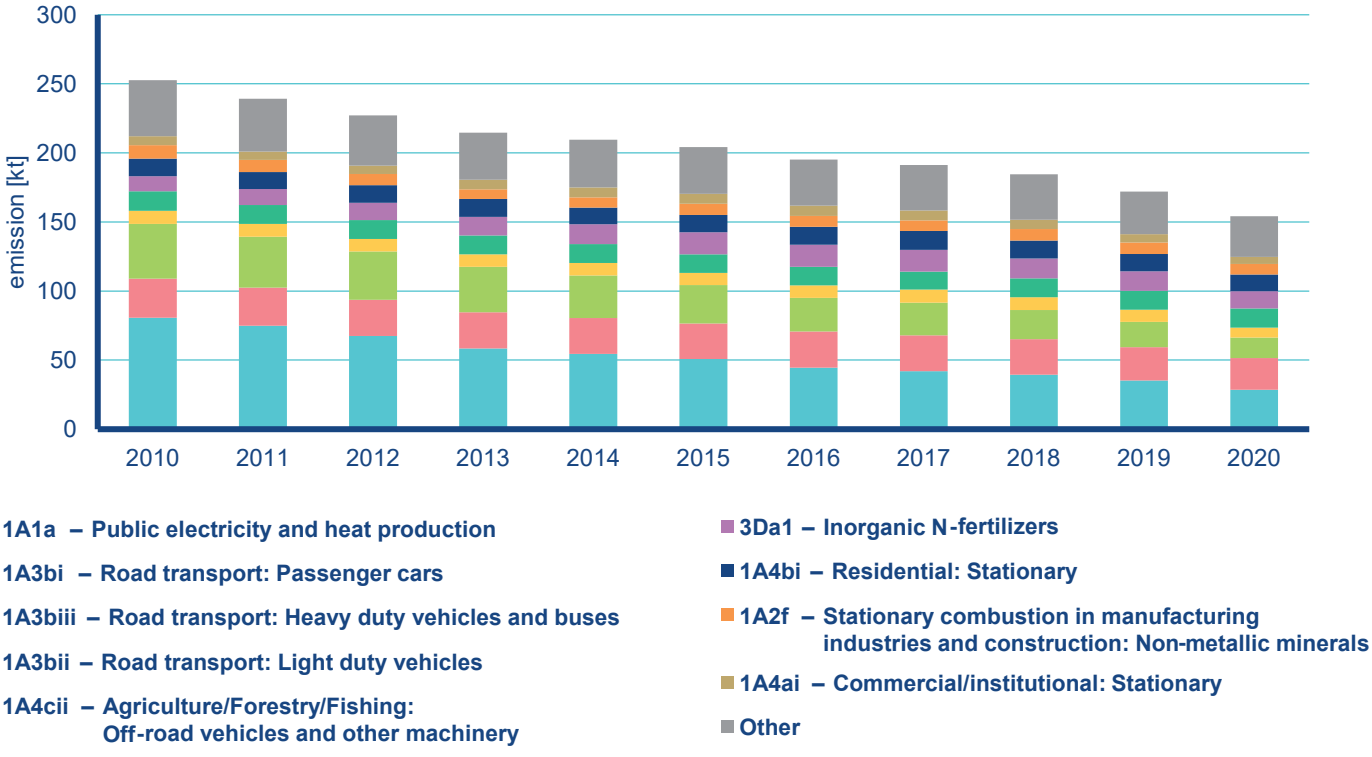


Fig. IV.3.11 Total NO_x emissions, 2010–2020

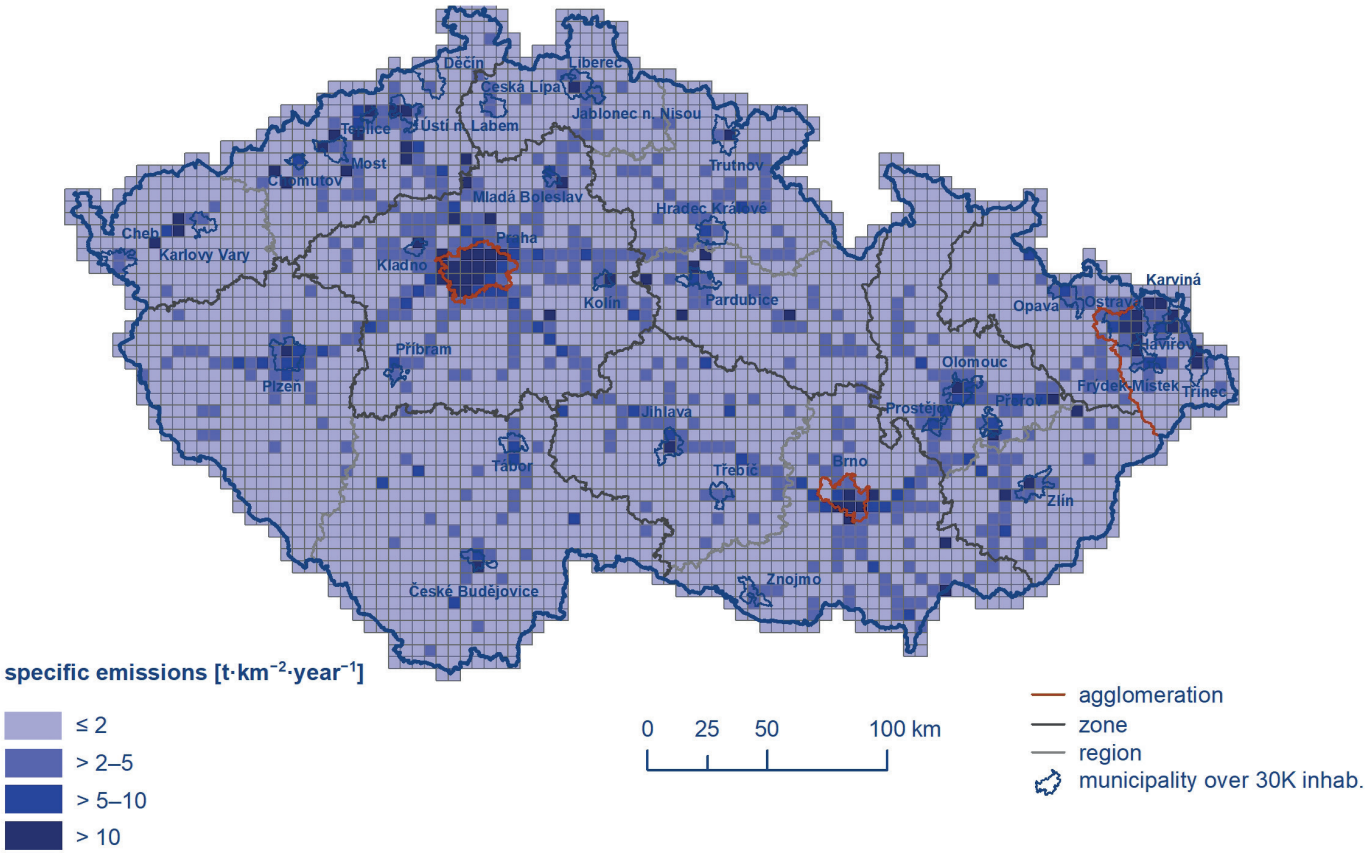


Fig. IV.3.12 Total NO_x in 5×5 km spatial resolution squares, 2020

intensity of traffic, which resulted in a decrease in emissions from traffic and subsequently in a decrease in the concentration of pollutants in the air. It can be assumed that under normal conditions, without protective measures to limit the pandemic, the measured concentrations of NO_2 and NO_x in 2021 would be higher.

IV.3.3 Nitrogen oxide emissions

Nitrogen oxides (NO_x) are formed during the combustion of fuels, depending on the temperature of combustion, nitrogen content of the fuel and excess of combustion air, and are also formed in some chemical-technological processes (the production of nitric acid, ammonia, fertilisers, etc.). While during the combustion of fuels in boilers the fraction of NO_2 in NO_x emissions is usually up to 5 %, the fraction of NO_2 in some chemical-technological processes can reach up to 100 % of total NO_x emissions (Neužil 2012). NO_x emissions with a higher fraction of NO_2 (10–55 %) are also produced by diesel engines (Carslaw at al. 2011).

The largest amount of NO_x emissions comes from mobile sources (CHMI 2021d). In 2020, 29.2 % of nationwide NO_x emissions came from sectors 1A3bi – Road transport: Passenger cars, 1A3biii – Road transport: Heavy duty vehicles over 3.5 tons, 1A3bii – Road transport: Light duty vehicles, and 8.9 % of emissions from sector 1A4cii – Agriculture/Forestry/Fishing: Off-road vehicles and other machinery. 18.6 % of NO_x emissions were introduced into the air from sector 1A1a – Public electricity and heat production, 8.2 % of emissions from sector 3Da1 – Use of inorganic N-fertilizers, and 7.8 % emissions from sector 1A4bi – Households: Heating, water heating, cooking (Fig. IV.3.10). The decreasing trend in NO_x emissions in the 2010–2020 period is related primarily to natural renewal of the vehicle fleet and the introduction of emission ceilings including stricter emission limits for NO_x emissions from sources in sector 1A1a – Public electricity and heat production (Fig. IV.3.11). The evaluation of the impact of the SARS-CoV-2 coronavirus pandemic on the year-on-year reduction of emissions in this sector by almost 5 kt cannot be carried out precisely with regard to the above-mentioned contexts. However, the presented data indicate an apparent year-on-year decrease in emissions related to traffic restrictions in 2020 due to the SARS-CoV-2 coronavirus pandemic. This applies mainly to sector 1A3biii – Road transport: Heavy duty vehicles over 3.5 tons (from 18.3 kt to 14.7 kt) and partly also to sector 1A3bi – Road transport: Passenger cars, for which emissions decreased from 24.6 kt to 23 kt.

The contributions of particular emission sources differ depending on the composition of sources in a given area. The production of NO_x emissions is concentrated primarily along motorways, roadways with heavy traffic, in large cities, and in the regions where more significant energy production facilities are located (Ústí nad Labem, Central Bohemia and Moravian-Silesia regions) (Fig. IV.3.12).

IV.4 Ground-level ozone

IV.4.1 Air pollution by ground-level ozone in 2021

Air pollution by ground-level ozone in 2021 in relation to limit values for the protection of human health

During the three-year period 2019–2021, the ground-level ozone (O_3) limit value was exceeded[1] at only 4 out of 65 stations (6 %), where O_3 concentrations were measured (Figures IV.4.1 and IV.4.2). This concerned three regional stations (Krkonoše-Rýchory, Rudolice v Horách, Sněžník) and one background suburban station (Ústí n. L.-Kočkov). For the previous three-year period 2018–2020, the ground-level O_3 limit value was exceeded at 34 out of 67 stations (51 %), in the period 2017–2019 at 36 out of 64 stations (56 %), in 2016–2018 at 33 of 65 stations (51 %), and in the period 2015–2017 at 21 of 71 (30 %) stations.

The O_3 pollution limit value was exceeded during the three-year period 2019–2021 just on 0.2 % of the territory of the CR with 0.02 % of the population (Fig. IV.4.3). Compared to the previous three-year periods (62 % of the territory of the CR with 52 % of the population in the period 2018–2020, 71 % of the territory with 57 % of the population in the period 2017–2019, 80 % of the territory with 52 % of the population in the period 2016–2018, and 31 % of the territory with 9 % of the population in the period 2015–2017), the extent of the area exceeding the limit value for O_3 was exceeded on the smallest territory with the lowest population. Within the individual years of the period 2019–2021, the lowest number of cases exceeding the pollution limit value occurred at almost 70 % of the stations in 2021 (Fig. IV.4.4). No smog situation was announced for ground-level O_3 in 2020 (for more see Chapter VI).

The annual variation in average monthly concentrations of ground-level O_3 (maximum 8-hour average for a given month) is characterized by an increase in concentrations in spring and summer months due to meteorological conditions (high intensity of solar radiation, high temperatures, lower air humidity) suitable for the formation of ground-level O_3. The highest O_3 concentrations in 2021 were measured in June, the warmest month of 2021.

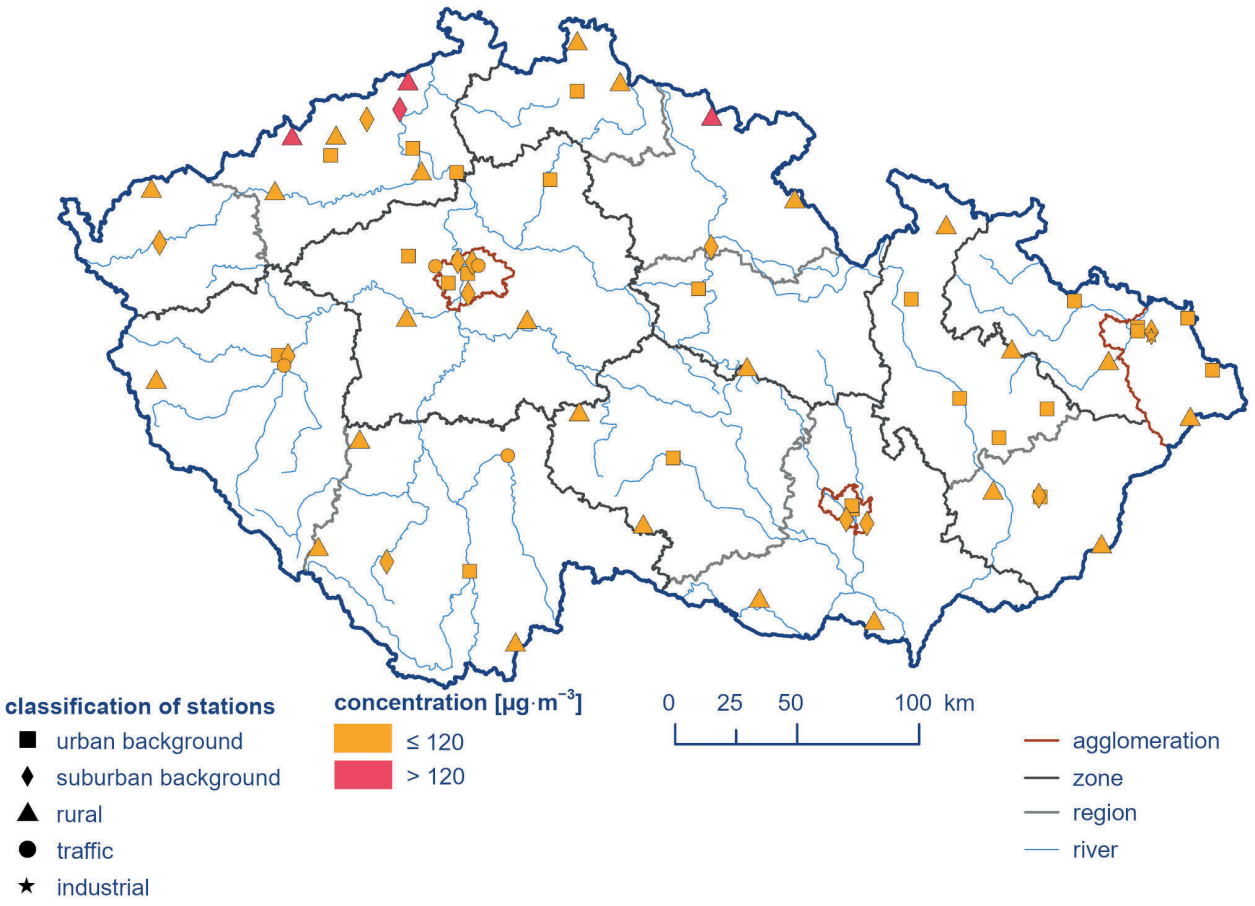


Fig. IV.4.1 The 26th highest values of maximum daily 8-hour running average of ground-level ozone concentrations (three-year average) in the ambient air quality network, 2019–2021

1 The limit value is exceeded if the O_3 maximum daily 8-hour running average was higher than 120 µg·m^{-3} at least 26 times in three-year average.

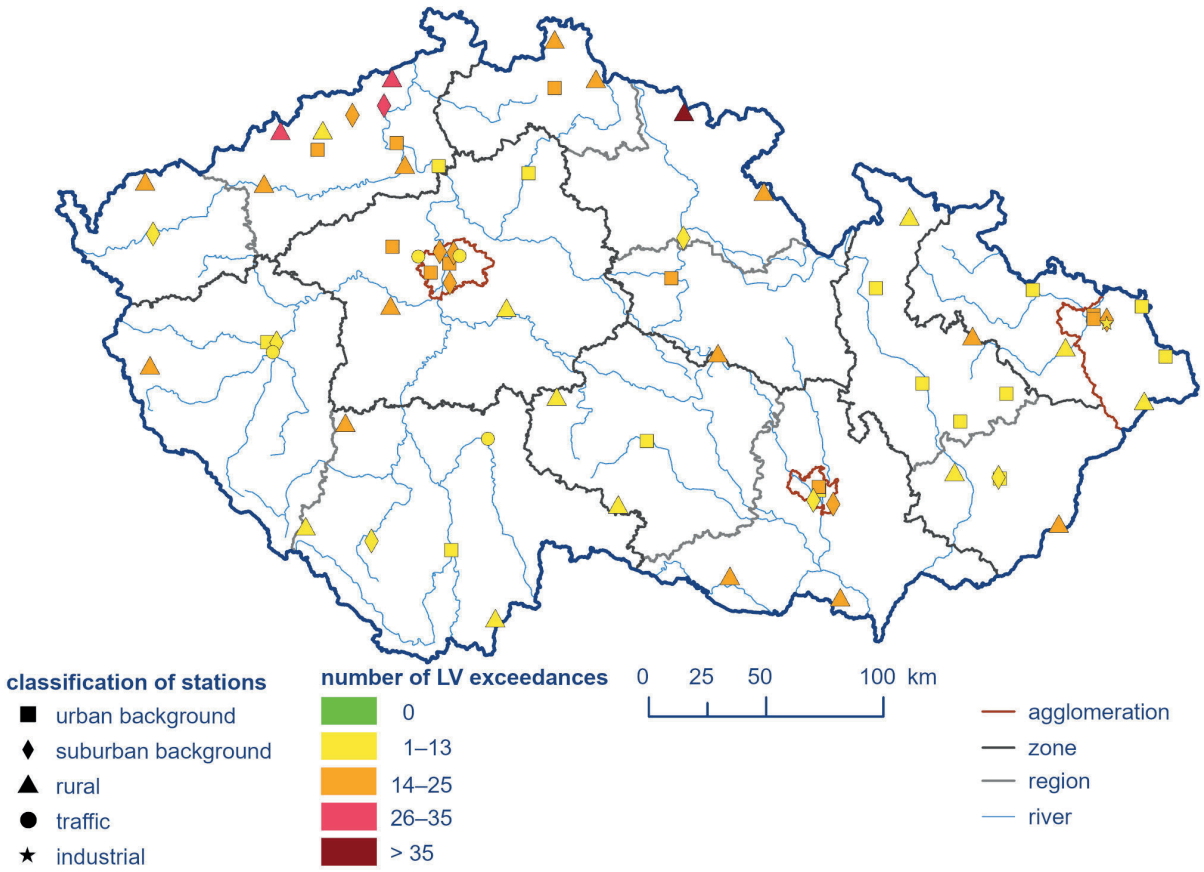


Fig. IV.4.2 Numbers of exceedances of the limit value for the maximum daily 8-hour running average of ground-level ozone concentrations in three-year average, 2019–2021

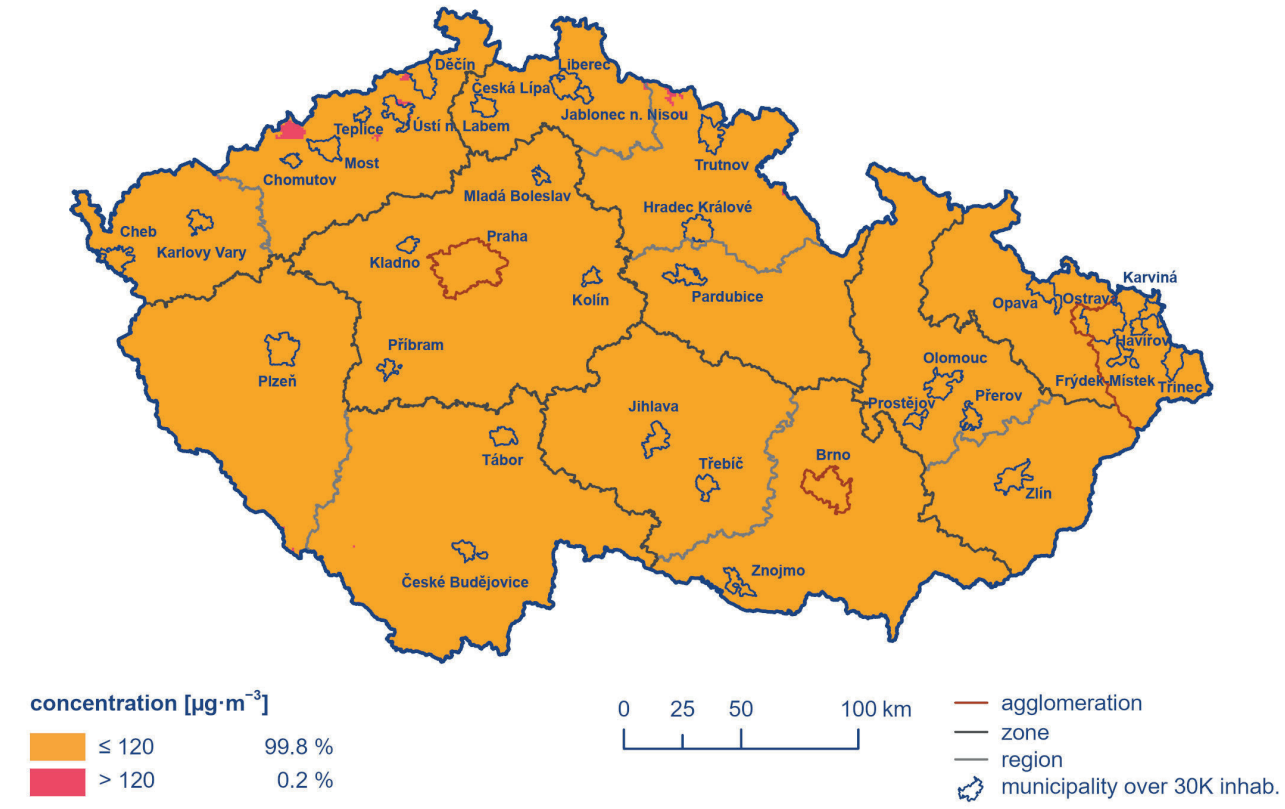


Fig. IV.4.3 Field of the 26th highest maximum daily 8-hour running average of ground-level ozone concentration in three-year average, 2019–2021

From the annual variation of average monthly concentrations, it follows that the significant drop in O_3 concentrations in 2021 was caused by a decrease in concentrations during warmer months of the year. These months typically experience high to the highest concentrations of the calendar year, leading sometimes to announcement of a smog situation. The drop in concentrations of about 7–17 % in April, May, July and August of 2021 compared to the 2011–2020 ten-year average corresponds to mostly normal to strongly below normal temperatures, and normal to above normal precipitation in these months (i.e., suppression of meteorological conditions adequate for the formation of ground-level ozone).

The lowest concentrations of ground-level O_3 are measured at localities subject to traffic loads (Fig. IV.4.5 and IV.4.9) where ground-level O_3 is decomposed by chemical reactions with NO (NO forms a part of NO_x). It can be assumed that O_3 concentrations

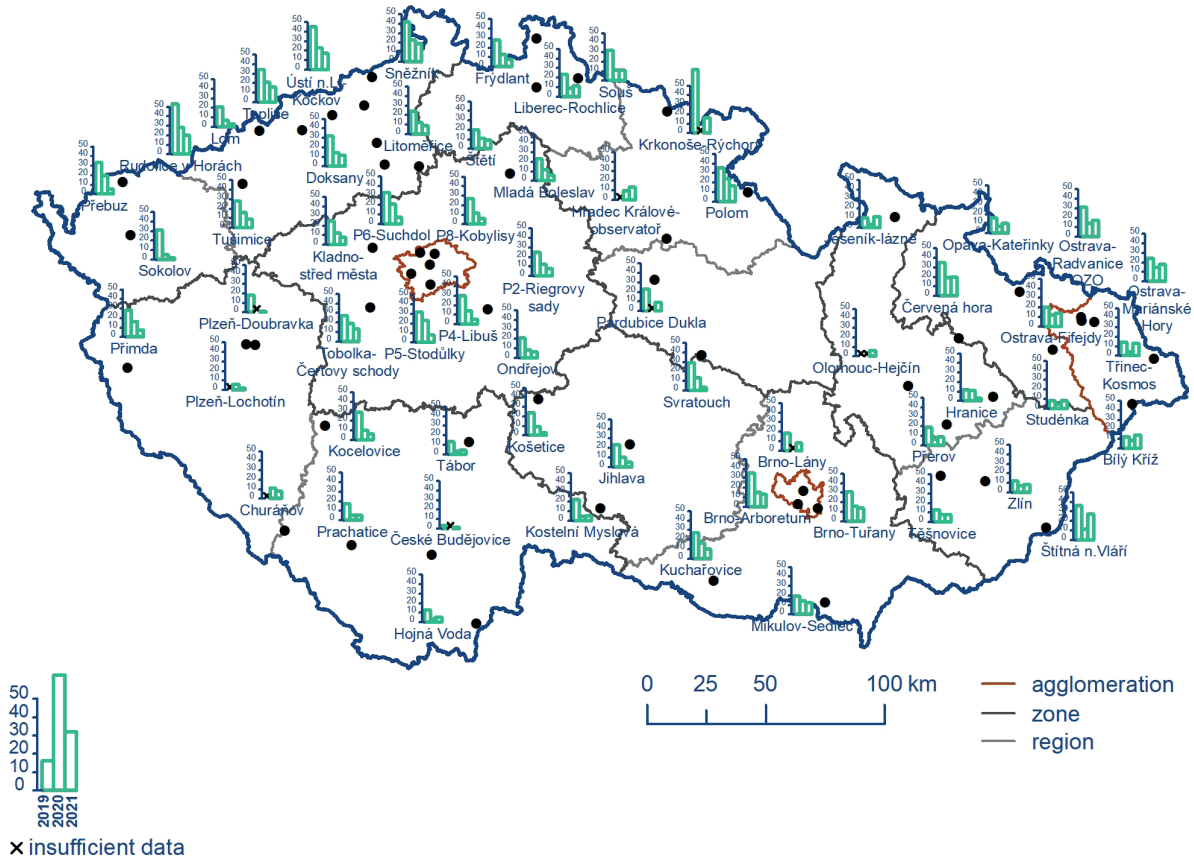


Fig. IV.4.4 Number of exceedances of 8-hour limit value of ground-level ozone per year for selected stations, 2019–2021

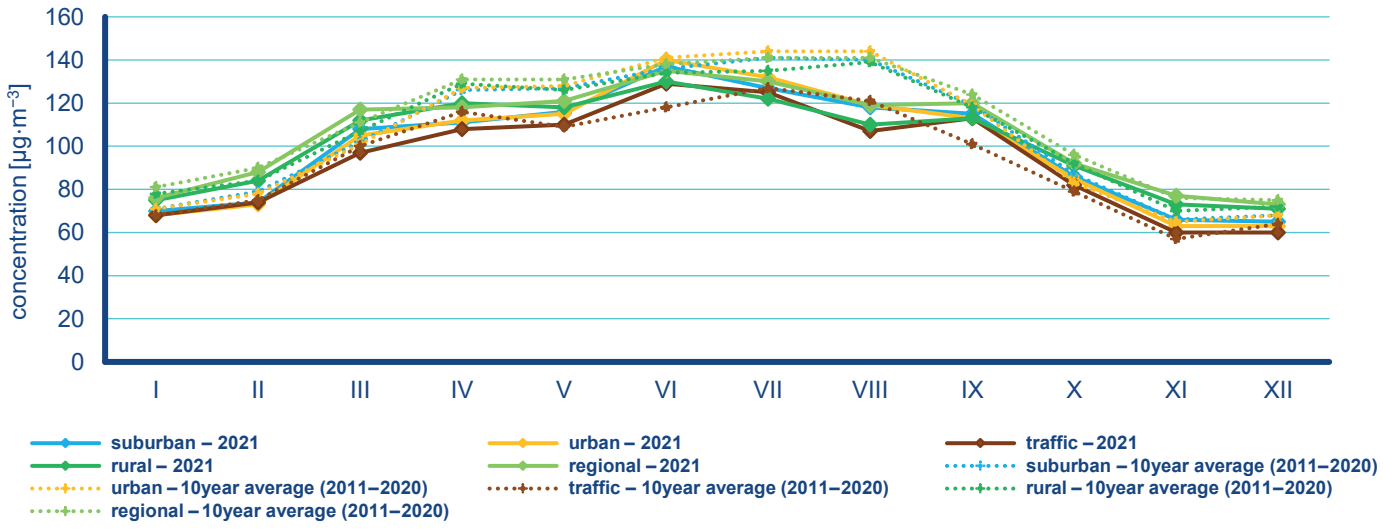


Fig. IV.4.5 Annual course of average monthly concentrations of max. 8-hour running average of O_3 (averages for the given type of station), 2021

are also lower or below the limit in other areas with heavy traffic where, however, this probable reduction cannot be documented using current methods of map preparation because of the lack of measurements. The values of ground-level O_3 concentrations at rural, suburban and urban stations reach similar levels, and are higher compared to concentrations at traffic stations (Fig. IV.4.5). This is also confirmed by the study by Paoletti et al. (2014), where between 1990 and 2010 a decreased difference was observed between the concentrations measured at rural and urban stations in Europe and the USA. Simultaneously, the maximum values measured at these stations also decreased. The aforementioned decrease in the concentrations of ground-level ozone is attributed, amongst other things, to the reduction in emissions of its precursors, especially NO_X, in developed countries. The reduction in concentrations in relatively clean areas is attributed to the reduction of both NO_X and VOC emissions on a wider (European to global) scale (Sicard et al. 2013).

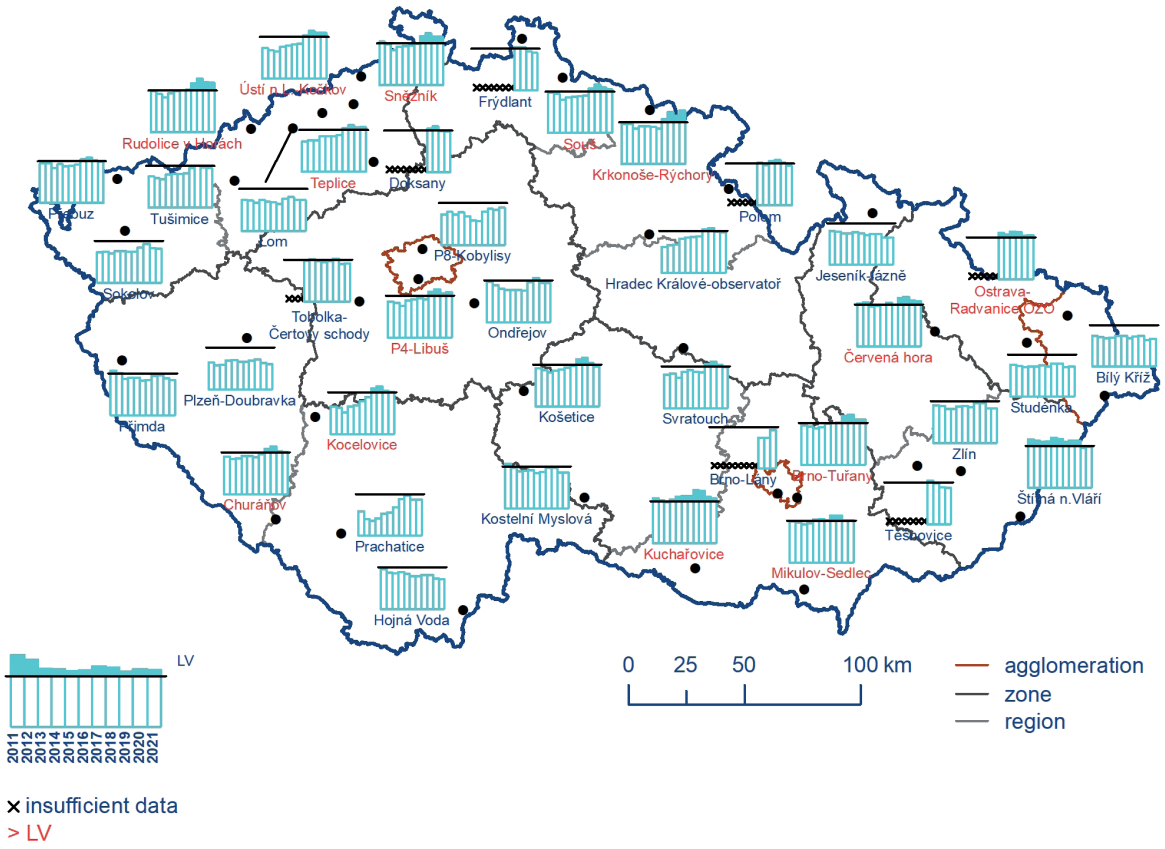


Fig. IV.4.6 Exposure index AOT40 values at selected stations, average of 5 years, 2011–2021

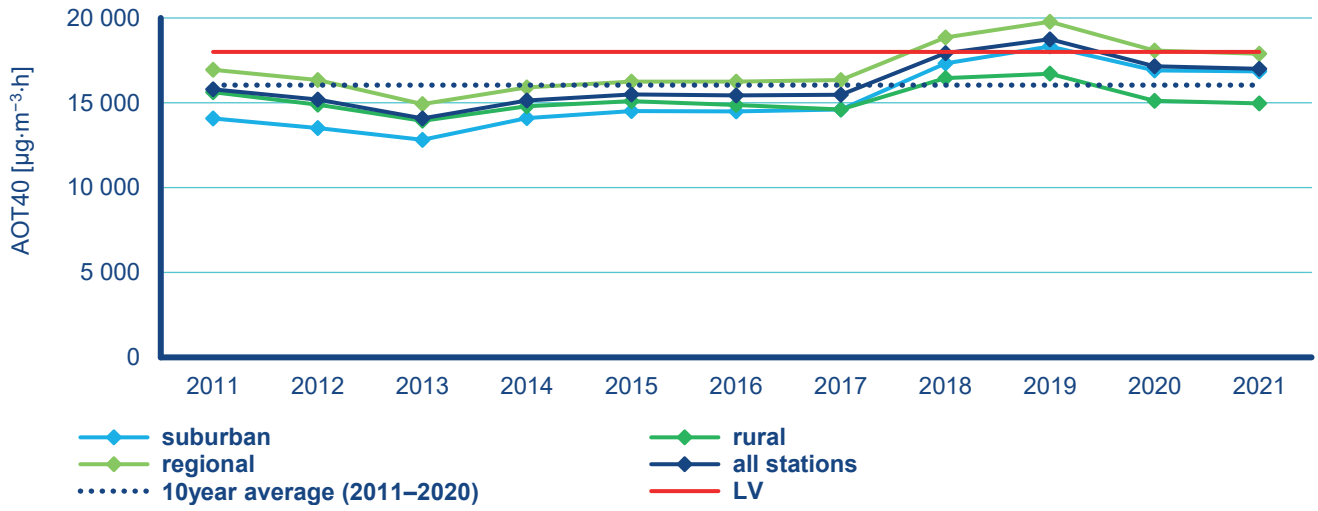


Fig. IV.4.7 Exposure index AOT40 values, average of 5 year, 2011–2021

Ground-level ozone in 2021 in relation to the limit value for the protection of ecosystems and vegetation

The ground-level O_3 pollution limit value for the protection of vegetation of 18 000 µg·m^{-3}·h (five-year average, Tab. I.2) was exceeded at 14 stations (5.9 %) of the total number of 39 rural and suburban stations for which calculation of the exposure index AOT40 is relevant according to legislation (relating to the 2017–2021 average). The highest values of the AOT40 index for the evaluation period 2011–2021 were found in 2018 and 2019 (on average for 32 rural and suburban stations with the complete time series 2011–2021). In 2021, the values of the AOT40 index were the fourth highest for the period 2011–2021 (Fig. IV.4.6, Fig. IV.4.7). The highest values of the AOT40 index in 2021 were found at the Krkonoše-Rýchory, Rudolice v Horách, Sněžník, Ústí n. L.-Kočkov, and Praha 4-Libuš stations. The occurrence of above-limit AOT40 values occurred in 2021 mainly in the mountain areas of the Ústí nad Labem and Liberec regions, as well as in the South Moravia and a border of the Prague and Central Bohemia regions (Fig. IV.4.8).

The annual values of the AOT40 index have long exceeded the value of the long-term pollution limit value (6 000 µg·m^{-3}·h) at all rural and suburban stations (the same set of stations for the last five years, Fig. IV.4.9). For the evaluated five-year period, the values of the AOT40 index in 2021 were the second lowest or the lowest at most stations.

IV.4.2 Trends in ground-level ozone concentrations

Unlike the previous assessment based mainly on three-year periods, an evaluation is carried out using maximum 8-hour average concentration and 26th highest maximum 8-hour average concentration in a given year. The first of these pollution characteristics can be compared with the long-term air pollution target for ground-level ozone or with the pollution limit value (120 µg·m^{-3}), respectively. Maximum annual 8-hour average concentration (in an average for all stations for which the measurement is available for the whole evaluated period) ranged from approx. 135 µg·m^{-3} to 173 µg·m^{-3} in the 2011–2021 period, and the 26th highest 8-hour average concentration from approx. 109 µg·m^{-3} to 129 µg·m^{-3}.

Maximum daily 8-hour concentrations and the 26th highest 8-hour average O_3 concentrations have not shown any significant trend since 2011 (Fig. IV.4.10 and Fig. IV.4.11); the highest concentrations were measured in 2013, 2015 and 2018. All these years were characterized by the occurrence of meteorological conditions adequate for the formation of ozone – in 2013 high concentrations of ground-level O_3 occurred especially at the turn of July and August during a series of tropical days. The years 2015 and 2018 were exceptionally above average in terms of temperature and highly below average in terms of precipitation (CHMI 2016, 2019). Concentrations in 2021 (135 µg·m^{-3} for the maximum daily 8-hour concentration and 109 µg·m^{-3} for 26th highest maximum daily 8-hour average

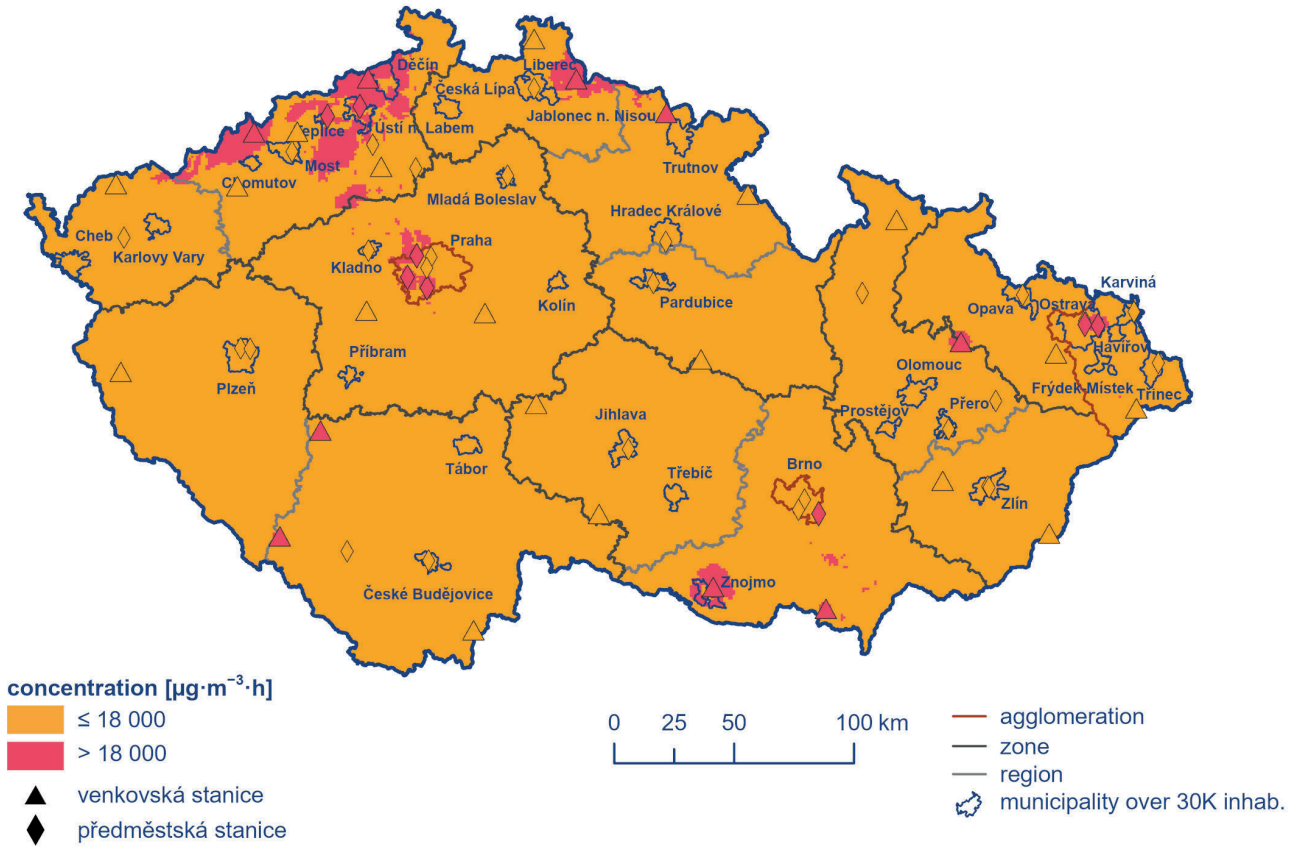


Fig. IV.4.8 Field of AOT40 exposure index values, average of 5 years, 2017–2021

concentration) were the lowest in the eleven-year evaluation period 2011–2021 (together with 2020 for the maximum daily 8-hour concentration). Compared to the ten-year average at 151 $\mu g \cdot m^{-3}$ and 117 $\mu g \cdot m^{-3}$ concentrations decreased by 11 % and 7 %, respectively. The decrease in the annual characteristics of ground-level ozone is a result of aforementioned drops in concentrations during warmer part of the year (April–September, except July).

In comparing concentrations, emissions of precursors and meteorological conditions, i.e., the intensity and length of sunshine, temperature, wind speed and precipitation or relative air humidity, respectively, play crucial roles (Blanchard et al. 2010; Ooka et al. 2011). However, the relationship between the amount of precursors emitted and ground-level O_3 concentrations is not linear. This non-linearity is caused by the complicated atmospheric chemistry of O_3 formation and decomposition, long-range transport of O_3 and its precursors, and other factors including meteorological conditions and climate change, emissions of non-methane volatile organic compounds (NMVOC) from vegetation and forest fires (EEA 2013). With regard to the above-mentioned factors, it is not possible to comment on the year-to-year changes in detail.

Based on the results of long-term monitoring in the CR, where a 25-year series of ground-level O_3 concentrations is available at a number of stations, long-term trends can be meaningfully evaluated despite the high year-to-year variability of O_3 (Weatherhead et al. 1998). A detailed analysis of spatio-temporal trends of long-term monitoring by 26 stations of varying types (urban, rural, mountain) for the 1994–2015 period indicated that despite a substantial decrease of precursor emissions and of ground-level O_3 pollution concentrations at a majority of stations, ground-level O_3 still represents a considerable problem for the CR. It has been clearly demonstrated that for an adequate decrease of ground-level O_3 levels, the NO/NO_2 ratio is critical and a concurrent substantial decrease of NO_X emissions alone is not therefore sufficient for a decrease of ground-level O_3 concentrations (Hůnová, Bäumelt 2018).

IV.4.3 Formation of ground-level ozone

Ground-level O_3 does not have a significant source of its own in the atmosphere. This is a "secondary" substance formed by a number of complicated non-linear photochemical reactions (e.g., Seinfeld and Pandis 2006). Precursors of ground-level O_3 include nitrogen oxides (NO_X) and non-methane volatile organic compounds (NMVOC), while methane (CH_4) and carbon monoxide (CO) play roles on a global scale. The photolysis of nitrogen dioxide (NO_2) by solar radiation with wavelength of 280–430 nm is an important reaction, forming nitric oxide (NO) and atomic oxygen (O). Ground-level O_3 molecules are formed by the reaction of atomic (O) and molecular oxygen (O_2) in the presence of a catalyst. Simultaneously, O_3 is titrated by nitrogen monoxide, NO, with the formation of NO_2 and O_2. If ground-level O_3 is replaced by radicals in this reaction, its concentration increases in the atmosphere. The OH radical plays an especially important role in this reaction (in more detail e.g., Hůnová, Bäumelt 2018). NO_X are formed in all com-

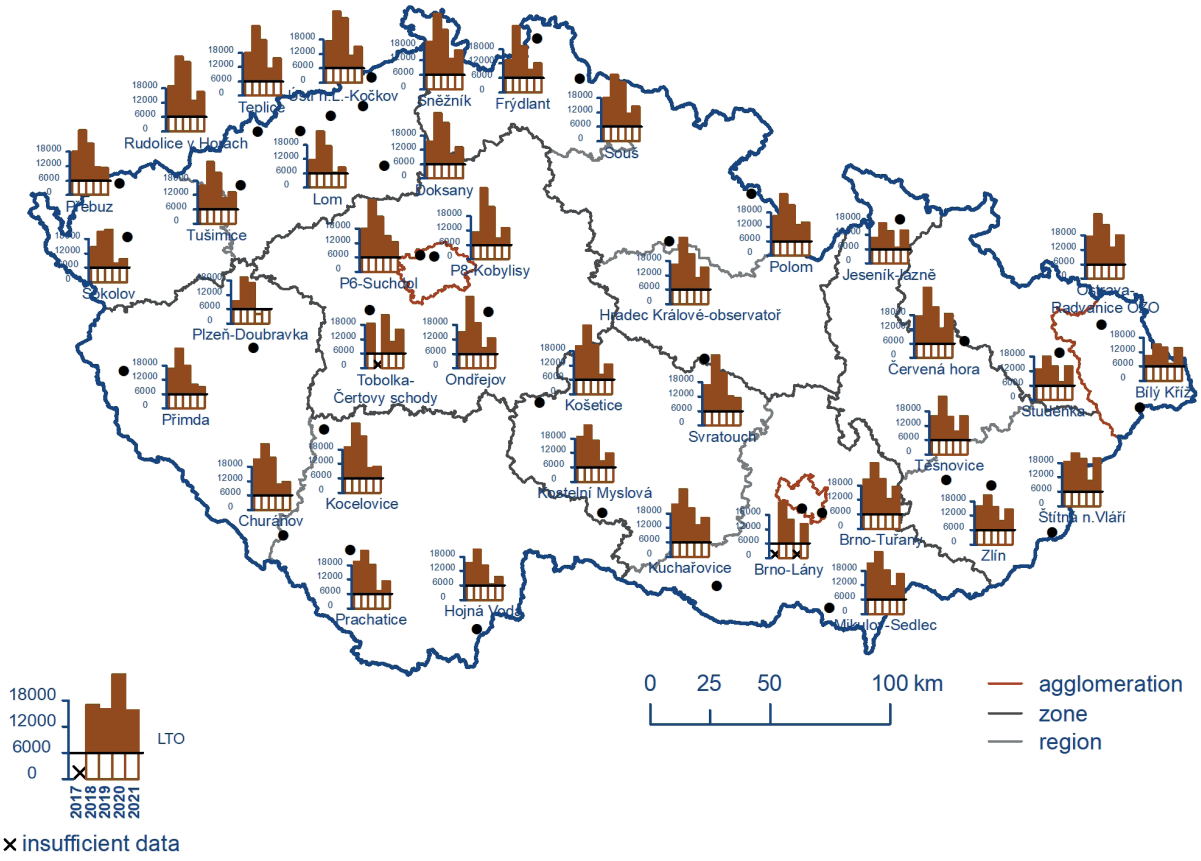


Fig. IV.4.9 Annual exposure index AOT40 values at selected stations in comparison with the long-term objective, 2017–2021

bustion processes. NMVOC are emitted from a number of anthropogenic sources (transport, manipulation with petroleum and its derivatives, refineries, the use of paint and solvents, etc.), and also natural sources (e.g., biogenic emissions from vegetation).

In the formation of ground-level O_3, not only the absolute amount of precursors but also their relative ratio is important (Sillman et al. 1990; Fiala, Závodský 2003). In rural areas where the reaction is limited by NO_X, characterized by relatively low concentrations of NO_X and high concentrations of VOC, the O_3 concentrations increase with increasing NO_X concentrations, but only minimally with increasing VOC concentrations. On the other hand, in areas with reactions limited by VOC, the O_3 concentrations decrease with increasing NO_X concentrations and increase with increasing VOC concentrations. An increase in O_3 concentrations due to a decrease in NO_X emissions or, respectively, an increase in NO_2/NO proportion (modernization and denitrification of large emission sources) was observed in north-western Bohemia (Hůnová, Bäumelt 2018).

Areas with a high NO_X/VOC ratio are typically polluted areas around the centres of large cities. The dependence of the formation of ground-level O_3 on the initial concentrations of VOC and NO_X is frequently expressed by ozone isopleth diagrams, which depict the maximum attained ground-level O_3 concentration as a function of the initial NO_X and VOC concentrations (Moldanová 2009). Aside from the concentrations of precursors, meteorological conditions also play an important role in the formation of ground-level O_3 (Colbeck, Mackenzie 1994). The pollution concentrations of ground-level O_3 increase with increasing ultraviolet radiation and temperature but decrease with increasing relative air humidity. These relations were also demonstrated from the results of long-term CHMI measurements (Hůnová et al. 2019a). High concentrations are often related to prolonged anticyclone situations. In addition to the above-described photochemical mechanisms, ground-level O_3 concentrations can also increase in episodes as a result of the penetration of stratospheric O_3 into the troposphere and also during thunderstorms. Recently, there has also been an increase in the importance of long-range ground-level O_3 transport in the northern hemisphere to Europe and North America from source areas in south-east Asia. Ground-level O_3 is removed from the atmosphere by reaction with NO, the mechanism of dry or wet deposition and interaction with plants (stomatal uptake).

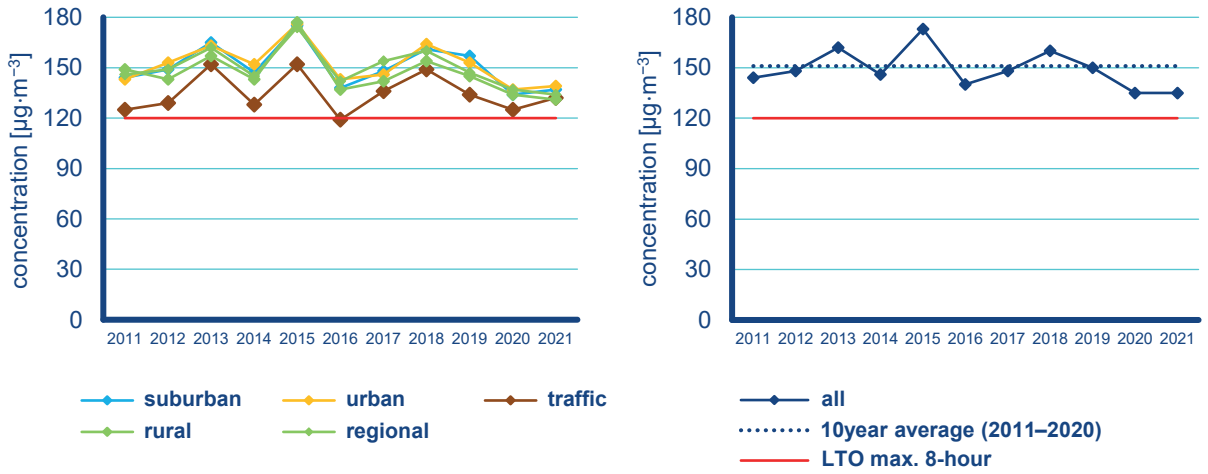


Fig. IV.4.10 Concentrations of ground-level ozone (maximum daily 8-hour running average), at particular types of stations, 2011–2021

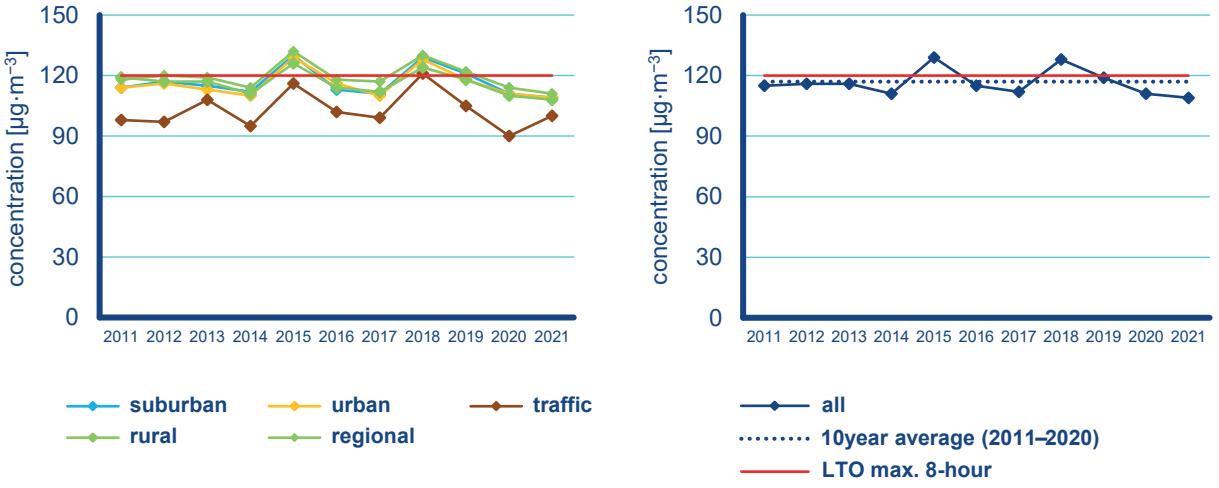


Fig. IV.4.11 Concentrations of ground-level ozone (the 26th highest values maximum daily 8-hour running average), at particular types of stations, 2011–2021

IV.5 Benzene

IV.5.1 Air pollution by benzene in 2021

The annual pollution limit value for benzene (5 $\mu g \cdot m^{-3}$) was not exceeded at any of 36 stations with valid annual average values in 2021 (Fig. IV.5.1). The highest annual average was detected, likewise in 2020, at the Ostrava-Přívoz industrial station, reaching the equal value of 3.5 $\mu g \cdot m^{-3}$. The O/K/F-M agglomeration was exposed to the highest concentrations of benzene (Fig. IV.5.2).

In the long term, benzene concentrations in the CR, except for the O/K/F-M agglomeration, are very low and do not even reach half of the pollution limit value (Fig. IV.5.3). Of the total of 33 stations measuring benzene concentrations in the CR in 2020 and 2021, the annual average concentrations were higher at 10 stations (30 %), while lower at 12 stations (37 %). The concentrations did not change at 11 stations (33 %).

IV.5.2 Trends in benzene concentrations

Until 2016, the trend of annual average benzene concentrations averaged for all types of stations can be characterized as declining, and then as stagnant from 2017. Since 2010, average concentrations have been below half of the limit value, and since 2016 even below the ten-year average of 2011–2020. The year 2021 is the fourth lowest year after 2016, 2019, and 2020 for annual average concentrations (Fig. IV.5.4).

Based on the evaluation of individual types of stations, the highest annual average concentrations are observed at industrial stations, which are situated mostly in the O/K/F-M agglomeration, where, however, the pollution limit value has not been exceeded since 2012, with some exceptions. The lowest annual average concentrations are observed at rural and regional stations that are little affected by emission sources (Fig. IV.5.5).

IV.5.3 Benzene emissions

Benzene is an organic compound, and it is used as a solvent or raw material for the production of a range of chemical substances. Benzene is part of crude oil and small amounts are added to automotive petrol to improve the octane number. It is produced

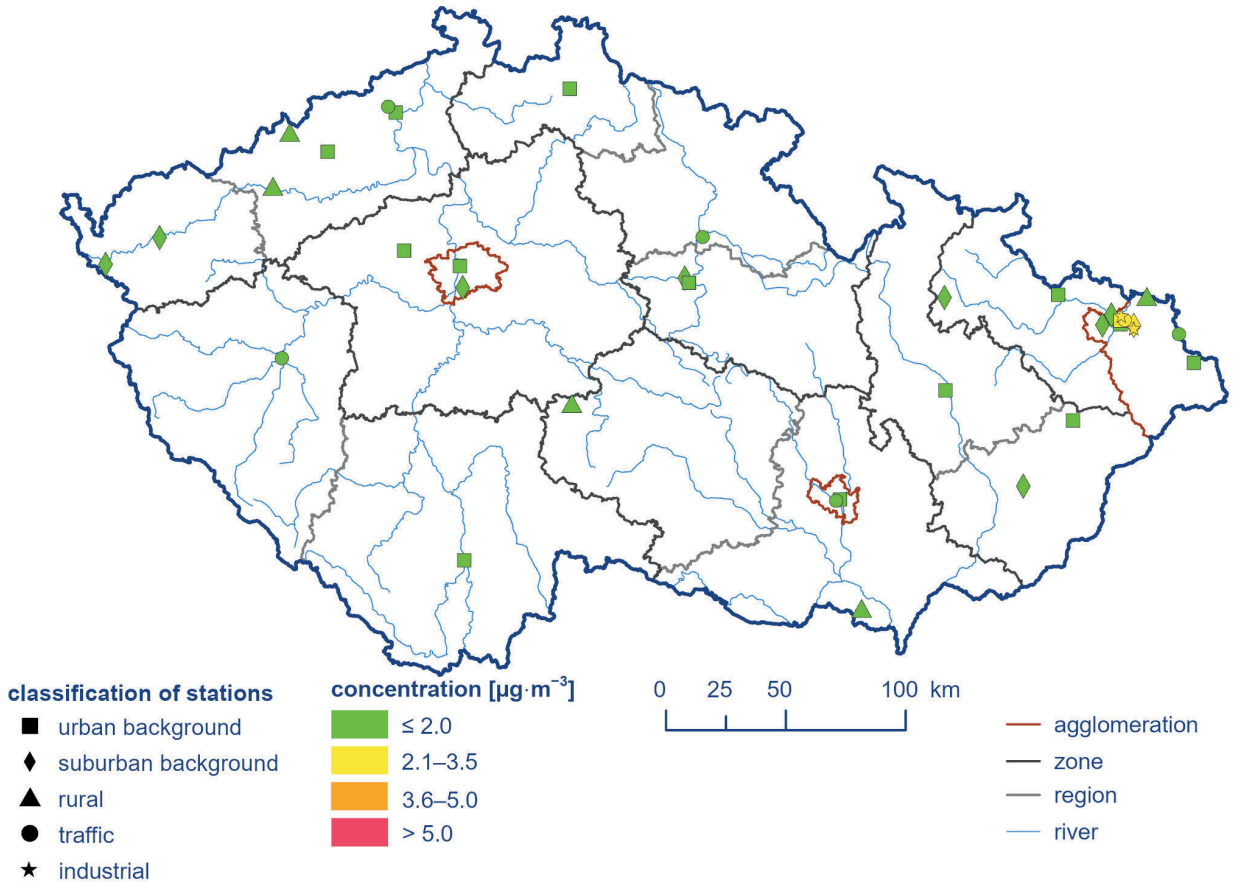


Fig. IV.5.1 Annual average concentrations of benzene at air quality monitoring stations, 2021

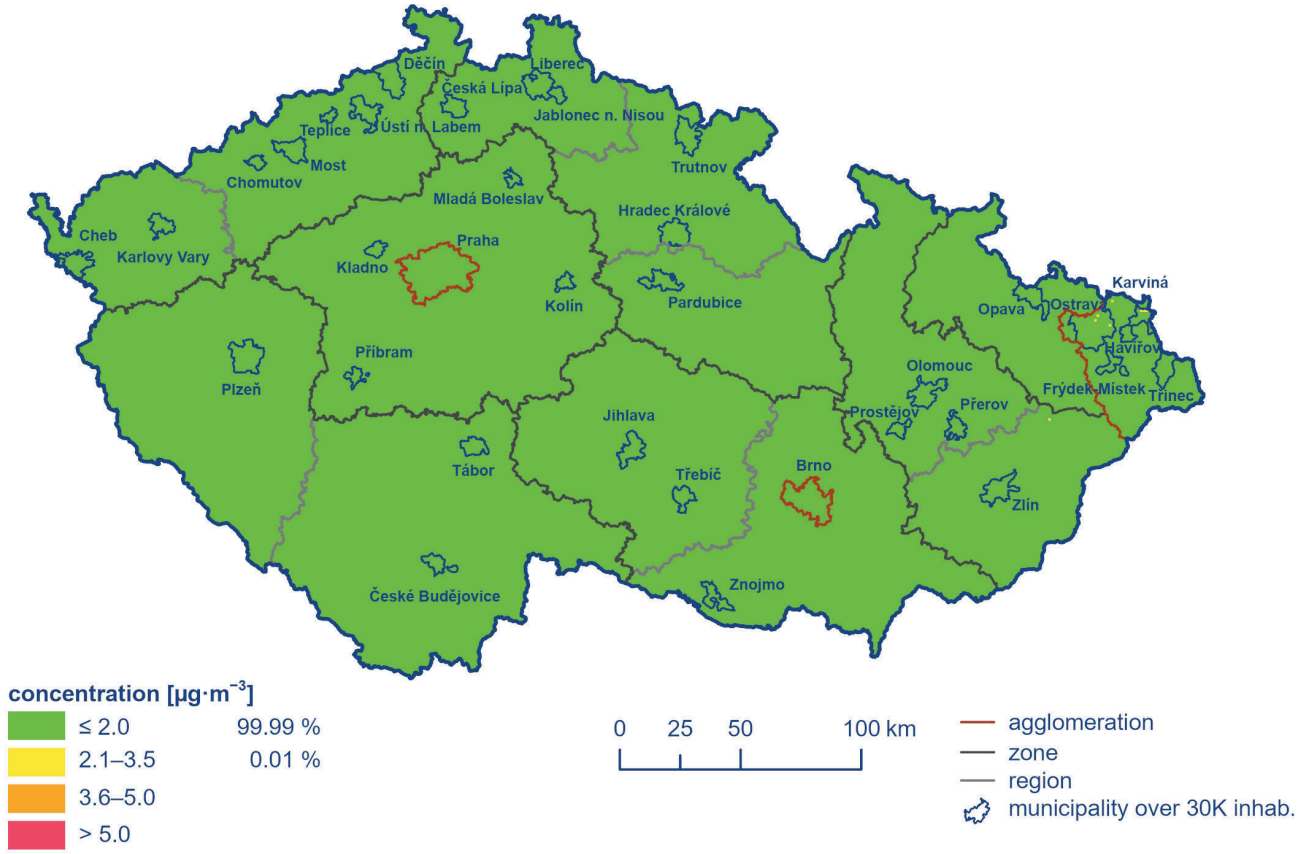


Fig. IV.5.2 Field of annual average concentration of benzene, 2021

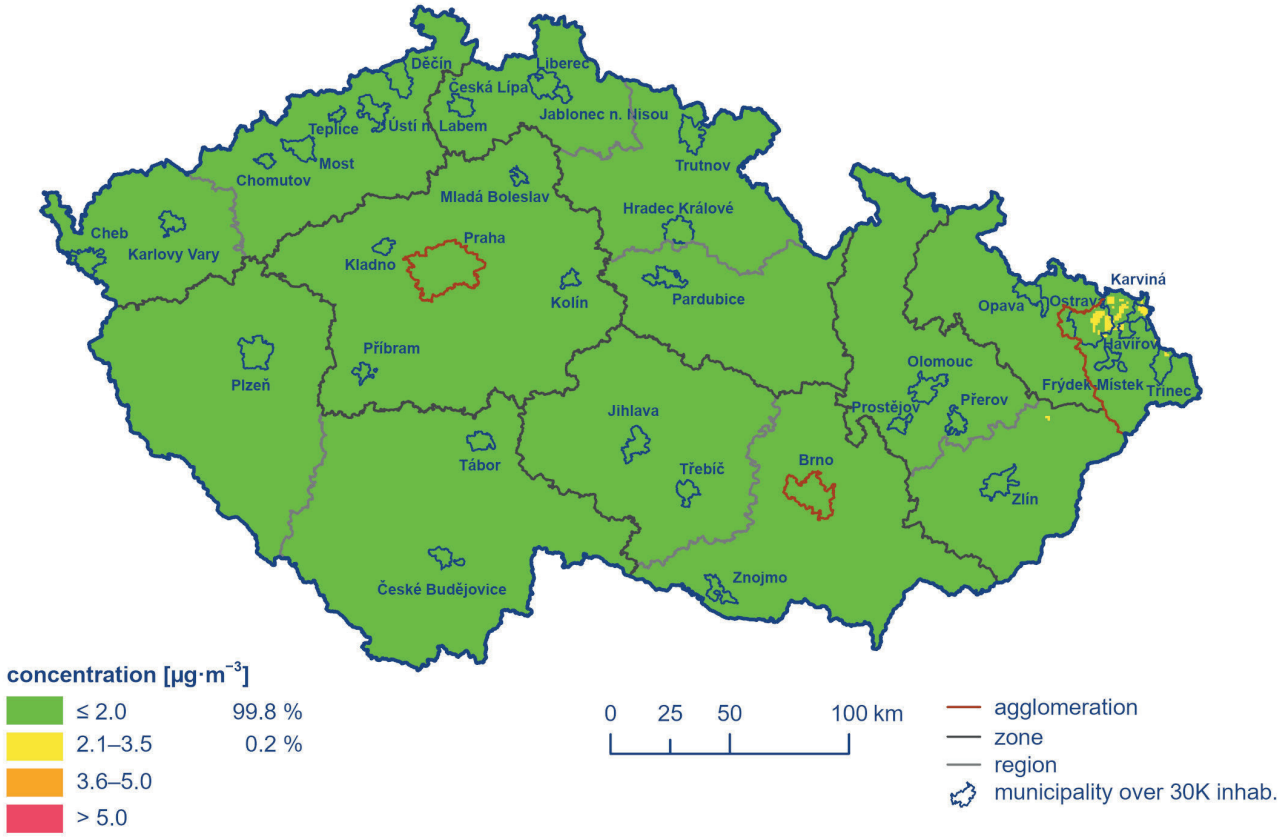


Fig. IV.5.3 Five-year average of annual average concentrations of benzene, 2017–2021

mainly by processing crude oil and from coal tar formed during coal coke production. As with other VOCs, it also originates from incomplete combustion.

Benzene is not included in the range of pollutants covered by the LRTAP Convention, and therefore inventories are not available based on the structure of NFR sectors but on REZZO categories only. According to an evaluation carried out for the purpose of updating the PZKO, 672.6 tonnes of benzene were released into the air in 2016. The largest benzene emissions were produced by REZZO 4 category sources (75 %), from which benzene is emitted through exhaust gases and by leaking from vehicle fuel systems. A significant amount of benzene emissions were produced by REZZO 3 category sources, through the household combustion of solid fuels (13 %), the general use of organic solvents (5 %) and fuel extraction (3 %). The contribution of REZZO 1 and REZZO 2 category sources amounted 4 % to the total benzene emissions, with the major proportion associated with the sectors Energy – fuel combustion (codes 1.1.–1.4. of the Annex No. 2 to the Act No. 201/2012 Coll., on protection of the air), reaching 2.2 %, and the Use of organic solvents (codes 9.1.–9.24. of the Annex No. 2 to the Act No. 201/2012 Coll., on protection of the air), reaching 0.7 %.

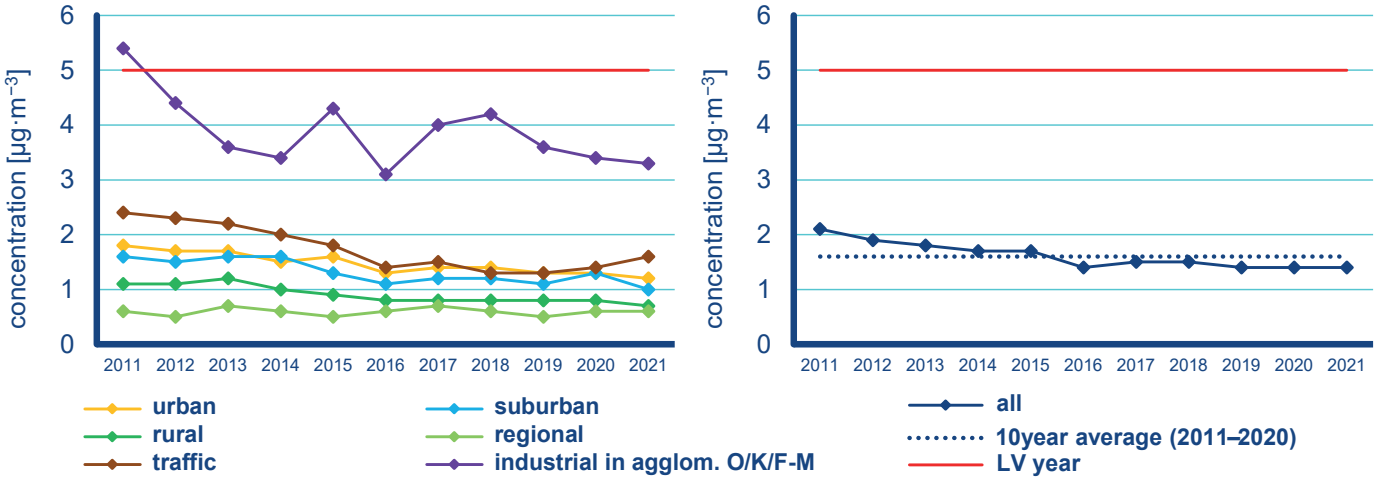


Fig. IV.5.4 Annual average concentrations of benzene, 2011–2021

Fig. IV.5.5 Annual average concentrations of benzene at selected stations, 2011–2021

IV.6 Heavy metals

IV.6.1 Air pollution by heavy metals in 2021

Arsenic

The annual pollution limit level for arsenic (6 ng·m^{-3}) was not exceeded at any of 55 stations with valid annual average values in 2021 (Fig. IV.6.1). The highest annual average (3.3 ng·m^{-3}) was observed at the Praha 5-Řeporyje urban background station. Compared to 2020 (2.3 ng·m^{-3}), this is an increase by 43 %.

In 2021, the annual average arsenic concentrations in the Czech Republic were low and below the lower assessment threshold (2.4 ng·m^{-3}). Concentrations above the lower assessment threshold occurred only at three observing stations (Lom, Rýmařov-Janovice, Praha 5-Řeporyje), but even there the upper assessment threshold (3.6 ng·m^{-3}) was not reached (Fig. IV.6.2).

Arsenic concentrations have long been below the limit value over most of the Czech Republic, except for the Kladno, Prague and Most areas (Fig. IV.6.3). In non-polluted areas, concentrations are below the lower assessment threshold, though polluted areas have concentration above the limit value. Of the total 46 stations that measured arsenic concentrations both in 2020 and 2021, the annual average concentration increased at 30 stations (65 %), and decreased at 9 stations (20 %). Concentrations remained unchanged at 7 stations (15 %).

Cadmium

The annual pollution limit level for cadmium (5 ng·m^{-3}) was not exceeded at any of 55 stations with valid annual average value in 2021 (Fig. IV.6.4). The highest annual average was observed at the Tanvald-školka urban background station (1.9 ng·m^{-3}). Compared to 2020 with 2.9 ng·m^{-3}, this is a decrease by 34 %.

In 2021, the annual average cadmium concentrations in the Czech Republic were low and below the lower assessment limit (2 ng·m^{-3}; Fig. IV.6.5).

In the long term, cadmium concentrations are below the lower assessment threshold throughout the territory of the Czech Republic, except for the Tanvald vicinity (Fig. IV.6.6). Of the total 46 stations measuring cadmium concentrations both in 2020 and 2021, the annual average concentration increased at only 2 stations (4 %), and decreased at 15 stations (33 %). Concentrations remained unchanged at 29 stations (63 %).

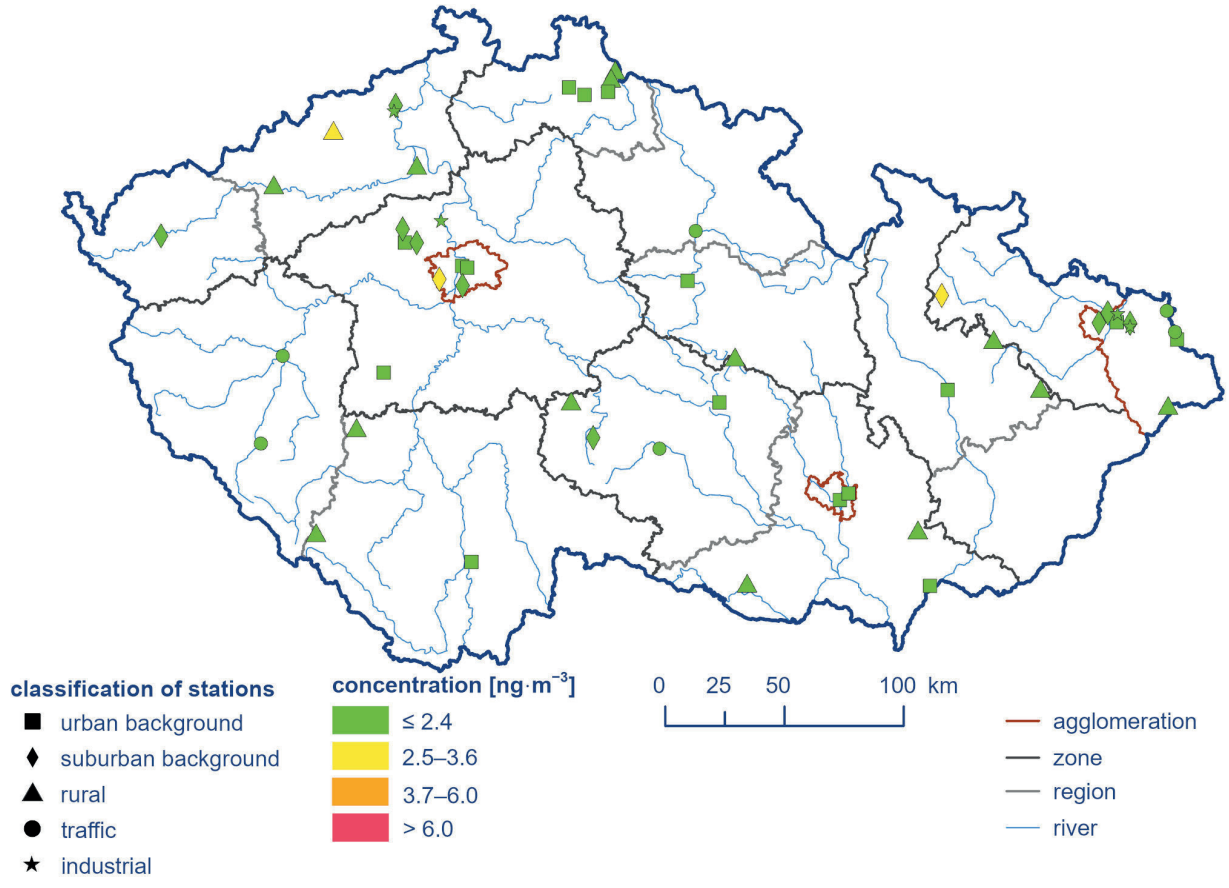


Fig. IV.6.1 Annual average concentrations of arsenic at air quality monitoring stations, 2021

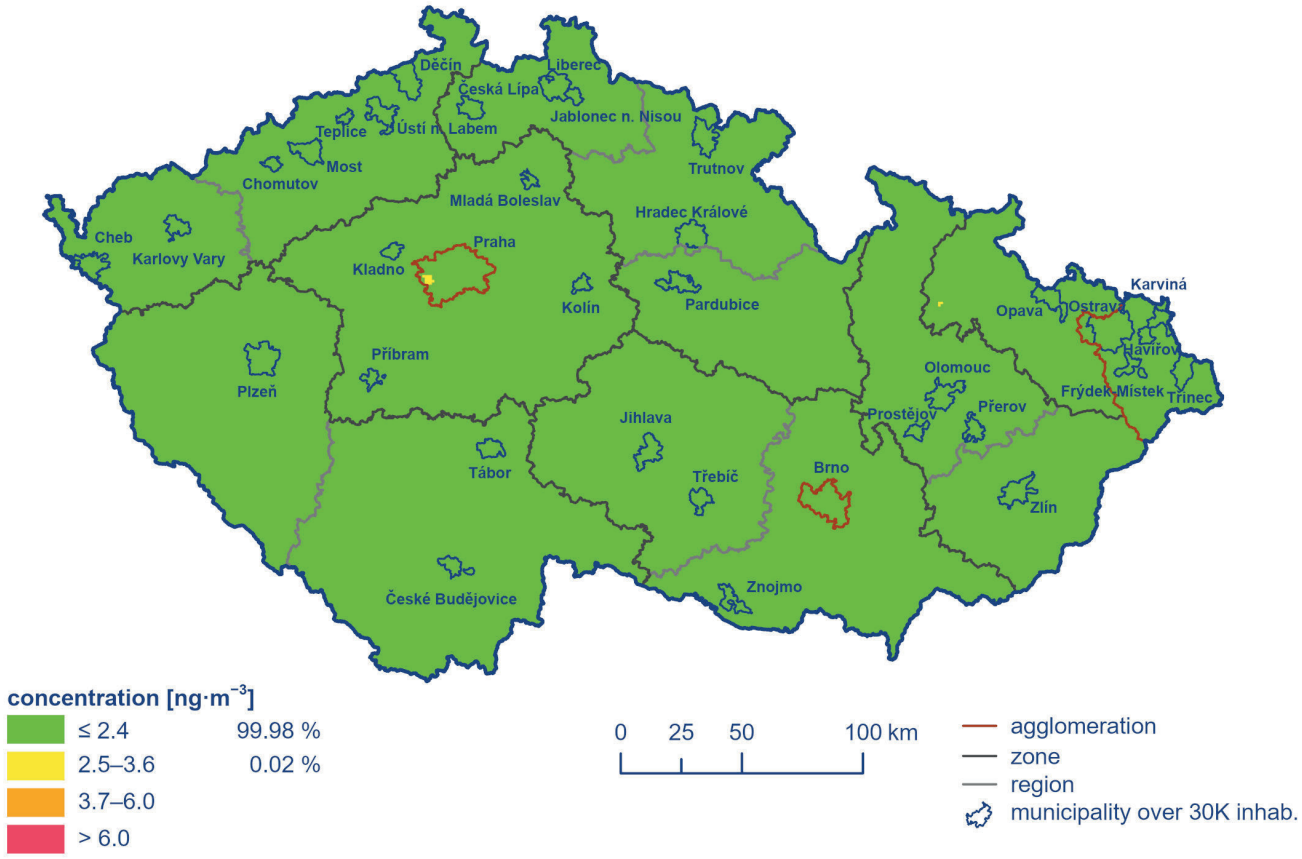


Fig. IV.6.2 Field of annual average concentration of arsenic, 2021

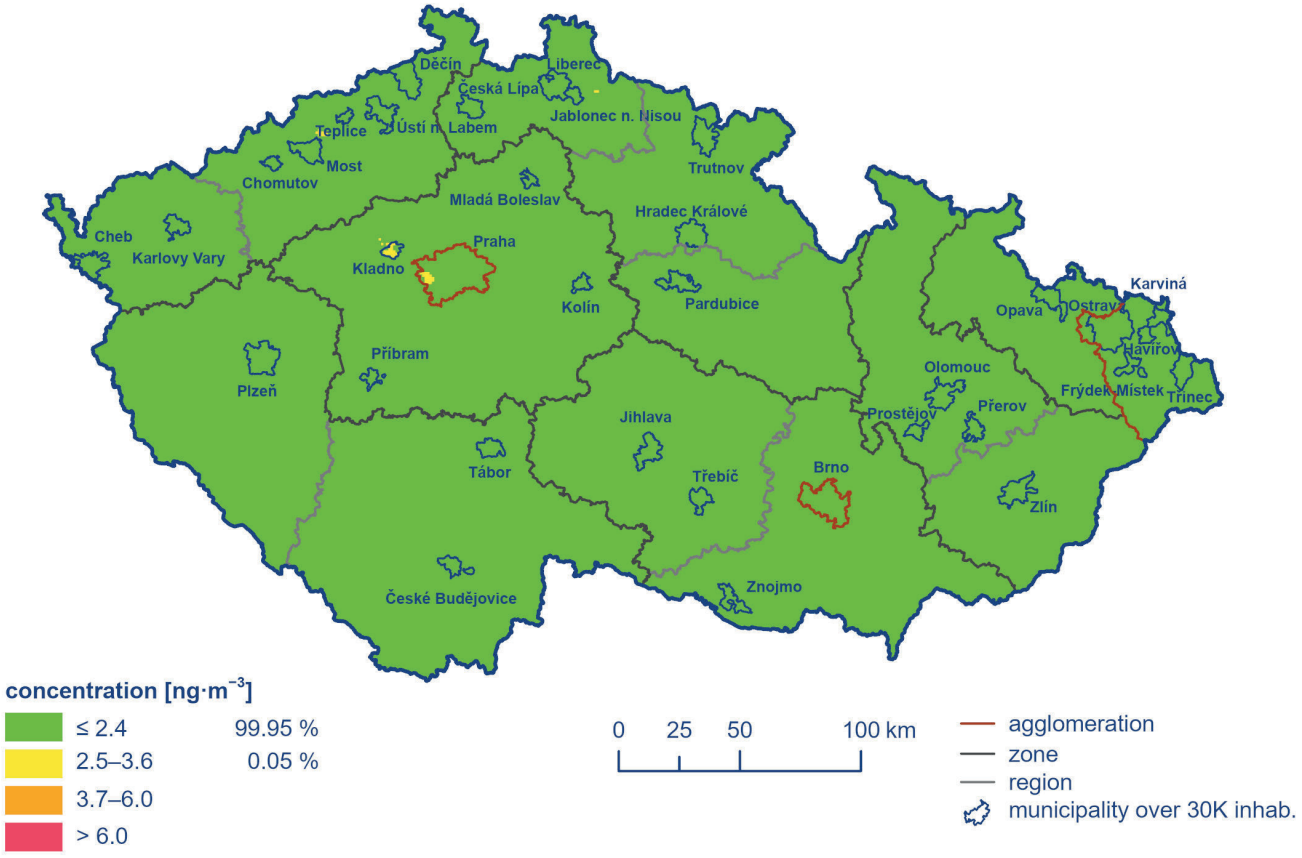


Fig. IV.6.3 Five-year average of annual average concentrations of arsenic, 2017–2021

Nickel

The annual pollution limit level for nickel (20 ng·m^{-3}) was not exceeded at any of 54 stations with valid annual average value in 2021. The highest annual average value (4.5 ng·m^{-3}) was observed at the Ostrava-Mariánské Hory urban background station (3.2 ng·m^{-3}). Compared to 2.8 ng·m^{-3} in 2020, this is an increase by 14 %.

Nickel concentrations have long been very low throughout the territory of the Czech Republic. The highest concentrations are repeatedly measured in the O/K/F-M agglomeration, but even there values do not reach the lower assessment threshold (10 ng·m^{-3}). Of the total 46 stations measuring nickel concentrations both in 2020 and 2021, the annual average concentration increased at 13 stations (28 %), and decreased at 16 stations (35 %). Concentrations remained unchanged at 28 stations (37 %).

Lead

The annual pollution limit level for lead (500 ng·m^{-3}) was not exceeded at any of 55 stations with valid annual average values in 2021. The highest annual average (50 ng·m^{-3}) was observed, likewise in the previous year, at the Ostrava-Radvanice ZÚ station. Compared to 52 ng·m^{-3} in 2020, this is a decrease by 2 %.

In the long term, lead concentrations are very low throughout the territory of the Czech Republic. The highest concentrations are repeatedly measured in the O/K/F-M agglomeration, but even there values do not reach the lower assessment threshold (250 ng·m^{-3}). Of the total 46 stations measuring lead concentrations both in 2020 and 2021, the annual average concentration increased at 26 stations (57 %), and decreased at 18 stations (39 %). Concentrations remained unchanged at 2 stations (4 %).

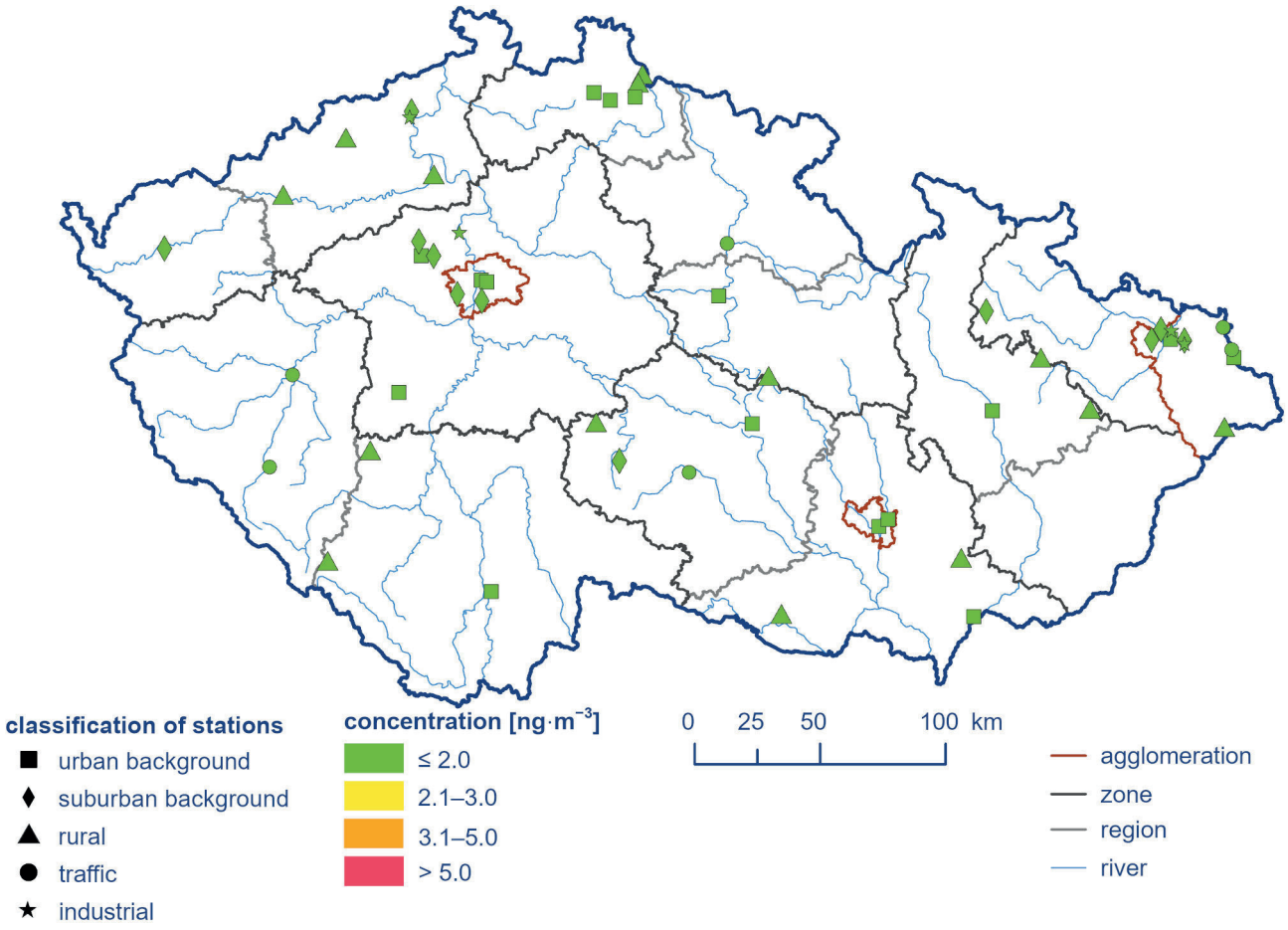


Fig. IV.6.4 Annual average concentrations of cadmium at air quality monitoring stations, 2021

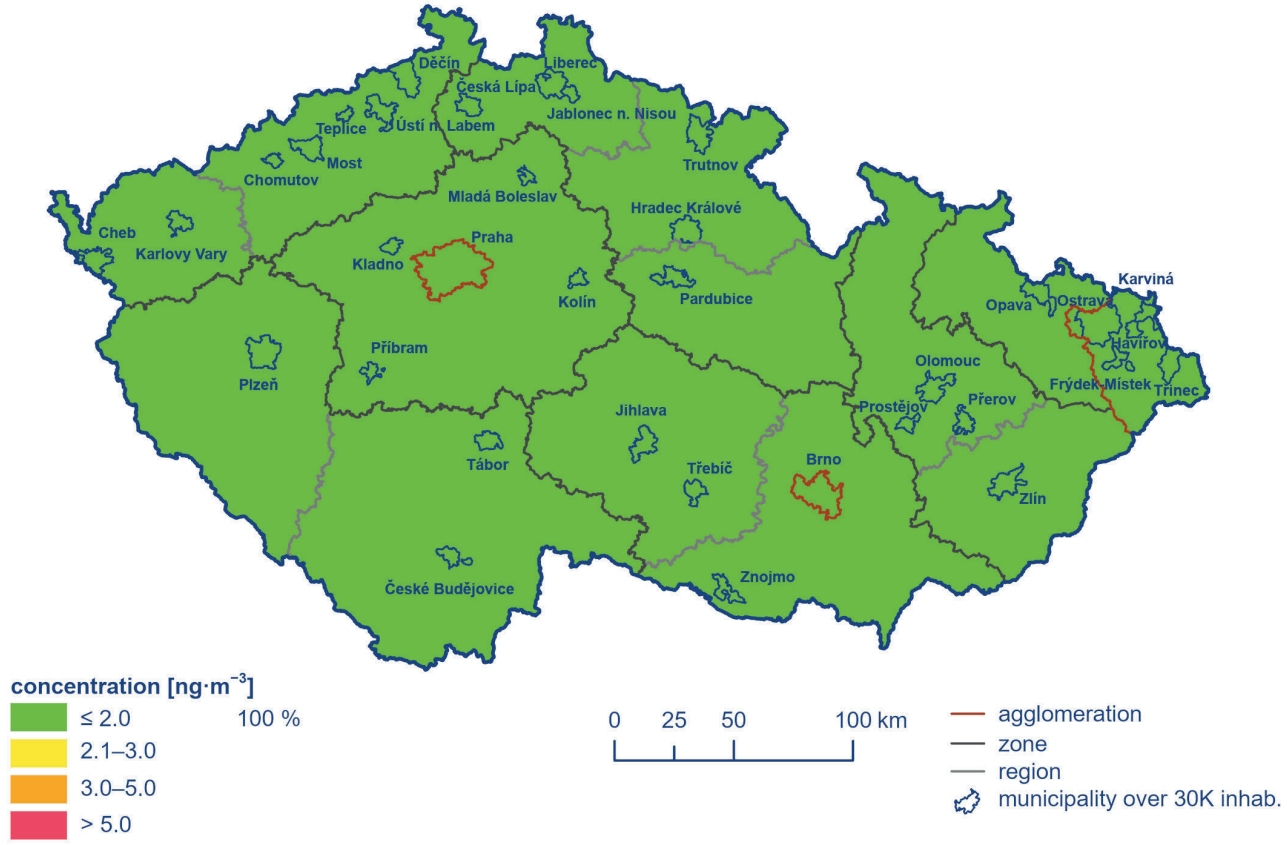


Fig. IV.6.5 Field of annual average concentration of cadmium, 2021

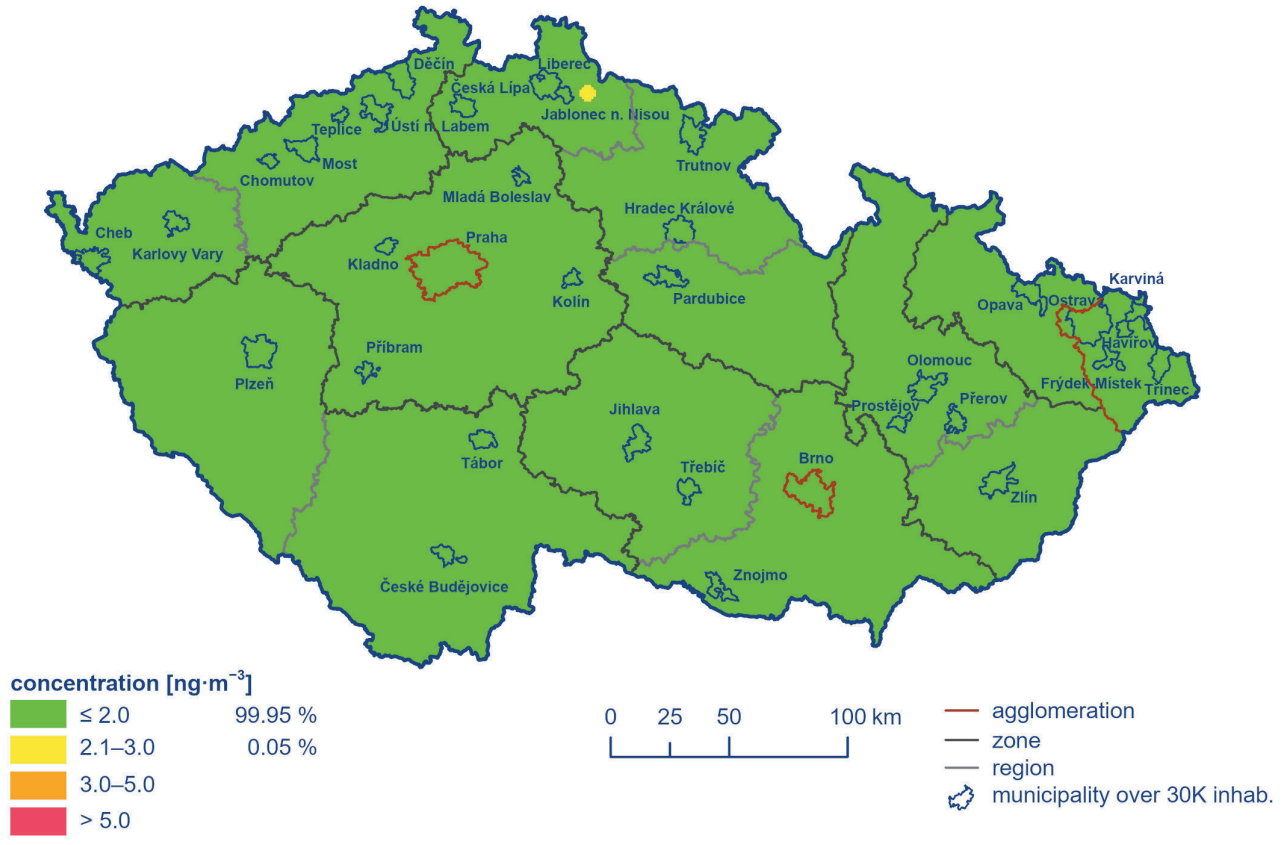


Fig. IV.6.6 Five-year average of annual average concentrations of cadmium, 2017–2021

IV.6.2 Trends in heavy metal concentrations

In 2021, the countrywide average of arsenic concentrations reached the second lowest value for the evaluated period 2011–2021. Lower values were reached only in 2020. (Fig. IV.6.7). The decreasing trend of concentrations is very gradual, in the last three years the countrywide concentration values are comparable. The exception is the Kladno area, which has long been the most exposed region. Until 2014, annual concentrations have been there high, close to the pollution limit value. Since 2014, annual concentrations have been above the upper assessment threshold, however, in the last three years, this value has not been exceeded and a decreasing tendency is evident

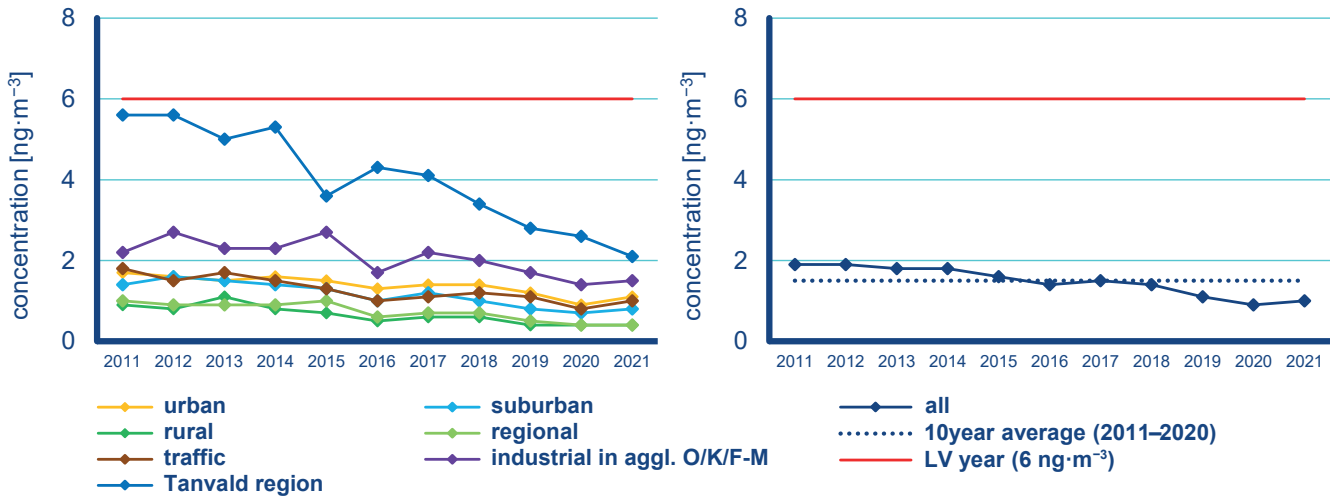


Fig. IV.6.7 Annual average concentrations of arsenic, 2011–2021

Fig. IV.6.8 Annual average concentrations of arsenic at selected stations, 2011–2021

(Fig. IV.6.8). The Kladno district is one of the areas included in a campaign to measure heavy metal concentrations under the Technology Agency of the CR project (No. TITSMZP704). Results show that increased arsenic concentrations in this region are due to the use of specific type of coal for individual household heating. The issue is subject to further investigation.

In 2021, as well as in 2017 and 2018, the national average of cadmium concentrations reached the lowest value for the evaluated period 2011–2021 (Fig. IV.6.9). A slight decrease has been observed since 2011, and a steady trend since 2016. The exception is represented by annual concentrations at industrial stations in the O/K/F-M agglomeration, which reached their lowest values in 2016 and 2017, and started to rise again in the following years.

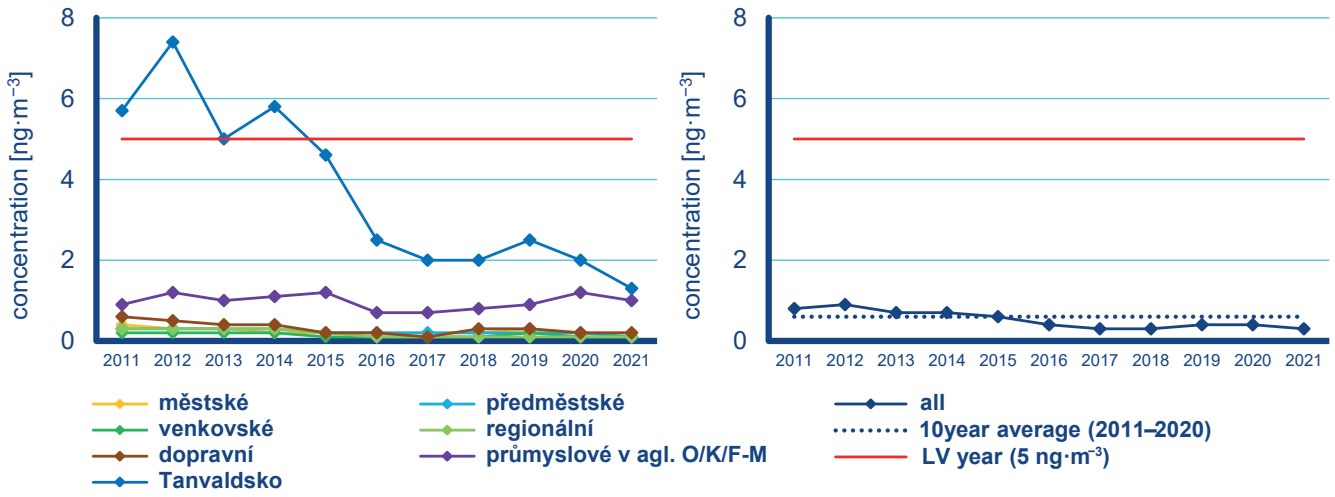


Fig. IV.6.9 Annual average concentrations of cadmium, 2011–2021

Fig. IV.6.10 Annual average concentrations of cadmium at selected stations, 2011–2021

A significant decrease in annual concentrations is observed in the Tanvald region, which has long been the most exposed area (Fig. IV.6.10). High to above-limit concentrations were observed there between 2012 and 2015. The Tanvald area is characterized by a high concentration of glass industry (ASKPCR 2014) which is a significant source of cadmium emissions from the application of paints and fluxing agents (Beranová 2013). In 2015 and 2016, the production operation was adapted to be more ecologically favourable, leading to a decrease in annual average cadmium concentrations below the limit level. However, annual evaluations of measurements at the Tanvald-školka station and monitoring of results are still needed to assess the effectiveness of specific measures.

The national average nickel concentrations have been slightly decreasing over the last 11 years with steady trend since 2015 (Fig. IV.6.11). In 2013, there was a significant increase in nickel concentrations at traffic stations. The highest concentrations since 2009 were recorded at industrial stations in 2018 and 2019. The cause of these fluctuations has not yet been sufficiently clarified.

Lead concentrations show a declining trend over the last 11 years, except for 2018, when there was a slight increase in concentrations at all types of stations (Fig. IV.6.12).

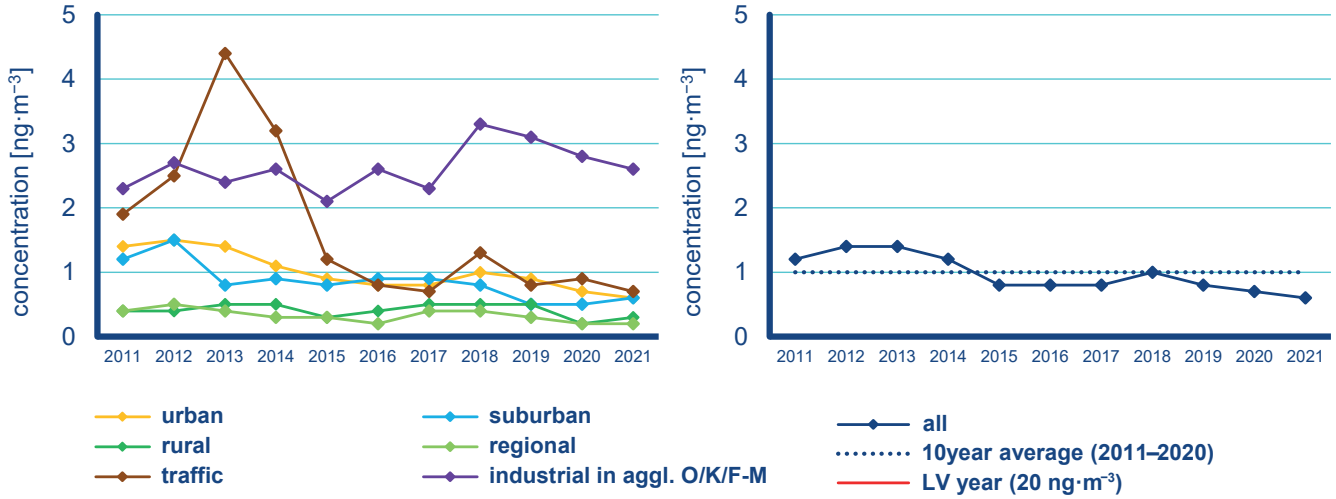


Fig. IV.6.11 Annual average concentrations of nickel, 2011–2021

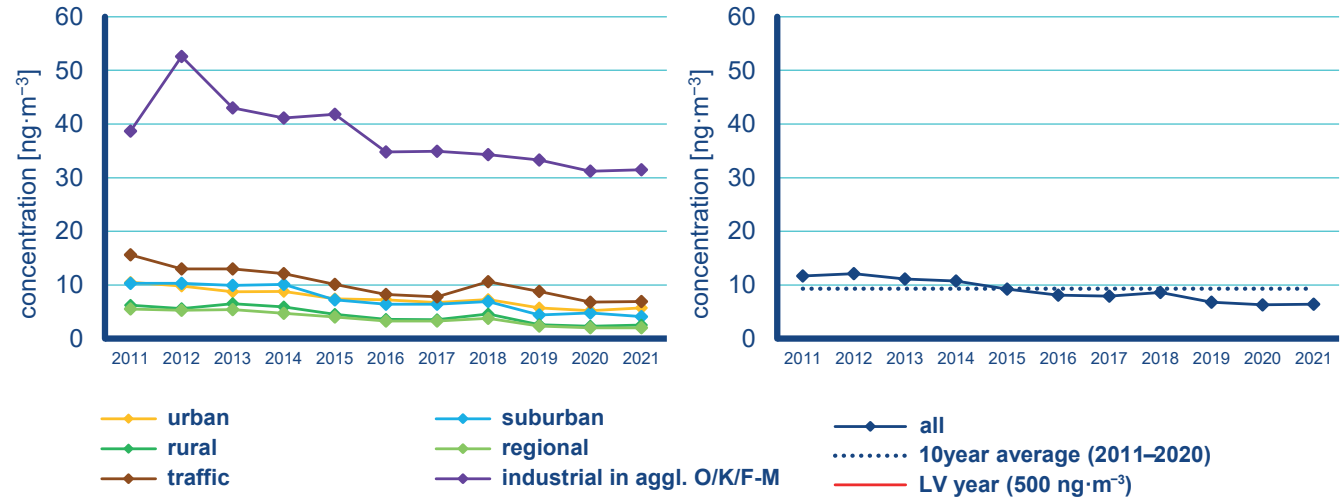


Fig. IV.6.12 Annual average concentrations of lead, 2011–2021

IV.6.3 Emissions of heavy metals

Heavy metals include metals with a specific density greater than 4.5 g·cm^{-3} and their compounds. Heavy metals are a natural component of solid fuels, while their contents in fuels vary depending on the mining site. The amounts of heavy metal emissions from the combustion of solid fuels depends primarily on the kind of fuel, type of combustion equipment, and combustion temperature which affects the volatility of heavy metals. Heavy metal emissions are also formed in some technological processes because they are contained in the input raw materials (e.g., iron ore, scrap metal, glass batches, paints, glass shards). In addition to these processes, there are also a number of sources of fugitive emissions containing heavy metals (for example, particles from the abrasion of brakes and tyres, or emissions related to old environmental burdens left by mining and metallurgical activities).

Combustion processes are of predominant importance primarily for the emissions of arsenic and nickel. The most significant sectors at a national scale include 1A1a — Public electricity and heat production which contributed 21.7 % to arsenic emissions and 32.9 % to nickel emissions in 2020 (Fig. IV.6.13 and Fig. IV.6.17). In 2020, there were significant contributions from the sectors of iron and steel production (2C1) related primarily to lead emissions (22.6 %; Fig. IV.6.19). The impact of sector 1A4bi — Residential: Stationary predominated in cadmium emissions, with a share of 52.1 % (Fig. IV.6.15), and also significantly contributed to arsenic emissions (33.1 %; Fig. IV.6.13). A significant proportion of total lead emissions is formed by emissions from the triggering of fireworks and pyrotechnics (29.5 %; Fig. IV.6.19), which belong to sector 2G – Other sources. The cadmium emissions from the 2G sector accounted for 9.2 %, with the main source of emissions being tobacco smoke (Fig. IV.6.15). The decreasing trend in emissions of heavy metals in the 2010–2020 period is associated with the rate of emissions of suspended particles (Chap. IV.1.3) to which these substances are bound (Figs. IV.6.14, IV.6.16, IV.6.18, and IV.6.20). Measures in the sector of iron and steel production made a substantial contribution to the decrease in heavy metal emissions, especially improvements in the dust-removal system for iron ore agglomeration sintering strands. Technical measures have also succeeded in reducing heavy metal emissions from glass production. In recent years, there has been an increase in the volume of the secondary production of non-ferrous metals, especially aluminium and lead, although this increase has possibly ceased in 2020 due to the COVID-19 pandemic. Emissions of heavy metals from these sources are very variable, and depend on the quality of the processed scrap metal.

In view of the predominant contribution of the sector of public electricity and heat production and the sector of iron and steel production, the territorial distribution of heavy metal emissions (excluding emissions from the sector 2G – Other sources) is determined mainly by the location of production facilities in these sectors. Emissions of arsenic and nickel are concentrated in areas in which thermal power plants and heating plants burning coal are located. These are primarily enterprises in the Ústí nad Labem, Central Bohemian and Pardubice regions. Emissions of cadmium and lead are predominantly produced in the O/K/F-M agglomeration due to concentration of enterprises producing iron and steel. A significant amount of lead emissions in the Central Bohemian region originates from secondary lead production at Kovohutě Příbram (Figs. IV.6.21, IV.6. 22, IV.6.23, and IV.6.24).

- 1A4bi – Residential: Stationary
- 1A1a – Public electricity and heat production
- 1A2c – Stationary combustion in manufacturing industries and construction: Chemical industry
- 1A2f – Stationary combustion in manufacturing industries and construction: Non-metallic minerals
- 1A3bvi – Road transport: Automobile tyre and brake wear
- 1A4ai – Commercial/institutional: Stationary
- 2A3 – Glass production
- 2C1 – Iron and steel production
- 2C5 – Lead production
- 2C6 – Zinc production
- 2G – Other product use
- 5C2 – Open burning of waste
- Other

Legend to Figs IV.6.13 and IV.6.20

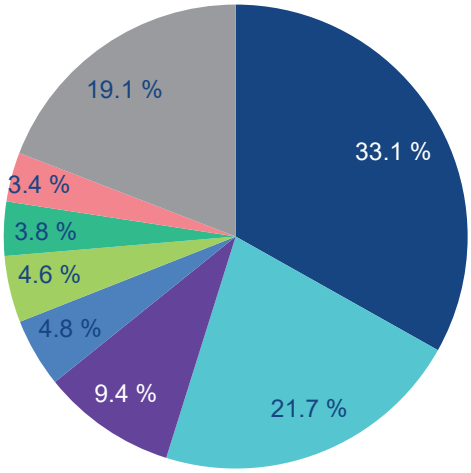


Fig. IV.6.13 Proportion of NFR sectors to total emissions of arsenic, 2020

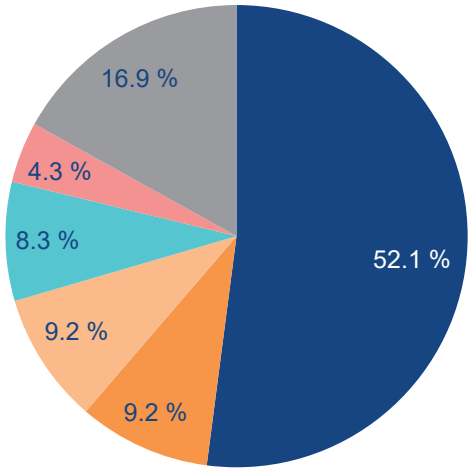


Fig. IV.6.15 Proportion of NFR sectors to total emissions of nickel, 2020

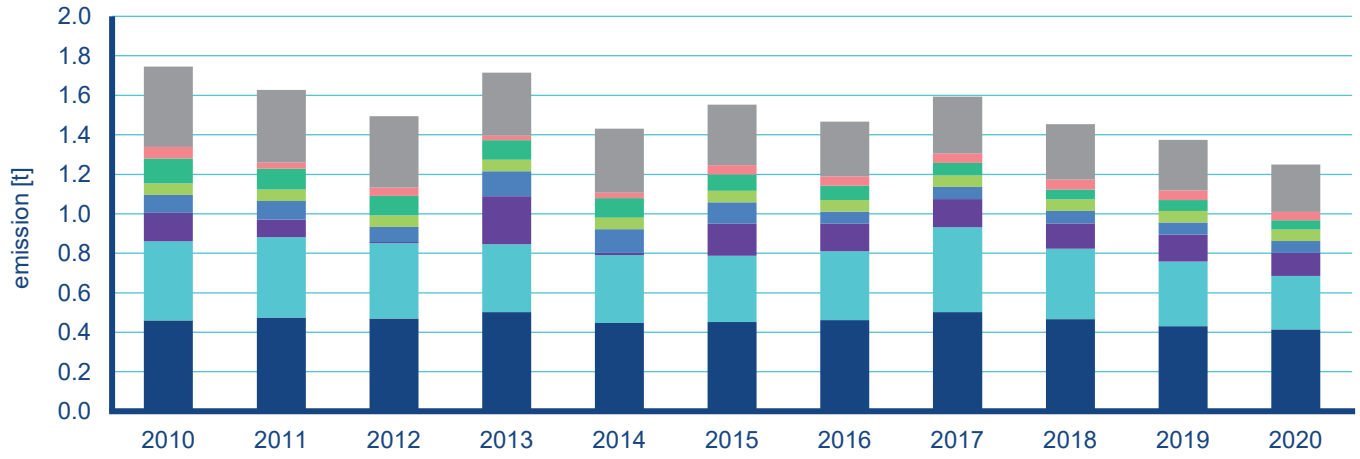


Fig. IV.6.14 Total arsenic emissions of arsenic, 2010–2020

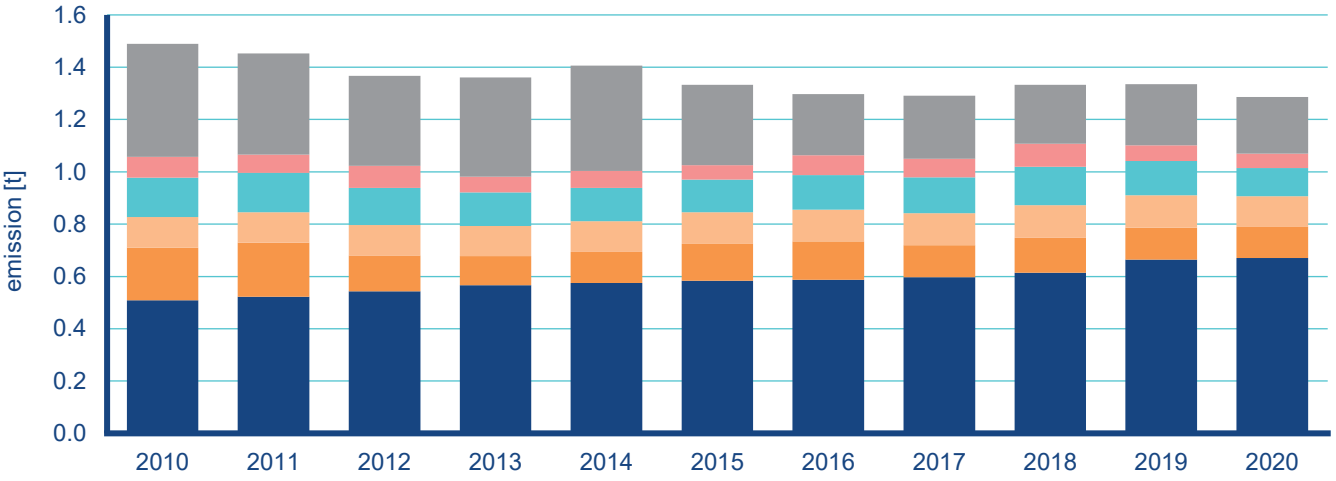


Fig. IV.6.16 Total emissions of nickel, 2010–2020

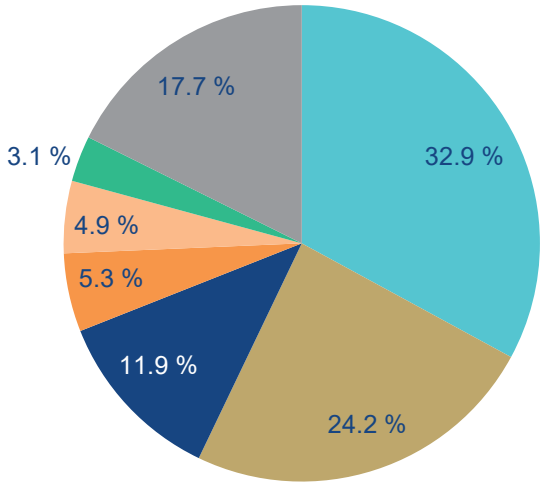


Fig. IV.6.17 Proportion of NFR sectors to total emissions of cadmium, 2020

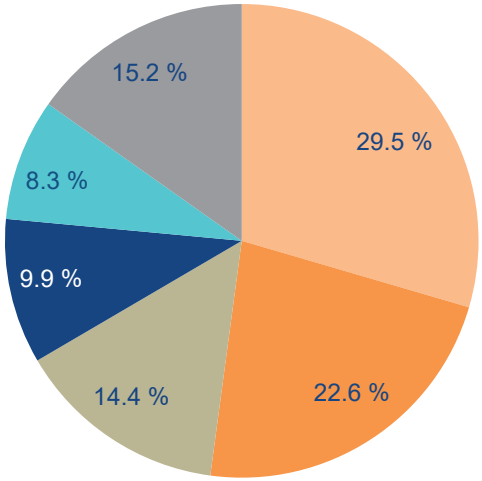


Fig. IV.6.19 Proportion of NFR sectors to total emissions of lead, 2020

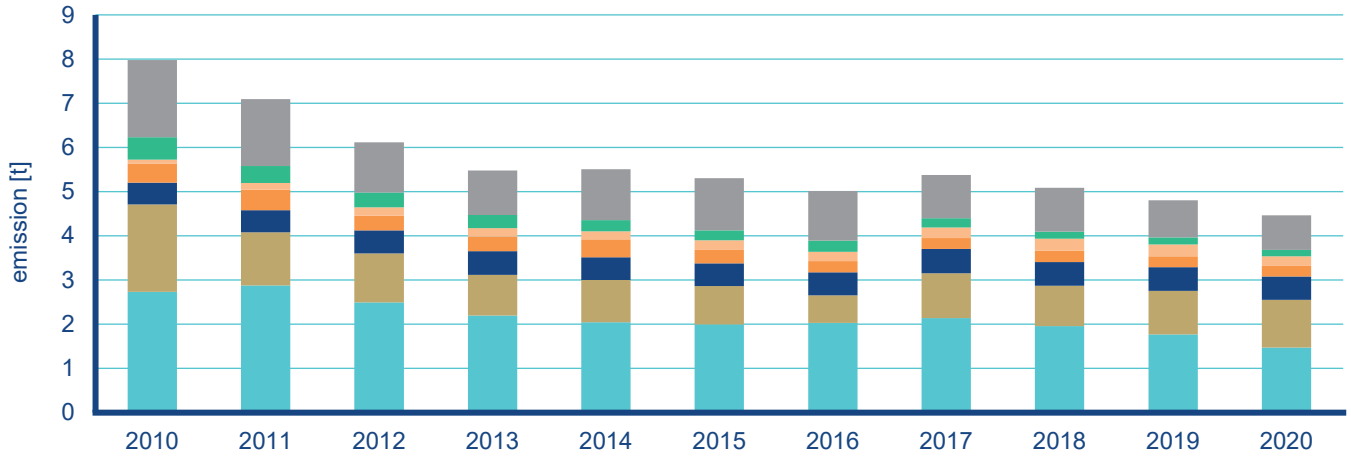


Fig. IV.6.18 Total emissions of cadmium, 2010–2020

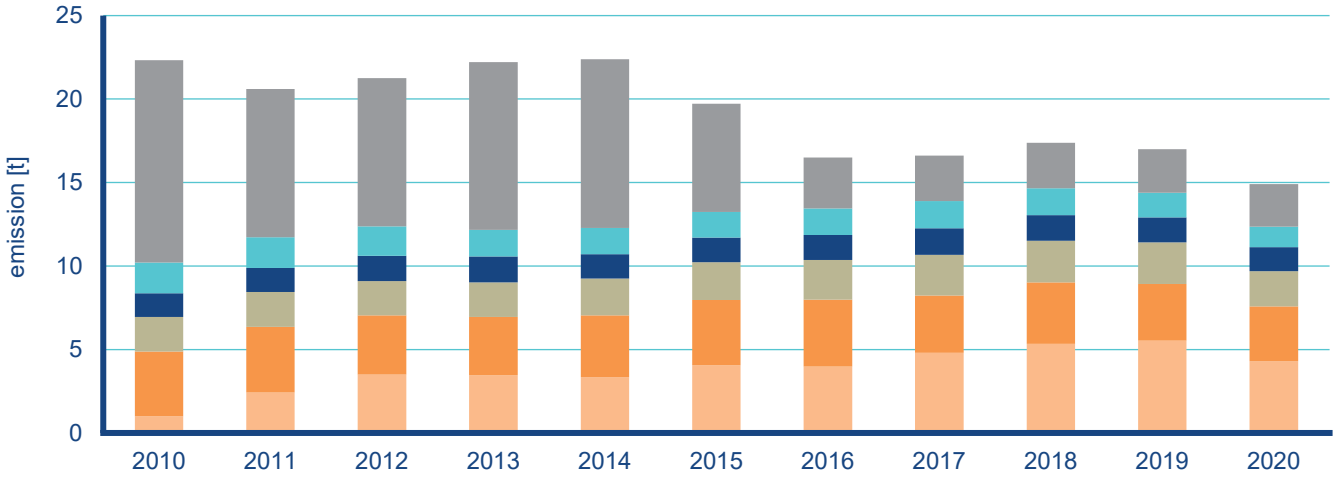


Fig. IV.6.20 Total emissions of lead, 2010–2020

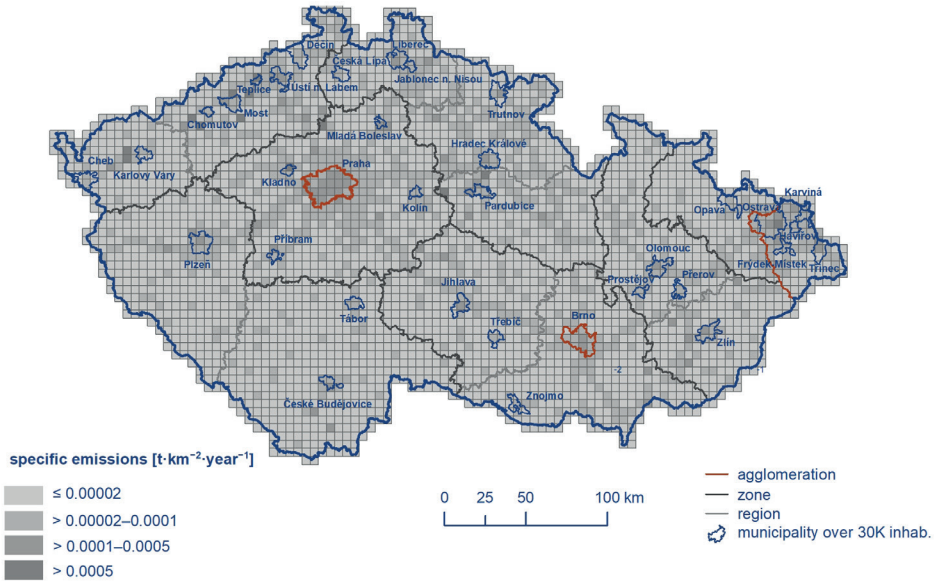


Fig. IV.6.21 Total arsenic emissions in 5×5 km spatial resolution squares, 2020

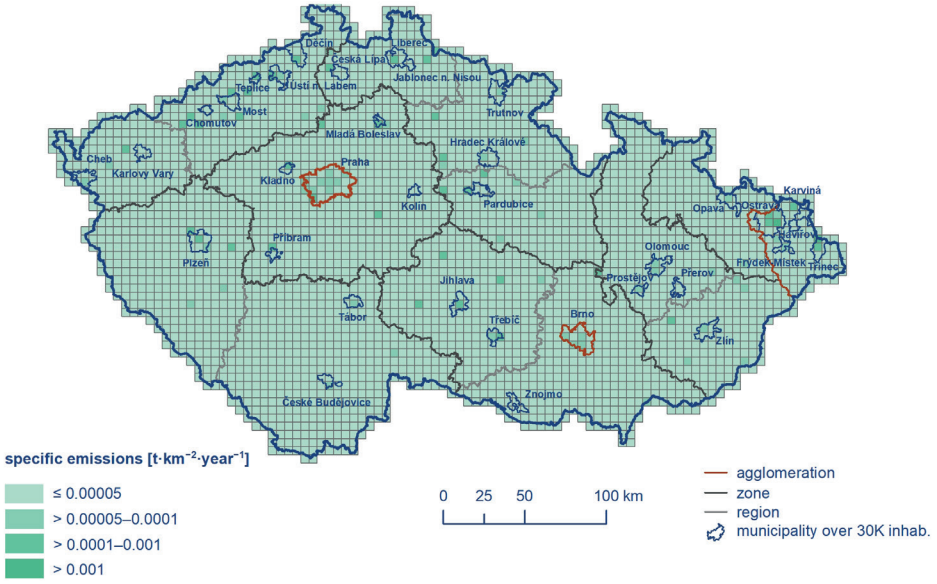


Fig. IV.6.22 Total nickel emissions in 5×5 km spatial resolution squares, 2020

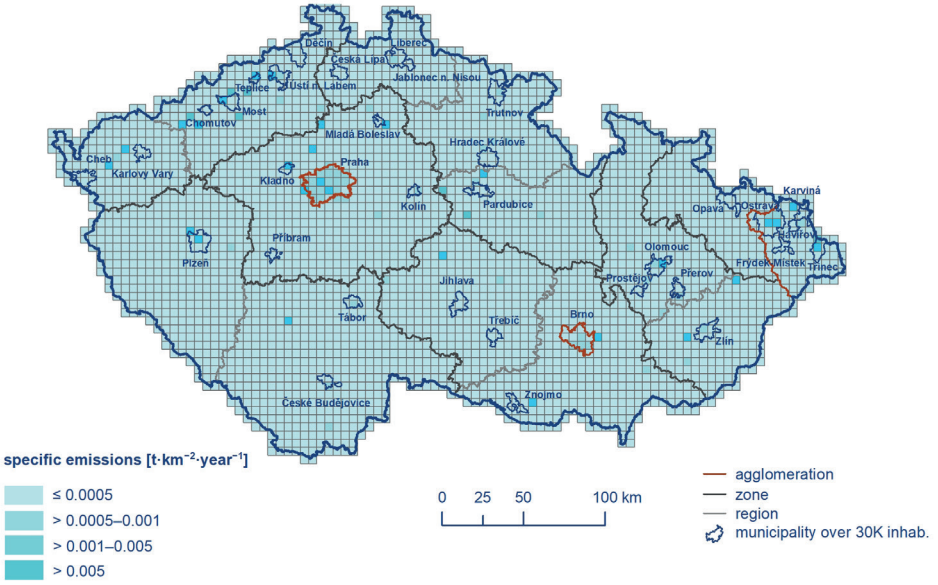


Fig. IV.6.23 Total cadmium emissions in 5×5 km spatial resolution squares, 2020

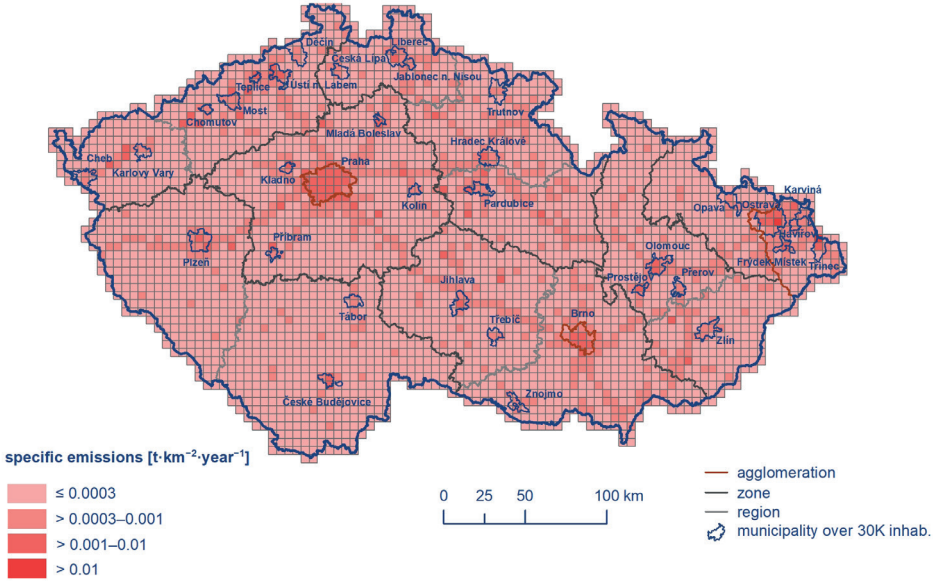


Fig. IV.6.24 Total lead emissions in 5×5 km spatial resolution squares, 2020

IV.7 Sulphur dioxide

IV.7.1 Air pollution by sulphur dioxide in 2021

Air pollution by sulphur dioxide in relation to the pollution limit value for the protection of human health

In 2021, neither the hourly nor 24-hour pollution limits for sulphur dioxide (SO_2) were exceeded at any monitoring station in the CR, so both pollution limits were met. Nor were any concentrations of this substance exceeding the limit values in the permitted number of cases observed.

The highest hourly SO_2 concentrations were measured at the stations of Lom (251 µg·m^{-3}), Český Těšín (240 µg·m^{-3}), and Chotěbuz (209 µg·m^{-3}).

The highest 24-hour SO_2 concentrations were measured at the Ostrava-Radvanice ZÚ (98 µg·m^{-3}), Český Těšín (73 µg·m^{-3}), and Lom (63 µg·m^{-3}) stations.

The 25th highest hourly SO_2 concentration value reached the highest levels at the Ostrava-Radvanice ZÚ (121 µg·m^{-3}), Český Těšín (103 µg·m^{-3}), Lom (91 µg·m^{-3}), Ostrava-Radvanice OZO (90 µg·m^{-3}), Chotěbuz (67 µg·m^{-3}), Krupka (57 µg·m^{-3}), and Karviná (56 µg·m^{-3}) stations.

The fourth highest 24-hour SO_2 concentrations reached their highest values at nearly the same stations, namely Ostrava-Radvanice ZÚ (54 µg·m^{-3}), Lom (43 µg·m^{-3}), Český Těšín (42 µg·m^{-3}), Chotěbuz (36 µg·m^{-3}), Ostrava-Radvanice OZO (34 µg·m^{-3}), and Teplice (30 µg·m^{-3}).

The influence of industrial sources can predominantly be expected at the Lom station, while the influence of local heating from the surrounding municipalities cannot be ruled out with a certain wind direction. At the Ostrava-Radvanice ZÚ and Ostrava-Radvanice OZO stations, increased concentrations of SO_2 occur mainly in connection with local sources in the vicinity of the stations. In the case of the Český Těšín station, but also other border station – Věřňovice, SO_2 emissions from local sources at the Czech-Polish border area are involved.

On 99.98 % of the area of the CR, the fourth highest 24-hour concentrations of SO_2 were under the lower assessment threshold (50 µg·m^{-3}). In only 0.02% of the territory the lower assessment threshold was exceeded, involving just the cities of Ostrava and Třinec (Fig. IV.7.1).

The point symbols at the stations designate the fourth highest 24-hour SO_2 concentrations measured at the air quality monitoring stations (Fig. IV.7.2).

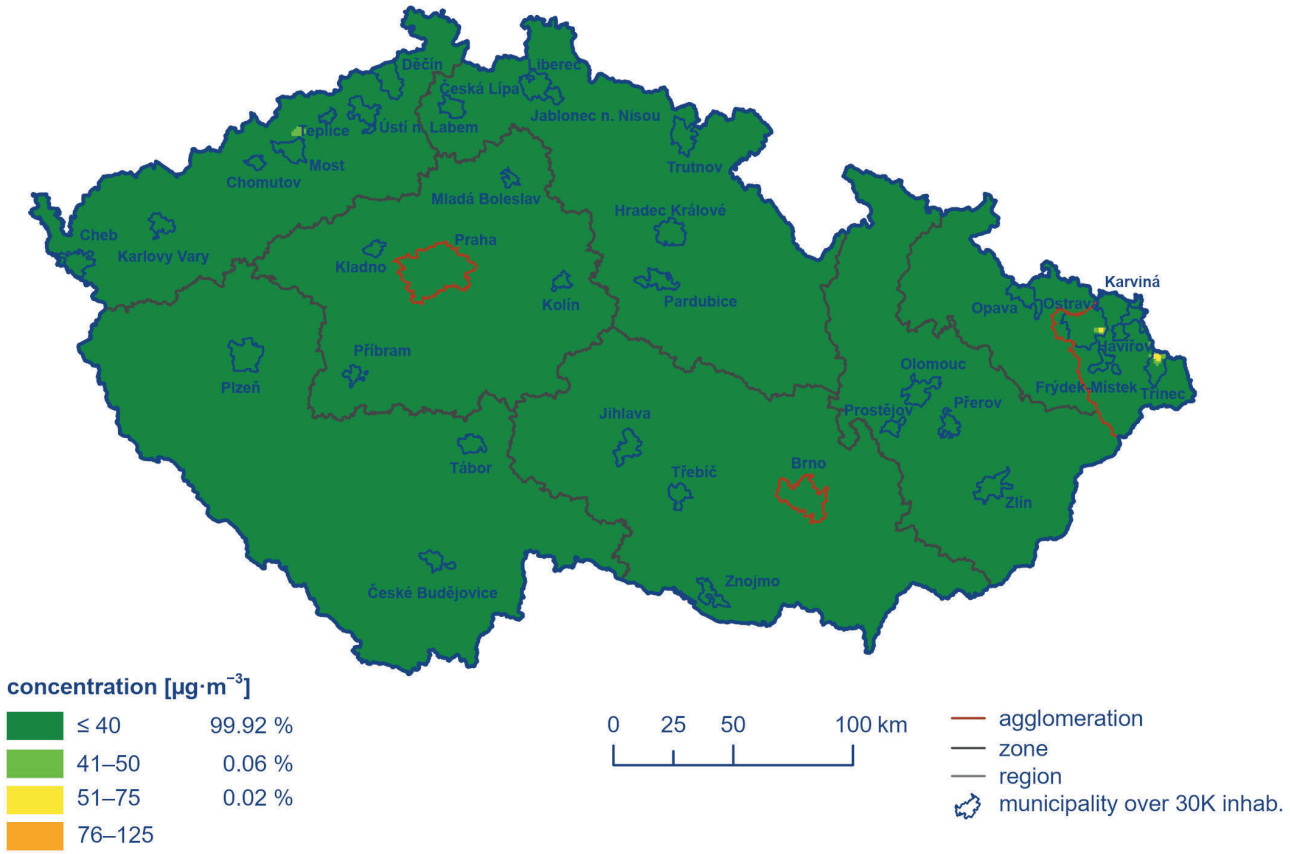


Fig. IV.7.1 Field of 4th highest 24-hour SO_2 concentration, 2021

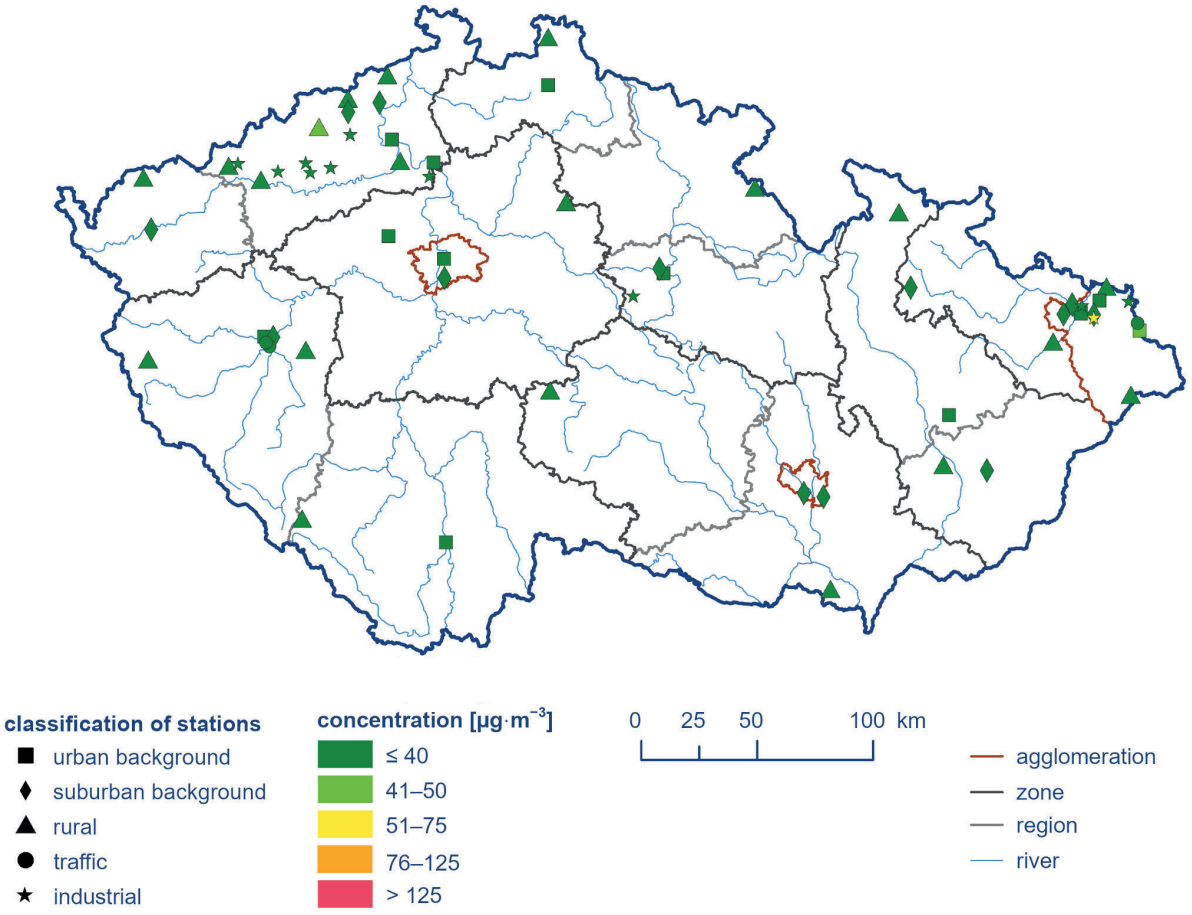


Fig. IV.7.2 4th highest 24-hour SO_2 concentrations at air quality monitoring stations, 2021

Air pollution by sulphur dioxide in 2021 in relation to the pollution limit value for the protection of ecosystems and vegetation

In 2021, neither the annual nor winter average concentrations exceeded the pollution limit value at rural locations. The highest winter average concentrations 2021/2022 were recorded at the Krupka (7.5 µg·m^{-3}), Věřňovice (7.2 µg·m^{-3}), Lom (6.5 µg·m^{-3}), Studénka (6.1 µg·m^{-3}), Sněžník (4.2 µg·m^{-3}), Těšnovice (3.8 µg·m^{-3}), and Rožďalovice-Ruská (3.8 µg·m^{-3}) stations. The annual average concentrations attained maximum values at the same stations in a different order – Lom (7 µg·m^{-3}), Krupka (6.8 µg·m^{-3}), Věřňovice (5.8 µg·m^{-3}), Studénka (4.7 µg·m^{-3}), Sněžník (4.1 µg·m^{-3}), Rožďalovice-Ruská (3.9 µg·m^{-3}), and Těšnovice (3.6 µg·m^{-3}).

In rural areas of the CR, the upper assessment threshold (12 µg·m^{-3}) was exceeded in 2021 neither for the annual average SO_2 concentration nor the average concentration of the winter period 2021/2022. The upper assessment threshold for the annual and winter average SO_2 concentration was exceeded only in the cities of Ostrava and Třinec, where the pollution limit of 20 µg·m^{-3} was also exceeded for both mentioned pollution characteristics (Fig. IV.7.3 and IV.7.4). This exceeded value is based on model calculations when constructing the map.

All the background stations measuring SO_2 were used to construct the two maps, taking into account their classification (Fig. IV.7.3 and Fig. IV.7.4). Point symbols on the maps designate only rural stations because the average winter and annual average SO_2 concentrations are only measured at these locations in relation to pollution limit values for the protection of ecosystems and vegetation.

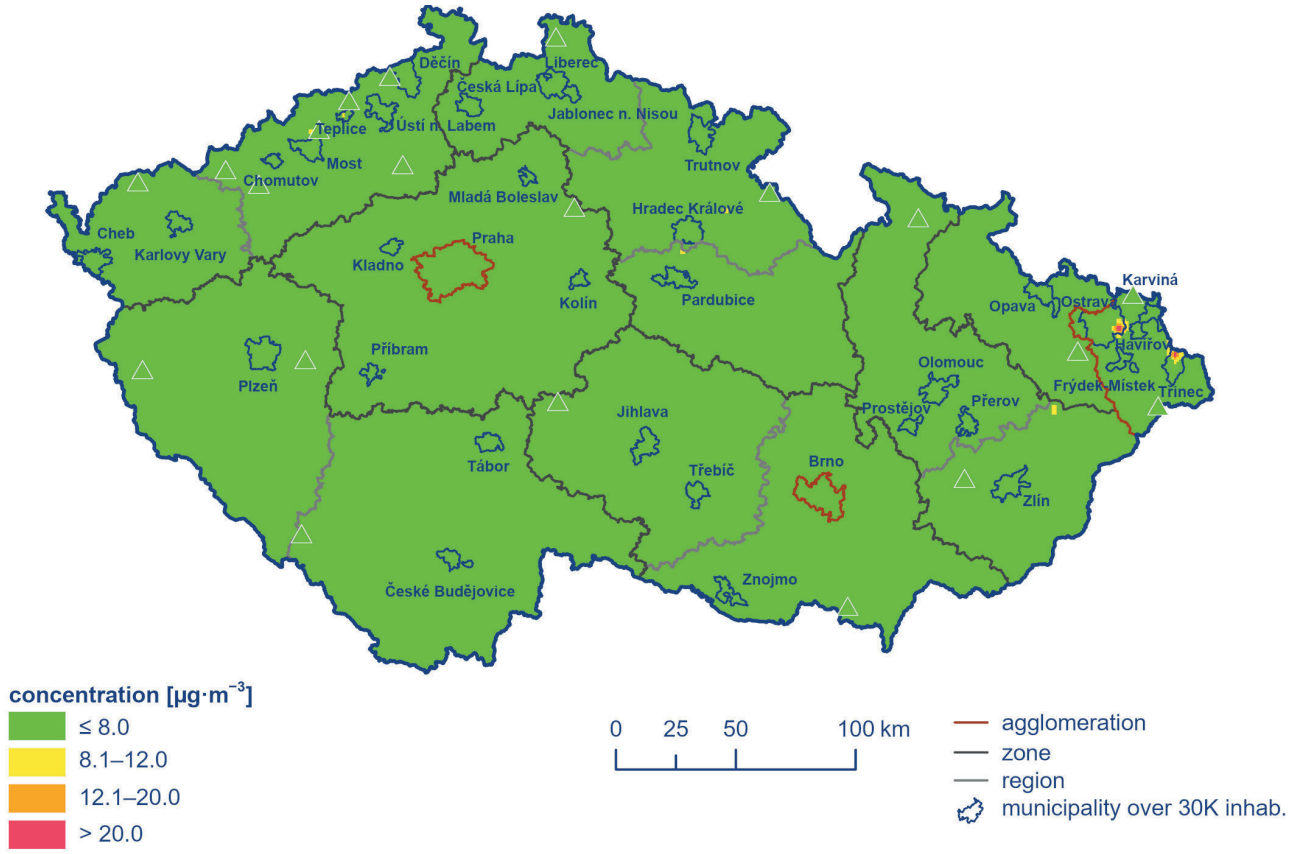


Fig. IV.7.3 Field of annual average SO_2 concentration, 2021

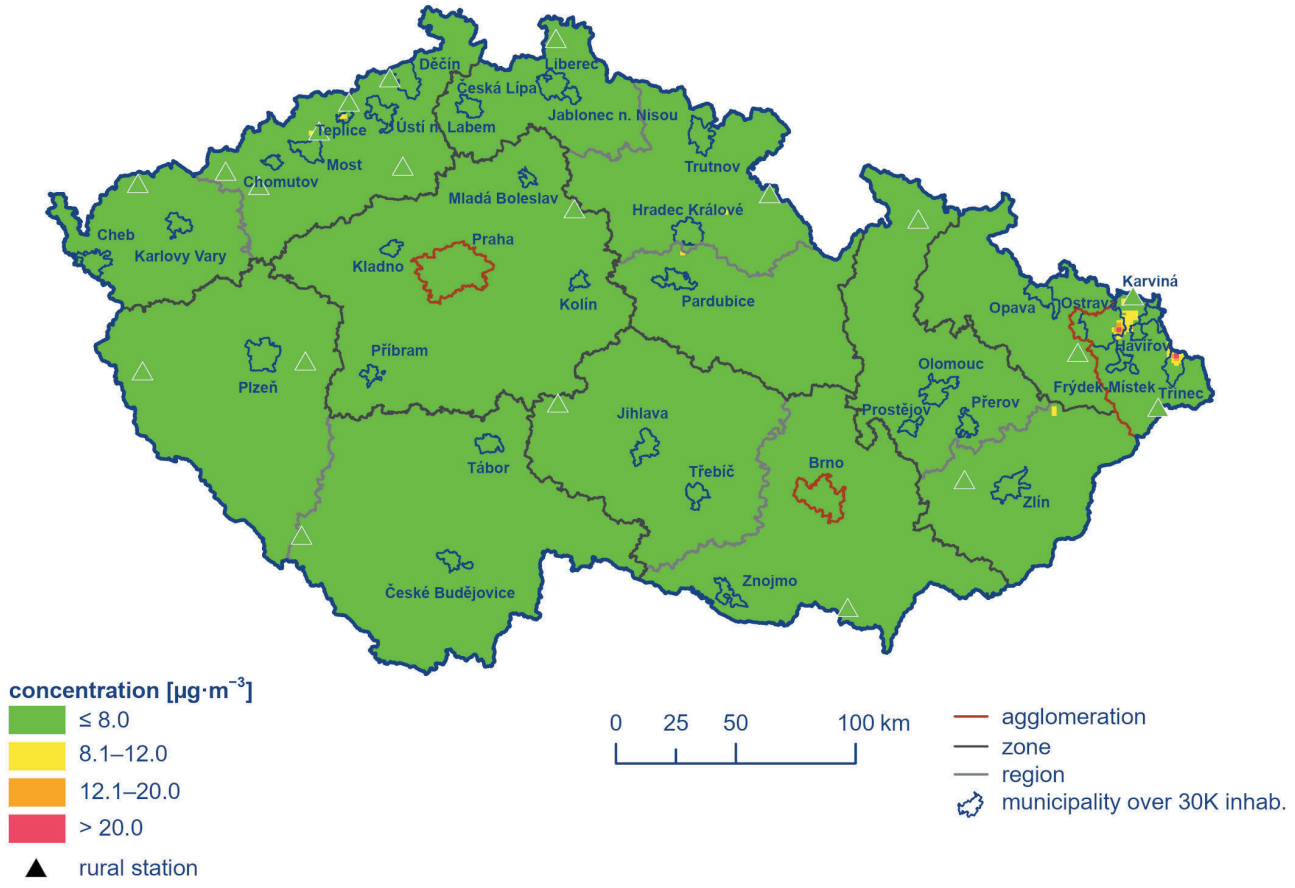


Fig. IV.7.4 Field of annual average SO_2 concentration in winter of 2021/2022

IV.7.2 Trends in sulphur dioxide concentrations

A substantial reduction in SO_2 concentrations occurred after 1998 in connection with Act No. 309/1991 Coll. coming into effect and ensuring compliance with the prescribed emission limits.

In the period 2011–2021, until 2016 a decreasing trend is evident at nearly all stations (Fig. IV.7.5). In 2017, the decrease was interrupted and in 2018 resumed at most locations. In 2019, 2020, and 2021, a slight decrease in SO_2 air pollution characteristics continued. This decrease is evident at most stations at both the fourth highest 24-hour and the 25th highest hourly SO_2 concentrations. On the contrary, the increase is clear in 2020 at the Lom station (Fig. IV.7.5). As already mentioned, the influence of industrial resources can predominantly be expected at the Lom station. In 2021, SO_2 concentrations at this station decreased compared to the previous year.

In evaluating trends in hourly and 24-hour SO_2 characteristics at individual types of stations in the CR according to the classification (Obr. IV.2), there was a significant increase identified in concentrations of this substance for both the characteristics in 2011 and 2018 at industrial stations in the Ostrava/Karviná/Frýdek-Místek agglomeration (Fig. IV.7.6 and IV.7.7)[1]. This increase was affected by concentrations observed at the Ostrava stations arising from remediation activities on the waste lagoons of the former OSTRAMO company. In 2019, the increase did not continue, on the contrary, there was a decrease in SO_2 concentrations, which was reflected in 2020 mainly in observations of urban, suburban and regional stations (Fig. IV.7.6 and Fig. IV.7.7). In 2021, this decrease was even more noticeable at almost all types of stations and in general in the average at all stations (Fig. IV.7.6 and Fig. IV.7.7).

The annual and winter averages show a clear decrease in SO_2 concentrations since 2017 until 2021 (Fig. IV.7.8). This decrease is apparent in all rural localities as well as in the category of regional localities. The 10-year annual and winter average (2011–2020) has a stable trend, with the winter average at a slightly higher level (Fig. IV.7.8).

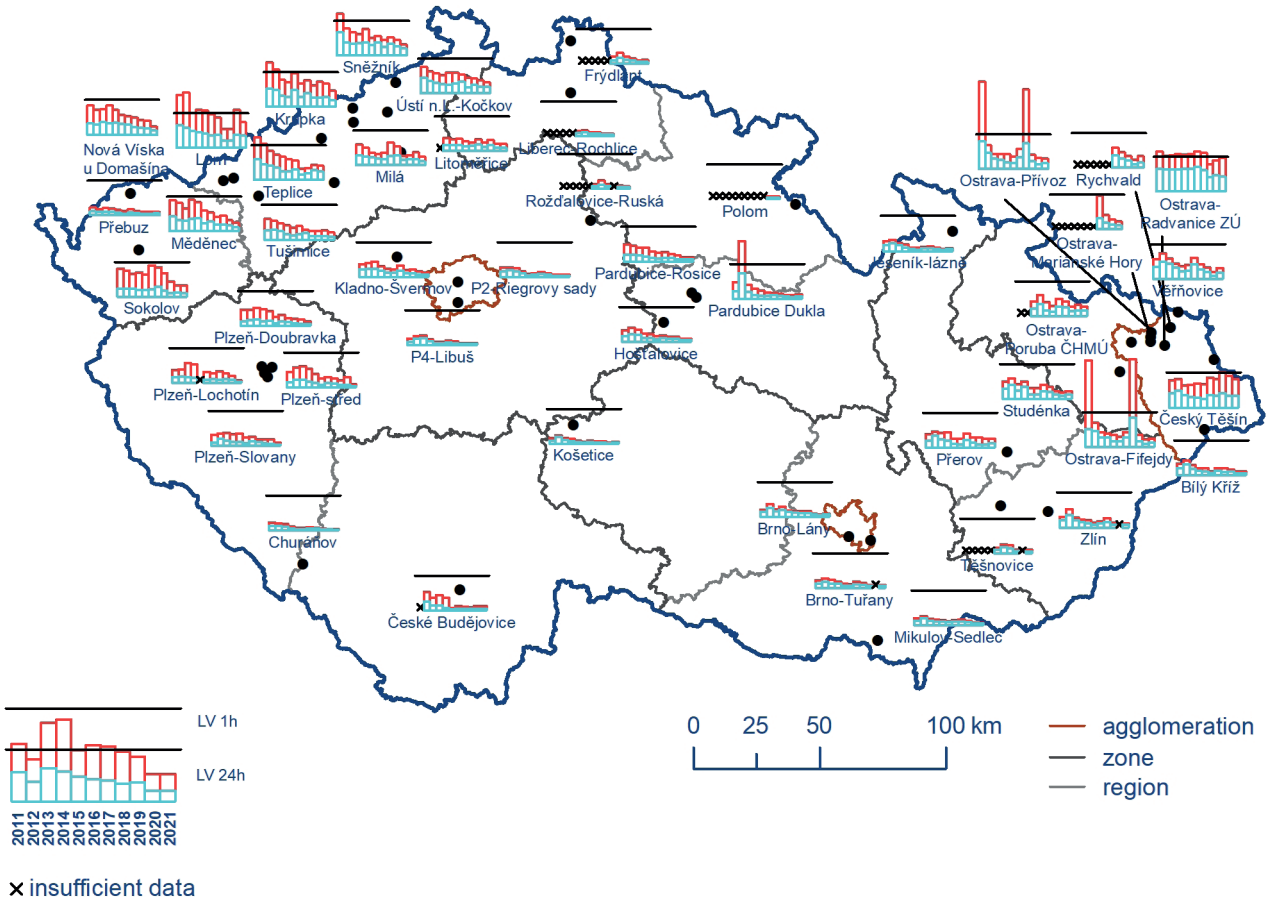


Fig. IV.7.5 4th highest 24-hour and 25th highest hourly SO_2 concentrations at selected stations, 2011–2021

1 Within the group of industrial stations, industrial stations in the O/K/F-M agglomeration were distinguished from industrial stations in the Ústí nad Labem region (ULK), which are operated by ČEZ a. s., and are located at the outskirts of small municipalities and in places outside settlements. The Ostrava stations, in particular, tend to be significantly affected by industry, while stations in the Ústí nad Labem region characterize rather the industrial background of the Krušné hory foothill area.

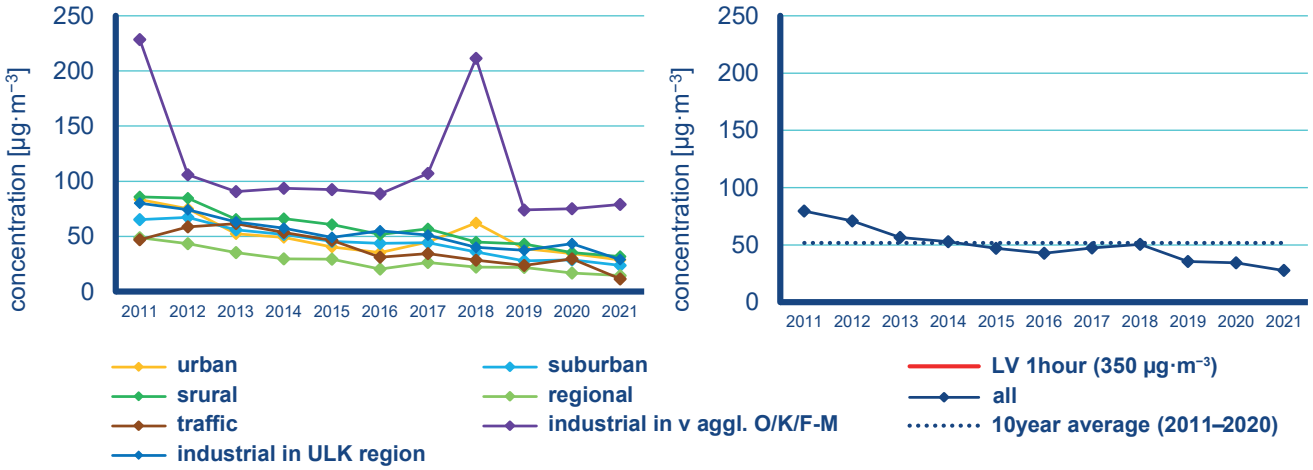


Fig. IV.7.6 25th highest 1-hour SO_2 concentrations at particular types of stations, 2011–2021

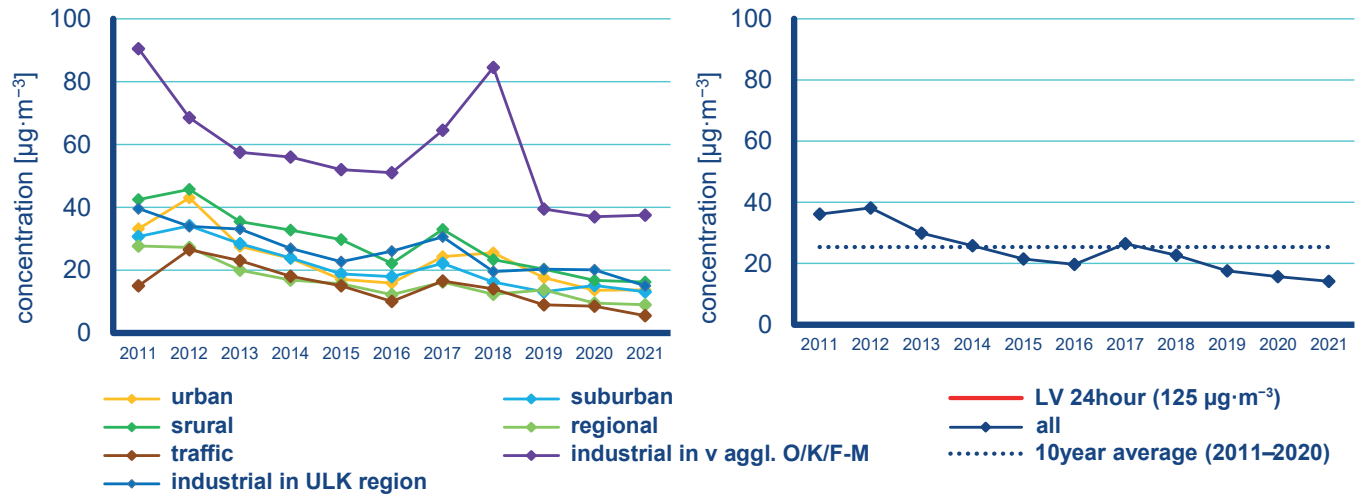


Fig. IV.7.7 4th highest 24-hour SO_2 concentrations at particular types of stations, 2011–2021

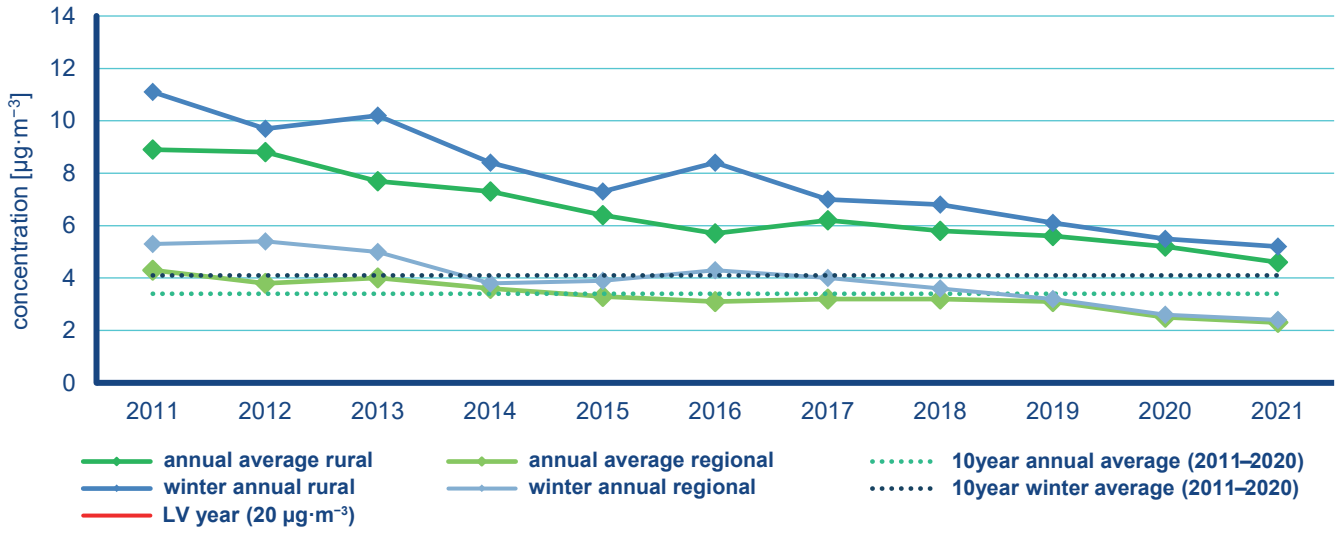


Fig. IV.7.8 SO_2 concentrations at particular types of stations, 2011–2021

The overall decreasing trend in SO_2 concentrations follows a reduction in emissions due to sulphur removal in coal-fired power plants and a change in the fuel types in use (see the emission trends in Chap. II). The varying meteorological and dispersion conditions in particular years also had an impact on the year-on-year variations in SO_2 concentrations.

IV.7.3 Sulphur oxide emissions

Sulphur oxide emissions originate mainly from the combustion of solid fossil fuels containing sulphur. In 2020, at a national scale, 39.4 % of SO_x emissions originated from sector 1A1a – Public electricity and heat production, and 21.6 % from sector 1A4bi – Residential: Heating, water heating, cooking (Fig. IV.7.9). Other more important sectors include combustion processes in industry (processing of mineral raw materials, chemical industry, processing of solid fuels, or food production). A reduction in SO_2 emissions in the 2010–2020 period took place after 2012 as a result of preparations at sources for stricter emissions limits (Fig. IV.7.10). In view of the predominant effect of the sector of public electricity and heat production, SO_x emissions appear mostly in the Ústí nad Labem, Moravian-Silesia and Central Bohemia regions, in which the larger energy production facilities are located (Fig. IV.7.11).

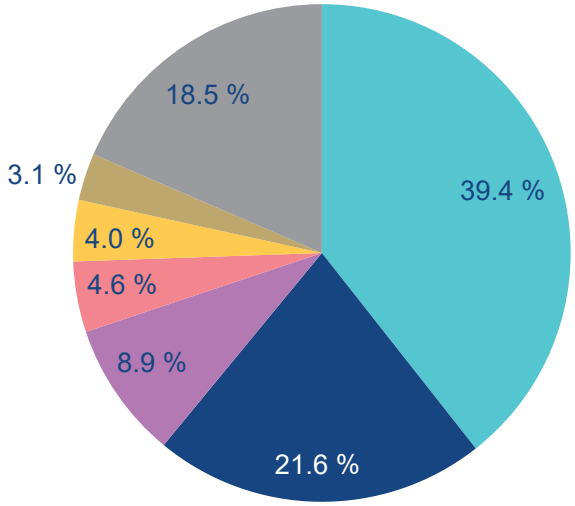


Fig. IV.7.9 Proportion of NFR sectors to total SO_2 emissions, 2020

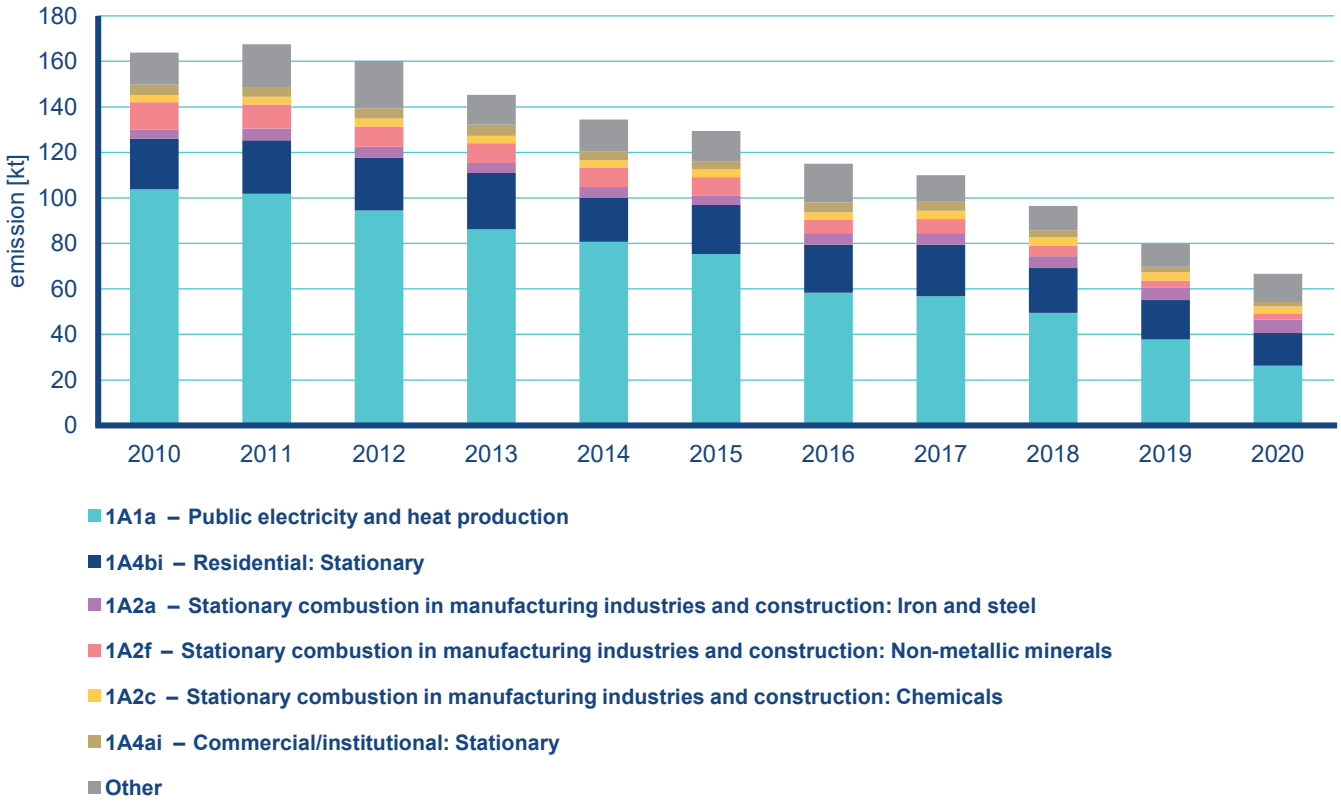


Fig. IV.7.10 Total SO_2 emissions, 2010–2020

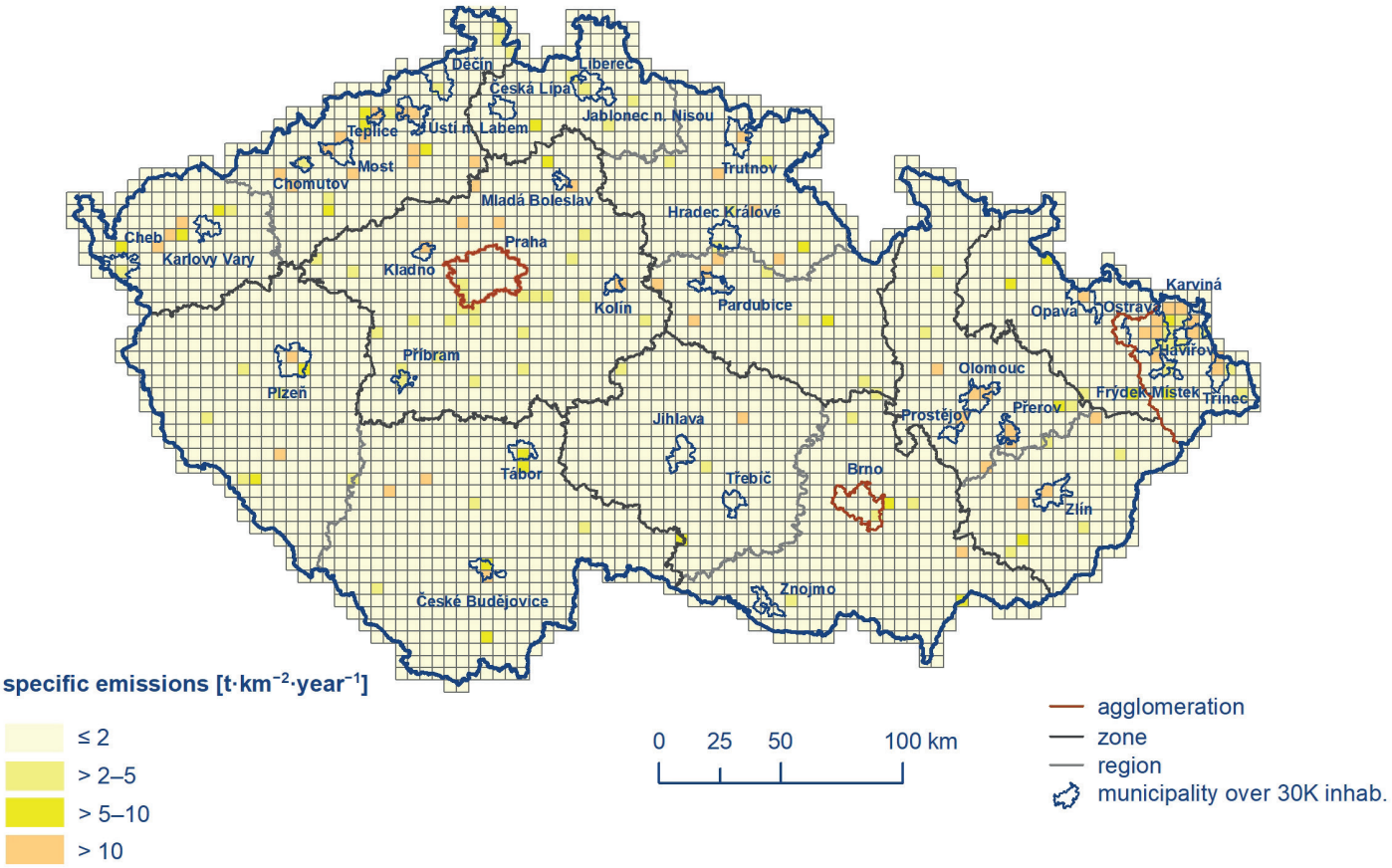


Fig. IV.7.11 Total SO_2 emissions in 5×5 km spatial resolution squares, 2020

IV.8 Carbon monoxide

IV.8.1 Air pollution by carbon monoxide in 2021

Similar to previous years, the 8-hour pollution limit value for carbon monoxide (CO) was not exceeded in the CR in 2021 at any of the total 21 stations with sufficient amount of measured data available for air quality assessment. The highest daily 8-hour average CO concentration occurred at the Tobolka-Čertovy schody rural station (6 863 $\mu g \cdot m^{-3}$), whereas the pollution limit value is 10 000 $\mu g \cdot m^{-3}$. This locality has long been affected by emissions from the nearby Čertovy schody lime manufacturing facility. Taking into account only a single maximum reported at a station, then the second highest 8-hour CO concentration was measured at the Ostrava-Radvanice ZÚ station (3 987 $\mu g \cdot m^{-3}$). This station is in a very exposed locality affected by industry, traffic and local emission sources. The third, fourth and fifth highest 8-hour CO concentrations were measured at the Beroun (2 524 $\mu g \cdot m^{-3}$), Chotěbuz (2 434 $\mu g \cdot m^{-3}$), and Ostrava-Českobratrská (hot spot) (2 157 $\mu g \cdot m^{-3}$) traffic stations, where an impact from traffic emissions has a role due to the location of the stations near busy roads.

Elevated CO concentrations occur primarily at urban locations affected significantly by traffic, so measurements of this substance have continued at localities classified as traffic sites. At urban and rural background locations, CO concentrations fall well below the pollution limit values. An exception is the Tobolka-Čertovy schody station, where 8-hour CO concentrations reached in several cases almost 70 % of the air pollution limit in 2021.

IV.8.2 Trends in carbon monoxide concentrations

A decreasing trend in the maximum daily 8-hour CO concentrations can be seen at most stations in the CR, as shown in Fig. IV.8.1. In 2021, the decrease in CO concentrations continued at most stations (Ostrava-Radvanice ZÚ, Chotěbuz, Tábor, Ostrava-Hošťálkovice, Studénka, Praha 4-Libuš, Hradec Králové-Brněnská). On the contrary, there was an increase in CO concentrations at some stations (Tobolka-Čertovy schody, Ostrava-Českobratrská, hot spot, Ústí nad Labem-Všebořická, hot spot).

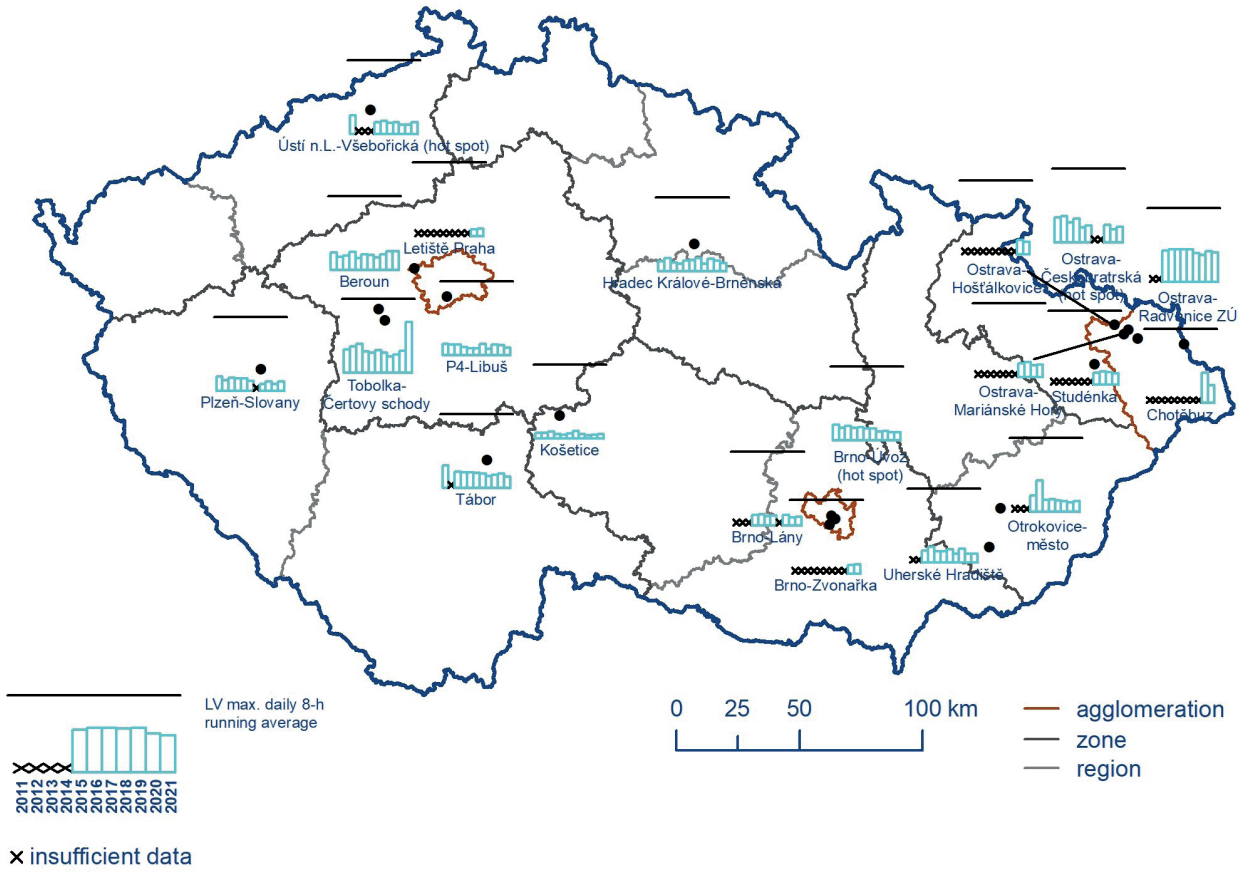


Fig. IV.8.1 Maximum hourly 8-hour running average concentrations of CO at selected stations, 2011–2021

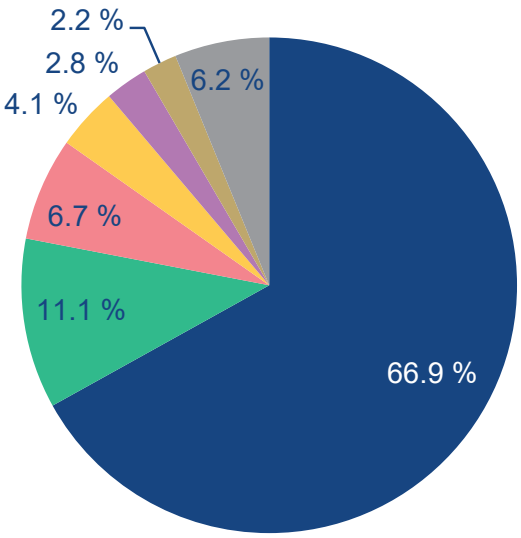


Fig. IV.8.2 Total emissions of CO sorted out by NFR sectors, 2020

IV.8.3 Carbon monoxide emissions

Carbon monoxide is a product of the combustion of carbon-containing fuels at low temperatures and insufficient availability of air for combustion. The greatest amounts of CO are formed in sector 1A4bi – Residential: Heating, water heating, cooking, which produced 66.9 % of national emissions in 2020. Other important sources included sectors 1A2a – Stationary combustion in manufacturing industries and construction: Iron and steel (11.1 %) and 1A3bi – Road transport: Passenger cars (6.7 %; Fig. IV.8.2). The decreasing trend in CO emissions in 2010–2020 (Fig. IV.8.3) was caused primarily by natural renewal of the vehicle fleet and a reduction in the production of iron and steel after 2011. In view of the predominant effect of sector 1A4bi, this trend is substantially affected by developments in the consumption of solid fuels by households (Fig. II.7).

For individual regions of the CR, contributions from sectors differ in relation to the composition of sources in a given area. Due to the predominant effect of local heating, CO emissions in the CR are distributed over the entire residential built-up area. The impact of transportation dominates alongside motorways, roadways with high traffic levels and in larger urban units. The large amount of CO emissions in the O/K/F-M agglomeration originates from the production of iron and steel (Fig. IV.8.4).

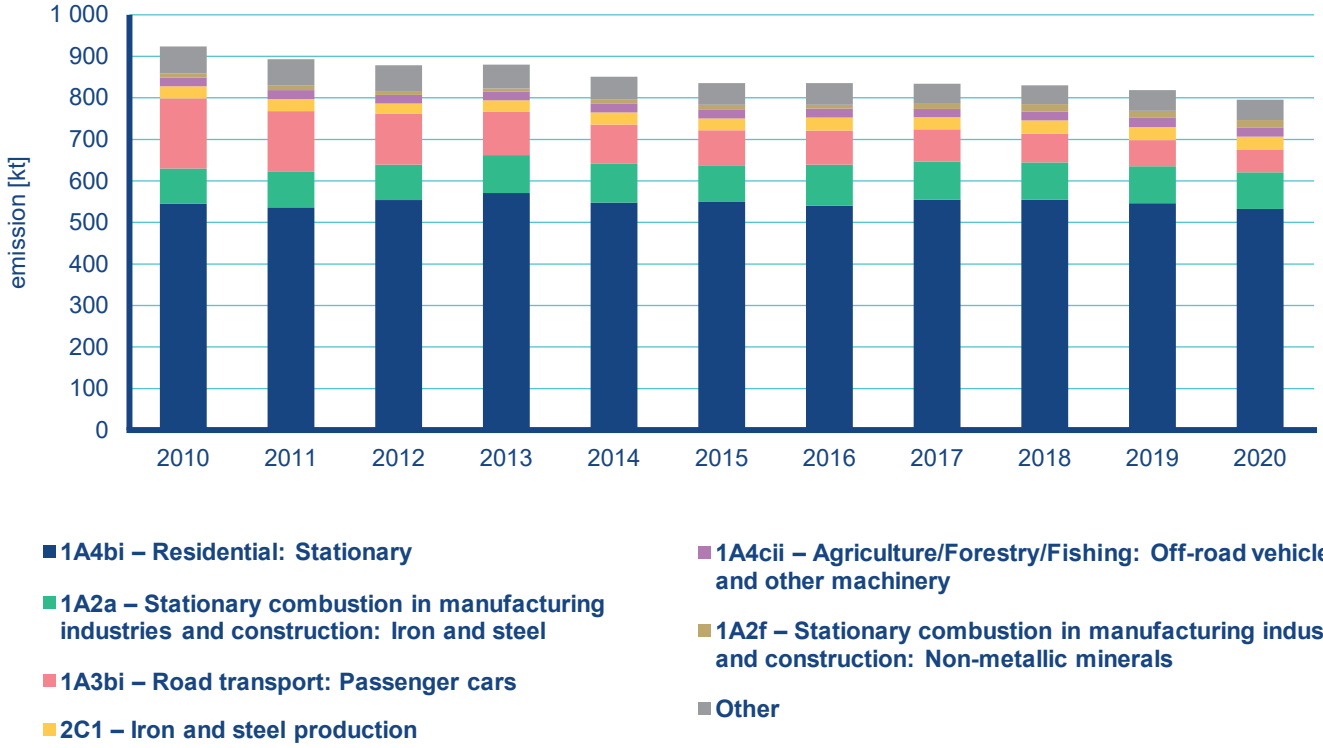


Fig. IV.8.3 CO total emissions, 2010–2020

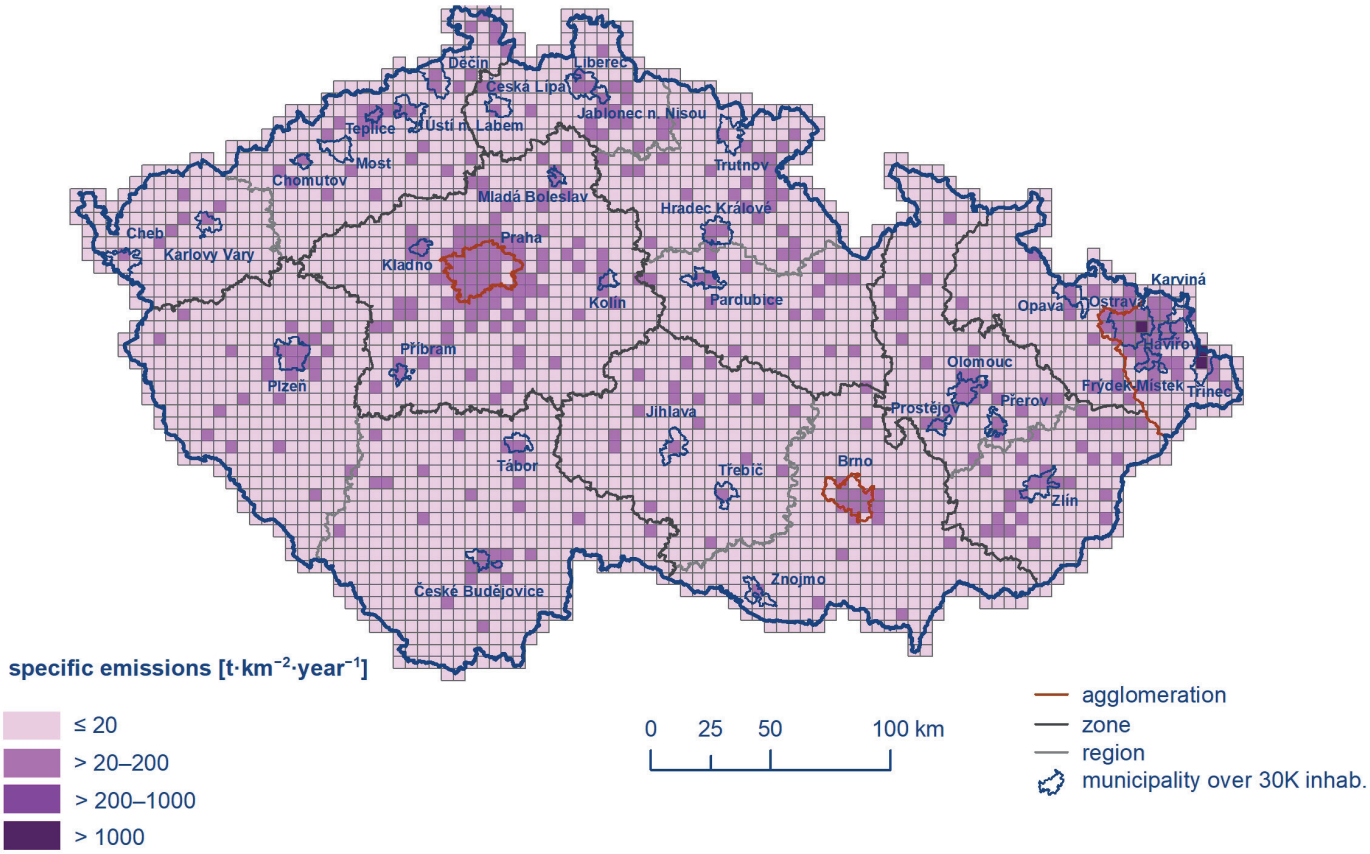


Fig. IV.8.4 CO total emission in 5×5 km resolution, 2020

IV.9 Pollutants without set limit values

IV.9.1 Volatile organic compounds

According to the Air Protection Act, a volatile organic substance is any organic compound or mixture of organic compounds, except methane, that has a vapour pressure of 0.01 kPa or more at 20 °C, or has a corresponding volatility under the specific conditions of its use. Volatile organic compounds (VOCs) play an important role in atmospheric chemistry and thus in the oxidation strength of the atmosphere, affecting the condition and quality of the air. Together with nitrogen oxides, VOCs play an important role in the process of the formation of ground-level ozone and other photo-oxidation pollutants. The conversion and decomposition of VOCs is usually initiated by reaction with a hydroxyl radical (Víden 2005). Because of the variability in the reactivity time of particular VOCs and their amounts, pollution limit levels have not been established for these substances.

Monitoring of VOCs was included in the EMEP programme on the basis of a decision by the EMEP Workshop on Measurements of Hydrocarbons/VOCs in Lindau in 1989 (EMEP 1990). Regular measurements at the Košetice Observatory were launched during 1992, and three years later were supplemented by identical measurements at the Prague-Libuš station. In the framework of EMEP, measurements were initially made at five stations; however, over 20 years the number of stations and range of measured hydrocarbons has changed several times. A homogeneous series of measurements has been maintained at the Košetice Observatory until the present. Since 2011, the Košetice Observatory has been involved in the ACTRIS project, carried out in the context of the EU 7th Framework Programme INFRA-2010-1-1.1.16: Research Infrastructures for Atmospheric Research. The successor ACTRIS-2 project, identified as H2020INFRAIA-20142015, followed on from this project and was implemented in the May 2015–April 2019 period. The subject of VOCs is part of the work of the Trace gases networking working group: Volatile organic carbon and nitrogen oxides, in an attempt to improve and harmonise VOC measurements in Europe. In the framework of the project, standard operational procedures were developed and the best measuring techniques for ensuring quality were tested. The CHMI laboratory regularly participated in a round-robin test, where the results of the analyses of VOCs confirmed that the laboratory has been complying with the recommended parameters of the GC system and has been meeting the required uncertainty values for all the substances in both standards and real samples. The ACTRIS-2 project was completed in 2019. VOC monitoring and research activities continue within the pan-European ACTRIS research infrastructure, which has been part of the Europe-

Tab. IV.9.1.1 Average annual concentrations of VOC in the ambient air at stations Košetice and Prague 4-Libuš

Volatile organic compound		Annual averge [µg·m^{-3}]									
		Košetice					Prague 4-Libuš				
		1995	2005	2010	2015	2021	1995	2005	2010	2015	2021
Alkane	etane	2.34	2.07	2.51	2.20	2.05	3.62	2.43	1.94	1.97	2.37
	propane	1.80	1.21	1.28	1.10	0.96	2.15	1.65	1.82	1.06	1.27
	butane	1.16	0.60	0.71	1.04	0.42	1.76	1.02	1.15	1.15	0.73
	2-methylpropane	0.68	0.37	0.47	0.32	0.30	1.14	0.80	1.03	0.45	0.59
	pentane		0.29	0.35	0.30	0.22	1.21	0.52	1.74	0.32	0.39
	2+3 - methylpentane		0.03	0.06	0.06	0.11	0.90	0.47	0.31	0.22	0.25
	hexane		0.09	0.11	0.07	0.08	0.60	0.16	0.18	0.09	0.13
	heptane		0.03	0.06	0.06	0.05	0.30	0.07	0.14	0.08	0.11
	oktane		0.02	0.05	0.10	0.04		0.06	0.09	0.11	0.08
Alkene	etene	1.28	0.77	0.55	0.55	0.64	2.52	1.32	0.45	0.62	0.94
	propene	0.32	0.15	0.16	0.12	0.14	0.68	0.34	0.30	0.14	0.23
	suma butene		0.14	0.20	0.18	0.20	0.87	0.42	0.38	0.26	0.38
	suma penetene		0.05	0.07	0.02	0.04		0.27	0.14	0.04	0.07
	isoprene	0.14	0.09	0.13	0.17	0.29		0.38	0.47	0.37	0.68
Aromatic hydrocarbon	benzene	1.05	0.42	0.58	0.41	0.46	1.51	0.62	0.72	0.42	0.62
	toluene	0.99	0.31	0.40	0.30	0.30	2.07	0.86	0.94	0.53	0.59
	ethylbenzene		0.06	0.06	0.19	0.11	0.42	0.19	0.18	0.27	0.15
	m,p-xylene		0.78	0.55	0.55	0.08	1.42	0.55	0.57	0.71	0.13
	o-xylene		0.05	0.04	0.29	0.05		0.16	0.14	0.35	0.06

an Strategy Forum on Research Infrastructures (ESFRI) activities since 2016. The average annual VOC concentrations at the Košetice Observatory and the Prague 4-Libuš stations over 26 years of monitoring exhibit a statistically significant decreasing trend, reflecting the decrease in VOC emissions both in the CR and also in the entire European area (Tab. IV.9.1.1). The trend in ethane concentrations is much stronger at the suburban station of Prague 4-Libuš than at the background station. The only exception is isoprene, which is of natural origin (emitted by deciduous trees) and exhibited an increasing trend at both stations. At the Praha 4-Libuš station, we even register a slight increase in concentrations. In general, it can be stated that suburban concentrations of the main VOCs in the 1990's were approx. 1.5–2 times higher than at the background station. The differences between the two stations have decreased substantially in the past decade. The results obtained in 2021 do not in any way deviate from the long-term trends (Tab. IV.9.1.1). The annual variation in most VOC concentrations reflects emission levels, and thus maximum values in the winter and minima in the summer, with the situation for isoprene being opposite (Fig. IV.9.1.1).

It follows from the report on VOC measurements in the context of the EMEP (Solberg et al. 2018) that VOC concentrations are continuously decreasing on a regional scale and thus reflect the decreasing trend in emissions. Concentration levels at the Košetice Observatory are comparable with those at German, Swiss and French stations The Czech station has long been characterised by lower annual average ethane concentrations. For most VOCs the concentrations measured in the winter are usually similar to those at German stations, while the values at the Košetice Observatory are slightly lower in the summer.

The Geneva Protocol concerning the Control of Emissions of Volatile Organic Compounds or their Transboundary Transmission was adopted in November 1991, and came into effect in September 1997 (UN-ECE 1991). The Protocol contained three options for reducing VOCs:

1. A 30 % reduction in VOC emissions by 1999, where the base values used were those for 1984 and 1990;

2. The same reduction as under (1), with the provision that the overall national emissions in 1999 do not exceed the 1988 level;

3. Where 1988 emissions did not exceed the set limits, countries could adopt the 1999 level as the emission ceiling.

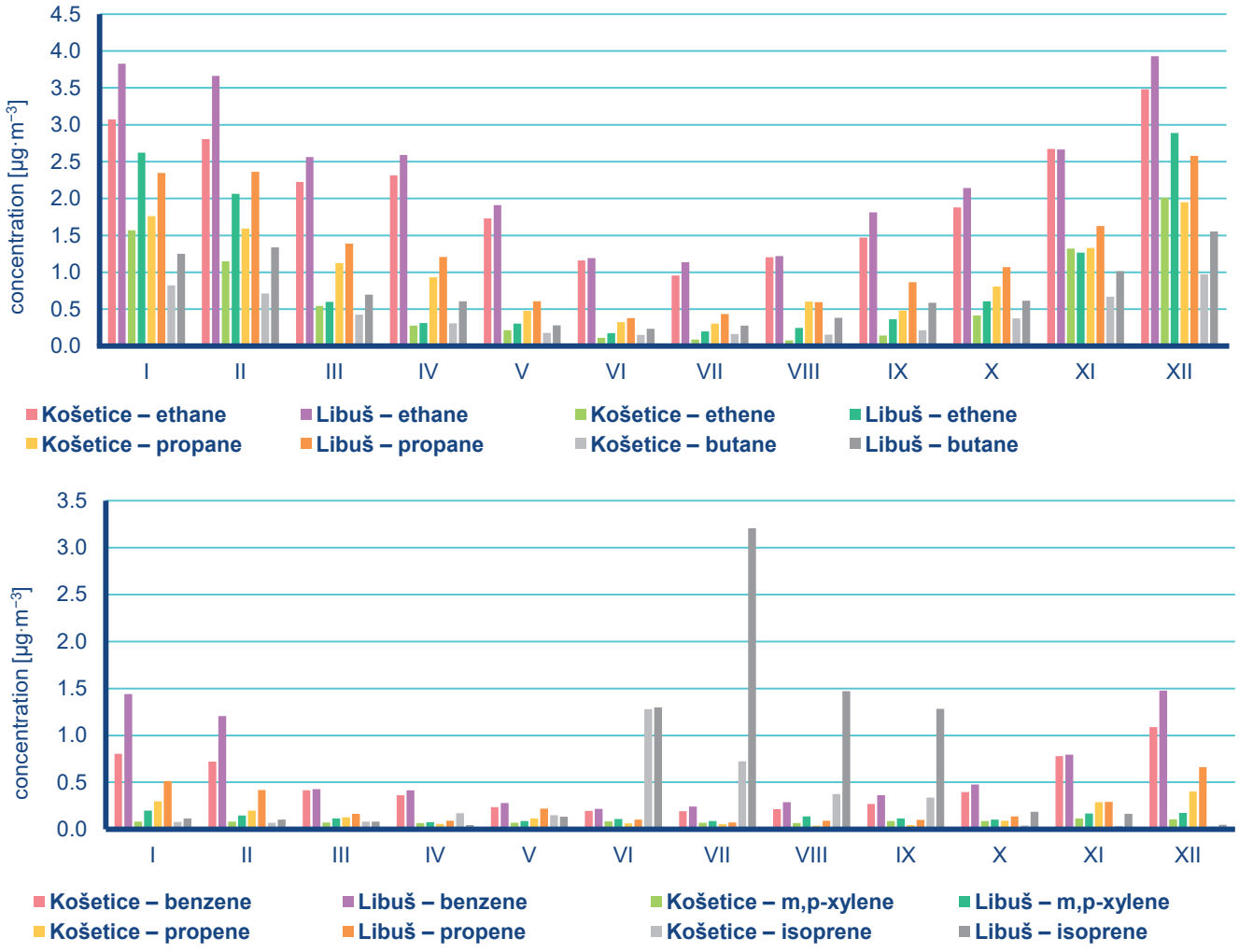


Fig. IV.9.1.1 Annual course of average monhtly concentrations of VOC, 2021

In 1999, the Göteborg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone was adopted, and came into effect on 17 May 2005 (UN-ECE 1999). The Protocol contains the emission ceilings for 2010 for four pollutants including VOCs. According to the Protocol, European VOC emissions were to be reduced by at least 40 % compared to 1990. The CR, similarly to most Central European countries (except Poland), has fulfilled this limit – VOC emissions in the CR decreased by 51 % in the 1990–2010 period (EEA 2013c).

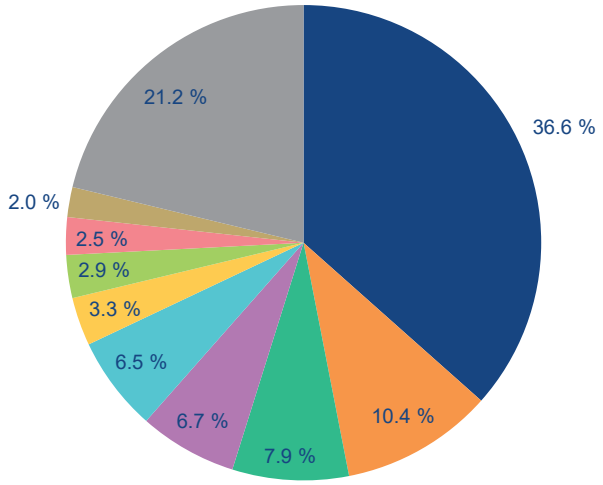


Fig. IV. 9.1.2 Share of NFR sectors in total emissions of NMVOC, 2020

Emissions of volatile organic compounds

Chemical products containing NMVOCs are used in a wide range of applications in households and industry as cleaning agents, solvents and degreasing agents. They can find use as components of paints, varnishes, adhesives and pharmaceutical products. NMVOCs are released during the storage and use of petroleum products. They are also formed during incomplete combustion.

In 2020, the largest amount of NMVOC emissions (Fig. IV.9.1.2) originated from the sector 1A4bi – Residential: Heating, water heating, cooking (36.6 %). The proportion of transport, including evaporation from the fuel system of vehicles, was 5.4 %. Significant sources of NMVOC emissions in the CR belong to the sector of the use and application of organic solvents (NFR 2D3), which contributed 26.6 % of the air pollution from these substances. This sector encompasses activities 2D3a – Domestic solvent use including fungicides (6.5 %), 2D3d – Coating applications (10.4 %), 2D3e – Degreasing (2 %), 2D3f – Dry cleaning (0.02 %), 2D3g – Chemical products (2.9 %), 2D3h – Printing (1.5 %) and 2D3i – Other solvent use (2.9 %). Some of these emissions are released into the air in a controlled manner, but a substantial proportion escape into the air in the form of fugitive emissions, which are difficult to control. Another significant sector producing NMVOC emissions is agriculture with a total proportion of almost 19 %. Among other sectors, e.g., emissions from combustion processes in the production of electricity, fugitive emissions in the transformation of solid fuels or in the food production are relevant. Due to a lack of data, the output for 2020 does not include the expected increase in emissions from disinfectants used during the

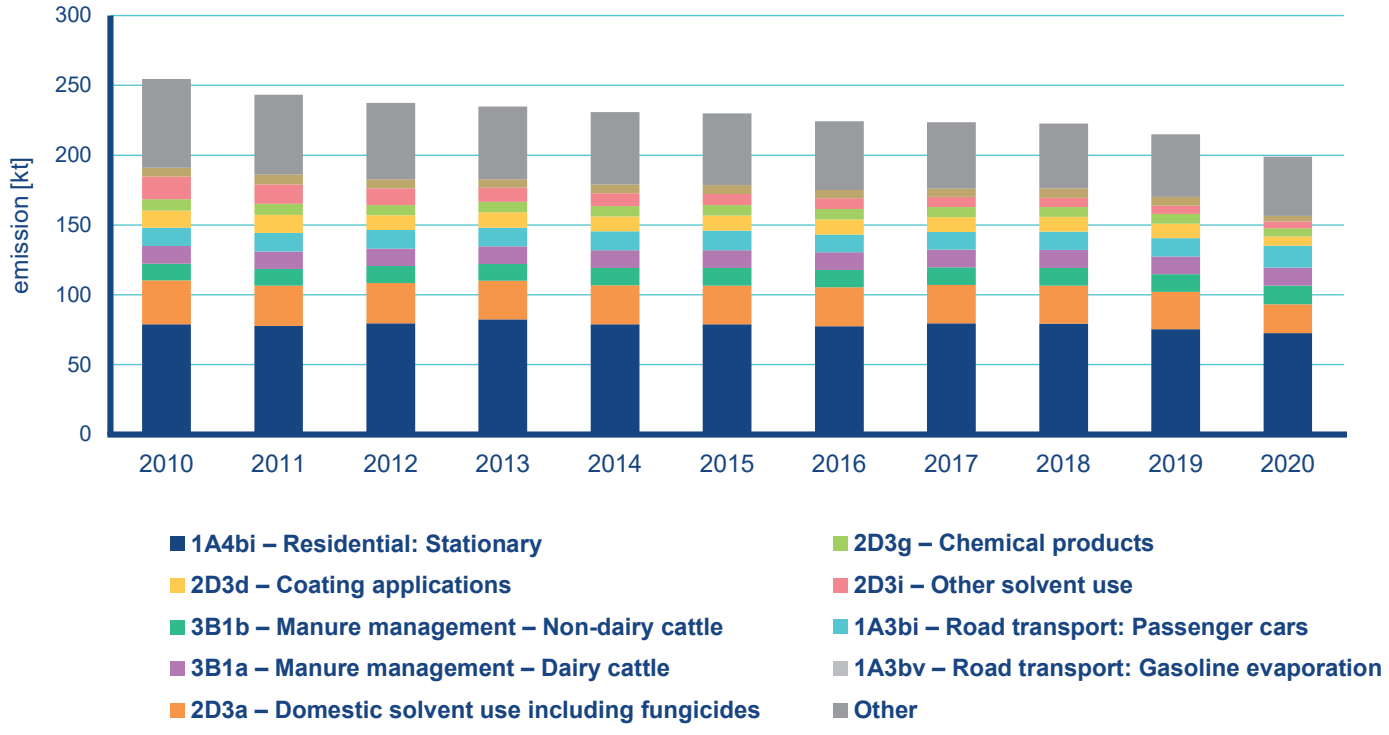


Fig. IV. 9.1.3 Total emissions of NMVOC, 2010–2020

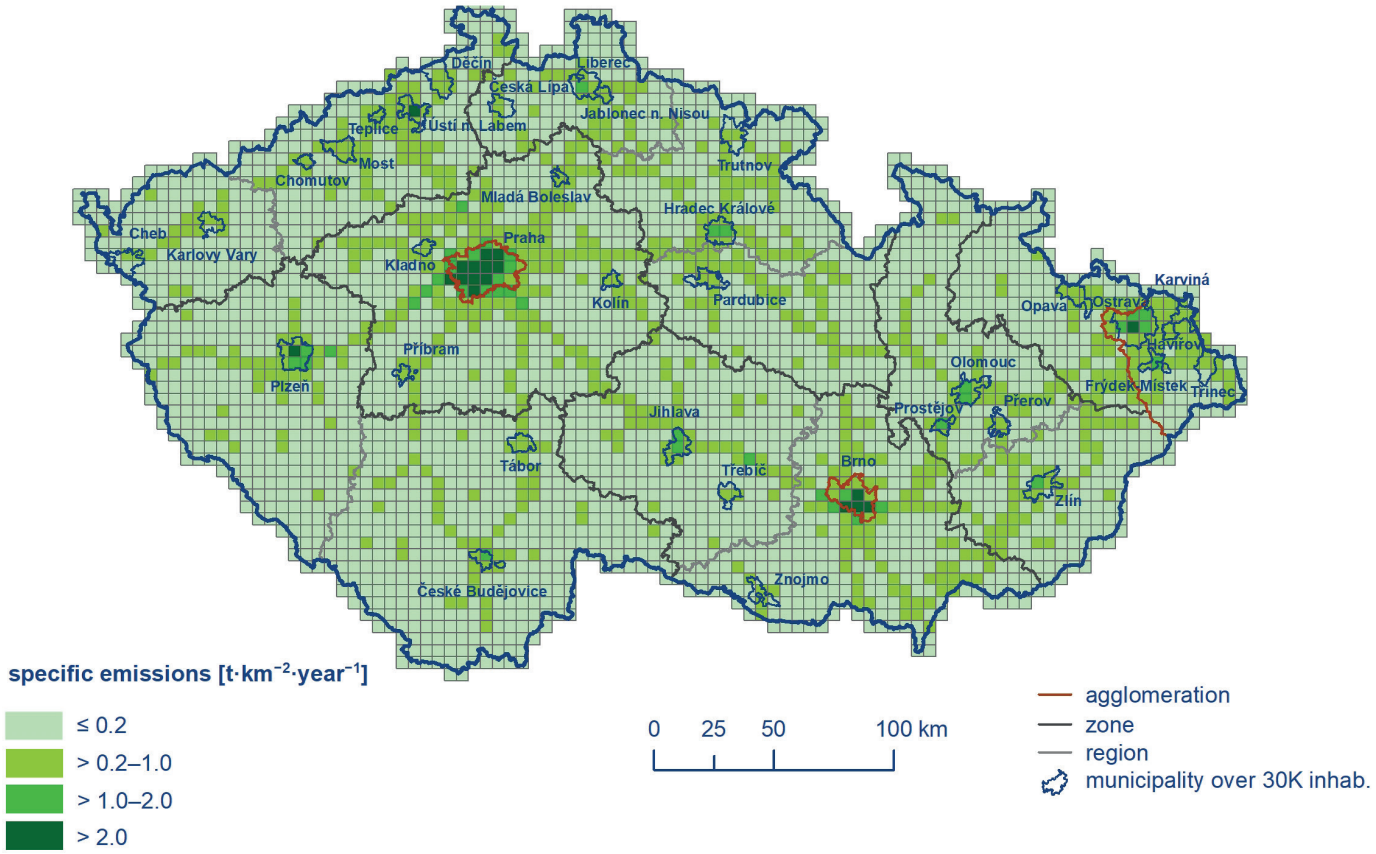


Fig. IV. 9.1.4 VOC total emission in 5×5 km resolution, 2020

SARS-CoV-2 pandemia. It is assumed that results of foreign studies will be used to update the emissions inventory for 2020 and the new inventory for 2021.

Total NMVOC emissions in the 2010–2020 period exhibited a decreasing trend (Fig. IV.9.1.3), caused by the use of products with lower volatile organic compound contents, e.g., water-based paints and plastic powders. Legislative regulations govern the retail packaging of paints, limiting the maximum solvent contents in products placed on the market. The ongoing renewal of the vehicle fleet has resulted in continuous reductions in NMVOC emissions from transport.

The proportion of individual types of sources in total emissions varies according to the specific composition of sources in a given area. In addition to areal emissions from household heating, the production of NMVOC emissions is concentrated, among other locations, along motorways, roads with intensive traffic, in large cities, and regions where more important energy and industrial production facilities are located (Fig. IV.9.1.4).

IV.9.2 Measurement of the numerical size distribution of aerosol particles

The numerical size distribution of aerosol particles is measured within the Czech Hydrometeorological Institute (CHMI) in the ultrafine particle network consisting of five basic stations: Hradec Králové-Brněnská, Lom, Mladá Boleslav, Plzeň-Slovany and Ústí nad Labem-město. Thanks to the long-term cooperation of the CHMI with the Institute of Chemical Process Fundamentals of the Czech Academy of Sciences (ICPF CAS), data from experimental measurements of the particle number size distribution from the Košetice observatory are also available. These measurements are part of the ACTRIS European Research Infrastructure monitoring network (Aerosols, Clouds, and Trace gases Research Infrastructure Network). Since 2016, this type of measurements has also been supported by ACTRIS-CZ, the Czech part of the large infrastructure research project, which also focuses on the Košetice locality. For operations involving research activities of the CHMI,

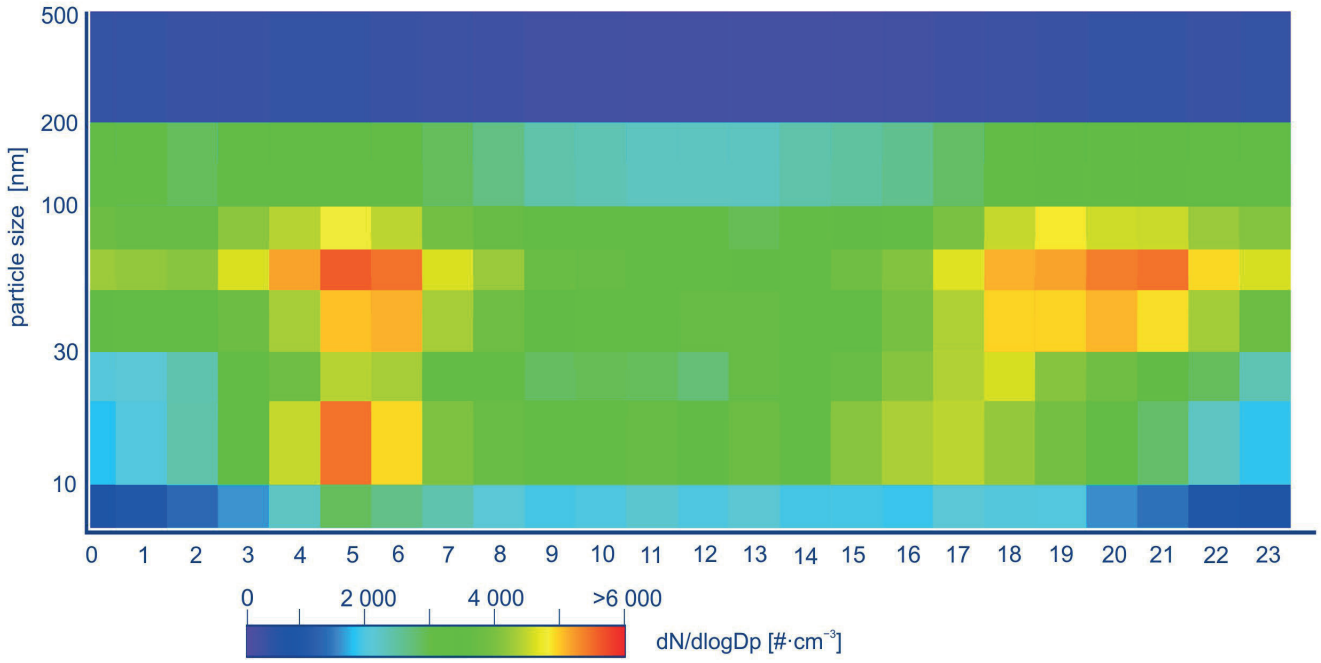


Fig. IV.9.2.1 Median spectrum of the daily progression of the number of particles, Hradec Králové-Brněnská, 2021

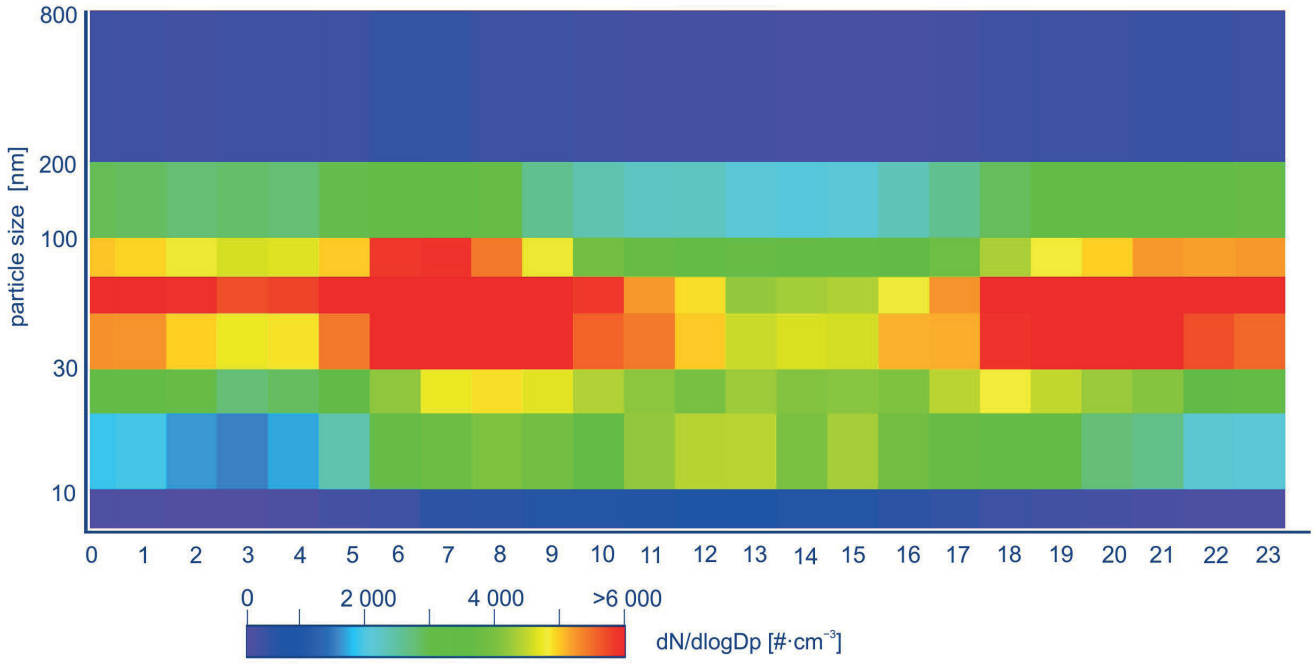


Fig. IV.9.2.2 Median spectrum of the daily progression of the number of particles, Lom, 2021

two institutes of the Academy of Sciences of the Czech Republic, and Masaryk University, a collective designation of the locality is used, namely the National Atmospheric Observatory Košetice (NAOK).

In the daily spectra measured at six localities (Hradec Králové--Brněnská, Lom, Mladá Boleslav, NAOK, Plzeň-Slovany and Ústí nad Labem-město) the differences in the number of particles in different size categories are detectable, which reflect the character of the localities. While the median spectrum from the NAOK station in the Vysočina region is rather affected by long-distance transport, at other stations, the influence of local sources (e.g., transport, industry) of anthropogenic origin can be identified. Despite some differences, the spectra can be described using common features. The highest concentrations of the number of particles are usually observed in the late evening, night and early morning hours. This phenomenon is probably associated with the development of an atmospheric boundary layer altitude and its stability during the night hours. This can lead to an accumulation of pollutants, and therefore aerosol particles, during the night.

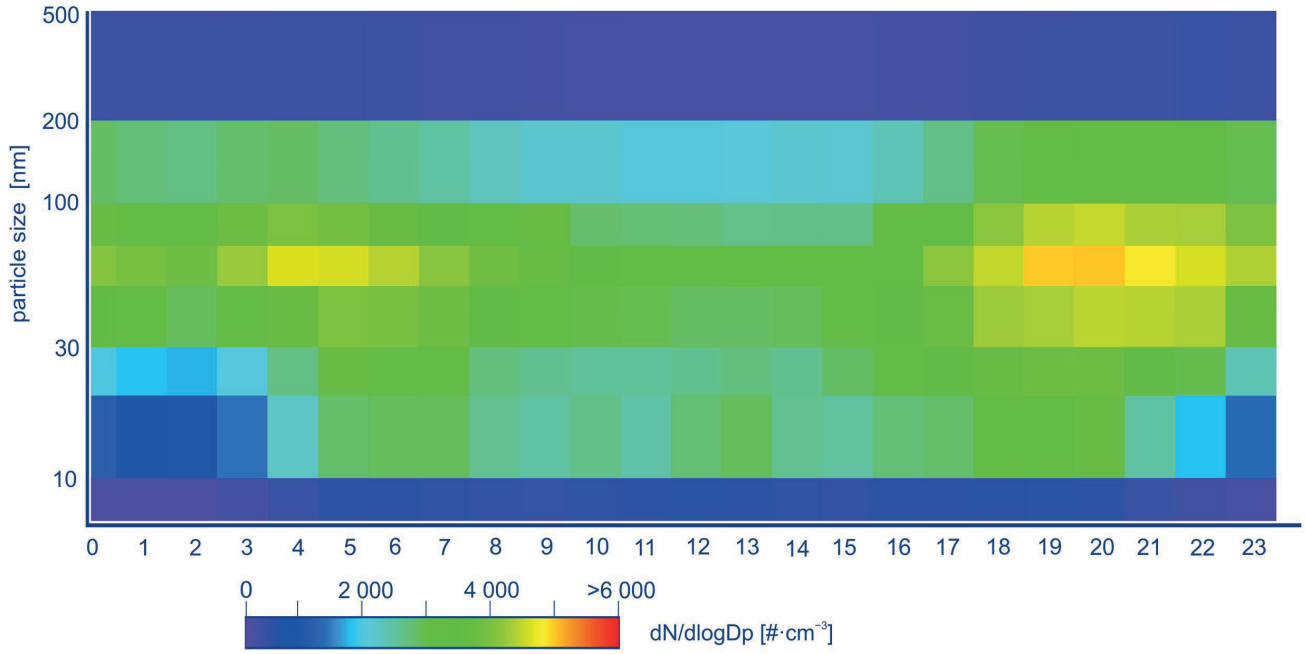


Fig. IV.9.2.3 Median spectrum of the daily progression of the number of particles, Mladá Boleslav, 2021

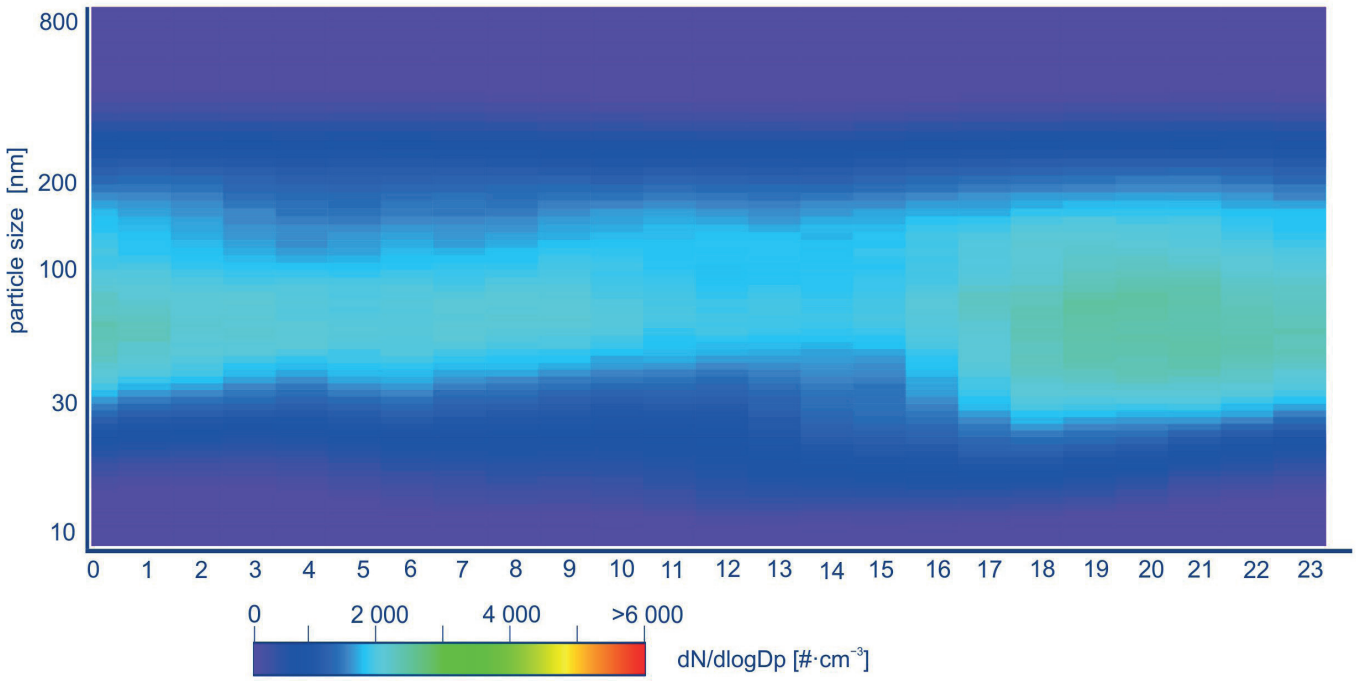


Fig. IV.9.2.4 Median spectrum of the daily progression of the number of particles, NAOK, 2021

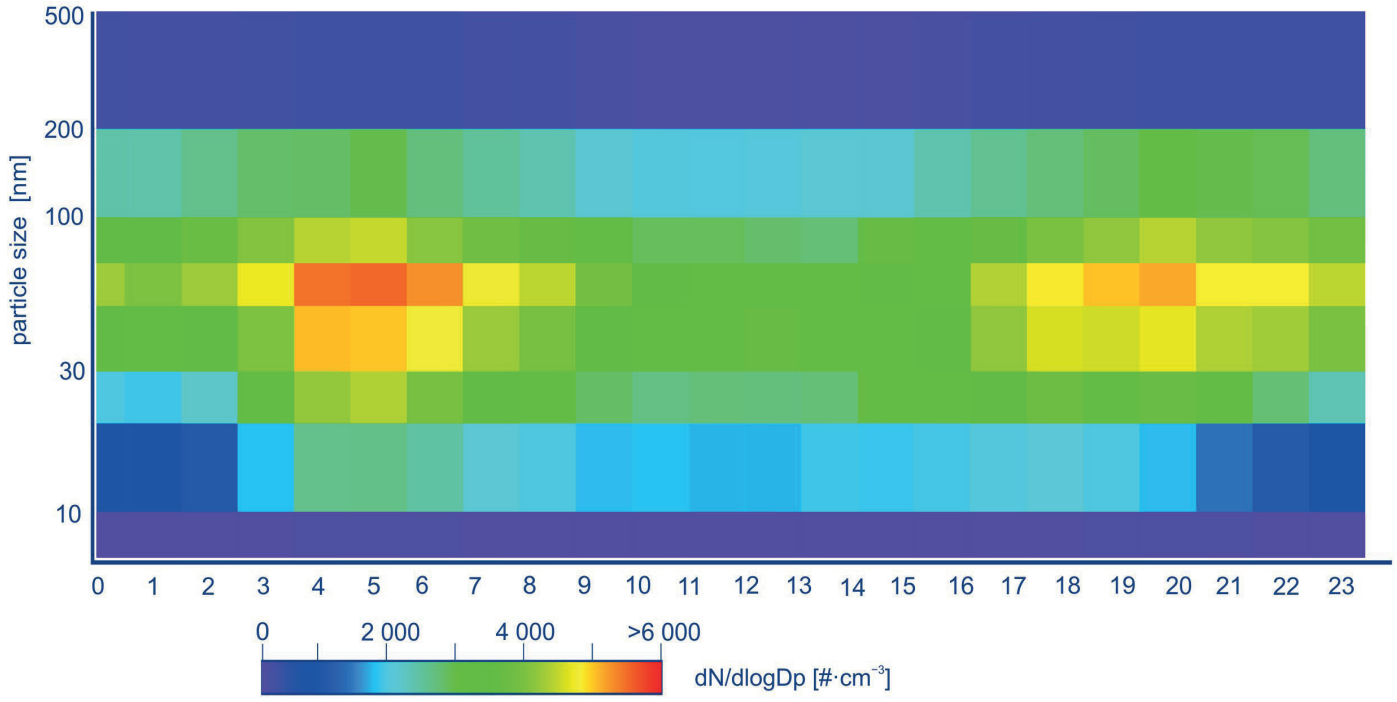


Fig. IV.9.2.5 Median spectrum of the daily progression of the number of particles, Plzeň-Slovany, 2021

After sunrise, an increase in photochemical reactions between accumulated substances can be observed, which can lead to the formation of secondary aerosols.

The impact of human activities in the form of increased traffic is evident at all stations except NAOK. The increasing number of particles in the morning and afternoon hours in all parts of the spectrum reflects not only the traffic peak but also the increasing occurrence of combustion products from industrial and local heating sources. These sources are associated with increased production of both particles and their gaseous precursors, from which secondary particles can be formed by photochemical processes. The most pronounced increase in particles is between 30 and 100 nm, which reaches a maximum between 4 and 10 h in the morning (Figs. IV.9.2.1, IV.9.2.2, IV.9.2.3, IV.9.2.5 and IV.9.2.6)[1]. At the Mladá Boleslav station a relatively stable number of nucleation mode particles (particle size up to 20 nm) has been observed after their increase in the morning hours, which may indicate a constant source of these particles during a day, whether of primary or secondary origin (Fig. IV.9.2.3). A continuous increase of nucleation mode particles has been observed between 10 and 18 h at the Ústí nad Labem-město (Fig. IV.9.2.6). At the Lom station, an increase in nucleation mode particles has been observed between 11 and 16 h (Fig. IV.9.2.2). This pattern of particle number evolution may be affected by industrial sources from the chemical industry and the topography of the local terrain.

In addition to emission sources and other processes in the atmosphere, changes in numerical concentration are also influenced by the stability of the atmosphere. While the atmosphere is well mixed during the day due to turbulent flow, the atmosphere becomes more stable in the evening when turbulence subsides (Stull 2003).

The median daily particle size spectrum in 2021 was, as in previous years, less distinct at NAOK compared to other measurements. Relatively constant concentrations of Aitken mode particles (20–100 nm) can be observed, which decrease slightly during the day (between 10:00 and 14:00 UTC) due to atmospheric dilution. On the contrary, the numbers of nucleation mode particles increase from the morning and reach a maximum after 17 h. The increase in the number of nucleation mode particles is probably associated with the process of particle formation and their subsequent growth to larger sizes. At NAOK, the effect of long-distance transport of particles in the form of relatively stable accumulation mode concentrations, and the effect of dilution and stability of the atmosphere on the concentrations of particles, can be well observed (Fig. IV.9.2.4).

1 The dN/dlogDp unit denotes the normalized number of particles in a given size category. The distribution of the number of aerosol particles does not correspond to a symmetrical normal distribution, therefore a logarithmic transformation is used to display the aerosol spectrum to obtain a log-normal distribution (Hinds 1999). The Y-axis indicates the nano-meter particle size categories of aerosol particles, the colour scale shows the number of particles in a given size category (the number of particles increases from cold to warm colours).

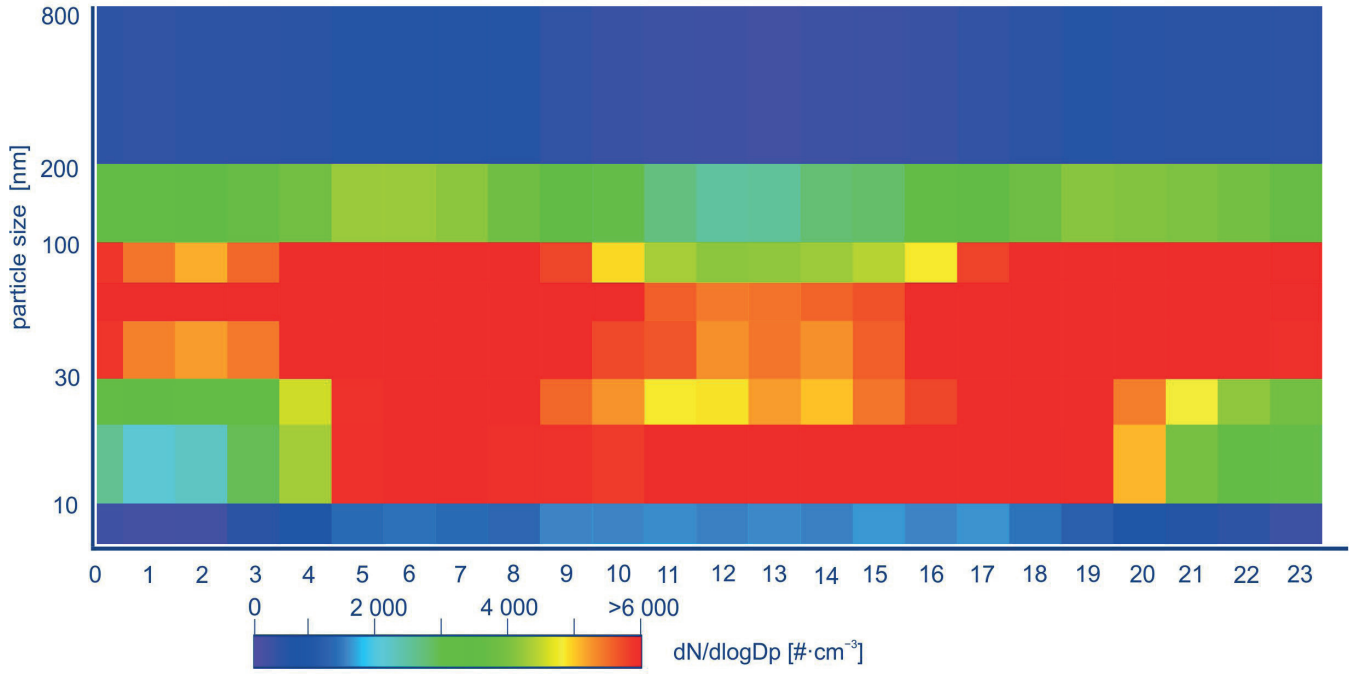


Fig. IV.9.2.6 Median spectrum of the daily progression of the number of particles, Ústí nad Labem-město, 2021

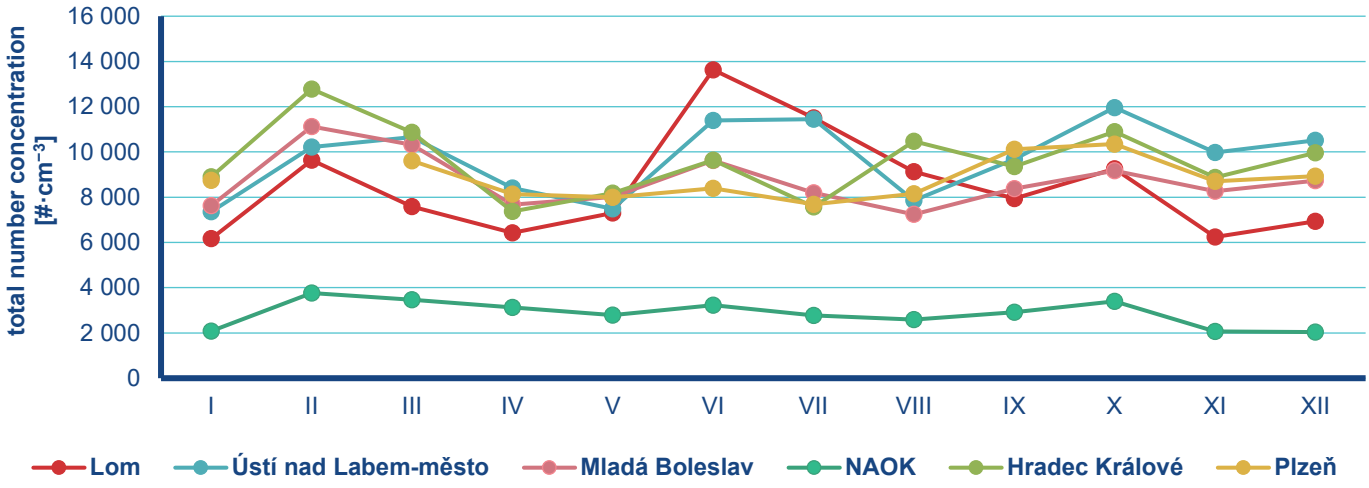


Fig. IV.9.2.7 Average monthly variability of the total particle number concentration Hradec Králové-Brněnská, Lom, Mladá Boleslav, NAOK, Plzeň-Slovany a Ústí nad Labem-město, 2021

The annual variability of the total number of particles is similar for the Hradec Králové-Brněnská, Mladá Boleslav, Plzeň-Slovany, and Ústí nad Labem-město stations. Higher values (in the range of 7 370–12 780 particles·cm^{-3}) were recorded at the Hradec Králové-Brněnská station, while the lowest variability among these stations was measured at the Mladá Boleslav station (7 687–10 350 particles·cm^{-3}). The annual course of the total number of particles at these stations was also similar at the NAOK station (range of values 2 038–3 764 particles·cm^{-3}). The Hradec Králové-Brněnská, Mladá Boleslav and NAOK stations had the highest total concentrations measured in February, the Plzeň-Slovany and Ústí nad Labem-město stations recorded a maximum in October. At the Lom station, the highest average number of particles was measured in June, namely 13 633 particles·cm^{-3} (Fig. IV. 9.2.7).

IV.9.3 Monitoring concentrations of elemental, organic and black carbon

The first regular measurements of elemental and organic carbon (EC, OC) in the CR were launched in February 2009 at the Košetice Observatory (OBK). The average concentration of total carbon (TC) in 2009–2021 in the sampled $PM_{2.5}$ fraction was 3.2 μg·m^{-3}, of which EC was 0.4 μg·m^{-3} and OC 2.8 μg·m^{-3}. In 2021, the highest average concentration of TC (5.7 μg·m^{-3}) was measured in February. In February, the average air temperature was 0.0 °C, which was the second lowest average temperature recorded in 2021 (the lowest average temperature of –1.4 °C was recorded in January). In 2021, the average TC concentration was 2.9 μg·m^{-3}, only 0.1 μg·m^{-3} higher than in 2020. The average annual EC concentration in 2021 was 0.3 μg·m^{-3} and the OC concentration reached 2.6 μg·m^{-3}. Overall, considering the trend in concentrations during the period of measurements, a slightly decreasing trend can be identified despite the increase in average annual concentrations in some years. While EC concentrations have been gradually decreasing since the beginning of measurements (2009 – 0.6 μg·m^{-3}), in 2012, 2013, and 2018, concentrations again increased. After the renewal of measurements in 2016, the annual average concentrations were slightly above 0.3 μg·m^{-3}. A significant increase was recorded in 2018. A similar but more noticeable trend was also observed for OC. The highest average value was observed in 2013 (3.7 μg·m^{-3}), while the lowest OC concentration was characteristic for 2016 (2.0 μg·m^{-3}) (Fig. IV.9.3.1).

Black carbon (BC) concentrations are measured at stations within the network of ultrafine particles – Hradec Králové-Brněnská, Lom, Mladá Boleslav, Plzeň-Slovany and Ústí nad La-

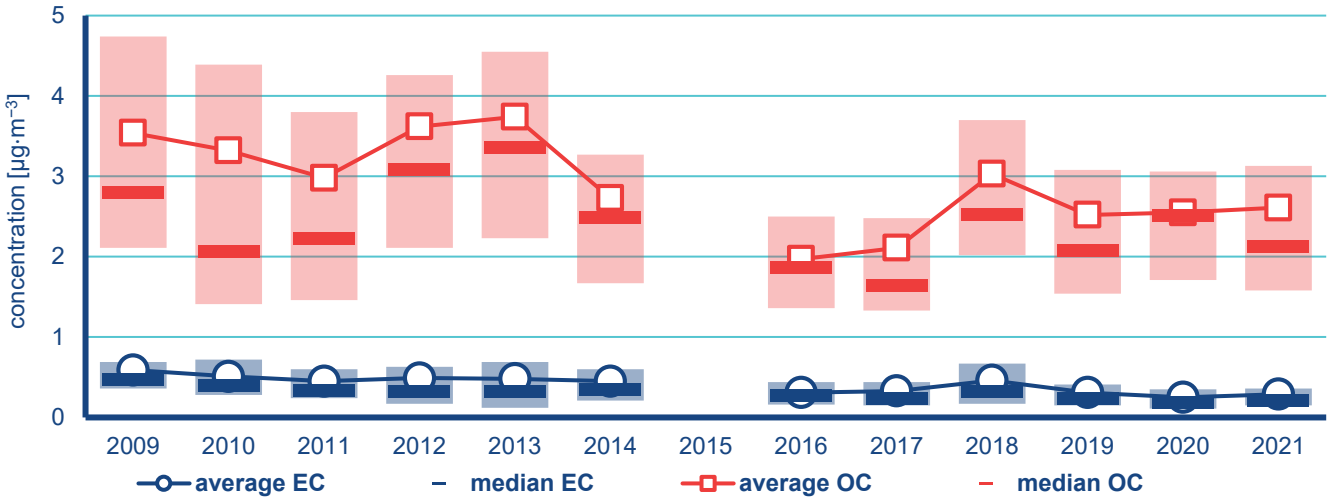


Fig. IV.9.3.1 Annual average concentrations of EC and OC, Košetice Observatory, 2009–2021
Note: The range of daily values is indicated by the top/bottom border of the boxes representing the value of 75th and 25th percentile respectively; the horizontal line indicates the median.

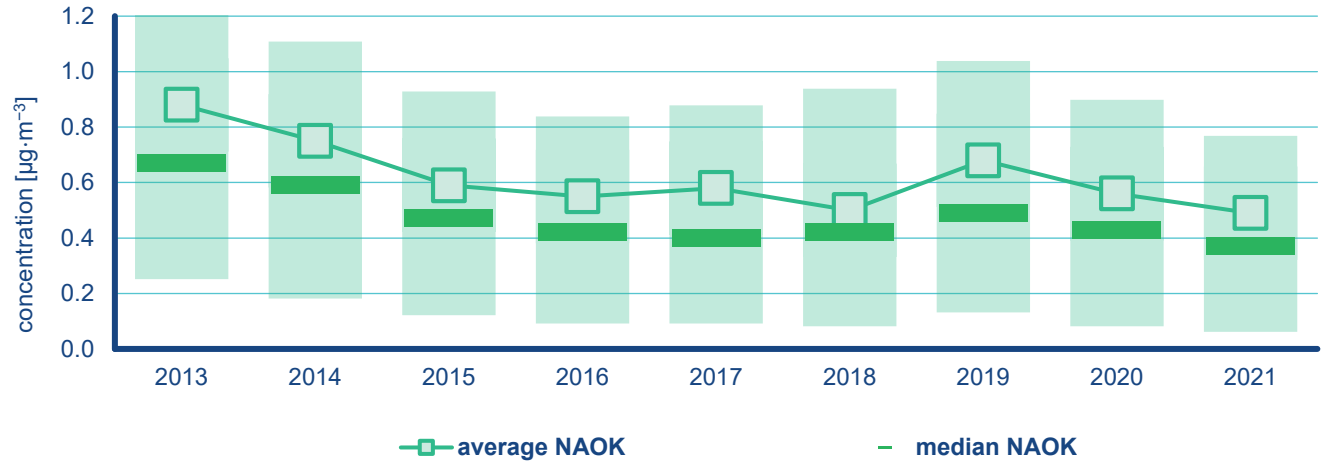


Fig. IV.9.3.2 Annual average concentrations of BC, NAO košetice, Lom, Ústí nad Labem-město, 2013–2021
Note: The range of daily values is indicated by the top/bottom border of the boxes representing the value of 75th and 25th perectentile respectively; the horizontal line indicates the median.

bem-město, and further at the National Atmospheric Observatory Košetice (NAOK)[1], where the Košetice Observatory represents the core station. Instrumentation was replaced in 2021 at some stations of the ultrafine particle network. Due to the need to test and set new coefficients required for data validation and verification, data from these stations are currently not available. Only data from the NAOK station, which is not part of the ultrafine particle network, and data from the Lom station are available. The other stations will be verified after the software for data processing from the new devices is completed, and relevant data will be added to the AQIS database. The annual variability of BC concentrations reflects higher amounts of emissions produced during the heating season, as increased values are recorded during the cold part of the year. Apart from the heating season, weekly maxima can be identified namely due to traffic. Another source of BC in the summer months are barbecues. The average annual concentration of BC at NAOK decreased from 0.9 $\mu g \cdot m^{-3}$ in 2013 to 0.5 $\mu g \cdot m^{-3}$ in 2021. The variability of the measured values was the lowest in 2021 (1st and 3rd quartiles reached 0.2 $\mu g \cdot m^{-3}$ and 0.6 $\mu g \cdot m^{-3}$, respectively); in the previous year the variability was slightly higher, as was the average concentration in 2019 (0.6 $\mu g \cdot m^{-3}$) (Fig. IV.9.3.2).

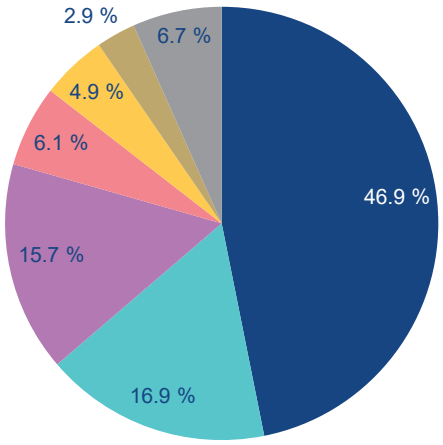


Fig. IV.9.3.3 Share of NFR sectors in total emissions of BC, 2020

Based on the results of emission inventories in the CR in 2020, up to 45 % of BC emissions originated from mobile sources (CHMI 2022d), particularly from the combustion of fuel in diesel engines. Of this, the following sectors contributed the most to the total BC emissions: Agriculture, forestry, fishing: Off-road vehicles and other machinery (1A4cii) by 16.9 %, and Road transport: Passenger cars (1A3bi) by 15.7 %. Of stationary sources, the highest BC emissions were produced in the sector Residential: Heating, water heating, cooking (1A4bi) with a proportion of 46.9 % to total emissions (Fig. IV.9.3.3). Developments in total BC emissions in the 2010–2020 period can be characterized by a decreasing trend, particularly due to measures in the transport sector (Fig. IV.9.3.4)[2].

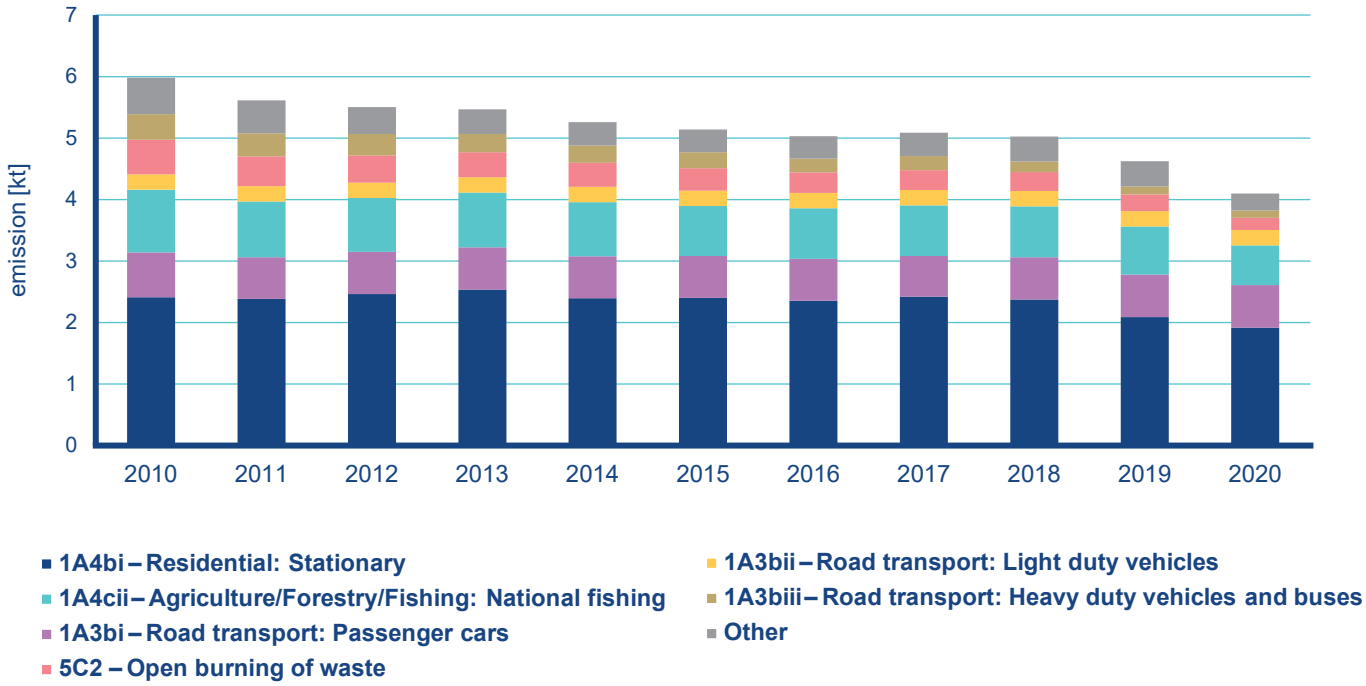


Fig. IV.9.3.4 Total emissions of BC, 2010–2020

1 The indication of the NAOK locality is used for measurements taken within the ACTRIS-CZ project. It is a part of research activities carried out by four partner organizations – the Czech Hydrometeorological Institute, the Institute of Chemical Process Fundamentals of the Czech Academy of Sciences, the Global Change Research Institute of the Czech Academy of Sciences, and the Masaryk University. The NAOK includes the Košetice Observatory and the facilities of the Atmospheric Mast.

2 The proportion of BC emissions by sectors has recently been recalculated and the results given in previous years may therefore differ.

V. AIR QUALITY IN REGIONS OF THE CZECH REPUBLIC

For assessing and evaluating air pollution levels, Act No. 201/2012 Coll., on air protection, divides the territory of the CR into zones and agglomerations, with zones consisting of one to three regions. This chapter deals with a more detailed assessment of air quality in regions of the CR, where a region means an administrative region, agglomeration, or the territory of an administrative region without an agglomeration. The following indicators are used for interregional air quality assessments: air quality index (Chap. V.II), the concentration of selected air pollutants weighted by population in regions of the CR and in cities with more than 30 000 inhabitants, the proportion of inhabitants living in areas with above-limit air pollution, and the proportion of the regional area exceeding air pollution limits (Chapter V.III). Characteristics of the regions focusing on effects related to air quality are supplemented by the composition of TSP, NO_x and SO_x emission sources in the given region (Figs. V.1.1, V.1.2, V.1.3).

V.1 Characteristics of regions

Agglomeration of Prague

In terms of air pollution, the capital of Prague ranks among the most polluted areas in the CR. This situation is a result of the interaction of a number of anthropogenic and natural factors. The location of Prague in the complex terrain of the Prague basin fundamentally affects the climatic and dispersion conditions in the territory (Ložek et al. 2005). Particularly in colder times of the year, suitable conditions appear in the Vltava River valley for the formation of temperature inversions, resulting in the accumulation of concentrations of harmful substances in the atmospheric ground layer.

The worsened air quality in Prague is mainly related to the heavy traffic load. Due to its location, Prague is not only the main hub of the road network in the CR, but is also an important hub for international transport. A large number of main transport roads go through the centre of Prague. The growth of the service sector and the associated construction of commercial and administrative centres have resulted in further demands on transport services and energy consumption, including heating.

The consumption of solid fuels for heating of family houses, especially in suburban parts of the city, and the growing popularity of the use of fireplaces and stoves (MHMP 2020) also have a significant impact on the current air pollution in Prague. On the contrary, only two boilers burning solid fuels remain included in the listed sources, using brown coal (NEXIMA Praha Řeporyje) and woodchips (FTV Lipence). The largest proportion of TSP and NO_x emissions comes from transport, with SO_x emissions mostly from household heating.

The most significant listed sources[1] of TSP emissions are permanent or temporarily operating recycling lines of construction wastes (e.g., KARE, Praha Chodovská) and the mining and processing of minerals (Českomoravský Cement – Radotín Plant, KÁMEN Zbraslav, or concrete plants). SO_x emissions are mostly produced by the Českomoravský Cement – Radotín Plant and KNAUF Praha companies, and to a lesser extent also by the NEXIMA coal boiler and Pražské služby – Malešice Incinerator. The most significant sources of NO_x emissions come from the Radotín Plant of Českomoravský Cement (more than 65 % of the listed sources emissions), and the Pražské služby, a. s. – Plant 14, Malešice Facility for Waste Energy Recovery. Other significant sources include Veolia Energie Praha, a. s. – Veleslavín Heating Plant and the operation of co–generation units burning sludge gas (Pražské vodovody a kanalizace, a. s., ÚČOV Praha 6) and landfill gas (TEDOM a. s. – Daewo–Avia Co–generation Heating Plant) are gradually increasing.

In terms of carbon monoxide emissions, the dominant proportion (more than 50 % of the total emissions from the listed sources) comes again from cement production (Českomoravský cement – Radotín Plant). As a result of the SARS-CoV-2 pandemia, NMVOC emissions from both important sources (Svoboda Press Printing House and Trelleborg Wheel Systems Czech Republic, Prague plant) decreased by about 20 % compared to 2020.

1 The sources listed in Annex No. 2 to Act No. 201/2012 on air protection are monitored individually, except for the livestock breeding category. Pursuant to Article 17(3)(c), the operators of these sources are obliged to keep operational records on permanent and variable data on a stationary source describing the source and its operation and data on inputs and outputs from this source (for more see CHMI 2022d).

Central Bohemia zone

Central Bohemia Region

The Central Bohemia Region is the largest region of the CR in terms of size, the number of municipalities, and population. The relief of the region is relatively featureless. The north and east are flat, while the south and south–west are dominated by highlands.

Air quality in the Central Bohemia Region has long been affected by the industrial character of the region; the key industries are mechanical engineering, chemistry and food production. The region has a dense transport infrastructure and high traffic intensity in connection with the Prague agglomeration (NO_x). There are dense residential areas using local heating. 40.7 % of the population live in municipalities with a population of up to two thousand (1 026 municipalities). The ratio of the urban population to the total population of the region was 51.7 % as of 31 December 2019, which was the lowest in the whole CR (CSO, 2020).

The most significant listed sources of TSP emissions include the production of electricity and heat (Energotrans Mělník, Kladno Heating Plant), ŠKODA AUTO – Mladá Boleslav Plant, ORLEN Unipetrol RPA – Kralupy Refinery and the mining or processing of minerals (Čertovy schody Lime Plant, SHB – Bernartice Quarry and other sources). SO_x emissions mainly come from the production of electricity and heat (Energotrans Mělník, Kladno Heating Plant – Kladno Power Plant, Veolia Energy Kolín – Kolín Power Plant) and industrial sources (e.g., ORLEN Unipetrol RPA – Kralupy Refinery). The most significant sources of NO_x emissions are also represented by sources producing electricity and heat (Energotrans Mělník, Kladno Heating Plant – Kladno Power Plant and Veolia Energy Kolín – Kolín Power Plant), and industrial sources (SPOLANA, KAVALIERGLASS Sázava Plant and ORLEN Unipetrol RPA – Kralupy Refinery).

The dominant proportion of other pollutants (approx. 55 % of the total emissions from listed sources) is represented by CO emissions from lime production (Čertovy schody Lime Plant), and by NMVOC emissions from car production (ŠKODA AUTO a. s. – Mladá Boleslav Plant and Toyota Peugeot Citroën Automobile Czech) and production of building materials (Styrotrade Čakovičky and TEMAC Zvěřínek) – together almost 50 % of the total emission of the listed sources.

South–western zone

South Bohemia Region

The South Bohemia Region is the second largest region in the CR by size, and at the same time it has the lowest population density in the entire country. The region represents a geographically relatively closed unit, the core of which is the South Bohemian Basin. The majority of the region lies at an altitude of 400 to 600 m a. s. l. About a third of the region's population lives in České Budějovice and in the four largest cities of the region.

The air quality of the South Bohemia Region within the CR can be evaluated as good. The mountain areas of the Šumava and Novohradské Mountains are among the least affected areas. Worse air quality can be expected in the České Budějovice agglomeration and in the centres of larger cities (Tábor, Písek, Strakonice), where the majority of industrial production in the region is concentrated. Road transport has an equally important effect on air quality in settlements.

The most significant listed sources of TSP emissions include sources producing electricity and heat (České Budějovice Heating Plant – Novohradská Street), the mining and processing of minerals (LB MINERALS – Borovany Branch and Kámen a písek – Plešovice quarry), and other industrial sources (Kasalova Sawmill – Jindřichův Hradec, DIAMO tailing pond, SUL Příbram – Mydlovary, and Aluprogress). The most significant sources of SO_x emissions include the REZZO 1–2 category sources, representing the production of electricity and heat (Strakonice Heating Plant, České Budějovice Heating Plant – Novohradská and Vráto, Písek Heating Plant, ZVVZ ENERGO Milevsko, Kaplice Technical Services – Municipal Heating Plant, Planá Power Plant, Tábor Heating Plant) and the most significant NO_x emission sources include also the production of electricity and heat (České Budějovice Heating Plant – Novohradská Street, Strakonice Heating Plant, C–Energy Planá, CARTHAMUS – Energoblok Domoradice).

Plzeň Region

The Plzeň Region is the third largest region in the CR in terms of area, but in terms of population it ranks eighth in the country. The Plzeň Region is characterized by diverse relief. The border mountains in the south–west (Šumava and Český les) dominate one side, in contrast to the Plzeň Basin in the north–east of the region. The region's topography is complemented by the central part formed by the Plzeň Uplands and partly by the Brdy Highlands.

The air quality of the Plzeň Region within the CR can be evaluated as relatively good. The least affected areas include the mountain areas of Šumava, Český les, western Brdy, and the area around the Manětín and Nečtiny municipalities. The situation is opposite in Plzeň and its surroundings, where specific emissions in the Plzeň–City District exceed the values of specific emissions in the CR by multiple times. Plzeň and its surroundings are affected by a high concentration of industrial activities and road traffic.

The Plzeň Region is characterized by a high number of small settlements with an uneven spatial distribution, but medium–sized cities are missing. The structure of the centres is atypical in comparison with the rest of the CR. Approximately 66.9 % of the total population of the region live in cities.

The most important listed sources of TSP emissions include industrial sources (LASSELSBERGER), the mining and processing of mineral resources (EUROVIA Quarries – Plzeň 6–Litice,

LB MINERALS – VJ Plzeňsko, Kaznějov and Horní Bříza Branch), and sources for electricity and heat production (Plzeňská teplárenská – Heating Plant). The most significant sources of SO_x emissions are represented by sources for electricity and heat production (Plzeňská teplárenská – Power Plant and Heating Plant, or Klatovská Heating Plant), and the most significant sources of NO_x emissions are also represented by sources for electricity and heat production (Plzeňská teplárenská – heating plant and power plant sites, Plzeňská teplárenská and ZEVO Plzeň) and other industrial sources (Pfeifer Holz and STOELZLE UNION).

North–western zone

Karlovy Vary Region

The Karlovy Vary Region is located in the westernmost part of Bohemia. The Karlovy Vary Region is the smallest region in the CR in terms of population, and the third smallest in terms of area. The region includes the Krušné hory mountain range and the terrain has a predominantly highland character.

Balneotherapy in spa facilities is a significant activity in the region. Another important economic sector is the mining of brown coal in the Sokolov region and kaolin in the Karlovy Vary Region. The chemical industry and energy production are located in the Sokolov area. There are also well–known glass and ceramic companies in the region. Light industry is mainly represented by the logging and wood processing industry, the production of parts for the automotive industry, and plastics production.

In terms of air pollution, the region can be divided into three areas. The first, the spa area, can be found in the southern part of the region. There is mainly light industry and food production in this area, with pollution mainly caused by local heating and transport. In the second area of the region, the chemical industry, a lignite mine, and the Vřesová and Tisová power plants are located. These contribute significantly to the pollution of the region, but the influence of light industry, including glassworks and ceramic plants, can also be identified. The third area includes the Krušné hory mountain range, where most of the pollution stems from local heating.

The most significant listed sources of TSP emissions include the production of electricity and heat (Sokolovská uhelná – Vřesová Processing Section and Tisová Power Plant), the mining and processing of coal and minerals (Sokolovská uhelná and Basalt CZ – Libá Processing Plant), and other industrial sources (Synthomer and Lias Vintířov). The most significant sources of SO_x and also NO_x emissions are again represented by sources for the production of electricity and heat (Sokolovská uhelná – Processing Section and Tisová Power Plant), and industrial sources (Lias Vintířov, O–I CR – Nové Sedlo and Synthomer Plants).

Ústí nad Labem Region

The Ústí nad Labem Region is located in northwestern Bohemia. The relief of the region is rather variable, ranging from the border ridge of the Krušné hory Mountains, through the volcanic Central Bohemian Uplands, the Elbe Lowlands, and down to the lowest point of the CR near the Hřensko municipality.

The economy of the region is specific for different parts of the region, ranging from agricultural areas in lowland localities, industrial areas, and mountain areas. In general, however, the economy of the region is characterized by a strong orientation towards heavy industry. Abundant deposits of brown coal have given rise to a coal energy processing industry. The strong pollution emission load of the region also stems from the presence of the largest Czech oil refinery, chemical and ceramic industries, and the processing of ferrous metals and copper. The food industry is also represented in the region, with viticulture and breweries, and agriculture. Light industry and local heating also contribute to the emission load of the region.

The geographical location of the Ústí nad Labem Region, which is further affected by emissions from surface lignite mines and thermal power plants, leads to the formation of inverse layers and the retention of emerging pollutants in the lower atmosphere. Thanks to desulphurisation and dust extraction of power plants and other industrial enterprises, pollution in the region is no longer as high as in the past, but the region is still loaded by higher concentrations of pollutants. This is one of the reasons why there are a larger number of stations for measuring ambient air pollution in the region.

The most significant listed sources of TSP emissions include electricity and heat production (Počerady Power Plant, ČEZ – Tušimice Power Plant, ČEZ – Ledvice Power Plant, ČEZ – Prunéřov 2 Power Plant), lignite and mineral resources mining (e.g., COLAS CZ Císařský Quarry), and industrial sources (e.g., Mondi Štětí – Cellulose Plant). The most significant sources of SO_x emissions are again represented by sources for electricity and heat production (Počerady Power Plant, ČEZ – Tušimice Power Plant, ORLEN Unipetrol RPA – T 700 Heating Plant, ČEZ – Trmice Heating Plant, United Energy – Komořany Heating Plant, ČEZ – Ledvice Power Plant, ČEZ – Prunéřov Power Plant), and industrial sources (e.g., AGC Flat Glass Czech – Řetenice Plant, and Lafarge Cement). The most significant sources of NO_x emissions are also represented by sources for electricity and heat production (Počerady Power Plant, ČEZ – Tušimice Power Plant, ČEZ – Ledvice Power Plant, ČEZ – Prunéřov 2 Power Plant, ORLEN Unipetrol RPA – T 700 Heating Plant), and industrial sources (e.g., ORLEN Unipetrol RPA – PETROCHEMIE plant).

Significant NMVOC emissions are produced during the processing of vegetable oils at the Viterra Czech and PREOL Company. NH_3 emissions originate from the production of mineral wool in the Knauf Insulation Company and glass in the AGC Flat Glass Czech – Řetenice Plant, or also from the denitrification process at the Počerady Power Plant.

North–eastern zone

Liberec Region

The Liberec Region is located in the very north of Bohemia, and its area is the second smallest after Prague. The relief of the region is rather variable – the Lužické and Jizera Mountains in the north, the Krkonoše Mountains in the north–east, and hilly areas in the middle and south of the region.

Air pollution in the Liberec Region is low, and there are no significant sources of heavy industry. The mining of glass and building sands and gravel and the quarrying of building stone, light industry (glassmaking, rubber industry, jewellery production and mint), the food industry, and local heating significantly contribute to the pollution in the region. A significant source of air pollution by cadmium is the glass industry in Desná and its surroundings (for more details see Chapter IV.6).

The most significant listed sources of TSP emissions include stone mining and processing (EUROVIA Quarries – Košťálov and DP Chlum, Provodínské písky and CEMEX Sand – Smrčí Quarry), and other industrial sources (MLÝN PERNER SVIJANY and Wotan Forest OPO JILOS). The most significant sources of SO_x emissions are represented by sources for the production of electricity and heat (ENERGIE Holding – Hradčany Heating Plant, Liberec Heating Plant) and industrial sources (Liberec Asphalt Mixing Plant, Sklostroj Turnov CZ – Turnov and Galvanoplast Fischer). The most significant sources of NO_x emissions are represented by sources for electricity and heat production (TERMIZO – Municipal Waste Incinerator, ENERGY Holding – Hradčany Heating Plant, and DIAMO TÚU Stráž pod Ralskem), and industrial sources (PRECIOSA ORNELA – Desná Plant and Polubný and Crystalex CZ – Nový Bor Plant). Significant NMVOC emissions are produced by the Fehrer Bohemia Česká Lípa Company, the Magna Exteriors (Bohemia) – Liberec Plant, and Bombardier Transportation Czech Republic.

Hradec Králové Region

The Hradec Králové Region is located in the north–east of Bohemia. The northern border of the region, formed by the Orlické hory Mountains and the Krkonoše Mountains, contrasts with the southern border formed by the Elbe Lowlands. Air quality in the Hradec Králové Region is at a relatively good level. It is mainly affected by the traffic load despite the very dense railway network, which is completely electrified on only two lines. The regional city of Hradec Králové is a major road junction, despite the fact that the motorway network is still under construction. Furthermore, the air quality is affected by local heating.

The most significant listed sources of TSP emissions include industrial sources (Tereos TTD – České Meziříčí Sugar Factory, Seco Industries foundry – Jičín plant), electricity and heat production (ČEZ – Poříčí Power Plant), and the mining and processing of minerals (production of mineral wool Saint–Gobain Construction Products CZ – Častolovice plant, Krkonoše Lime Production Kunčice – Lánov Quarry and ENVISTONE Předměřice). The most significant sources of SO_x emissions are again represented by industrial sources (Tereos TTD – České Meziříčí Sugar Factory and Saint–Gobain Construction Products CZ – Častolovice plant), and sources for the production of electricity and heat (ČEZ – Poříčí Power Plant and Dvůr Králové Heating Plant, Heat Management – Draha Plant). The most significant sources of NO_x emissions are represented by sources for the production of electricity and heat (ČEZ – Poříčí Power Plant operation and Dvůr Králové Heating Plant), and industrial sources (Tereos TTD – České Meziříčí Sugar Factory and Saint–Gobain Construction Products CZ – Častolovice plant). Considerable NMVOC emissions are produced by car industry (Škoda Auto – Kvasiny) and packaging production (AMCOR Nový Bydžov). NH_3 emissions are produced in manufacturing mineral wool at Saint–Gobain Construction Products CZ – Častolovice plant.

Pardubice Region

The Pardubice Region is located in the south–east of the CR. The northern border is formed by the Orlické hory mountain area and the Kralický Sněžník mountain range. It borders the Vysočina Region in the south, which is a moderate hilly area. Flat terrain is mainly located in the vicinity of the regional town of Pardubice and the neighbouring town of Chrudim. It is the tenth largest region in terms of area.

Air quality in the region is mainly affected by the chemical industry (for example, the world–famous Semtex production), transport, and local heating.

The most significant listed sources of TSP emissions include the production of electricity and heat (Chvaletice Power Plant, Opatovice Power Plant), and other industrial sources (CEMEX CR, P-D Refractories CZ a. s., division 06 – firing Anna, ALL-IMPEX Pardubice – Dried Milk Manufacture). The most significant sources of SO_x emissions are also represented by sources for electricity and heat production (Opatovice Power Plant, Chvaletice Power Plant and Synthesia – Energy Department), and industrial sources (CEMEX CR, Synthesia – SBU Nitrocellulose – Inorganic Part or P–D Refractories CZ). The most significant NO_x sources are again represented by sources for the production of electricity and heat (Chvaletice Power Plant and Opatovice Power Plant) and industrial sources (CEMEX CR). Considerable NMVOC emissions originate from asphalt roofing manufacture (KVK Parabit) and the truck production (IVECO Czech Republic – Vysoké Mýto). NH_3 emissions are produced in manufacturing cement (CEMEX Czech Republic) and mineral wool (Saint-Gobain Adfors CZ – Litomyšl plant).

South–eastern zone

Vysočina Region

The Vysočina Region is one of the larger regions of the CR in terms of area. It differs from the surrounding regions by having a higher average altitude, a higher fragmentation of the territory, and a sparse population (it is the fifth largest region, but also has the fourth lowest population). More than half of the territory is covered by agricultural land (60.6 %) and the rest predominantly by forests (30.4 %). The whole area lies in the Bohemian–Moravian Highlands.

In terms of air pollution, the region can be assessed very positively. The high proportion of forests, the smaller proportion of cities and at the same time the absence of significant industry mean that air quality is good in most places. Air quality in the region is affected by local heating (the main source of TSP and SO_X) and traffic, especially by the D1 motorway (the main source of NO_X).

The most significant listed sources of TSP emissions include stone mining and processing (COLAS CZ – Rančířov, Mirošov and Vícenice quarries), and other industrial sources (Lukaform, Stora Enso Timber Ždírec, KRONOSPAN CR and Lukavec Woodworking Cooperative). The most significant sources of SO_X emissions are represented by the ŽĎAS energy sources, and also by the boiler room of the ATOS – Stínadla boiler and Woodworking Cooperative. The most significant sources of NO_X emissions are mainly represented by the KRONOSPAN OSB and KRONOSPAN CR industrial sources, and the boiler rooms of the Lukavec Woodworking Cooperative, Stora Enso Timber Ždírec and ŽĎAS. Considerable NMVOC emissions originate from wood processing (KRONOSPAN OSB, Lukaform, KRONOSPAN CR and Woodworking Cooperative).

South Moravia Region without Brno agglomeration

The South Moravia Region is located in the south–east of the CR. Its centre is Brno – the second largest city in the CR. From a meteorological point of view, it is one of the warmest areas within the CR. Agriculture is particularly widespread in the southern part of the region, with more than 90 % of all vineyards in the CR. In total, agricultural land makes up approximately 60 % of the territory. Compared to other regions, the South Moravia Region has a higher population density.

Air quality in the South Moravia Region is affected by local household heating (especially in small municipalities), while the influence of the already mentioned agriculture and soil erosion in the southern part of the region is more pronounced. Locally, air quality is also significantly affected by transport, especially in urban areas and in areas with higher traffic intensity (for example, along the D1 and D2 motorways, which pass through the region).

The most important listed sources of TSP emissions include electricity and heat production (ČEZ – Hodonín Power Plant), food processing (NAVOS Hustopeče), the mining and processing of minerals (Českomoravský Cement – Mokrá Plant, COLAS CZ – Tasovice Quarry, KAMENOLOMY ČR – Lhota Rapotina Quarry), and other industrial sources (e.g., P-D Refractories CZ – Velké Opatovice). The most significant sources of SO_X emissions are represented by industrial production (VETROPACK MORAVIA GLASS and SAINT-GOBAIN ADFORS CZ – Hodonice), sources for the production of electricity and heat (ČEZ – Hodonín Power Plant), and processing of mineral resources (Českomoravský Cement – Mokrá Plant). The most significant sources of NO_X emissions are represented by industrial sources (Českomoravský Cement – Mokrá Plant, VETROPACK MORAVIA GLASS and CARMEUSE CR – Mokrá Lime Production), and sources for the production of electricity and heat (ČEZ – Hodonín Power Plant).

The emissions of other pollutants are dominated (by more than 70 % of the total emissions of the listed sources) by CO from cement production at the Českomoravský Cement – Mokrá Plant, which also produces higher NH_3 emissions. Considerable NMVOC emissions are produced by the GUMOTEX Coating – Břeclav.

Agglomeration of Brno

The Brno agglomeration covers the territory of the second largest city in the CR, Brno. It lies approximately in the middle of the South Moravia Region.

As in every major city, air quality in Brno is affected by traffic, which is a source of NO_X in particular. On the contrary, local household heating is not such a significant problem, as the whole area is gasified and heating in solid fuel boilers is not very common. However, this source of pollution in Brno cannot be neglected and mainly affects the outskirts of the city.

Recently, two negative aspects in connection with air quality have manifested themselves in the territory of Brno. The first is the still unfinished large city ring road, which would divert transit as well as some passenger traffic outside the densely populated area and increase the smooth flow of traffic. The second aspect includes construction activities, which in some localities (especially south of the main railway station) very locally but very significantly negatively affect air quality by increasing the concentrations of suspended PM_{10} particles.

Under specific dispersion and meteorological conditions, the impact of long–range transport is also more pronounced in the territory of Brno, especially during north–east wind flows, when the agglomeration receives pollution from the Moravia–Silesia Region or across the border as far as from Poland through the Moravian Gate geomorphologic formation.

The most important listed source of TSP emissions is the Eligo – Brno Branch Plant. The most significant sources of SO_X emissions are represented by sources for the production of electricity and heat (SAKO Brno – ZEVO Division 3 and Brno Heating Plant facilities), as well as industrial sources (e.g., HEUNISCH Brno Foundry). The most significant sources of NO_X emissions are also repre-

sented by sources for the production of electricity and heat (Brno Heating Plant and SAKO Brno – ZEVO Division 3), and industrial sources (REMET – Brno facility and Brno mixing plant).

Central Moravia zone

Olomouc Region

The Olomouc Region is average in terms of population density and area in the CR. Geographically, it includes the north and north–west of Moravia (where the territory reaches the highest altitude in the Hrubý Jeseník Mountains) and the west of Bohemian Silesia. It borders Poland to the north. The south–eastern parts of the region are characterized by lowland areas of Haná, rimmed by highland protrusions. The Morava River flows through the region from north to south. These geographical conditions affect not only the location of the main transport corridors, but also the transmission of pollutants in the atmosphere.

The region is dominated by the manufacturing and engineering industries and agricultural activities. The D1, D35 and D46 motorways pass through the region. Long–range and regional transborder air pollution from abroad (Poland) and from the neighbouring Moravia-Silesia Region also contributes to the air pollution. However, a significant amount of local emissions arise from the incomplete combustion of fuels in the household heating sector.

The most significant listed sources of TSP emissions include stone mining and processing (Cement Hranice, PRECHEZA, OMYA CZ – Pomezí Plant, CIDEM Hranice), and other industrial sources, e.g., Javořice Ptení. The most significant sources of SO_x and NO_x emissions are represented by sources for the production of electricity and heat (Veolia Energy ČR – Přerov Heating Plant and Olomouc Heating Plant), and industrial sources (PRECHEZA, Tereos TTD, Kojetín Distillery Plant, Vrbátky Sugar Factory and Litovel Sugar Factory).

Concerning other pollutants, the dominant proportion (more than 50 % of the total emissions of the listed sources) is generated by CO emissions of the Cement Hranice Company, which also produces greater NH_3 emissions. Significant NMVOC emissions are produced by the ADM Olomouc Company.

Zlín Region

The Zlín Region lies in the east of the CR and is formed by hilly terrain, which in places turns mountainous. In whole, the Zlín Region covers 5 % of the total territory of the CR. The region has above–average forest cover in comparison with other regions in the CR. Agricultural land makes up approximately half of the region's territory.

The air quality in the Zlín Region can be assessed as generally worsened in comparison with other regions in the CR. This is largely due to small sources of pollution, mainly local household heating. These smaller sources of air pollution are dominant in the case of TSPs and benzo[*a*]pyrene. To some extent, larger industrial sources also contribute to pollution, especially for NO_x and SO_x. NO_x emissions come mainly from transport, which affects air quality in this region locally, especially in urban areas and areas with higher traffic intensity. Deteriorated air quality in the region is also to a large extent due to the long–range transport of pollutants from nearby areas, especially from the north and north–east, that is from the areas of the Moravia-Silesia Region or across border from Poland.

The most important listed sources of TSP emissions include sources for the production of electricity and heat (DEZA – Energy, Otrokovice Heating Plant) and also industrial sources (CS CABOT, SAKER o.z., ALUSAK – Kroměříž, ZEVOS Dolní Němčí Drying Facility and Pellets Bylnice). The most significant sources of SO_x and NO_x emissions are represented by sources for the production of electricity and heat (DEZA – Energy, Otrokovice Heating Plant, Zlín Heating Plant, and CTZ Uherské Hradiště), and industrial sources (DEZA – Chemical Production and CS CABOT and SAKER o.z. ALUSAK).

Among the emissions of other pollutants, NMVOC emissions from SPUR – Zlín are among the most significant.

Moravia-Silesia Region

According to Act No. 201/2012 Coll., on air protection, the Moravia-Silesia Region is divided into the Moravia-Silesia zone and the O/K/F-M agglomeration for the purposes of assessing and evaluating air quality (Fig. I.2).

The Moravia-Silesia Region is the third most populous in the CR, and the second largest in terms of population density after Prague. Most of the region lies in Bohemian Silesia. Its location in the north–east of the country includes both the most industrialized regions of the CR, as well as agricultural and mountain areas. This diversity is caused by geographical and geological conditions (ranging from mountainous to hilly areas, plateaus to lowland terrain). In addition, the location on the border with Poland plays an important role. The D47–Lipník–Ostrava motorway is an important traffic route, and two international railway corridors pass through the region.

The natural character and different economic development contribute to differences in the quality of the environment of individual areas of the region. The most serious impacts on the environment are apparent in the central and north–eastern part of the region (Ostrava, Karviná, Frýdek-Místek and Třinec areas), where the population is exposed to the highest levels of air pollution in the CR. On the other hand, the Moravia-Silesia Region also includes places with significant and valuable natural resources, which are protected within three PLAs.

Moravia-Silesia zone

Outside the industrial centre of the region, located in the separately described Ostrava/Karviná/Frýdek-Místek (O/K/F-M) agglomeration, there are only a relatively small number of listed sou-

rces of pollution. The most important such technological source is lime production; others are heating and technological sources (food industry, pharmaceuticals). Although central heating sources predominate on average for domestic heating, the region still has a high proportion of solid fuel combustion in obsolete types of combustion equipment.

Apart from the industrial centre of the region, the most important listed sources of TSP emissions include stone mining and processing (EUROVIA Quarries, Jakubčovice nad Odrou, Quarries of the CR – Bohučovice Quarry) and other industrial sources (Moravia-Silesia Sugar Factory – Opava Branch Plant, TATRA METALLURGY – foundry and Břidličná AL INVEST). The most important sources of SO_x and NO_x emissions are represented by industrial sources (Moravia-Silesia Sugar Factory – Opava Branch Plant, LB Cemix, KOTOUČ ŠTRAMBERK – lime production) and sources for electricity and heat production (TEPLO BRUNTÁL – Central Heating Plant, Veolia Energy ČR – Krnov Heating Plant).

Among other pollutants, the dominant proportion (more than 85 % of the total emission of the listed sources) is represented by CO emissions from lime production (LB Cemix, KOTOUČ ŠTRAMBERK). Significant NMVOC emissions are produced by the Teva Czech Industries, STYROTRADE Rýmařov and AL INVEST Břidličná companies.

Agglomeration of Ostrava/ Karviná/Frýdek-Místek

The character and area of the Ostrava/Karviná/Frýdek-Místek agglomeration differ significantly from the other two agglomerations in the CR (Prague and Brno). This agglomeration includes the area of three whole districts, not just urban areas. In total, the O/K/F-M agglomeration covers more than a third of the Moravia-Silesia Region. The area is historically burdened by extensive industrial activity in the Upper Silesian Basin. The key factors affecting the resulting air quality are the high concentration of industrial production, the high density of built–up areas with local solid–fuel heating, and the dense transport infrastructure on both sides of the Czech–Polish border. Municipalities in most of the agglomeration are directly connected to each other (a so–called Silesian type of urban development) and industrial areas are often located within municipalities.

A significant factor that contributes to the resulting reduced air quality in the agglomeration is the extent and nature of cross–border and interregional pollution transfer in the predominant directions of wind flow. In the area at the Czech–Polish border, this flow typically occurs along the south–west — north–east axis. Air quality in the agglomeration (and not only in the immediate vicinity of the border at the Karviná region) is also significantly affected by cross–border emissions and air pollution originating from Poland (in certain meteorological situations even dominating). Other meteorological factors also determine the potential for dispersion or transport of pollutants in the atmosphere (Chapter III). There are frequent weather inversions with stable thermal stratification of the atmosphere and thus worsened dispersion conditions, not only in the lowlands of the Ostrava Basin but also in the mountain valleys of the agglomeration, which also significantly contribute to increasing concentrations of air pollutants. The most frequent smog episodes with above–threshold concentrations of suspended PM_{10} particles within the agglomeration occur in the Olše River and Odra River valley areas, mostly from December to February (details are presented in Chapter VI).

Individual categories of emission sources show different proportions in the O/K/F-M agglomeration compared to other areas of the CR. The proportion of industrial and energy sources in emissions of major pollutants has been continuously declining. However, significant metallurgical complexes together with coal coke production, energy and other individually monitored sources still produce a substantial part of pollution.

In view of heating, significant differences can be found in the area, resulting mainly from the character of the households in individual districts. While in the Frýdek-Místek district the proportion of flats heated locally by solid fuels is close to 20 %, in the district of Karviná it is about 8 %, and in the district of Ostrava it is 4 %. This fact, accompanied by the higher average altitude of settlements in the Frýdek-Místek district and the larger average size of flats, is reflected mainly in emissions for which the REZZO 3 category forms a more significant proportion, namely for TSPs and particulate matter, VOCs, benzene and especially for emissions. benzo[*a*]pyrene.

The most important listed sources of TSP emissions include industrial sources (Liberty Ostrava with particularly Plant 13 Steelworks, Plant 12 Blast Furnaces and Coke Plant, TŘINECKÉ ŽELEZÁRNY Ironworks – Production of pig iron and also OKK Coke Productioin – Svoboda Coke Plant), sources for electricity and heat production (Dětmarovice Power Plant, TŘINEC Energy and Veolia Energy ČR – Třebovice Power Plant), and industrial sources (OKK Coke Production – Svoboda Coke Plant and Lenzing Biocel Paskov). The most significant sources of SO_x emissions are industrial sources (Liberty Ostrava – Plant 12 Blast Furnaces, TŘINECKÉ ŽELEZÁRNY Ironworks – Production of pig iron) and sources for electricity and heat production (Veolia Energy ČR – Třebovice Power Plant and ČSA, TAMEH Czech and TŘINEC Energy). The most significant sources of NO_x emissions are also represented by industrial sources (TŘINECKÉ ŽELEZÁRNY Ironworks, Liberty Ostrava and Biocel Paskov) and electricity and heat production (TAMEH Czech – Heating Plant of the company, Veolia Energy CR – Třebovice Power Plant, TŘINEC ENERGY and Dětmarovice Power Plant).

The emissions of other pollutants are dominated by CO emissions from the steel production (TŘINECKÉ ŽELEZÁRNY Ironworks and Liberty Ostrava). Significant NMVOC emissions are produced by car manufacturing of the HYUNDAI MOTOR MANUFACTURING CZECH and Lenzing Biocel Paskov companies. Higher NH_3 emissions are generated by the ROCKWOOL Company, Bohumín Production Plant and BorsodChem MCHZ.

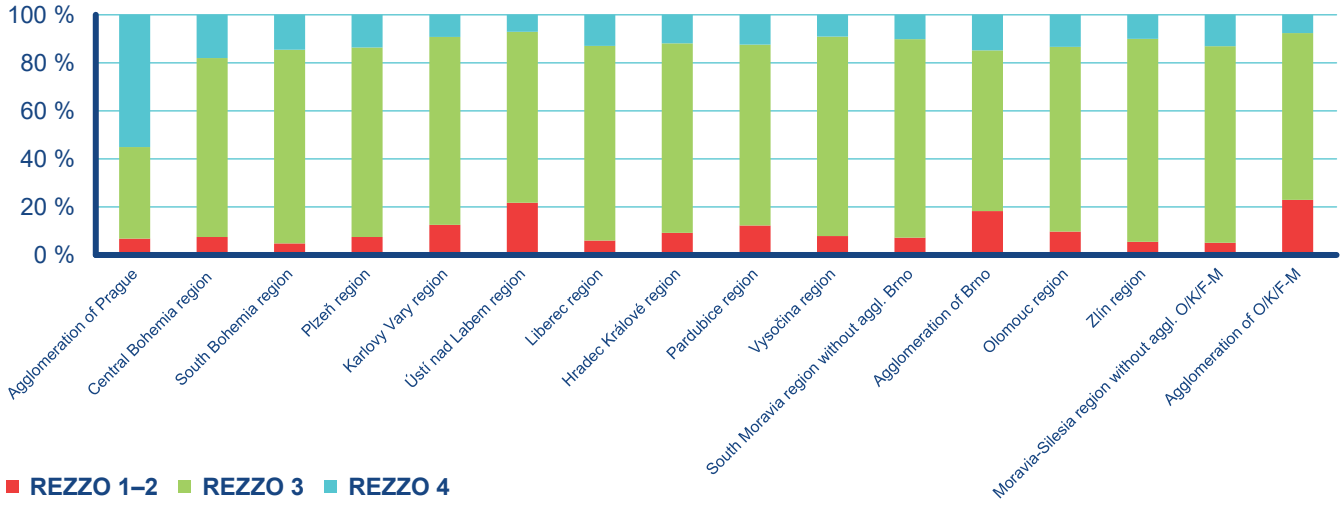


Fig. V.1.1 Composition of TSP emissions in regions of the Czech Republic, 2020

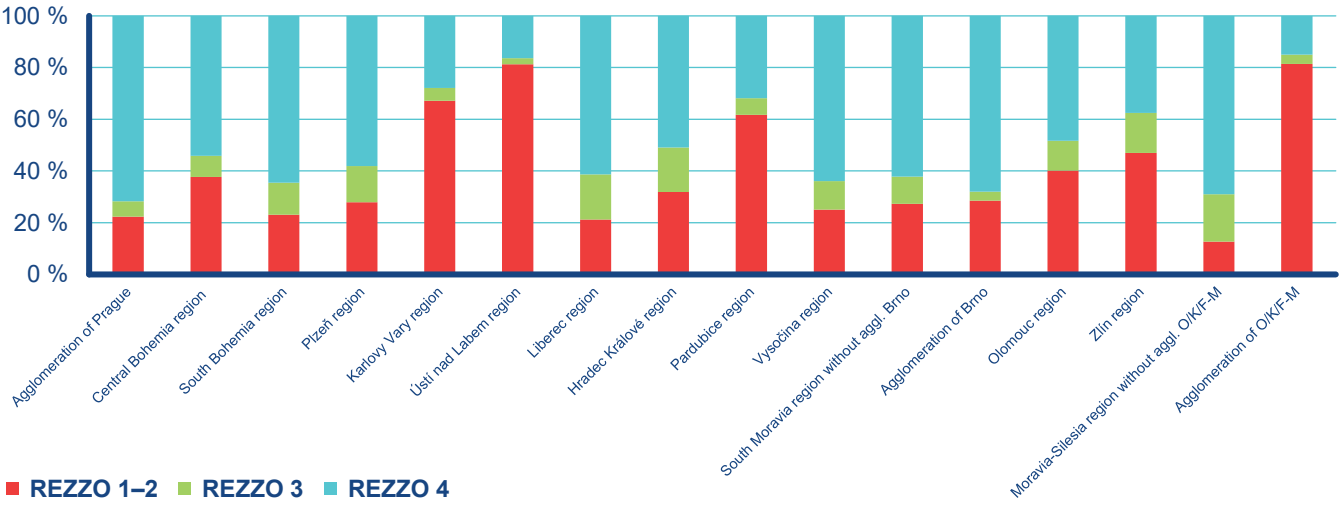


Fig. V.1.2 Composition of NO_x emissions in regions of the Czech Republic, 2020

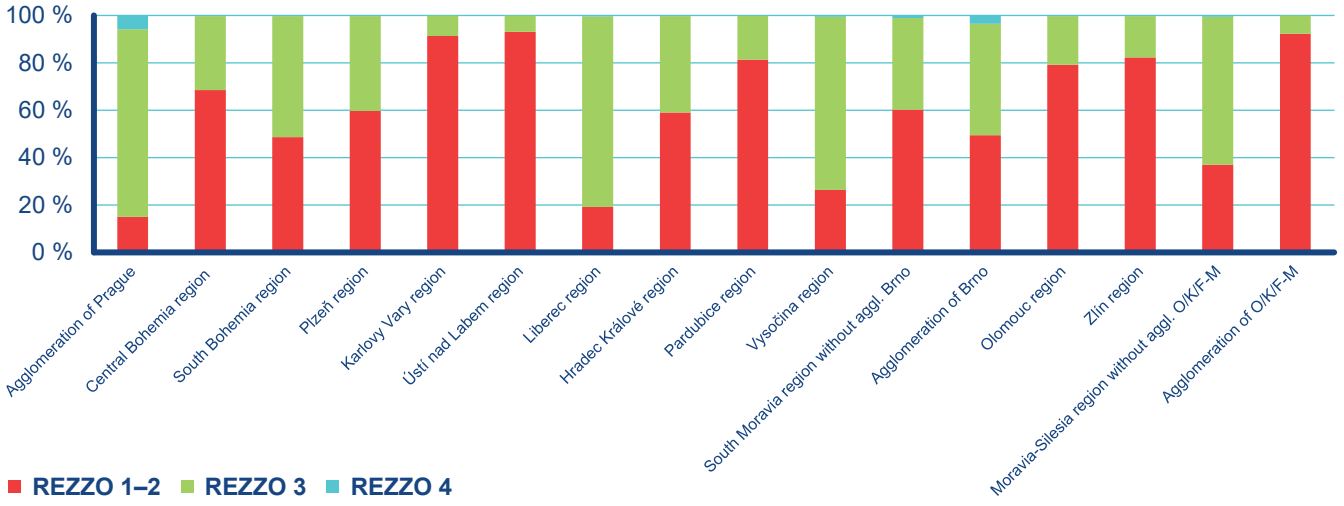


Fig. V.1.3 Composition of SO_x emissions in regions of the Czech Republic, 2020

V.2. Air quality index in regions of the Czech Republic

The air quality index (AQI) provides summary information on air quality at a specific measuring station. The air quality index (AQI) was designed by the CHMI Air Quality Department in cooperation with the National Institute of Public Health (SZÚ). The AQI calculation is based on simultaneous evaluation of 3-hour moving average concentrations of sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and suspended particles (PM_{10}). For the summer period (1 April to 30 September), 3-hour moving average concentrations of ground-level ozone (O_3) are also evaluated. The 3-hour moving average describes the potential impact of air pollution on the population health better than hourly or daily average concentrations. An advantage of the AQI is the basic three-level colour indication of the index level. AQI current values are available on the CHMI website[2], together with specific advice and recommendations of the SZÚ[3] to ensure the protection of human health (Table V.2.1). These health recommendations are based on evaluations by the World Health Organization (WHO 2000).

In individual regions, very good to good air quality prevailed in 2021 (level 1A, 1B), at the range of 57–74 % (Fig. V.2.1). Moderate air quality (level 2A, 2B) at the range of 26–42 %. Poor to very poor air quality occurred in all regions of the CR, except for the Karlovy Vary and Liberec Regions, at the range of 0–1 %.

Tab. V.2.1 V.2.1 Recommendations of the SZÚ for reducing the exposure of the population to air pollutants and for the health protection

Level	Index range	Air quality	Sensitive and vulnerable groups	General population
1A	< 0.34	Very good to good.	Ideal conditions for outdoor activities.	Ideal conditions for outdoor activities.
1B	≥ 0.34–0.67		Outdoor activities without restrictions.	Outdoor activities without restrictions.
2A	≥ 0.67–1.00	Moderate.	There might be a slight risk of inconvenience to a very small number of persons who are extremely sensitive to air pollution. No need to change your usual outdoor activities if you do not notice symptoms such as coughing and throat irritation.	Outdoor activities without restrictions.
2B	≥ 1.00–1.50		Consider reducing or postponing/moving intense outdoor activities, notably if your health condition aggravates or you experience symptoms such as coughing and throat irritation.	No need to change your usual outdoor activities.
3A	≥ 1.50–2.00	Poor to very poor.	Reduce intense activities, particularly outdoors, notably if your health condition aggravates or symptoms such as coughing and throat irritation occur. Asthmatics and persons with chronic disease may need to use a relief medicine more often. All older people and children should limit their physical activity.	Consider reducing or postponing/moving intense outdoor activities if you experience symptoms such as coughing and throat irritation occur.
3B	≥ 2.00		Shorten your stay outdoors and avoid physical activities. Asthmatics and persons with chronic disease may need to use a relief medicine more often.	Reduce or postpone intense outdoor activities, notably if you experience any discomfort and symptoms such as irritation in the throat, eye irritation, coughing, etc.

2 www.chmi.cz/files/portal/docs/uoco/web_generator/actual_3hour_data_CZ.html
3 www.chmi.cz/files/portal/docs/uoco/web_generator/d_szu.pdf

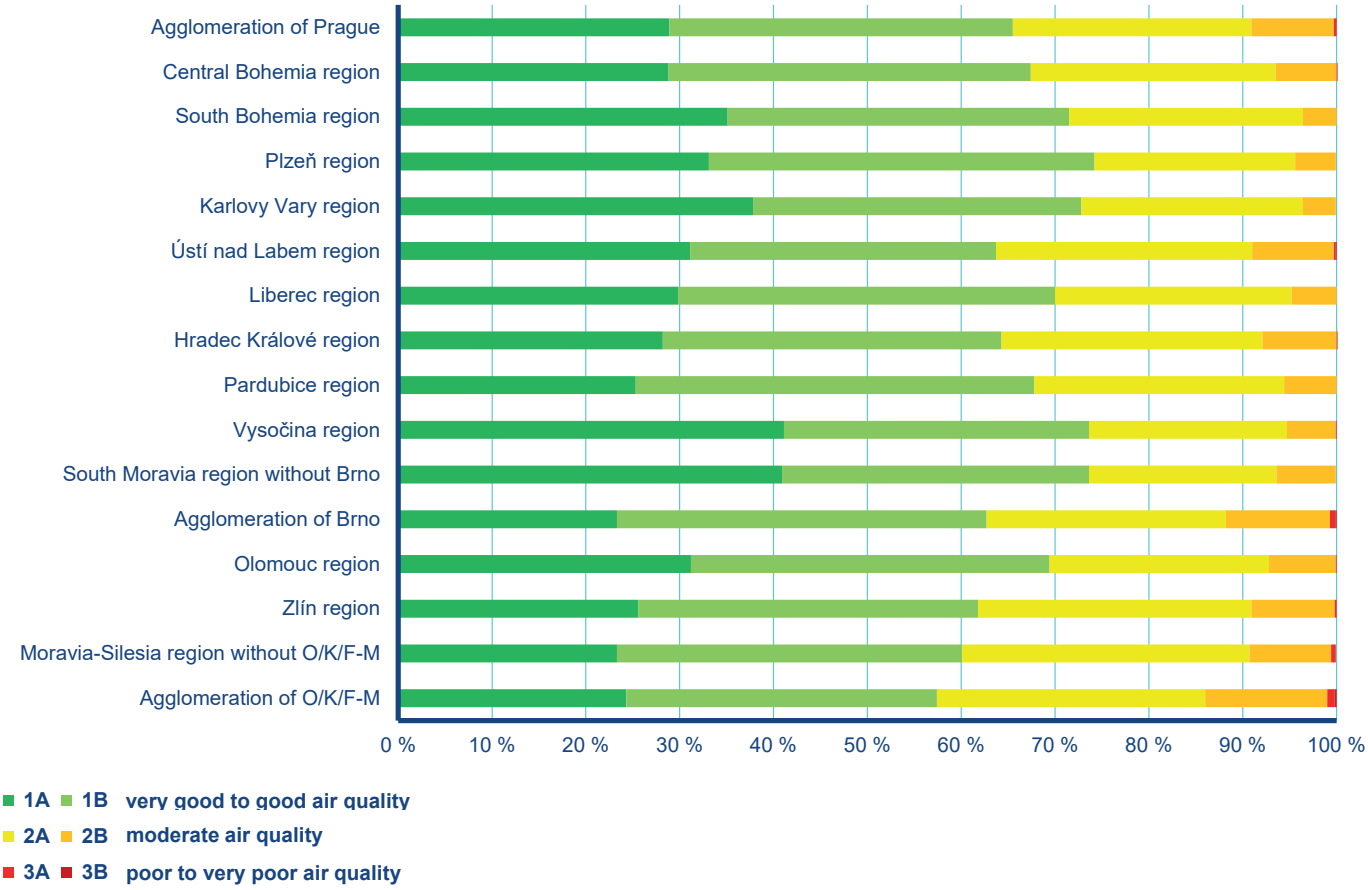


Fig. V.2.1 Proportional representation of the air quality index in individual regions of the Czech Republic, 2021

Air quality index at urban and suburban stations

At urban and suburban stations, the first AQI level (1A and 1B, very good to good air quality) occurred most frequently in 2021, at the range of 60–80 %, depending on the particular region (Fig. V.2.2). The highest rate was recorded in the Vysočina Region (80 %), the lowest in the O/K/F-M agglomeration (60 %). The second AQI level (2A and 2B, moderate air quality) was most often recorded in the O/K/F-M agglomeration (39 %), least frequently in the Vysočina Region (20 %). Except for the Karlovy Vary, Liberec, and South Moravia Regions, all regions experienced also the third AQI level (3A and 3B, poor to very poor air quality), mostly the O/K/F-M agglomeration (1 %).

Air quality index at rural stations

At rural stations, the first AQI level occurred most frequently in 2021, at the range of 54–71 %, depending on the particular region (Fig. V.2.3). The highest occurrence of the first AQI level was recorded in the South Moravia Region (71 %), the lowest in the Zlín Region (54 %). The second AQI level was most often recorded in the Zlín Region (45 %), the least often in the South Moravia Region (28 %). The third AQI level was recorded in the Moravia-Silesia Region, including the O/K/F-M agglomeration, and in the South Bohemia, South Moravia, Olomouc, Central Bohemia, Ústí nad Labem and Zlín Regions. The third AQI level most often occurred in the Moravia-Silesia Region without the O/K/F-M agglomeration (0.4 %).

Air quality index at traffic stations

In 2021, the first AQI level occurred at traffic stations most often, at the range of 48–77 %, depending on the particular region (Fig. V.2.4). An exception represented the Ústí nad Labem Region, where the second AQI level prevailed (51 %) in comparison to the first level (48 %). The highest occurrence of the first AQI level was recorded in the Plzeň Region (77 %). After the Ústí nad Labem Region, the second AQI level was most often recorded in the O/K/F-M agglomeration (44 %), the least frequently in the Plzeň Region (23 %). The third AQI level occurred in all regions where measurements from traffic stations were available. The third AQI level most often occurred in the O/K/F-M agglomeration (1.2 %).

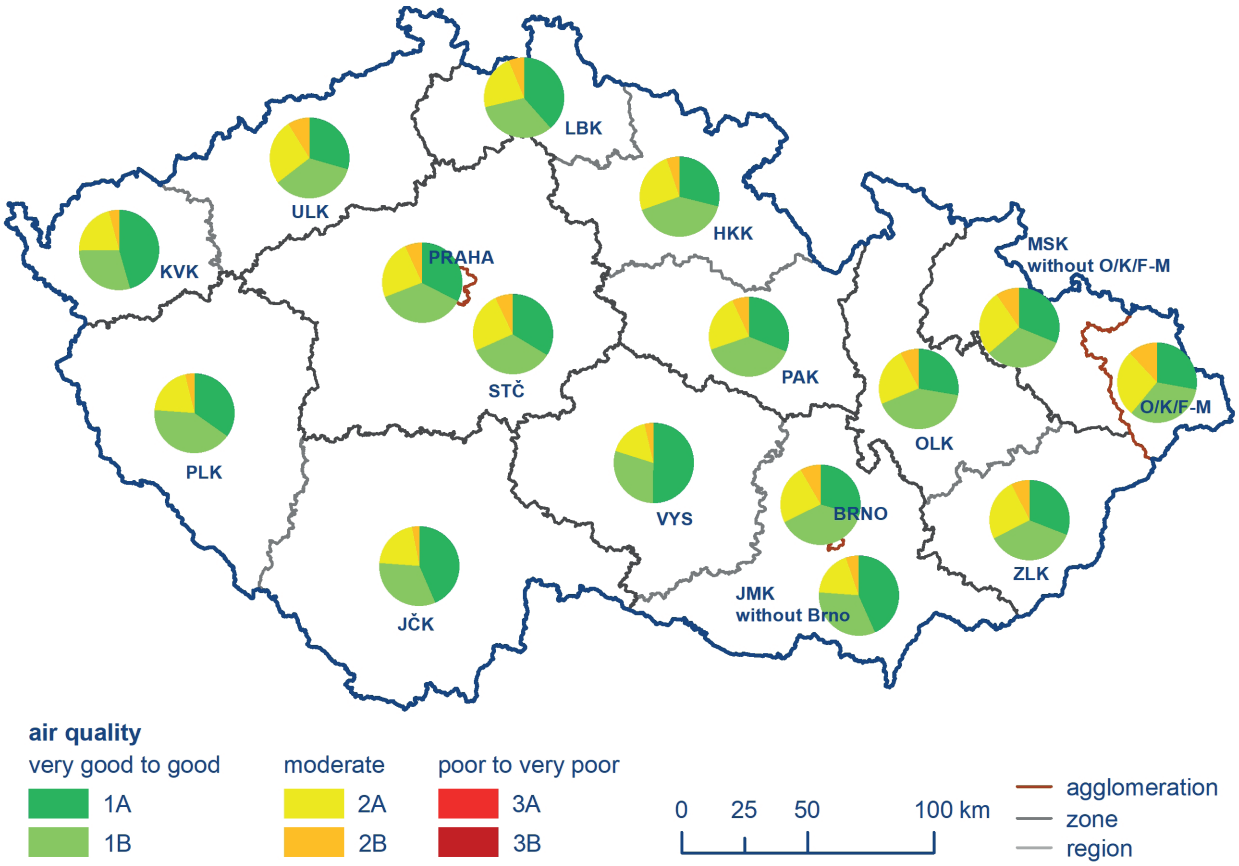


Fig. V.2.2 Proportional representation of the air quality index at urban and suburban background stations in individual regions of the Czech Republic, 2021

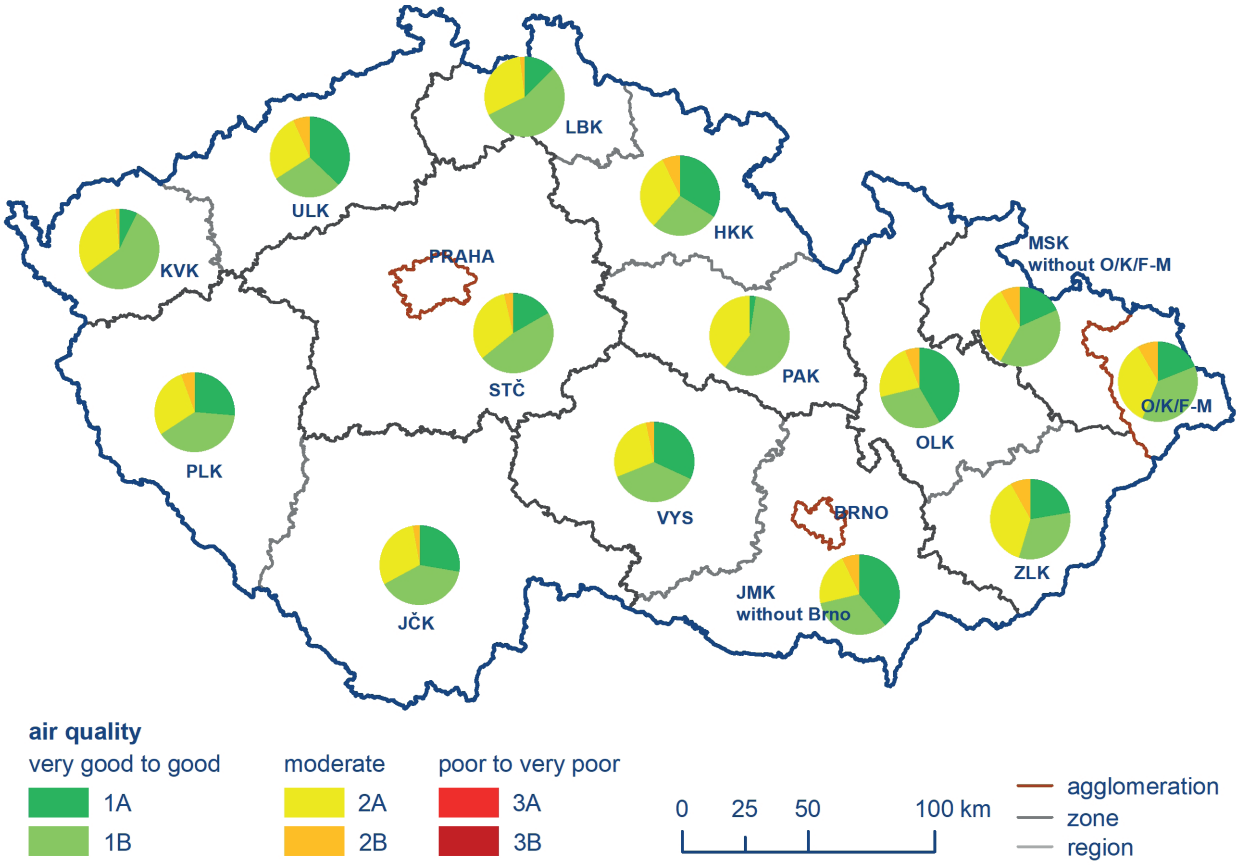


Fig. V.2.3 Proportional representation of the air quality index at rural background stations in individual regions of the Czech Republic, 2021

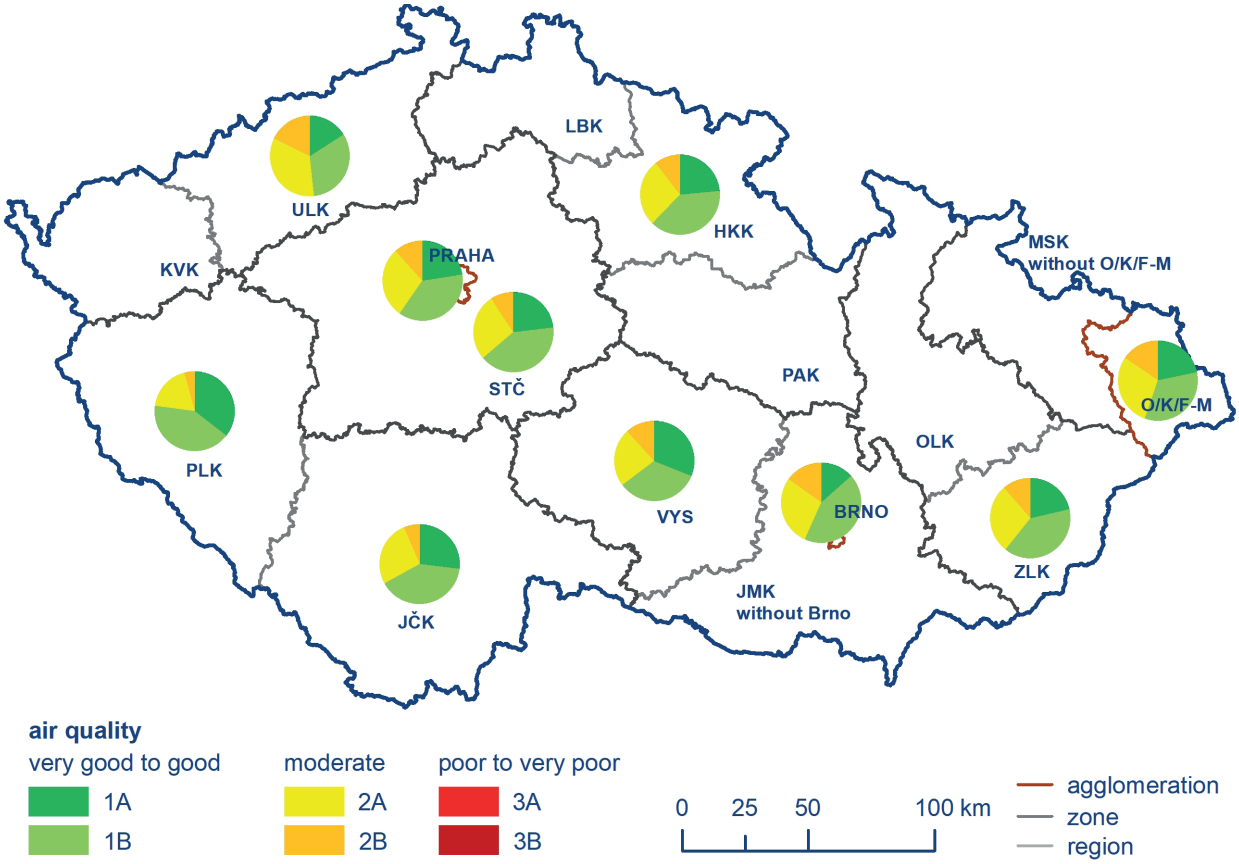


Fig. V.2.4 Proportional representation of the air quality index at traffic stations in individual regions in the Czech Republic, 2021

V.3 Regional differences in air quality in the Czech Republic

V.3.1 Proportion of the territory and population of regions exposed to above-limit concentrations

Changes in the extent of areas with above-limit concentrations of pollutants, excluding O_3, in zones and agglomerations between 2012 and 2021[4] point to significant regional differences in air quality in the CR (Fig. V.3.1.1). The O/K/F-M agglomeration, the Moravian-Silesia region without the O/K/F-M agglomeration, and the Olomouc and Zlín regions have long been the most polluted territories in terms of proportion of the area where the pollution limit value for at least one air pollutant was exceeded. Until 2018, the regions with a significant part of the territory with above-limit concentrations included also the Prague agglomeration, in which the area with above-limit concentrations decreased most significantly in 2019 in relation to decreasing concentrations of benzo[a]pyrene and suspended PM_{10} particles. A similar situation takes place in the Brno agglomeration, and in the Ústí nad Labem and Central Bohemia regions, although in these three regions the proportion of areas with above-limit concentrations was lower in comparison with Prague before 2019. On the contrary, the Karlovy Vary, Plzeň, Vysočina and South Bohemia regions belong to territories with the lowest or, in some years, even zero proportion of the area with above-limit concentrations.

After the inclusion of ground-level O_3, there is a significant increase in the proportion of areas with above-limit concentrations, namely in regions where air pollution from other pollutants is not dominant (Fig. V.3.1.2). Except for the Vysočina region in 2014, such areas occurred in all regions for the evaluated period 2012–2020. In some regions in the CR (the Karlovy Vary, Ústí nad Labem, South Bohemia and Plzeň regions, the Prague agglomeration, and the Central Bohemia and Liberec regions), there is an apparent increase in this proportion for the period 2012–2020, while in Moravia (the Olomouc, Zlín and Moravian-Silesia regions), areas with above-limit concentrations decrease. In other regions, the changes are volatile. In 2021, however, a situation occurred when the pollution limit for ground-level O_3 was not exceeded in most regions. Specifically, these included Prague, the Central Bohemia, Pardubice and Vysočina regions, Brno, the South Moravia region without Brno, as well as the Olomouc, Zlín and Moravian-Silesia regions, and the O/K/F-M agglomeration. In the remaining regions, the pollution limit for ground-level O_3 was exceeded in a very small area (for details see Tab. VII.1.2). This situation resulted from relatively low concentrations of ground-level O_3 measured in the last two years, 2020 and 2021, and the following reduction of the area exceeding the O_3 pollution limit in the three-year period 2019–2021 to only 0.2 % of the CR territory with 0.02 % of the population (for more see Chapter IV.4).

In addition to the comparison of areas with exceeded air pollution limits in the regions, a comparison of the percentage of the population living in these areas in 2012–2021 is also presented (Fig. V.3.1.3 and Fig. V.3.1.4).

Due to the fact that population densities differ among regions, the indicator of the proportion of the territory of regions with above-limit concentrations is supplemented by the indicator of the population living in these areas, as the affected territories in some regions (if O_3 is included) may cover areas with low population density. However, in densely populated areas, the opposite situation may occur, where a relatively small area with above-limit concentrations is inhabited by a large population (i.e., in areas without including O_3, where air pollution is affected by emissions of suspended particulates and benzo[*a*]pyrene, in particular from domestic heating and traffic).

For the above reason, the indicator of the number of inhabitants living in above-limit exposed areas was used to compare the regions (Fig. V.3.1.5 and Fig. V.3.1.6).

In 2021, a majority of population exposed to above-limit concentrations, except for O_3, lived in the O/K/F-M agglomeration (more than 750 000 inhabitants). Other affected regions were the Olomouc, Zlín, and Moravian-Silesia regions with approximately 403 000, 284 000, and 276 000 inhabitants exposed to above-limit concentrations. In Prague and in the South Bohemia, Karlovy Vary, and Vysočina regions the population exposed to above-limit concentrations of pollutants (excluding ground-level O_3) was zero in 2021.

After including ground-level O_3 in the evaluation, it can be stated that in 2021 there was no significant increase in the number of inhabitants exposed to above-limit concentrations of pollutants in any region, except for the Ústí nad Labem. The reason is the already mentioned exceeding the O_3 pollution limit in only 0.2 % of the territory of the CR. The pollution limit for ground-level O_3 is being evaluated for a three-year average. The evaluation of exceeding the O_3 pollution limit in 2021 thus includes the years 2019–2021, when low concentrations were measured in 2020 and 2021 (the lowest for the evaluated period, see Chapter IV.4 and Fig. IV.4.11). In the Ústí nad Labem region, where some of the highest concentrations of ground-level O_3 are measured in the CR, the number of inhabitants affected increased by approximately 2 500 after the inclusion of O_3 in the assessment.

4 In 2012, a new Act No. 201/2012 Coll., on air protection, entered into force, which introduced a new specification of areas with above-limit concentrations of air pollutants.

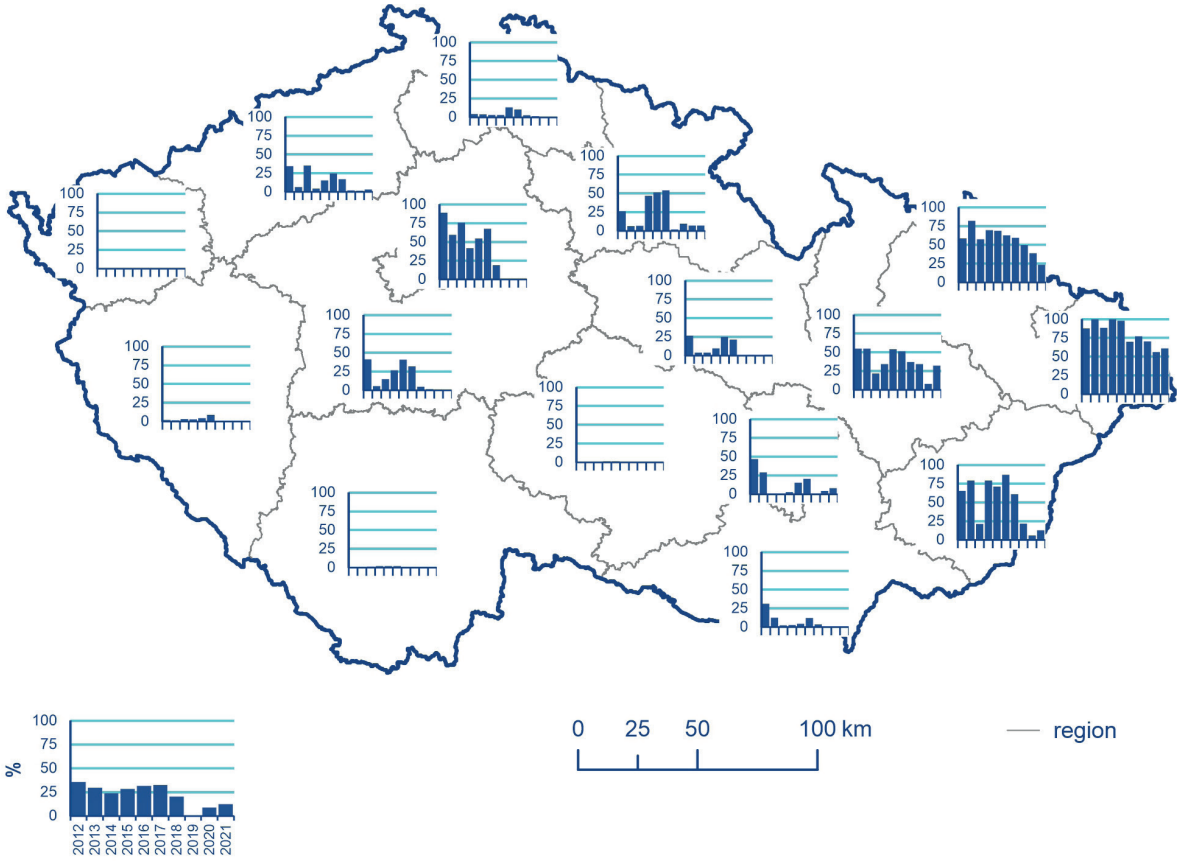


Fig. V.3.1.1 Proportion of region areas exceeding the pollution limit values (excluding ground-level O_3), 2012–2021

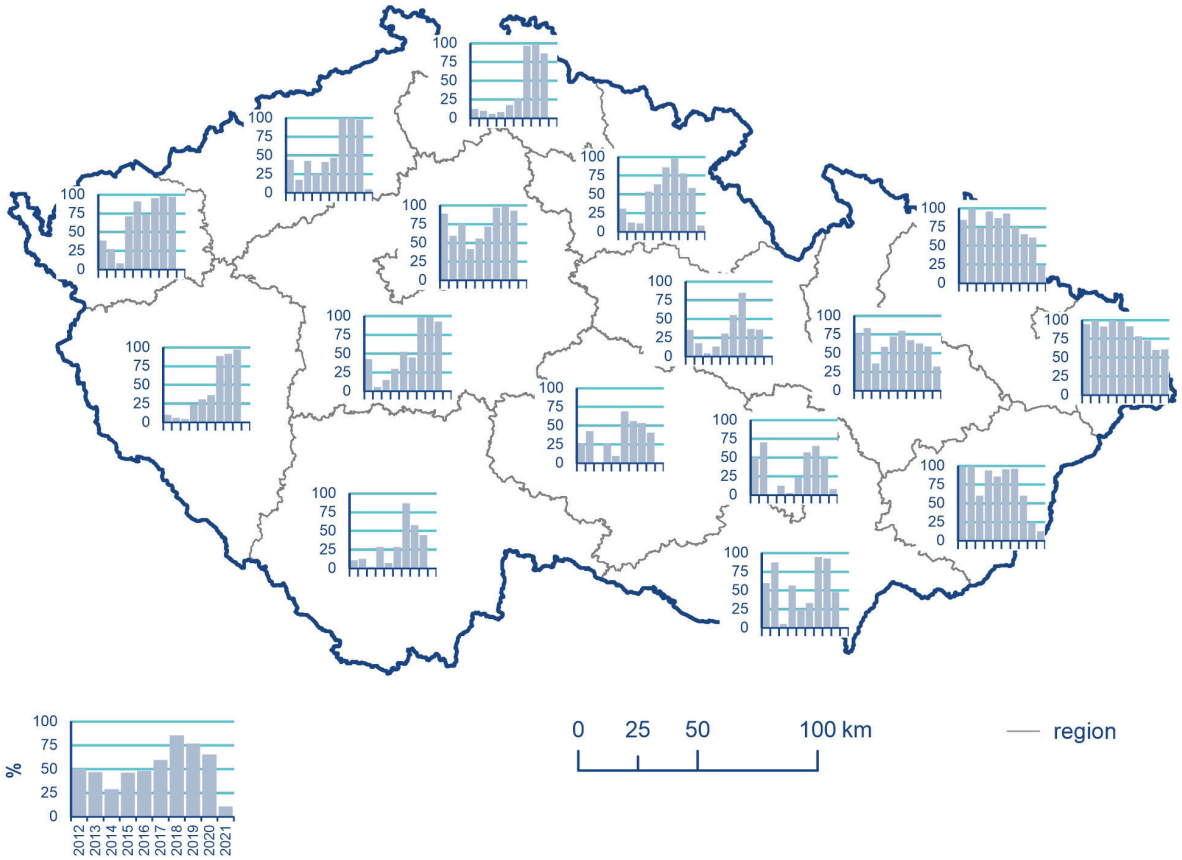


Fig. V.3.1.2 Proportion of region areas exceeding the pollution limit values (including ground-level O_3), 2012–2021

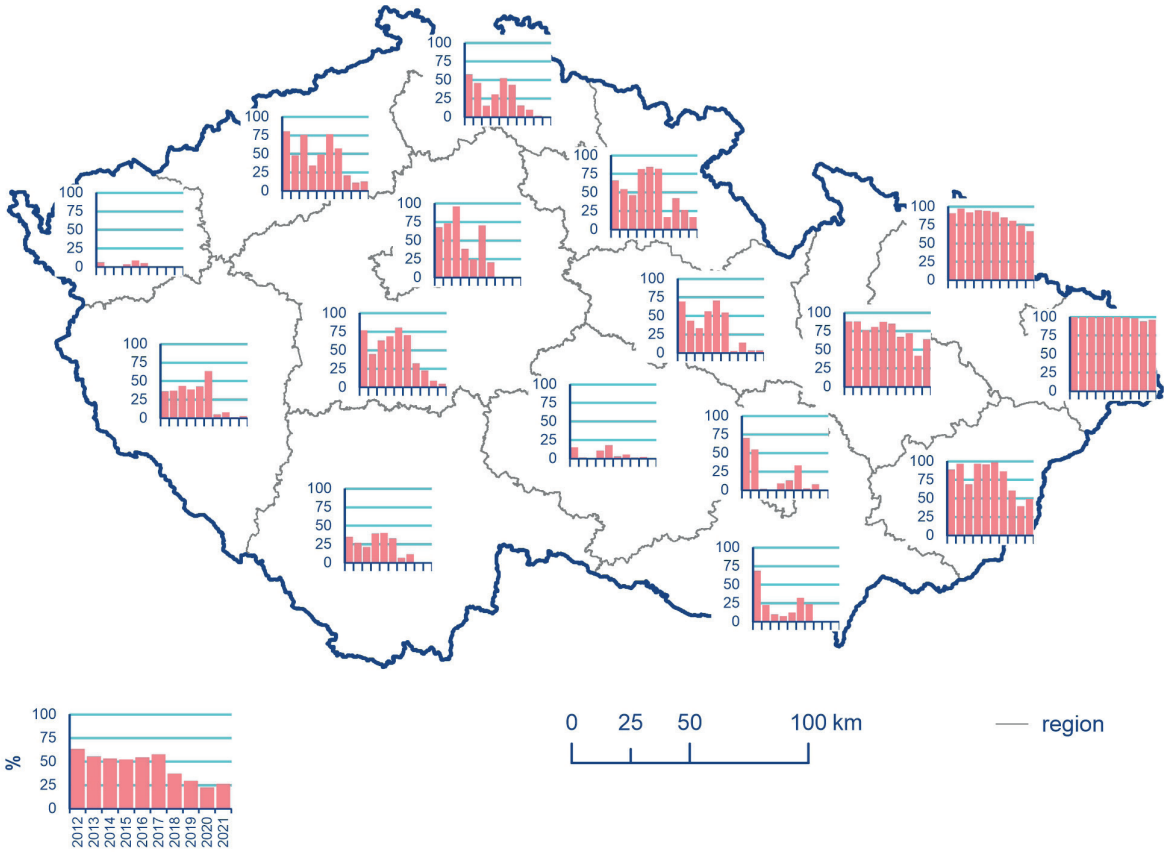


Fig. V.3.1.3 Proportion of inhabitants in areas exceeding the pollution limit values (excluding ground-level O_3), 2012–2021

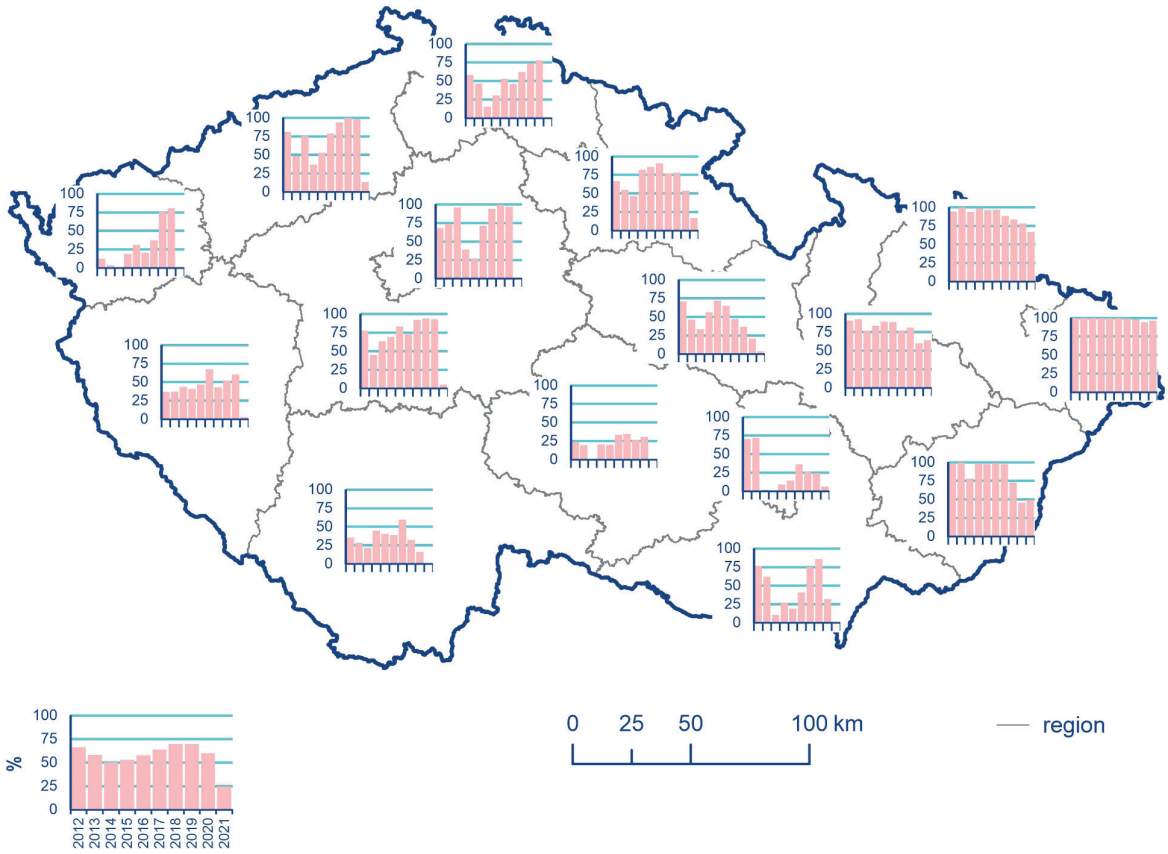


Fig. V.3.1.4 Proportion of inhabitants in areas exceeding the pollution limit values (including ground-level O_3), 2012–2021

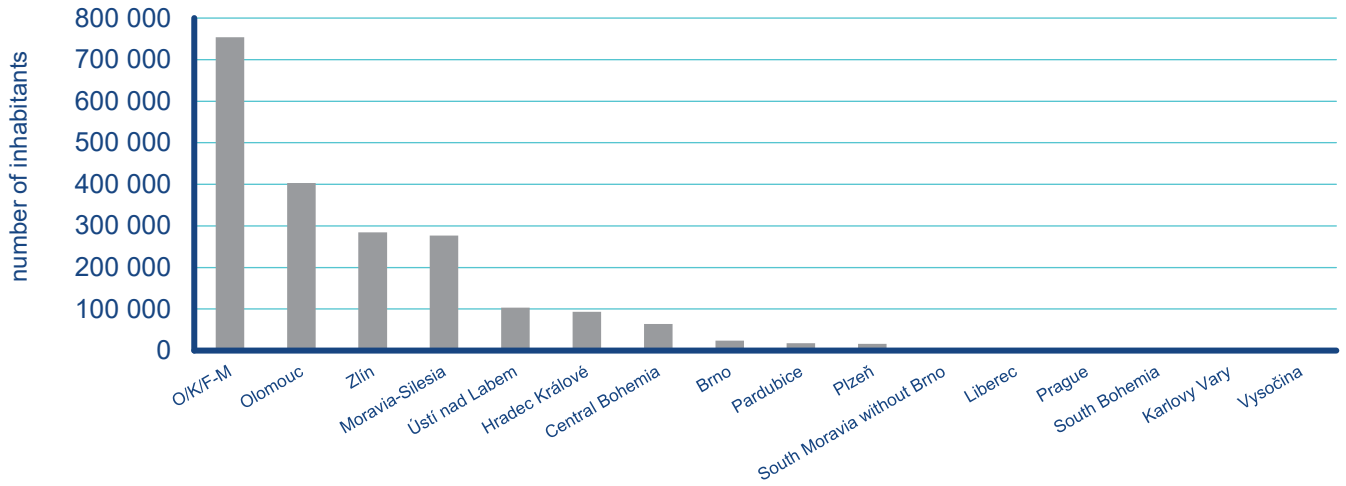


Fig. V.3.1.5 Number of inhabitants living in areas exceeding the pollution limit values (excluding ground-level O_3) in individual regions of the Czech Republic, 2021

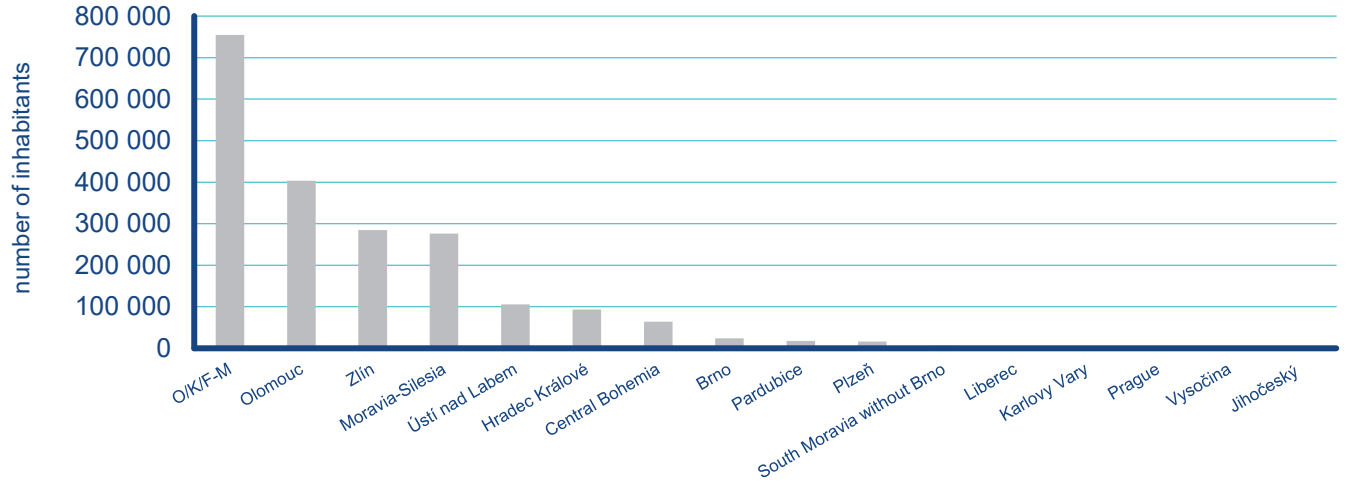


Fig. V.3.1.6 Number of inhabitants living in areas exceeding the pollution limit values (including ground-level O_3) in individual regions of the Czech Republic, 2021

V.3.2 Population-weighted PM_{10}, $PM_{2.5}$, NO_2, and O_3 concentrations

As part of the population exposure assessment, population-weighted average concentrations for PM_{10} and $PM_{2.5}$ suspended particulates, NO_2, and O_3 were calculated for regions (Fig. V.3.2.1) and cities with more than 30 000 inhabitants (Fig. V.3.2.2). Population-weighted concentrations can be simply characterized as pollutant concentrations to which a person living in a given city/region is exposed to on average. This characteristic is published for individual countries within the European air quality assessment (ETC/ACM 2018).

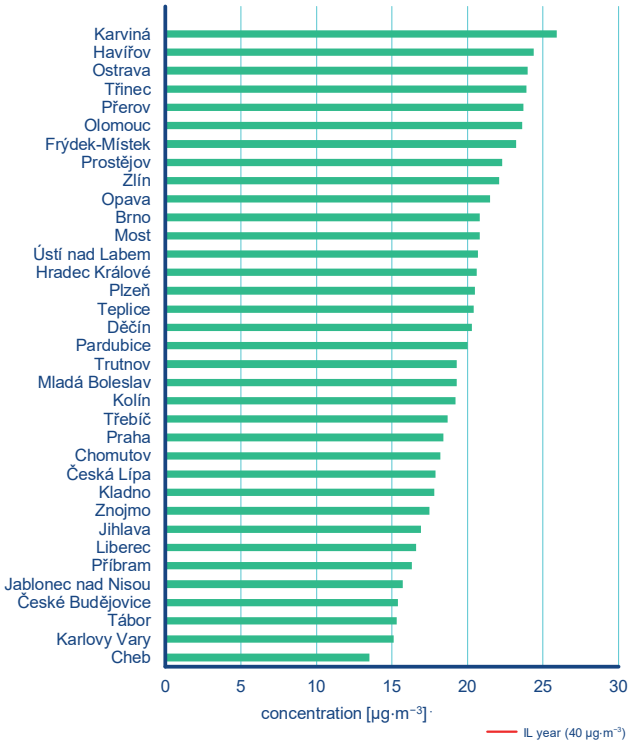
In 2021, the annual weighted average concentrations of PM_{10} and $PM_{2.5}$ suspended particulates did not exceed the limit value in any region. A comparison of weighted concentrations in the regions of the CR shows that inhabitants in the O/K/F-M agglomeration, Brno, and the regions of Olomouc, Zlín and Moravian-Silesia without the O/K/F-M agglomeration were exposed to the highest PM_{10} and $PM_{2.5}$ suspended particulates concentrations. Large cities with the highest weighted PM_{10} and $PM_{2.5}$ suspended particulates concentrations (Karviná, Havířov, Ostrava, Třinec) are located in the most exposed region of the CR – the O/K/F-M agglomeration. Levels of average weighted concentrations of PM_{10} in the CR do not exceed the pollution limit. The average weighted concentration of $PM_{2.5}$ above the pollution limit was determined for the only city with more than 30 000 inhabitants, namely the city of Karviná. The lowest weighted PM_{10} suspended particulate concentrations were calculated for the Plzeň, Liberec, Vysočina, South Bohemia and Karlovy Vary regions. The lowest weighted concentrations for $PM_{2.5}$ suspended particulates were calculated for the Liberec, Plzeň, Vysočina, South Bohemia and Karlovy Vary regions. The cleanest cities in terms of evaluation of suspended particle concentrations include Cheb, Karlovy Vary, Tábor, Příbram, and Jablonec nad Nisou. Relatively low values in cities located in the Karlovy Vary and South Bohemia regions are related to the local low regional background concentrations of suspended particles. Unlike the most exposed regions, long-range transport of air pollution is not as important there and the landscape character allows good ventilation (particularly in the South Bohemia area). The low emission burden of these areas is also significant.

In view of evaluating the level of NO_2 air pollution, the situation is somewhat different. This is mainly due to different main emission sources than in the case of suspended particles. The main sources of NO_x emissions, which incorporate NO_2, include public energy, heat production and road transport. The evaluation for 2021 shows that in connection with intensive traffic and reduced traffic flow, inhabitants are exposed to the highest NO_2 concentrations in the two most populous cities in the CR, i.e. Prague and Brno. The next in standing are cities in the Olomouc, Moravian-Silesia, and Ústí nad Labem regions. In 2021, inhabitants of the cities of Trutnov, Jablonec nad Nisou, Příbram, Tábor, and Cheb were exposed to the lowest NO_2 concentrations within large cities. Relatively low NO_2 concentrations are observed in cities with lower population and related lower traffic intensity, and in areas with lower regional background NO_2 concentrations due to lower emissions from large pollution sources and less significant long-range transport of pollution (the South Bohemia and Vysočina regions). Average weighted NO_2 concentration levels in the CR do not exceed the pollution limit value, however, from long-term NO_2 measurements in some traffic localities, particularly in sites with high traffic intensity experiencing poor ventilation (dense build-up areas) and frequent restrictions of traffic flow (intersections and traffic jams), instances exceeding the pollution limit values in the immediate vicinity of heavily busy roads can be assumed.

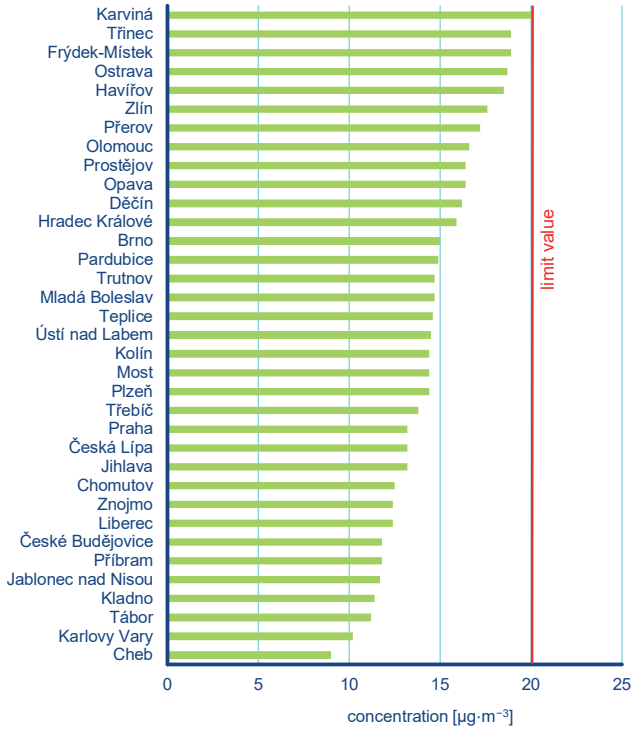
Weighted ground-level O_3 concentrations (26th highest maximum daily 8-hour average in 2021) can be compared with the pollution limit value (120 $\mu g \cdot m^{-3}$) in contrast to the air pollution limit based on a three-year average (Table I.1). In view of the fact that ground-level O_3 does not have its own emission source and the formation and chemistry of O_3 is complex and depends on many factors, its increased concentrations may occur in even relatively clean areas (for more see Chapter IV.4). In 2021, weighted O_3 concentrations higher than the pollution limit value were not observed in any region. In 2021, inhabitants in the O/K/F-M and Brno agglomerations, and in the South Moravia without Brno, Moravian-Silesia without O/K/F-M and Central Bohemia regions were exposed to the highest weighted O_3 concentrations. However, differences between individual regions were not as pronounced as in the case of other pollutants.

Weighted ground-level O_3 concentrations did not exceed the value of the pollution limit in any city with more than 30 000 inhabitants. The highest concentrations were determined for Karviná, Ostrava, Havířov, Třinec, Brno, Teplice and Ústí nad Labem cities.

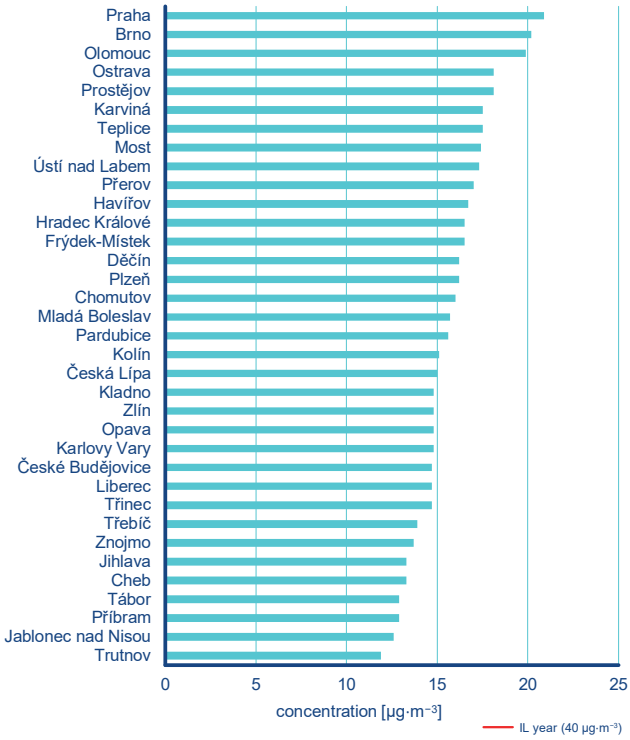
Fig. V.3.2.1 Average population-weighted concentrations of pollutants in regions of the Czech Republic, 2021



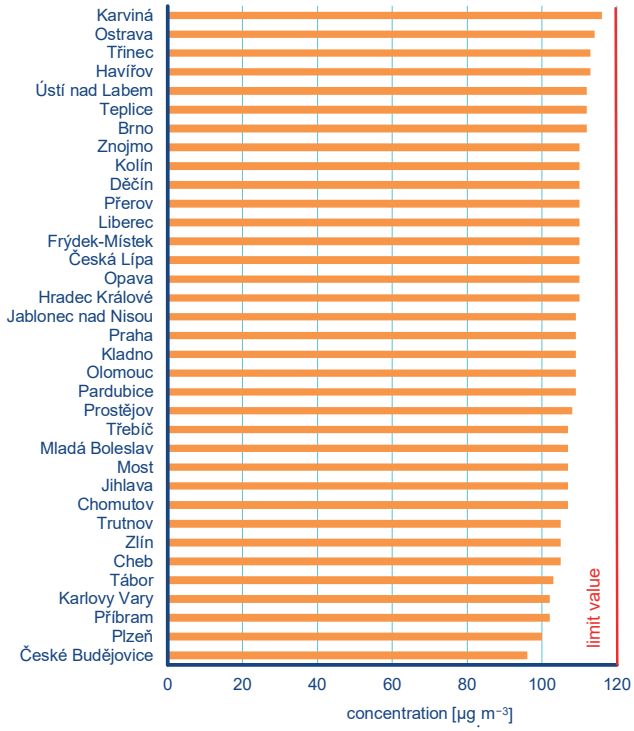
PM_{10} – annual average



$PM_{2,5}$ – annual average



NO_2 – annual average



O_3 – 26. highest max. 8hour average

Fig. V.3.2.2 Average population-weighted concentrations of pollutants in municipalities with more than 30 000 inhabitants, 2021

VI. SMOG WARNING AND REGULATION SYSTEM

With credentials issued by the Ministry of the Environment (MoE), the CHMI operates the Smog Warning and Regulation System (SWRS). Information provided through this system serves both for issuing warnings of extreme levels of air pollution (smog situations, or local exceeding of threshold values) and for regulating (reducing) the release of pollutants from selected sources significantly affecting ambient air quality in the respective area. The monitored pollutants include PM_{10} suspended particles, sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and ground-level (tropospheric) ozone (O_3).

Since 1 September 2012, the SWRS has been regulated by Act No. 201/2012 Coll., on air protection, and Decree No. 330/2012 Coll., as amended. The respective rules are summarized in Tab. VI.3. When announcing the smog situation and regulation for PM_{10}, SO_2 and NO_2, the expected outlook for the next 24 hours is also evaluated. In contrast, when declaring a smog situation for O_3 and warnings for O_3, NO_2 and SO_2, the expected evolution of concentrations is not assessed and the public is informed, in accordance with Article 13 of Directive 2008/50/EC, immediately after the relevant threshold value is exceeded. For the same reason, exceeding the threshold value at one station is sufficient to announce a smog situation and a warning for ozone.

The current list of SWRS areas is given in Tab. VI.2. Areas and representative stations for PM_{10}, SO_2, and NO_2 (Figs. VI.1, VI.3, and VI.4) are specified by the Bulletin of the MoE, and for O_3 (Fig. VI.2) by the CHMI Director's Directive. Throughout 2021, a list published in the MoE Bulletin No. 4/2021 (MŽP 2021) applied for PM_{10}, SO_2 and NO_2, while for O_3, the list specified by the CHMI Director's Directive No. 2019/12, as amended. Compared to the previously valid lists, the Karviná station (TKARA; representative for PM_{10}, SO_2, NO_2 and O_3) was removed as of 1 January 2021 inclusive due to the commencement of long-term construction activities in the vicinity of the station, which reduced its representativeness and led to a change in classification from background to industrial. Furthermore, on November 6, 2021, the Jihlava (JJIHA) station, representative for PM_{10}, SO_2, NO_2 and O_3, stopped measuring due to the termination of the lease agreement by the landowner. Its exclusion from the list of representative stations was retroactively confirmed by the MoE Bulletin No. 3/2022 (MŽP 2022).

Announced smog situations and regulations (warnings)

In 2021, the only one smog situation was announced due to exceeding the threshold values of suspended PM_{10} particles, namely for the territory of the O/K/F-M agglomeration without Třinec on 27–29 December. Its total duration was 58 h (Tab. VI.1). The threshold values for NO_2 and O_3 were not exceeded at any representative SWRS station. The informative threshold value for SO_2 was exceeded at the Lom station (3 March 2021) and it concerned a single hour in the whole the year.

Synoptic situation during smog situations

27–29 December 2021

On the night of December 25, a cold front crossed the Czech Republic from the north, behind which an anticyclone expanded on the territory. Cold air penetrated the territory from the north and in the north-east of the Czech Republic, the temperature dropped temporarily to –10 °C at 850 hPa pressure level. During 26 December, the anticyclone advanced further east from Central Europe via Ukraine. In the first half of 27 December, a warm front crossed the Czech Republic from the south-west, behind which warmer air began to flow to the territory in the upper atmosphere. This created an inverse air stratification preventing the dispersion of pollutants in the air, leading to increased PM_{10} concentrations, especially in the Ostrava-Karviná region. In the following days, a depression advanced from the Atlantic over western Europe. The associated frontal system quickly occluded and as an occlusion front crossed Moravia and Silesia on the night of 29 December. The mild wind associated with this front led to improved dispersion conditions, which together with occurrence of precipitation caused a subsequent decrease in concentrations.

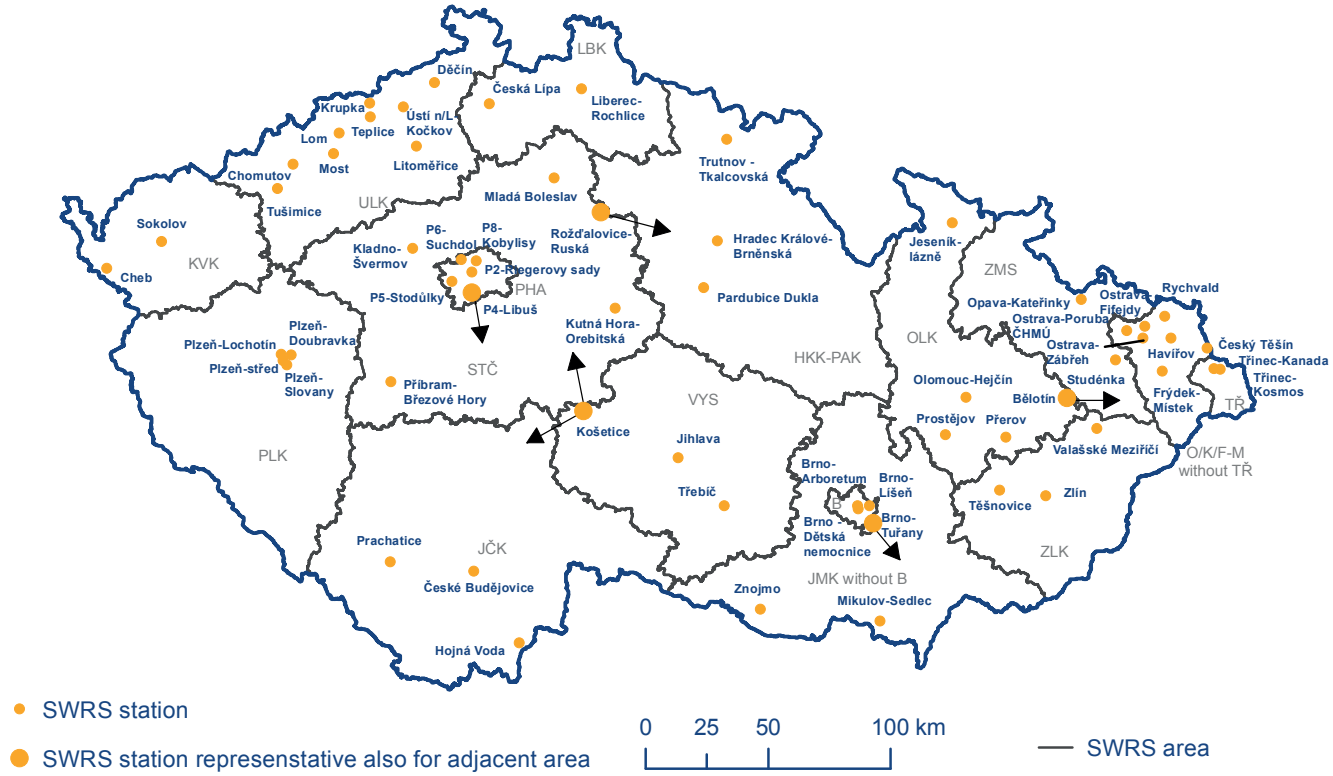


Fig. VI.1 SWRS areas and representative stations for PM_{10} (in effect as of 1 January 2021)

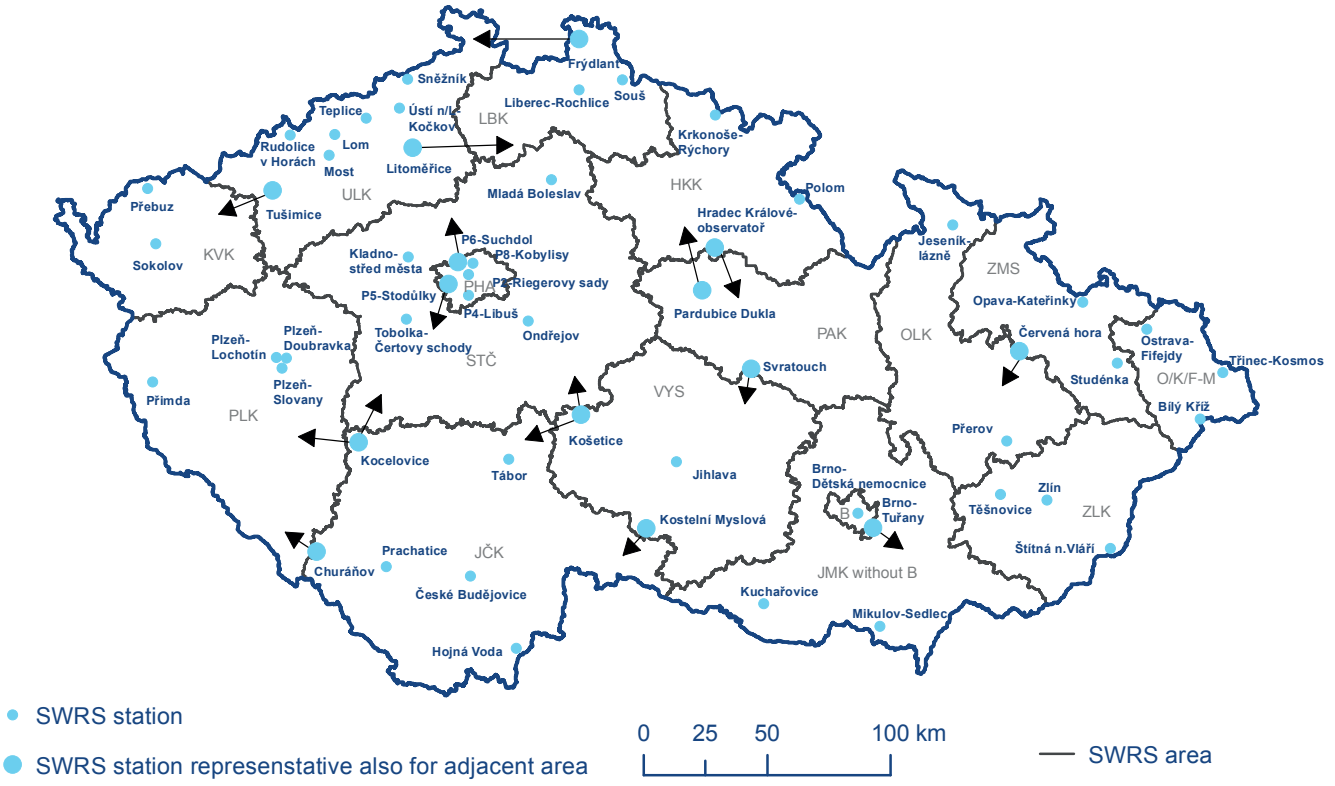


Fig. VI.2 SWRS areas and representative stations for O_3 (in effect as of 1 January 2021)

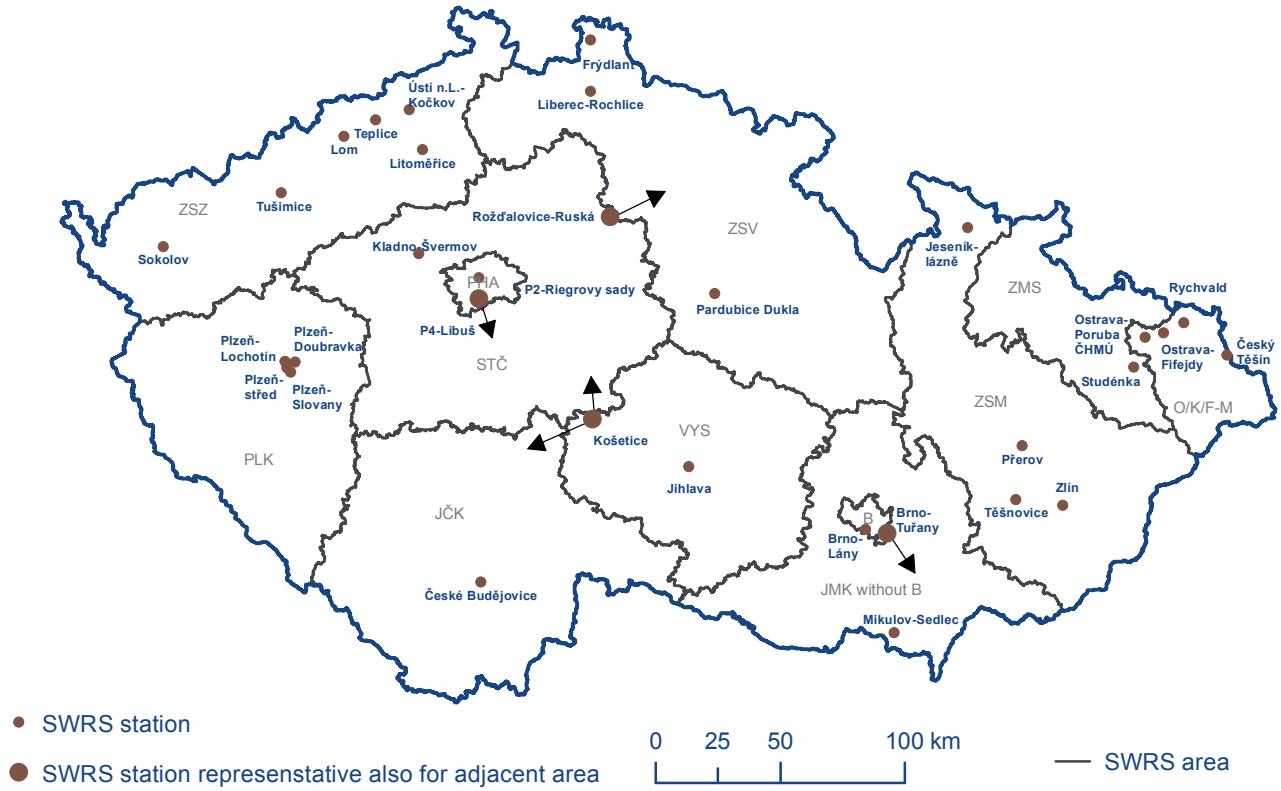


Fig. VI.3 SWRS areas and representative stations for SO_2 (in effect as of 1 January 2021)

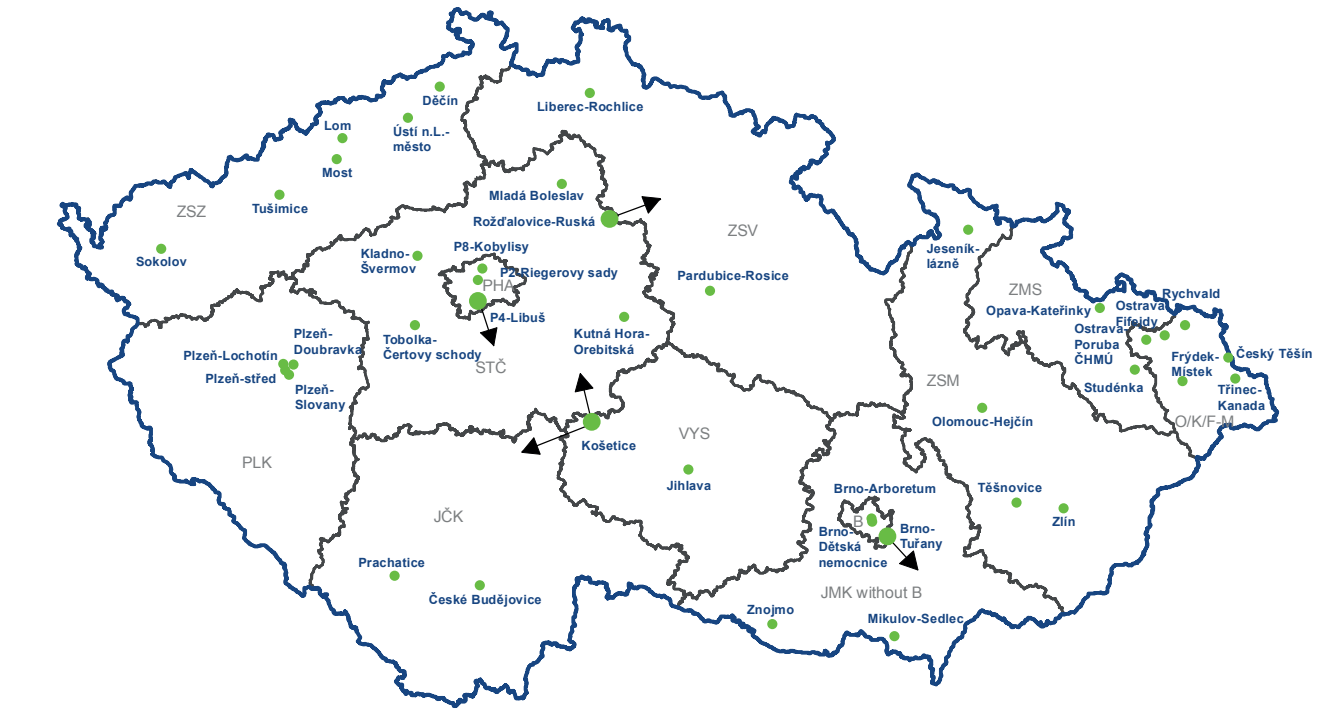


Fig. VI.4 SWRS areas and representative stations for NO_2 (in effect as of 1 January 2021)

Tab. VI.1 Smog situations and regulations for PM_{10} – dates and times of announcement, 2021

Announcement		Cancellation		Duration	
Smog situation	**Regulation**	**Regulation**	**Smog situation**	**Smog situation**	**Regulation**
day and hour CET				**[h]**	
Agglomeration of Ostrava/Karviná/Frýdek-Místek without Třinec area					
27.12.2021 1:51 AM	x	x	29.12. 2021 12:00 PM	58	x

Note: CET – local time, i.e. Central European Time. The duration of the smog situation includes also the duration of the regulation, if announced.

Tab. VI.2 SWRS areas for individual pollutants

Zone / Agglomeration	SWRS area* (abbreviation)		
	SO_2, NO_2	PM_{10}	O_3
Agglomeration of Prague	PHA		
Central Bohemia zone	STČ		
South-western zone	Plzeň region (PLK)		
	South Bohemia region (JČK)		
North-western zone	ZSZ	Ústí nad Labem region (ULK)	
		Karlovy Vary region (KVK)	
North-eastern zone	ZSV	Hradec Králové region and Pardubice region (HKK-PAK)	Hradec Králové region (HKK)
			Pardubice region (PAK)
		Liberec region (LBK)	
South-eastern zone	Vysočina region (VYS)		
	South Moravia region without agglomeration of Brno (JMK without B)		
Agglomeration of Brno	B		
Central Moravia zone	ZSM	Olomouc region (OLK)	
		Zlín region (ZLK)	
Moravia-Silesia zone	ZMS		
Agglomeration of Ostrava/ Karviná/Frýdek-Místek	O/K/F-M	Agglomeration of Ostrava/Karviná/Frýdek-Místek without Třinec area (O/K/F-M without TŘ)	O/K/F-M
		Třinec area (TŘ)**	

* the name of the SWRS area indicated if it differs from the name of the zone or agglomeration
** territory of municipalities with extended powers - Jablunkov (8110) and Třinec (8121)

Tab. VI.3 The rules for the announcement and cancellation of smog situations and regulations (alerts)

Substance	Threshold value			Exceedance duration	Number of stations*	Supplementary condition
	Abbreviation	µg·m^{-3}	Interval			
Announcement of smog situation						
PM_{10}	**IPH**	100	12 h	1 h	50 % (two stations if there are just two of them)	Based on an evaluation of the forecast of meteorological conditions and pollution situation no decrease of the concentration below the informative threshold value can be expected during next 24 hours.
NO_2		200	1 h	3 h	1 station	
SO_2		250				
O_3		180		1 h		---
Announcement of regulation						
PM_{10}	**RPH**	150	1 h	1 h	50 % (two stations if there are just two of them)	Based on an evaluation of the forecast of meteorological conditions and pollution situation no decrease of the concentration below the informative threshold value can be expected during the next 24 hours.
NO_2		400		3 h		
SO_2		500				
Announcement of alert						
O_3	**VPH**	240	1 h	1 h	1 station	---
NO_2	**RPH**	400		3 h		
SO_2	**RPH**	500				
Cancellation						
The smog situation terminates and the regulation is revoked if no measuring site representative for the pollution level in an area of minimum 100 km^2 reports the concentration of polluting substances above the corresponding threshold value and this state lasts continuously for at least 12 hours and no recurrent instance of exceeding the informative, regulatory or warning threshold value can be expected in the next 24 hours based on the meteorological forecast.						
12-hour time interval is being reduced up to 3 hours in a case when meteorological conditions cannot be assessed as leading to the smog situation and recurrent instance of exceeding the informative, regulatory or warning value can almost be excluded in the next 24 hours in accordance with the meteorological forecast.						

* Station must be representative for the pollution level in an area of minimum 100 km^2.
Note: **IPH** – information threshold value, **RPH** – regulatory threshold value, **VPH** – alert threshold value. The requirements for the number of stations are related to the representative stations for the given SWRS area.

VII. AREAS WHERE THE POLLUTION LIMIT VALUES ARE EXCEEDED

VII.1 Areas where the pollution limit values for the protection of human health are exceeded

Annually, areas in the CR are defined where the pollution limit values are exceeded collectively for all pollutants monitored for the protection of human health. The map of areas where at least one pollution limit value[1], not including ground-level ozone, is exceeded provides comprehensive information on ambient air quality in the CR. In 2021, 6.1 % of the territory of the CR, inhabited by approx. 20 % of the population, was designated as an area where pollution limit values were exceeded (Fig. VII.1.1; Tab. VII.1.1). In the vast majority of cases, the delimitation of these areas is a result of exceeding the annual pollution limit values for benzo[*a*]pyrene (Tab. VII.1.1). To a minimal extent, these areas delimited in 2021 were a result of exceeding the 24-hour pollution limit value for suspended particulates PM_{10} and the annual pollution limit value for $PM_{2.5}$. The largest extent of areas exceeding the limit values were in the O/K/F-M agglomeration (61 %), and in the Central Moravia zone (24 %) (Tab. VII.1.2). In addition, in the O/K/F-M agglomeration, the vast majority of the population (96 %) has been exposed to above-limit concentrations (Tab. VII.1.3) and it is the most burden area in the CR for a long time. In the year-on-year comparison 2020/2021, the areas where at least one pollution limit value was exceeded except for ozone increased slightly (by approx. 1.5 %). The year-on-year increase of the area with exceeded pollution limits except for ozone occurred mainly in the Central Moravia zone (Fig. VII.1.2). The area with at least one pollution limit value exceeded in 2021 except for ozone is the second smallest within the evaluation period 2012–2021 (Fig. VII.1.3).

Tab. VII.1.1 Percentage of the area exceeding the pollution limit (%) and percentage of population resident in areas exposed to above-limit values (%) in the Czech Republic, 2021

Czech republic	Pollutants specified in Annex 1 to Act No. 201/2012 Coll., as amended						
	Item 1 of the Annex			Item 3 of the Annex		Item 4 of the Annex	
	PM_{10}	$PM_{2.5}$		BaP		O_3	
	36^{th} max. 24-h average > 50 µg·m^{-3}	annual average > 20 µg·m^{-3}	Total LV exceedances	annual average > 1 ng·m^{-3}	Total exceedances, ozone excluded	26. highest values max. daily 8-h runing average (in the three–year average) > 120 µg·m^{-3}	Total exceedances, including ozone
Inhabitants	0.4	1.5	1.5	19.7	19.7	0.02	19.7
Area	0.1	0.3	0.3	6.1	6.1	0.2	6.4

1 The annual pollution limit values for PM_{10}, $PM_{2.5}$, benzo[*a*]pyrene, NO_2, lead, cadmium, arsenic, nickel, and benzene, the pollution limit value for CO (max. daily 8-hour moving average), the 24-hour pollution limit values for PM_{10} and SO_2, and the hourly pollution limit value for SO_2 and NO_2.

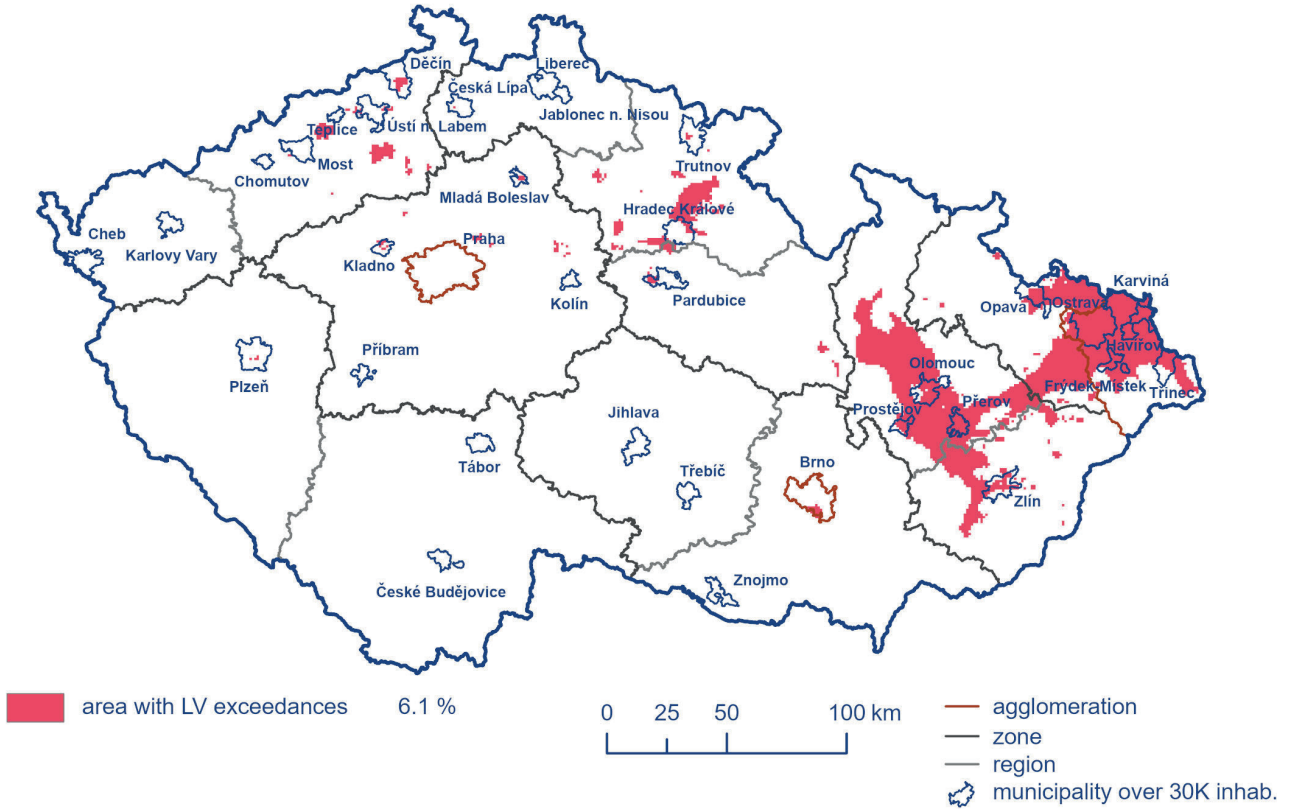


Fig. VII.1.1 Areas with exceeded air pollution limits for the protection of human health excluding ground-level ozone, 2021

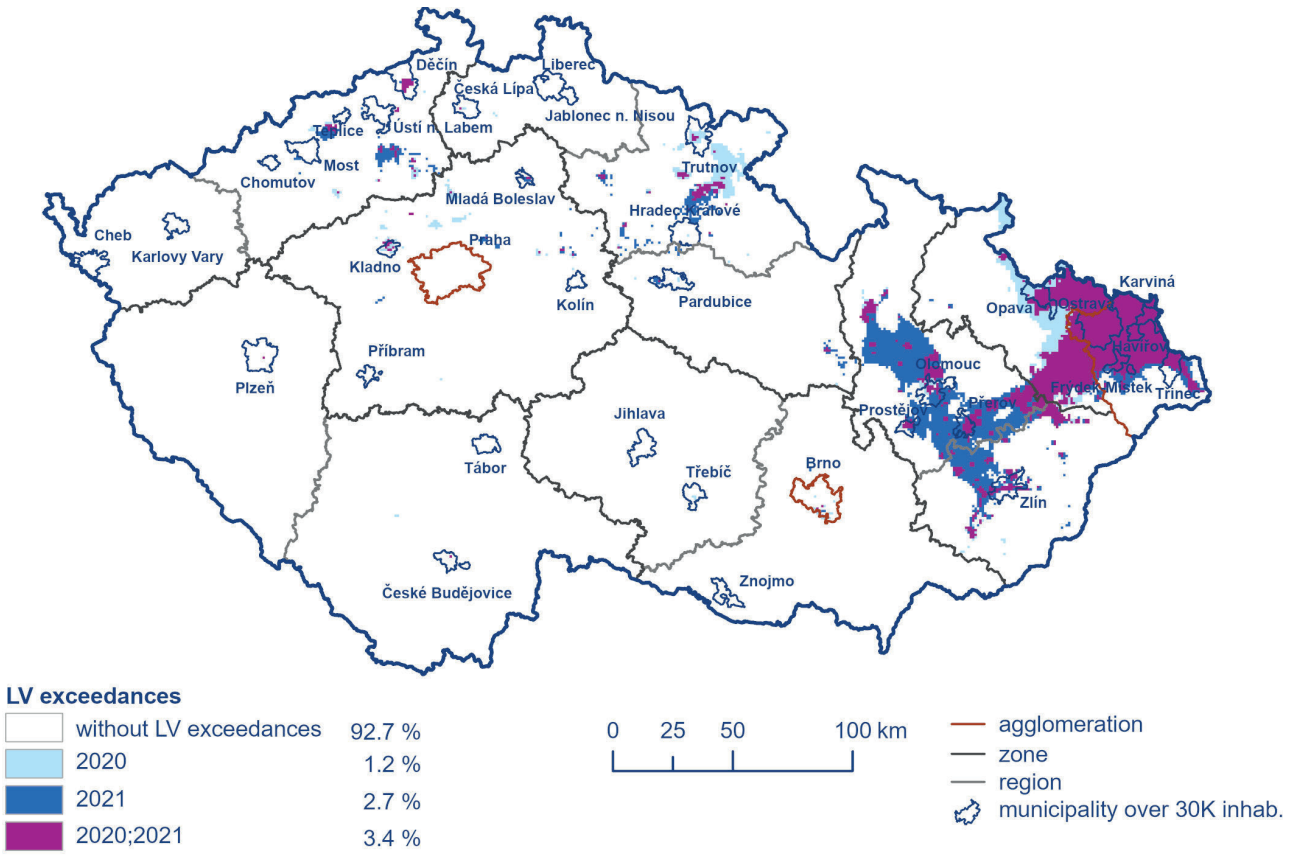


Fig. VII.1.2 Comparison of areas with exceeded air pollution limits for the protection of human health excluding ground-level ozone in 2020 and 2021

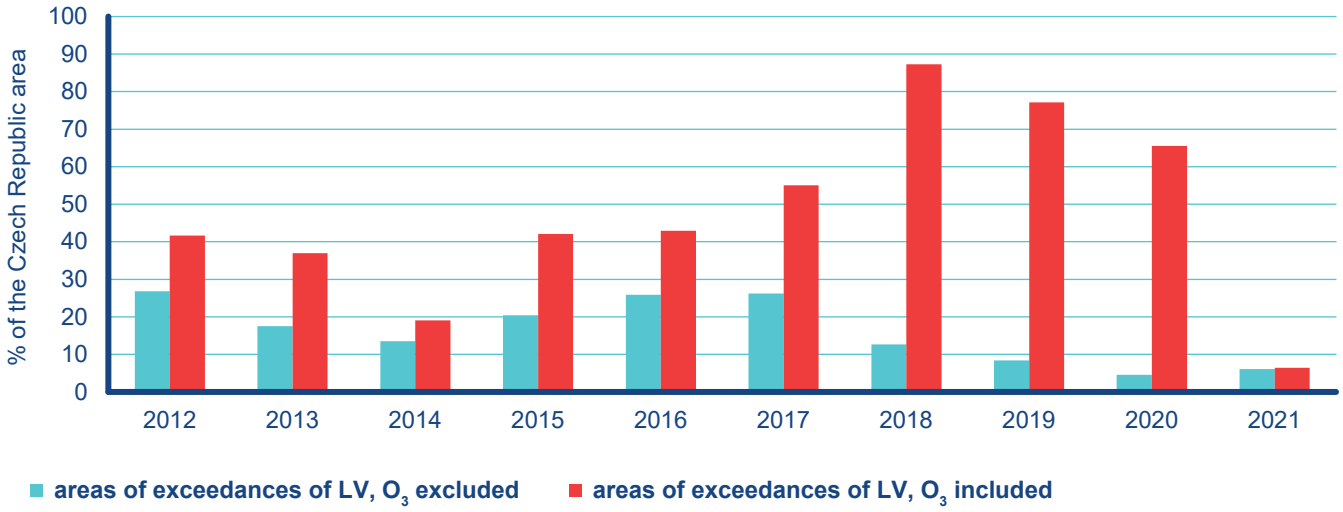


Fig. VII.1.3 Exceeded air pollution limit in the Czech Republic, percentage of the area, 2012–2021

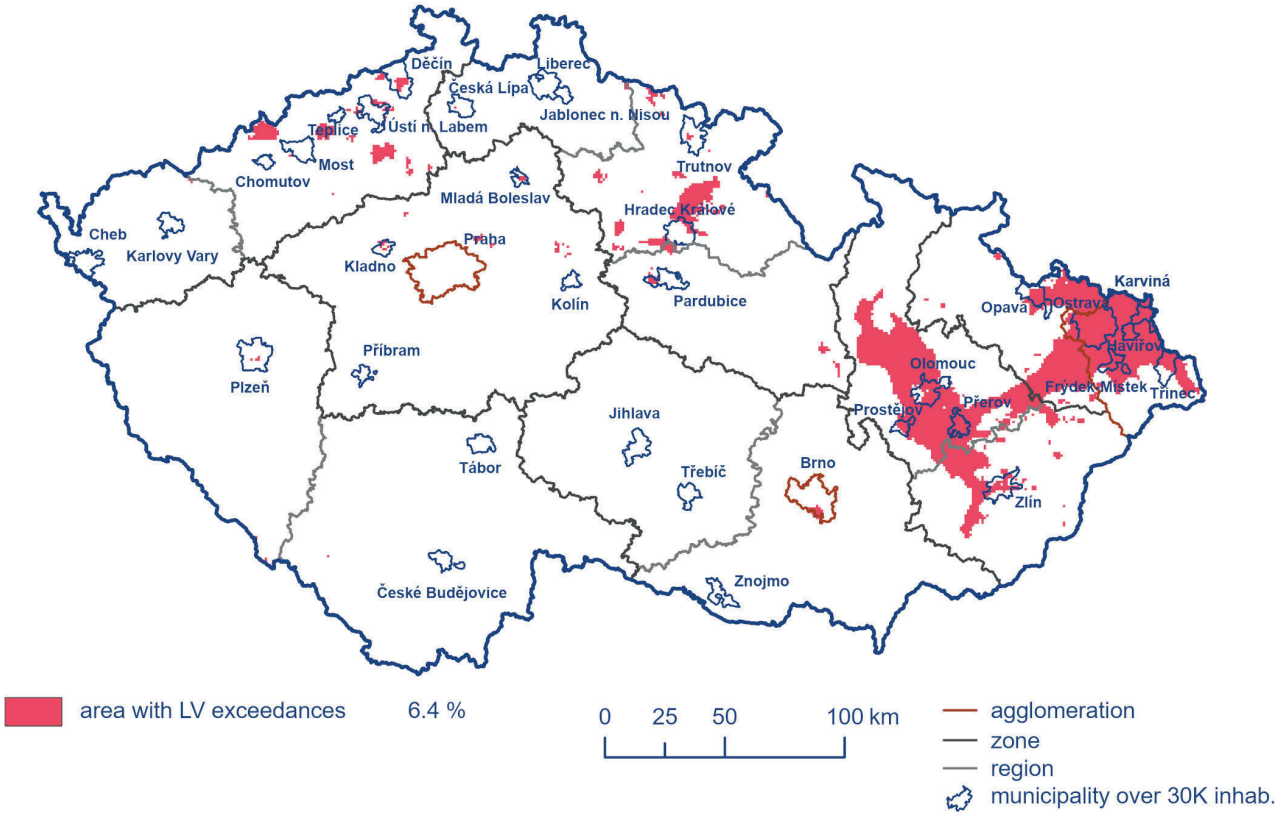


Fig. VII.1.4 Areas with exceeded air pollution limits for the protection of human health including ground-level ozone, 2021

The relatively good air quality in the CR in 2021 was mainly contributed by the less frequent occurrence of adverse conditions in January and November compared to ten-year values (Fig. III.3, Fig. III.4). The improvement of air quality in the long term can also be attributed to already implemented measures to improve air quality (particularly the replacement of boilers), the ongoing renewal of the vehicle fleet, and measures taken at large source facilities (for more see Chapters II and IV.).

After including ground-level ozone, the area where at least one pollution limit value was exceeded in 2021 corresponded to 6.4 % of the territory of the CR (Fig. VII.1.4) with approximately

Tab. VII.1.2 Limit value (LV) exceedances in the zones/agglomerations, regions and municipalities with extended competencies of the Czech Republic, % of the area of the administrative unit, 2021

Zone / agglomeration	Region	Pollutants specified in Annex 1 to Act No. 201/2012 Coll.. as amended						
		Item 1 of the Annex			Item 3 of the Annex		Item 4 of the Annex	
		PM_{10}	$PM_{2.5}$	Total LV exceedances	BaP	Total exceedances. excluding ozone	O_3	Total exceedances. including ozone
		36^{th} max. 24-h average > 50 $\mu g \cdot m^{-3}$	annual average > 20 $\mu g \cdot m^{-3}$		annual average > 1 $ng \cdot m^{-3}$		26. highest values max. daily 8-h runing average (in the three–year average) > 120 $\mu g \cdot m^{-3}$	
Agglomeration of Prague	Prague	–	–	–	–	–	–	–
Central Bohemia zone	Central Bohemia region	–	–	–	0.41	0.41	–	0.41
South-western zone	South Bohemia region	–	–	–	–	–	0.02	0.02
	Plzeň Region	–	–	–	0.05	0.05	0.14	0.19
		–	–	–	0.02	0.02	0.07	0.09
North-western zone	Karlovy Vary region	–	–	–	–	–	0.11	0.11
	Ústí nad Labem region	–	–	–	3.05	3.05	1.92	4.97
		–	–	–	1.89	1.89	1.23	3.11
North-eastern zone	Liberec region	–	–	–	0.03	0.03	0.24	0.27
	Hradec Králové region	–	–	–	7.28	7.28	0.88	8.16
	Pardubice region	–	–	–	1.26	1.26	–	1.26
		–	–	–	3.25	3.25	0.40	3.65
South-eastern zone	Vysočina region	–	–	–	–	–	–	–
	South Moravia region without agglomeration of Brno	–	–	–	0.05	0.05	–	0.05
		–	–	–	0.05	0.05	–	0.05
Agglomeration of Brno		–	–	–	7.75	7.75	–	7.75
Central Moravia zone	Olomouc region	–	–	–	32.29	32.29	–	32.29
	Zlín region	–	0.03	0.03	12.93	12.93	–	12.93
		–	0.01	0.01	23.98	23.98	–	23.98
Moravia-Silesia zone	Moravia-Silesia region	–	0.02	0.02	23.40	23.40	–	23.40
Agglomeration of Ostrava/Karviná/ Frýdek-Místek		4.40	11.60	11.60	61.09	61.09	–	61.09
		1.54	4.05	4.05	36.56	36.56	–	36.56

Tab. VII.1.3 Limit value (LV) exceedances in the zones/agglomerations, regions and municipalities with extended competencies of the Czech Republic, % of the inhabitants, 2021

Zone / agglomeration	Region	Pollutants specified in Annex 1 to Act No. 201/2012 Coll., as amended						
		Item 1 of the Annex			Item 3 of the Annex		Item 4 of the Annex	
		PM_{10}	$PM_{2.5}$	Total LV exceedances	BaP	Total exceedances, ozone excluded	O_3	Total exceedances, including ozone
		36th max. 24-h average > 50 µg·m^{-3}	annual average > 20 µg·m^{-3}		annual average > 1 ng.m^{-3}		26. highest values max. daily 8-h runing average (in the three–year average) > 120 µg·m^{-3}	
Agglomeration of Prague	Prague	–	–	–	–	–	–	–
Central Bohemia zone	Central Bohemia region	–	–	–	4.97	4.97	–	4.97
South-western zone	South Bohemia region	–	–	–	–	–	–	–
	Plzeň Region	–	–	–	2.88	2.88	–	2.88
		–	–	–	1.37	1.37	–	1.37
North-western zone	Karlovy Vary region	–	–	–	–	–	0.0005	0.0005
	Ústí nad Labem region	–	–	–	12.81	12.81	0.31	13.11
		–	–	–	9.37	9.37	0.23	9.59
North-eastern zone	Liberec region	–	–	–	0.36	0.36	0.0004	0.36
	Hradec Králové region	–	–	–	17.02	17.02	0.01	17.03
	Pardubice region	–	–	–	3.50	3.50	–	3.50
		–	–	–	7.55	7.55	0.0004	7.55
South-eastern zone	Vysočina region	–	–	–	–	–	–	–
	South Moravia region without agglomeration of Brno	–	–	–	0.80	0.80	–	0.80
		–	–	–	0.49	0.49	–	0.49
Agglomeration of Brno		–	–	–	6.34	6.34	–	6.34
Central Moravia zone	Olomouc region	–	–	–	64.21	64.21	–	64.21
	Zlín region	–	1.13	1.13	49.08	49.08	–	49.08
		–	0.54	0.54	56.95	56.95	–	56.95
Moravia-Silesia zone	Moravia-Silesia region	–	0.01	0.01	66.72	66.72	–	66.72
Agglomeration of Ostrava/ Karviná/Frýdek-Místek		5.52	19.50	19.50	96.31	96.31	–	96.31
		3.61	12.76	12.76	86.07	86.07	–	86.07

20 % of population (Tab. VII.1.1). In the year-on-year comparison 2020/2021, the area exceeding at least one limit value including ozone significantly decreased (by approx. 59 %). In the evaluated period 2012–2021 (Fig. VII.1.3), the territory with above-limit concentrations of at least one polluting substance covered the smallest area. The graph also shows a decrease in the extent of the above-limit concentration area in the last four years associated with decreasing ozone concentrations (Chap. IV.4).

VII.2 Areas where the pollution limit values for the protection of ecosystems and vegetation are exceeded

From the viewpoint of the protection of the most valuable natural locations of the CR, the exceeding of pollution limit values for the protection of ecosystems and vegetation[2] in National Parks (NPs) and Protected Landscape Areas (PLAs) are also evaluated (Tab. VII.2.1). In 2021, at least one of these limit values was exceeded over nearly 9 % of the territory of NPs and PLAs (Fig. VII.2.1).

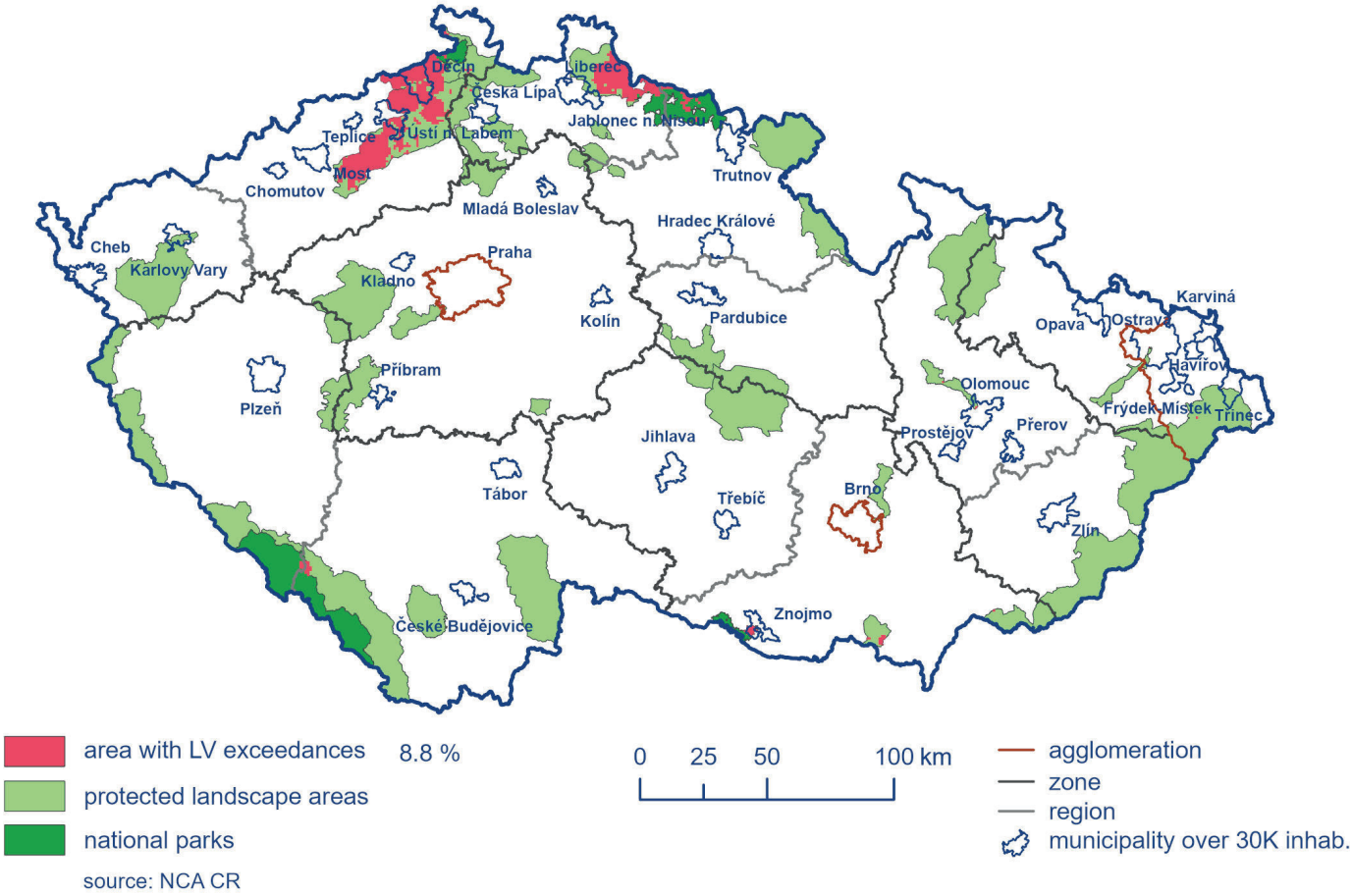


Fig. VII.2.1 Areas with exceeded air pollution limits for the protection of ecosystems and vegetation in NPs and PLAs including ground-level ozone, 2021

2 Pollution limit values for the annual and winter average concentrations of SO_2, the pollution limit value for the annual average concentration of NO_x, and the pollution limit value for O_3 expressed as the AOT40 exposure index.

Tab. VII.2.1 Exceedances of the limit value (NO_x and AOT40) for the protection of ecosystems and vegetation within NP and CHKO, % of the territory of NP and CHKO, 2021

National park and protected landscape area	NO_x	O_3	Sum
	annual average > 30 $\mu g \cdot m^{-3}$	AOT 40 > 18 000 $\mu g \cdot m^{-3} \cdot h$	
Krkonoše Mountains NP	–	25.1	25.1
České Švýcarsko NP	–	23.0	23.0
Podyjí NP	–	21.6	21.6
Šumava NP	–	1.9	1.9
Beskydy PLA	–	0.2	0.2
Bílé Karpaty PLA	0.1	–	0.1
Blaník PLA	–	–	–
Blanský les PLA	–	–	–
Brdy PLA	–	–	–
Broumovsko PLA	–	–	–
České středohoří PLA	2.7	52.4	54.8
Český kras PLA	1.0	2.0	2.9
Český les PLA	–	–	–
Český ráj PLA	–	–	–
Jeseníky PLA	–	–	–
Jizerské hory PLA	–	51.0	51.0
Kokořínsko - Máchův kraj PLA	–	–	–
Křivoklátsko PLA	–	–	–
Labské pískovce PLA	1.7	66.9	68.6
Litovelské Pomoraví PLA	1.8	–	1.8
Lužické hory PLA	–	1.9	1.9
Moravský kras PLA	0.6	–	0.6
Orlické hory PLA	–	–	–
Pálava PLA	1.7	9.6	11.3
Poodří PLA	0.1	–	0.1
Slavkovský les PLA	–	–	–
Šumava PLA	–	0.7	0.7
Třeboňsko PLA	–	–	–
Žďárské vrchy PLA	–	–	–
Železné hory PLA	–	–	–

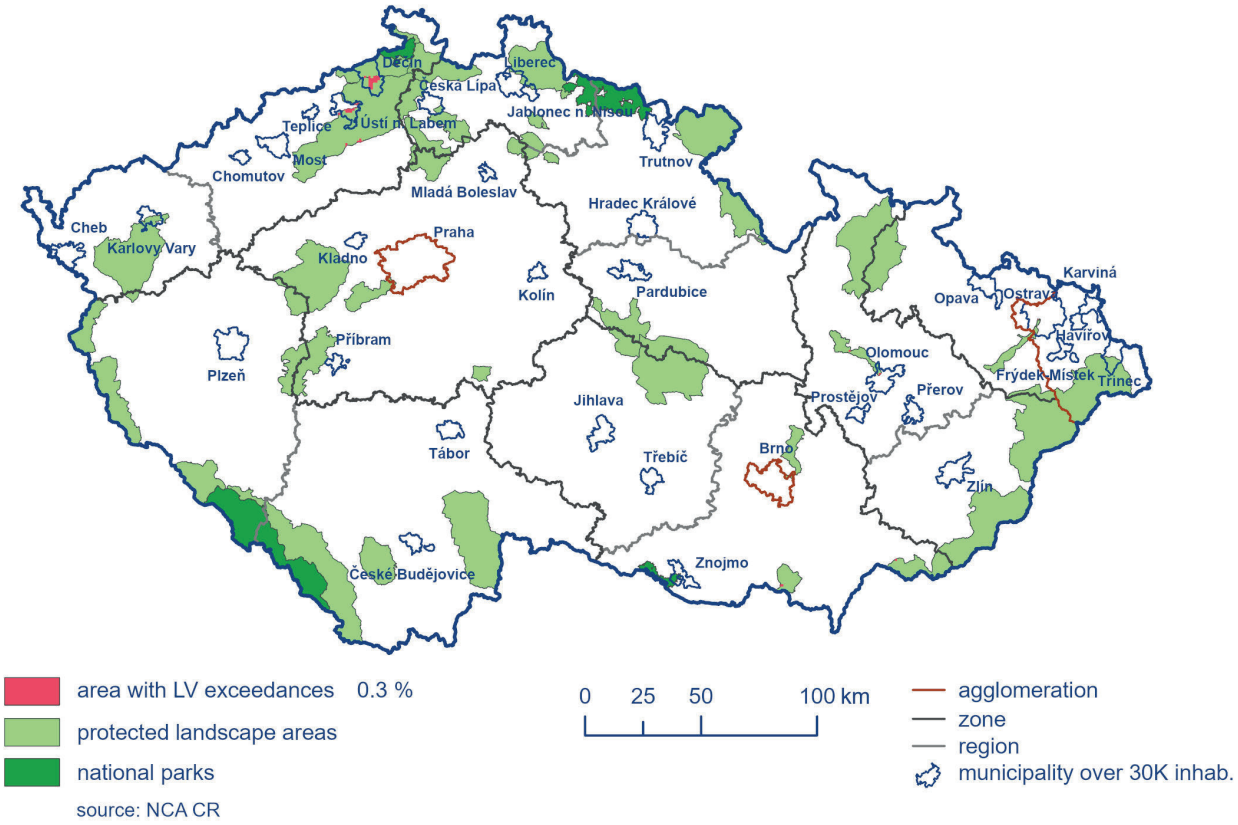


Fig. VII.2.2 Areas with exceeded air pollution limits for the protection of ecosystems and vegetation in NPs and PLAs excluding ground-level ozone, 2021

Above-limit NO_x concentrations occur particularly around transport roads; concerning the most valuable natural territories of the CR, the pollution limit value for NO_x was exceeded over only a very small area of several PLAs (Tab. VII.2.1, Fig. VII.2.2).

In 2021, the limit value for AOT40 was exceeded at least in part of the territory in all NPs and some PLAs (Tab. VII.2.1).

The pollution limit values for the annual and winter average concentrations of SO_2 were not exceeded in 2021 in the territory of any PLA or NP, similarly as in previous years.

VIII. EUROPEAN CONTEXT

Air pollution in large industrial areas has been one of the serious environmental problems in Europe since roughly the middle of the last century. The well-known episodes of the so-called smog of London forced not only the UK, but also other Western European countries to gradually adopt national laws to reduce air pollution.

In the 1960s, it became apparent that the problem could only be solved through international cooperation. Studies within a program for investigating the long-range transmission of air pollution, carried out under the auspices of the Organisation for Economic Cooperation and Development (OECD) in 1971–1977, showed that the acidification of rivers and lakes in Scandinavia was a result of so-called acid rain, caused by pollutants released into the atmosphere over continental Europe. Consequently, the first internationally binding document was adopted to resolve problems connected with air pollution at a broad regional level, namely the Convention on Long-Range Transboundary Air Pollution (CLRTAP), which was adopted by the UN Economic Commission for Europe in 1979.

Due to measures introduced both under CLRTAP and especially later within European Union (EU) legislation, air quality in Europe has improved substantially over the past decades. Emissions of many pollutants have been reduced, but pollution from suspended particulate matter and ozone still poses serious risks. Considerable parts of the European population and ecosystems continue to be exposed to higher concentrations of pollutants than legislatively stipulated limit levels and values recommended by the World Health Organisation (WHO).

Despite the improvements mentioned above, air pollution in Europe is one of the highest-risk environmental factors, causing premature deaths, increasing the incidence of a wide range of diseases, damaging vegetation and ecosystems, and leading to a loss of biodiversity. All these factors also lead to significant economic losses. A further improvement will require measures and cooperation on global, continental, national and local levels in most branches of the economy with public participation. The measures must include technological development, structural changes including optimisation of the infrastructure and territorial planning, as well as a change in behaviour. The protection of natural capital, the promotion of economic prosperity, human well-being and social development are parts of the European Union 2050 vision, set out in the 7th EU Environmental Action Programme (EU 2013).

Emissions of pollutants and greenhouse gases within Europe

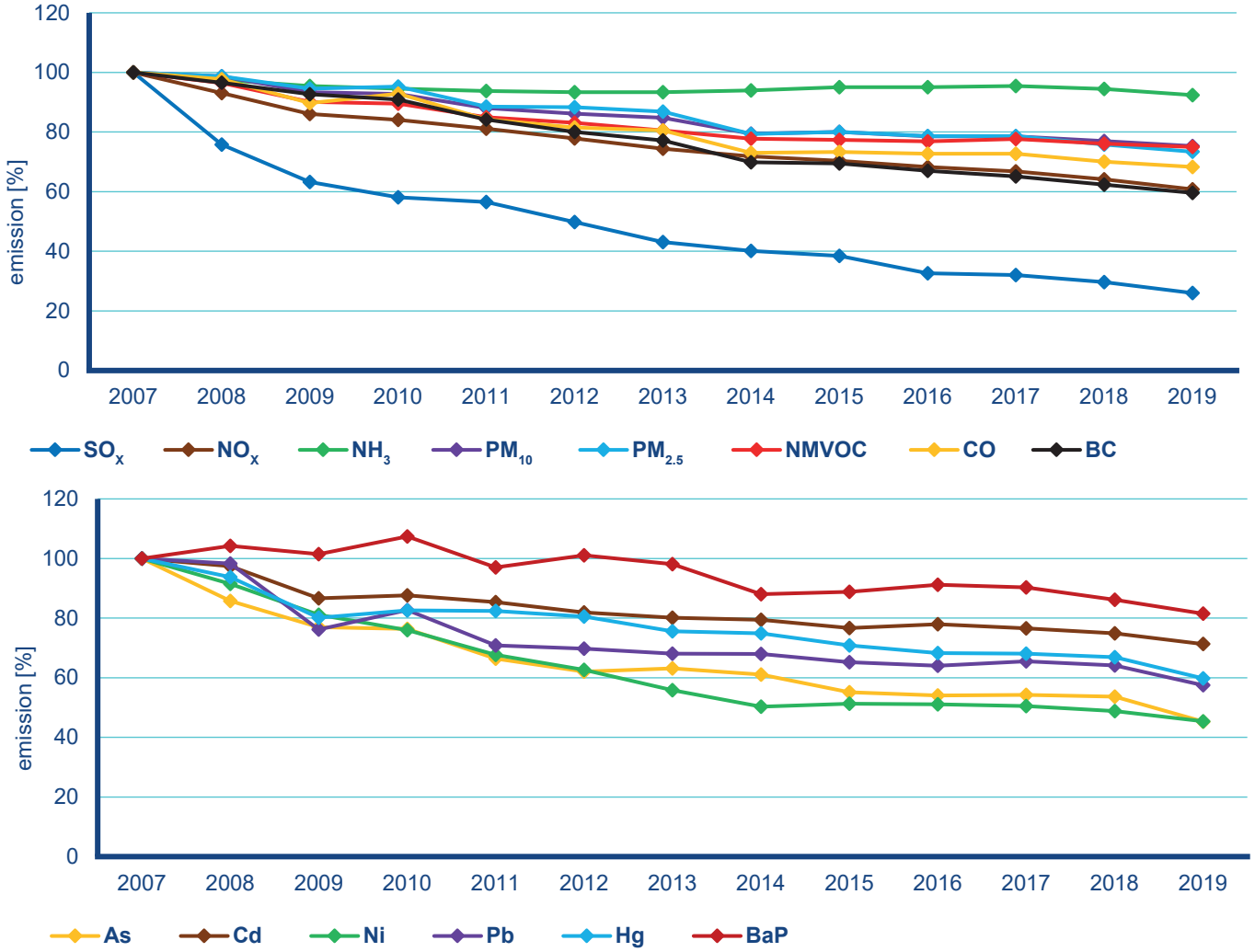
Emissions of the main pollutants released into the ambient air in Europe have decreased since 1990. Nonetheless, this reduction has not been sufficient in all the sectors and the emissions of some pollutants have even increased. For example, there has not been a sufficient reduction in NO_x emissions from mobile sources and therefore air pollution limits are not met in many cities. In the past decade, $PM_{2.5}$ and benzo[*a*]pyrene emissions have also increased in the EU as a result of the incomplete combustion of coal and biomass in households and in private and public buildings. These sources now make the greatest contribution to emissions of particulates and benzo[*a*]pyrene in the EU (Fig. VIII.1).

Greenhouse gas emissions are declining, particularly CO_2, CH_4 and N_2O emissions (Fig. VIII.2). On the contrary, there was an apparent increase in fluorinated hydrocarbon emissions until 2014. In recent years, however, the effects of EU regulations restricting the use of F-gases have begun to manifest and their emissions are gradually declining. In 2020, their amount decreased below the level of the reference year 2007 for the first time.

Overall, there are international obligations for European countries to reduce greenhouse gas emissions based on the requirements of both the UN Framework Convention on Climate Change and related regulations of the European Union. Reducing emissions of fluorinated gases and limiting their use is also required by the Montreal Protocol.

Air quality monitoring in Europe

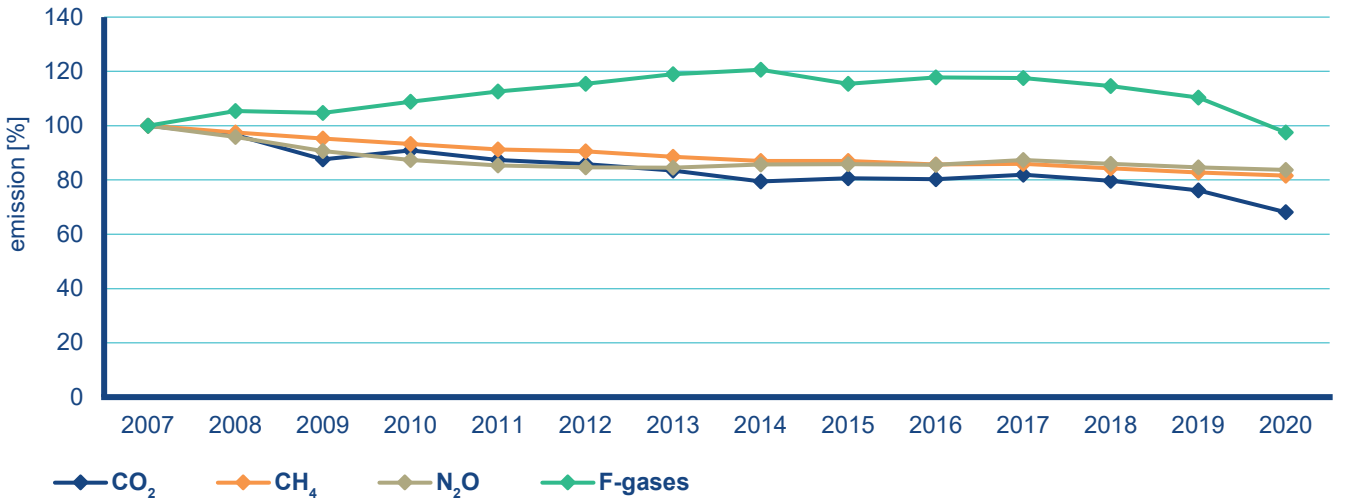
Long-term monitoring of air quality is at a high level in Europe, which together with North America are continents with the highest density of measuring stations. The national air quality monitoring networks are operated by individual countries in accordance with EU legislation, but practical provisions for these networks differ in the countries. In some, they are managed centrally by environmental agencies or meteorological institutes, in others by regional authorities. The central European database of pollutant concentrations measured at air quality monitoring stations (the AQ e-reporting database) is operated by the European Environment Agency (EEA). Each year, individual countries transmit data measured within their monitoring networks to the EEA according to EU legislation.



Note: The emission are expressed as a percentage of the emissions in 2007. Land use, lande-use change and forestry data are only available until 2012. Reporting on BC emissions has been made on a voluntary basis and has not been made for every country.

Source of data: EEA

Fig. VIII.1 Total emissions in 27 Member States of the European Union and United Kingdom, 2007–2019



„Note: The emission are expressed as a percentage of the emissions in 2007. Emissions are represented including emissions from Land use, lande-use change and forestry. Data viz National inventory of greenhouse gas emissions 2022 (UNFCCC) https://unfccc.int/ghg-inventories-annex-i-parties/2022

Source of data: UNFCCC

Fig. VIII.2 Total greenhouse gas emissions in 27 Member States of the European Union and United Kingdom, 2007–2020

In addition to the national networks, long-term pan-European projects are being implemented, whose main goals include detecting long-term trends in air quality in a European-wide context. These programmes are implemented under CLRTAP (EMEP and the group for evaluating the impacts of long-range transboundary air pollution), within the World Meteorological Organization (WMO) GAW programme, and in the framework of European research infrastructures (ACTRIS, ICOS). The long-range transport of pollutants across the continent and beyond is addressed by the CLRTAP convention under the EMEP program. The program was established in 1977 and one of its main goals is to monitor long-term trends in air quality on a regional scale, based on measurements at selected background locations.

Current state of air quality in Europe

From the viewpoint of damage to human health in Europe, the greatest problems are caused by concentration levels of suspended particulate matter (PM), ground-level ozone (O_3), nitrogen dioxide (NO_2) and carcinogenic benzo[*a*]pyrene. Polluted air causes serious health problems, especially for the inhabitants of cities and municipalities. Damage to ecosystems is caused most extensively by O_3, in addition, increased concentrations of nitrogen oxides (NO_x) contribute to excessive atmospheric deposition of nitrogen leading to a number of negative impacts to ecosystems (mainly eutrophication, acidification and reduction of biodiversity).

It has been estimated that in the three-year 2018–2020 period, 8–13 % of the population in Europe[1] was exposed to above-limit 24-hour PM_{10} concentrations, 1–2 % to above-limit annual $PM_{2.5}$ concentrations, 7–37 % to O_3 concentrations greater than the target value and 0.2–2 % to above-limit annual NO_2 concentrations (ETC/ATNI 2022). Approximately 15–22 % of the EU urban population was exposed to annual benzo[*a*]pyrene concentrations higher than the target value in the five-year period 2015–2019 (EEA 2021).

In the three-year 2018–2020 period, estimates of the percentage of the European population exposed to concentrations higher than values recommended by WHO 2021 (Tab. I.3) were even greater, namely 62–83 % concerning annual concentrations of PM_{10}, 97–98 % concerning annual concentrations of $PM_{2.5}$, and 72–83 % concerning annual concentrations of NO_2 (ETC/HE 2022). In 2019 (the latest year evaluated so far in the EEA reports), 99 % of the EU urban population was exposed to daily O_3 concentrations higher than the WHO 2021 recommended value; for the annual benzo[*a*]pyrene concentration it was 75 % and for the 24-hour SO_2 concentration 7 % of the EU urban population (EEA 2021).

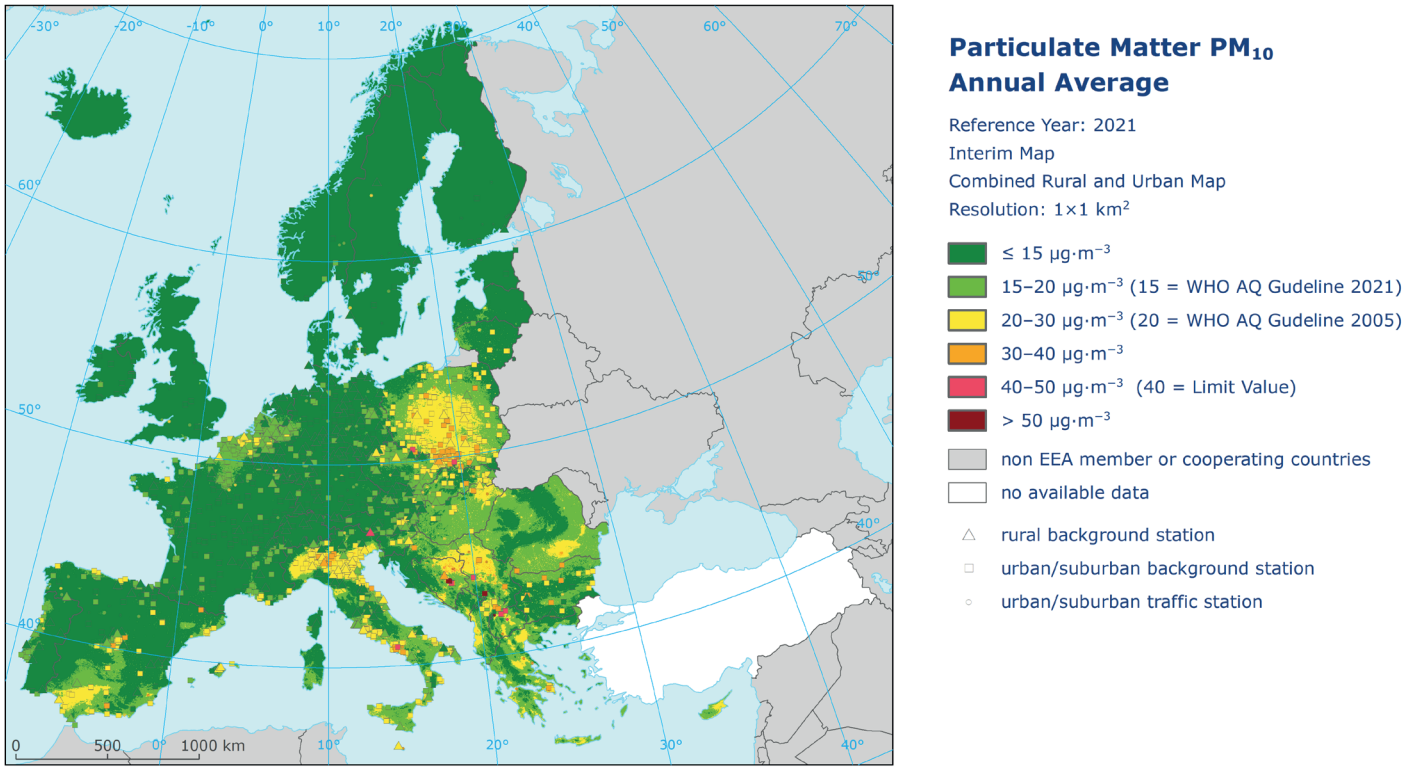
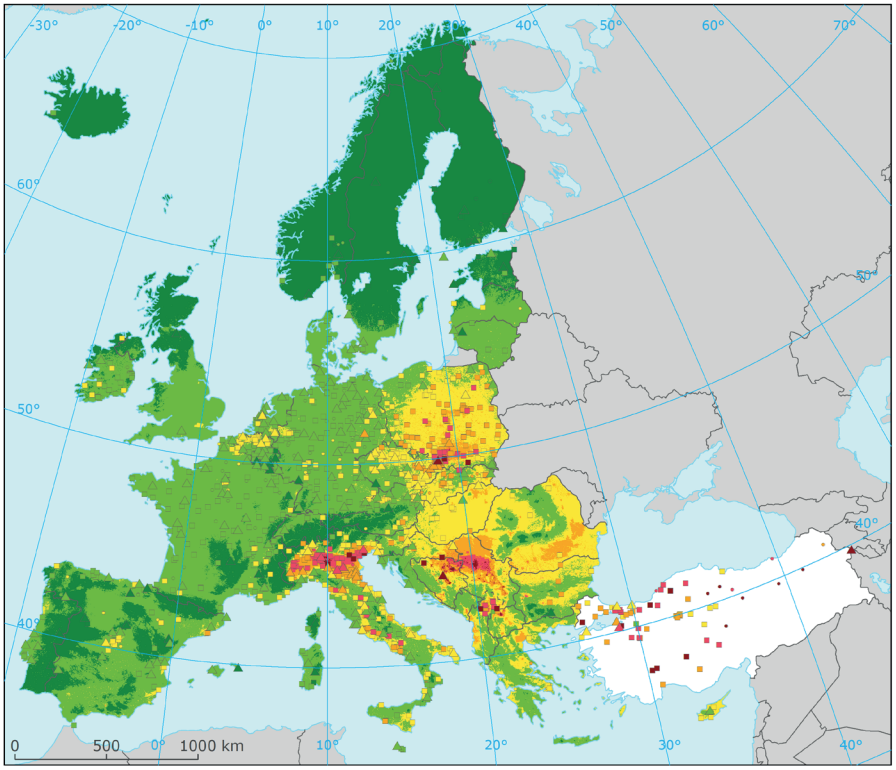


Fig. VIII.3 Field of annual average concentration of PM_{10} in Europe, 2021, preliminary map

1 Including the territory of Cyprus, without the territory of Belarus, Moldova, Ukraine and the European parts of Kazakhstan, Russia and Turkey.

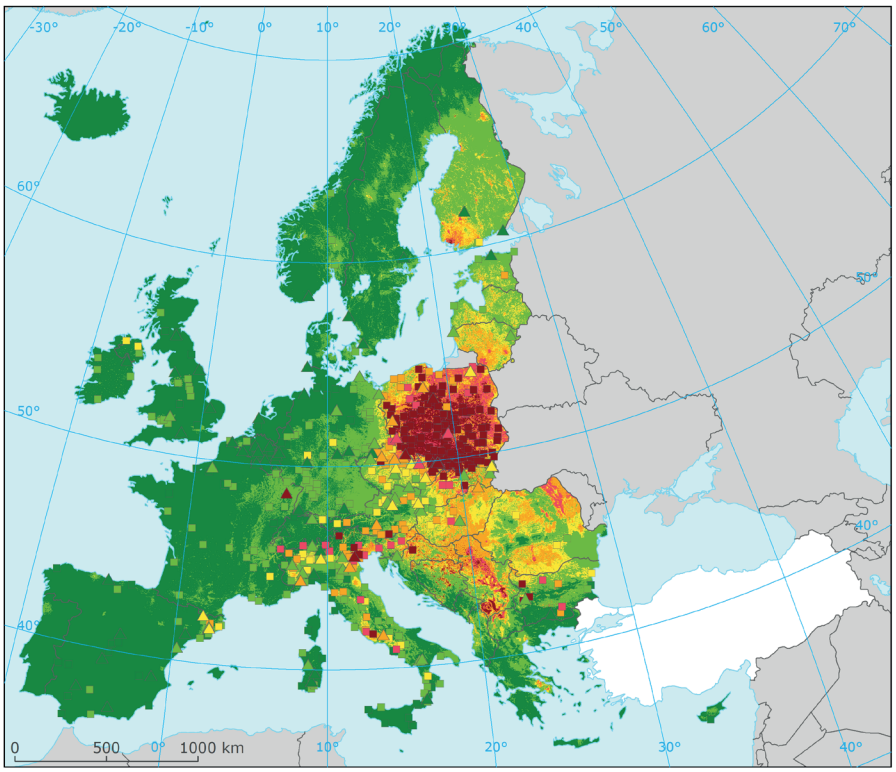


Fine Particulate Matter $PM_{2.5}$ Annual Average

Reference Year: 2020
Combined Rural and Urban Map
Resolution: 1×1 km²

- ≤ 5 µg·m⁻³
- 5–10 µg·m⁻³ (5 = WHO AQ Guideline 2021)
- 10–15 µg·m⁻³ (10 = WHO AQ Guideline 2005)
- 15–20 µg·m⁻³
- 20–25 µg·m⁻³ (20 = Indicative Limit Value)
- > 25 µg·m⁻³ (25 = Limit Value)
- non EEA member or cooperating countries
- no available data
- △ rural background station
- □ urban/suburban background station
- ○ urban/suburban traffic station

Fig. VIII.4 Field of annual average concentration of $PM_{2.5}$ in Europe, 2020

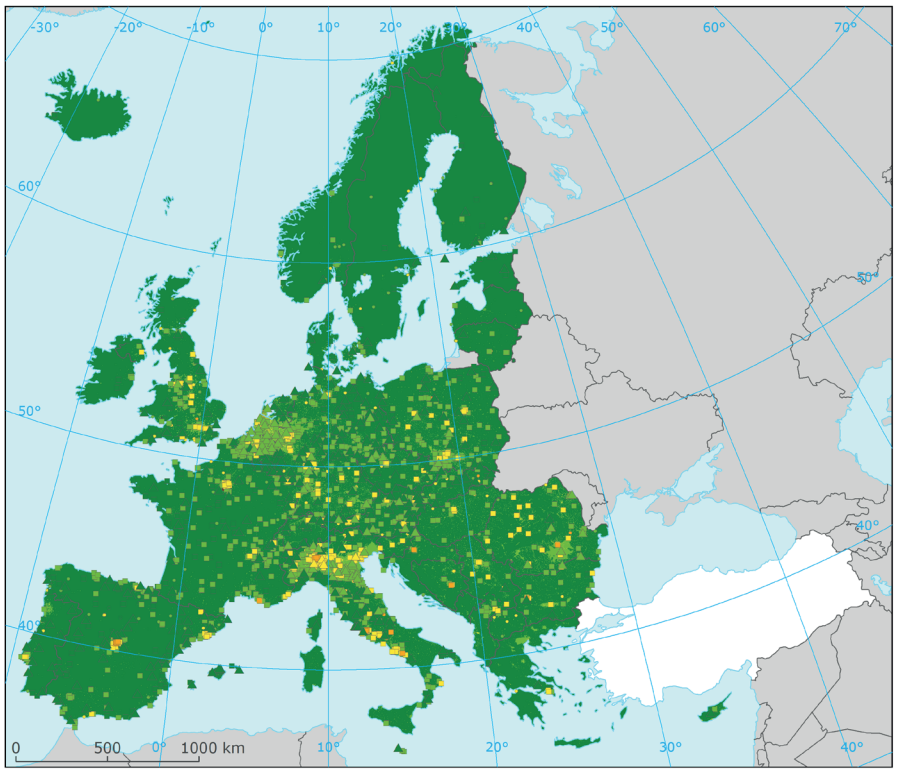


Benzo[*a*]pyrene Annual Average

Reference Year: 2020
Experimental Map
Combined Rural and Urban Map
Resolution: 1×1 km²

- ≤ 0.12 ng·m⁻³
- 0.12–0.4 ng·m⁻³
- 0.4–0.6 ng·m⁻³
- 0.6–1 ng·m⁻³
- 1–1.5 ng·m⁻³ (1 = Target Value)
- > 1.5 ng·m⁻³
- non EEA member or cooperating countries
- no available data
- △ rural background station
- □ urban/suburban background station

Fig. VIII.5 Field of annual average concentration of benzo[*a*]pyrene in Europe, 2020

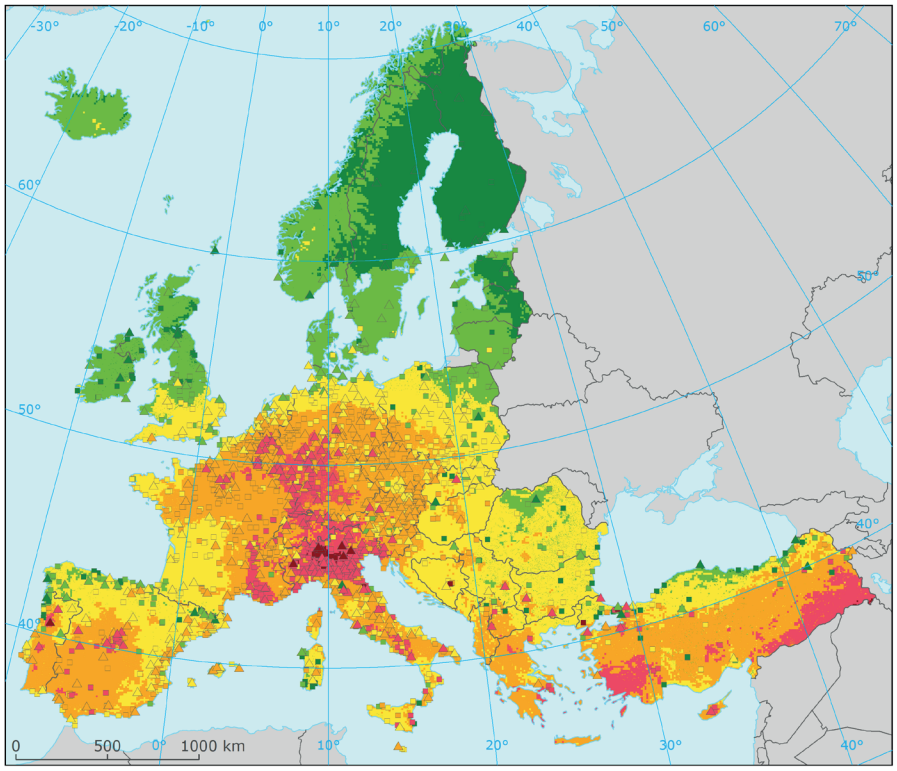


Nitrogen Dioxide (NO_2) Annual Average

Reference Year: 2021
Interim Map
Combined Rural and Urban Map
Resolution: 1×1 km²

- ≤ 10 µg·m⁻³
- 10–20 µg·m⁻³ (10 = WHO AQ Guideline 2021)
- 20–30 µg·m⁻³
- 30–40 µg·m⁻³
- 40–45 µg·m⁻³ (40 = Limit Value)
- > 45 µg·m⁻³
- non EEA member or cooperating countries
- no available data
- △ rural background station
- □ urban/suburban background station
- ○ urban/suburban traffic station

Fig. VIII.6 Field of annual average concentration of NO_2 in Europe, 2021, preliminary map



Ozone – 93.2 Percentile of Maximum Daily 8-hour Means

Reference Year: 2020
Combined Rural and Urban Background Map
Resolution: 1×1 km²

- ≤ 90 µg·m⁻³
- 90–100 µg·m⁻³
- 100–110 µg·m⁻³
- 110–120 µg·m⁻³
- 120–140 µg·m⁻³ (120 = Target Value)
- > 140 µg·m⁻³
- non EEA member or cooperating countries
- no available data
- △ rural background station
- □ urban/suburban background station

Fig. VIII.7 Field of 93.2 percentile of daily maximum 8-hour O_3 concentrations in Europe, 2020

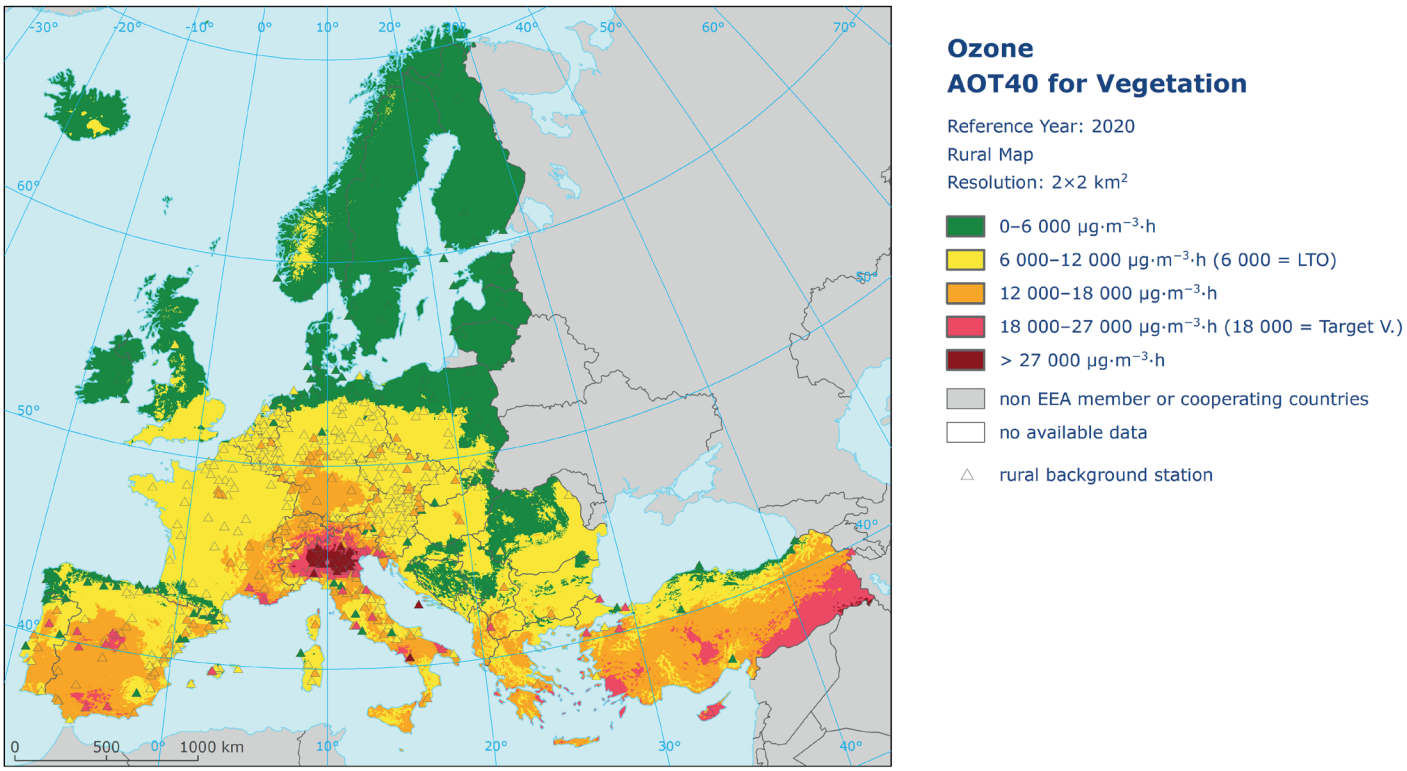


Fig. VIII.8 Field of AOT40 exposure index values for the protection of vegetation in Europe, 2020

Estimates of health impacts from the effects of polluted air indicate that in 2019, long-term exposure to fine $PM_{2.5}$ particulates in Europe contributed to approx. 373 thousand premature deaths, long-term exposure to high NO_2 concentrations to 48 thousand premature deaths, and short-term exposure to O_3 concentrations to approx. 19 thousand premature deaths (EEA 2021).

The inhabitants of Central and Eastern Europe, including the Balkan Peninsula, suffer from the greatest exposure to above-limit concentrations of suspended particulates and benzo[*a*]pyrene, while areas with the most widespread pollution also include the Po Valley in northern Italy (Fig. VIII.3, Fig. VIII.4, and Fig. VIII.5).

Limit NO_2 concentrations are exceeded particularly in areas affected by transportation (Fig. VIII.6). The occurrence of above-limit concentrations can also be anticipated in countries where these pollutants are monitored only at a limited number of sites or are not monitored at all, or this data is not provided to the EEA.

Primary pollutants coming from local and regional emission sources are also accompanied by air pollution from secondary aerosols (Chap. IV.1.3, Chap. IV.9.2) and O_3. In relation to the mechanisms of ozone formation (Chap. IV.4.3), O_3 concentrations increase from low values in northern Europe to the highest values especially in countries around the Mediterranean Sea (Fig. VIII.7, Fig. VIII.8).

Air quality of the Czech Republic in the European context

Pollution levels in various parts of the CR differ substantially. On the one hand, there are areas with very low pollution levels, in which the air quality is similar to that in the clean continuously populated regions of Europe and the pollutant concentrations are well below the air quality limit levels. The data from the Czech EMEP background stations are comparable with concentrations measured at similarly located Central European stations. On the other hand, the O/K/F-M agglomeration, together with adjacent areas in the Republic of Poland, is among the most highly polluted regions of Europe in the long run, both from the standpoint of the extent and the level of concentrations. Transmission of pollutants across the border between the CR and neighbouring countries is the most intense in the Silesia area (for more details see Chap. V.3 and Blažek et al. 2013). Obviously, polluted air flows across the state borders in other areas, but the mutual transboundary effect is much lower and quantification or even estimates of probable impacts are mostly not available. In addition to the Silesia area, the proportion of various sources to air pollution levels have only been described in detail in the Czech-Slovak boundary area of the Moravian-Silesia and Žilina regions (VŠB-TU Ostrava 2014).

Regarding the level of average concentrations per capita, the CR is among above-average polluted countries in terms of suspended particulate matter $PM_{2.5}$ and benzo[*a*]pyrene, among average to above-average polluted countries in terms of PM_{10} and O_3, and among average to below-average polluted countries in terms of NO_2 (ETC/HE 2022, EEA 2021).

IX. ATMOSPHERIC DEPOSITION IN THE TERRITORY OF THE CR

Atmospheric deposition refers to the flux of substances from the atmosphere to the surface of the Earth (Braniš, Hůnová 2009). This is an important process contributing to self-purification of the air; but it is also responsible for the input of pollutants into other components of the environment. Atmospheric deposition has both wet and dry components. The wet component is connected with the occurrence of atmospheric precipitation (vertical deposition: rain, snow, hail, and horizontal deposition: fog, rime, icing) and is thus episodic in character. The dry component corresponds to the deposition of gases and particles by various mechanisms and occurs continuously.

The atmospheric deposition of most monitored substances in Europe has decreased substantially over the past twenty years, but still remains a problem in a number of regions (EEA 2011). In the CR, the chemical composition of atmospheric precipitation and atmospheric deposition has been monitored for a long time at a relatively large number of localities.

In 2021, data on the chemical composition of atmospheric precipitation were provided to the Air Quality Information System (AQIS) from 39 locations in the CR. Measurements in the CR are provided by CHMI (14 localities), CGS (10 localities), VÚLHM (10 localities), HBÚ AV ČR (2 localities), and ÚH AV ČR, ÚVGZ AV ČR and GLÚ AV ČR (1 locality each). Furthermore, data from 2 Slovak localities (SHMI) were provided for border areas (Fig. IX.1, CHMI 2022e).

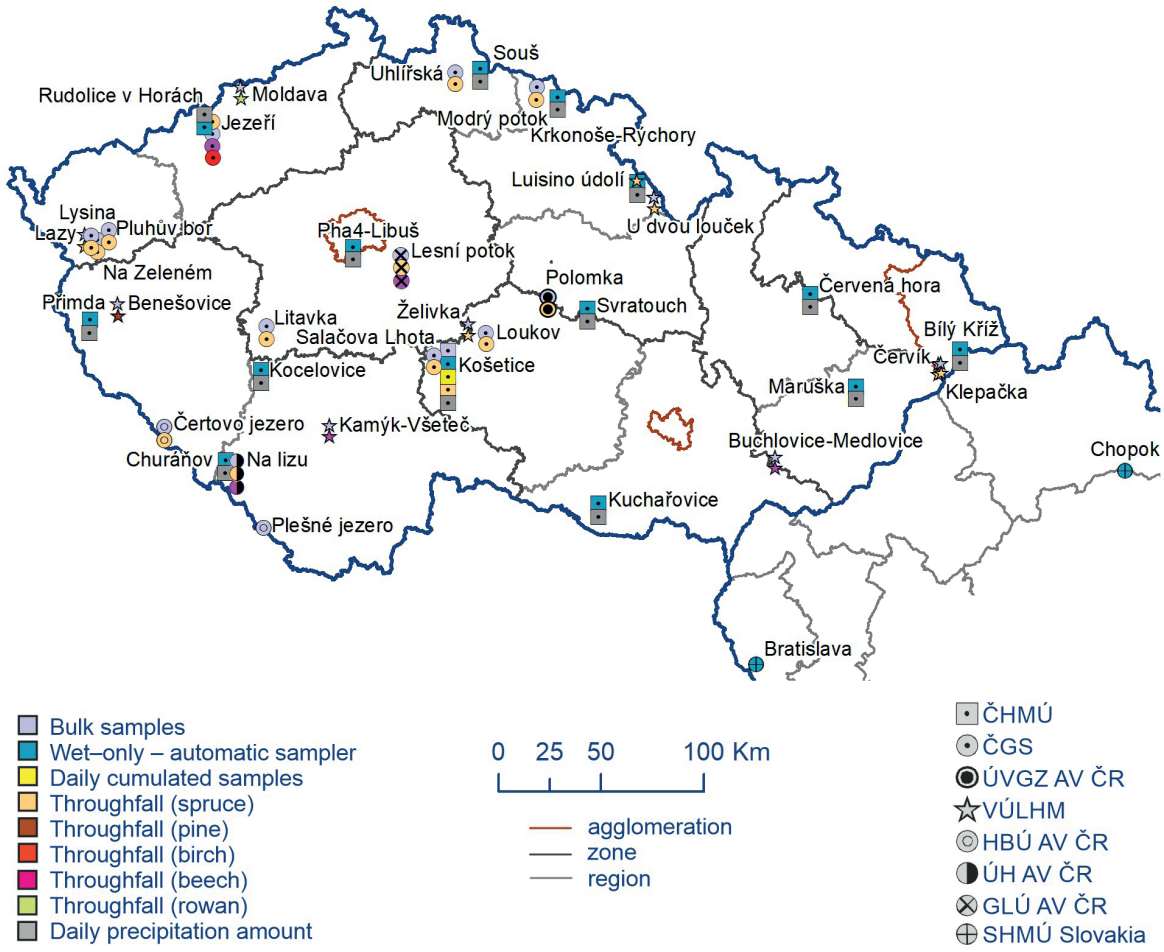


Fig. IX.1 Station networks monitoring atmospheric precipitation quality and atmospheric deposition, 2021

The substances presented in the chapter on atmospheric deposition have no limit values set by legislation, as is the case for ambient air pollutants. Therefore, another colour scale has been chosen to improve the clarity of deposition maps. More detailed information on atmospheric deposition, sampling, measurement and quantification of its components and specifications for preparation of maps are available at CHMI (2022d).

Results

The year 2021 was normal in terms of precipitation. The average annual precipitation of 683 mm represents 100 % of the long-term 1991–2020 normal (for more see Chapter III). Lower precipitation totals compared to 2020 (766 mm) resulted in a decrease in the wet deposition of reduced forms of nitrogen ($N\_NH_4^+$), the total wet deposition of nitrogen, and the total deposition of nitrogen.

Deposition of sulphur

The average sulphur deposition flux in 2021 was 0.385 $g \cdot m^{-2} \cdot year^{-1}$ (Table IX.1). Compared to 2020 (0.388 $g \cdot m^{-2} \cdot year^{-1}$), this is a decrease by 1 %.

The field of total sulphur deposition represents the total level of sulphur deposition on the area of the CR. Its quantification is based on SO_4^{2-} concentrations measured in atmospheric precipitation and SO_2 air pollution concentrations. In 2021, total sulphur deposition amounted to 30 335 t (Tab. IX.2), which is a decrease of less than 1 % compared to 2020 (30 577 t). In 2021, the value of the total sulphur deposition flux was lower than 0.5 $g \cdot m^{-2} \cdot year^{-1}$ on 86 % of the area of the CR. Higher values were observed in the areas of Krušné hory, Jizerské hory, Krkonoše, Orlické hory, Jeseníky, Ostrava, and Moravian-Silesia Beskydy. (Fig. IX.2).

Wet deposition of sulphur ($S\_SO_4^{2-}$) reached the value of 14 786 t in 2021, compared to 13 793 t in 2020 (increase by 7 %). In most of the CR territory (99.8 %), the values of the deposition flux were below 0.5 $g \cdot m^{-2} \cdot year^{-1}$. Higher values of the wet component were observed in the Jizerské and Orlické hory (Fig. IX.3). Dry deposition of sulphur (S_SO_2) reached 15 549 t in 2021, while it was 16 784 t in 2020 (decrease by 7 %). As with the wet component, the S_SO_2 deposition flux values were below 0.5 $g \cdot m^{-2} \cdot year^{-1}$ in most of the CR territory (99.4 %). Higher values of the dry component were monitored in the areas of Krušné hory and Ostrava (Fig. IX.4).

In 2021, throughfall deposition of sulphur ($S\_SO_4^{2-}$) in forested areas of the CR reached 7 174 t, which is a decrease of 4 % compared to 2020 (7 492 t) (Tab. IX.3). The maximum values (0.5 $g \cdot m^{-2} \cdot year^{-1}$) occurred in border mountain areas (0.7 % of the forested area of the CR; Fig. IX.5). A map showing throughfall sulphur deposition was prepared for forested areas on the basis of fields of sulphur concentrations in throughfall precipitation and from verified fields of precipitation, modified by the percentage amount of precipitation measured under vegetation at individual stations, which ranged from 35 % (Salačova Lhota) to 88 % (Lazy) of the total precipitation in open areas in 2021. Throughfall deposition generally includes wet vertical and horizontal deposition (from fogs, low clouds and rime) and the dry deposition of particles and gases in forests.

Table IX.1 Average deposition fluxes of S, N and H in the Czech Republic, 2021

Element	Deposition	$g \cdot m^{-2} \cdot year^{-1}$	$keq \cdot ha^{-1} \cdot year^{-1}$
S (SO_4^{2-})	wet	0.188	0.117
S (SO_2)	dry	0.197	0.123
S	total	0.385	0.240
N (NO_3^-)	wet	0.239	0.171
N (NH_4^+)	wet	0.278	0.199
N (NO_x)	dry	0.185	0.132
N	total	0.702	0.502
H (pH)	wet	0.003	0.028
H (SO_2, NO_x)	dry	0.026	0.253
H	total	0.028	0.281

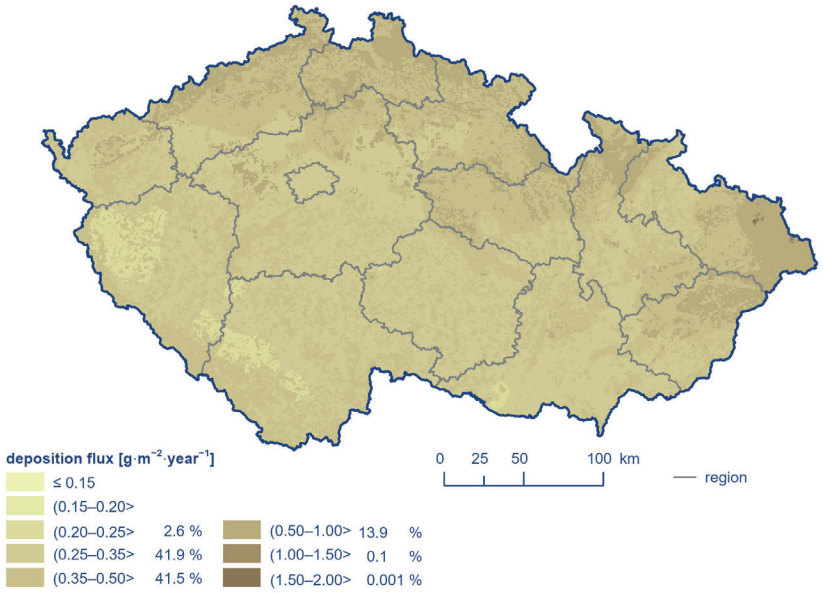


Fig. IX.2 Field of annual total deposition of sulphur, 2021

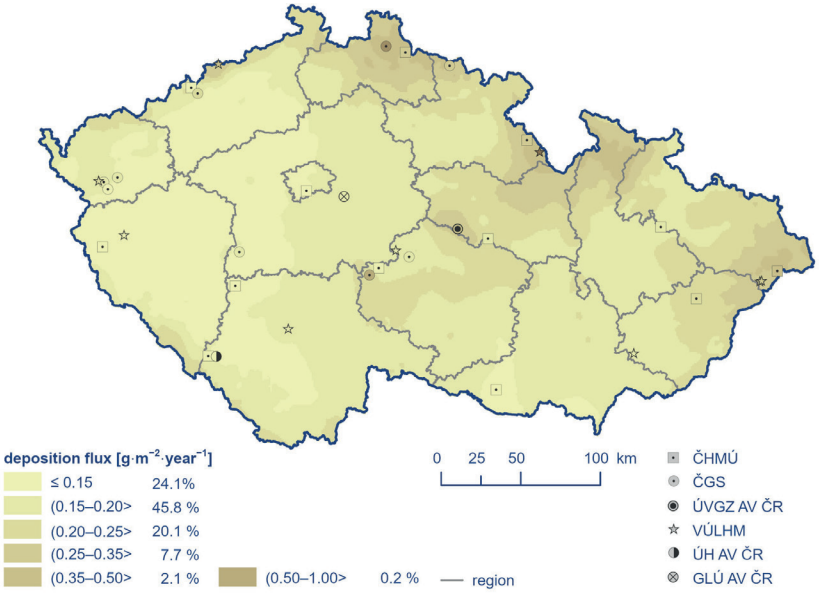


Fig. IX.3 Field of annual wet deposition of sulphur ($S\_SO_4^{2-}$), 2021

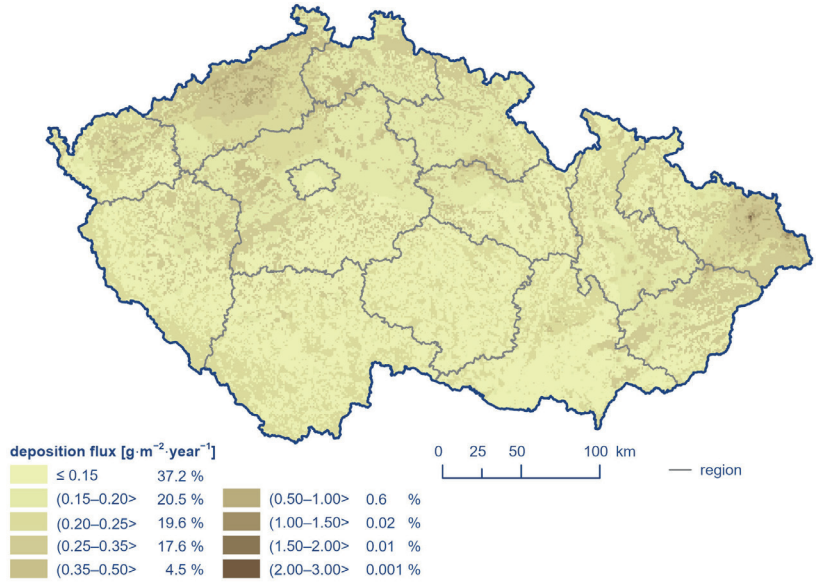


Fig. IX.4 Field of annual dry deposition of sulphur (S_SO_2), 2021

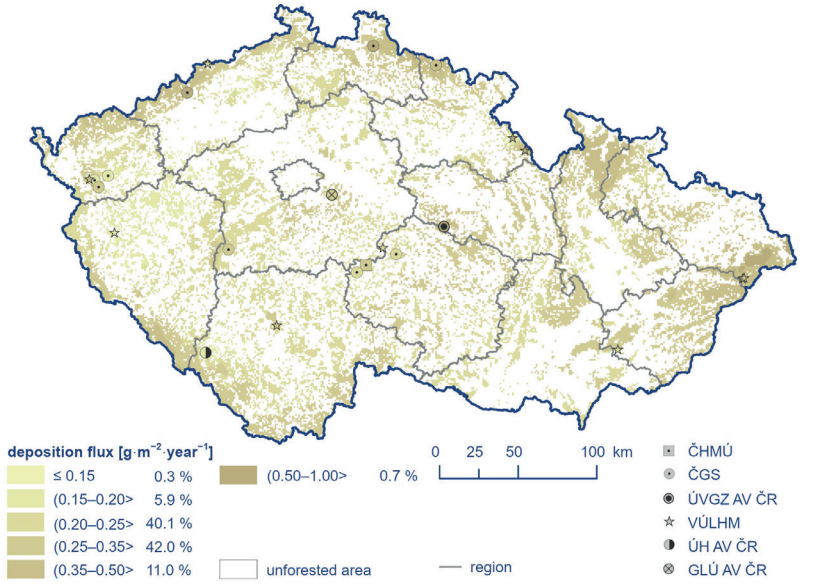


Fig. IX.5 Field of annual throughfall deposition of sulphur, 2021

Deposition of nitrogen

The average nitrogen deposition flux in 2021 was 0.702 g·m^{-2}·year^{-1} (Table IX.1). Compared to 2020 (0.715 g·m^{-2}·year^{-1}), this is a decrease of 2 %.

The total nitrogen deposition on the area of the CR in 2021 amounted to 55 383 t (Tab. IX.2). Compared to 2020 (56 396 t), this is a decrease of 2 %. In 2021, the value of the total nitrogen deposition flux was lower than 0.75 g·m^{-2}·year^{-1} on 67 % of the CR area. Higher values occurred in the areas of Jizerské hory, Orlické hory, and Jeseníky (Fig. IX.6).

On the contrary, the deposition of oxidized forms of nitrogen ($N\_NO_3^-$) reached higher value, namely 33 451 t in 2021, while in 2020 the value was 27 779 t (an increase of 20 %). The wet component of the deposition amounted to 18 876 t, which is an increase of 31 % compared to 2020 (14 382 t), and the dry component to 14 575 t, making an increase of 9 % compared to 2020 (13 397 t). Wet deposition of reduced forms ($N\_NH_4^+$) decreased in 2021, same as total nitrogen deposition, to a value of 21 932 t, and compared to 2020, when the value was 28 617 t it is a decrease of 23 %. The total wet deposition of nitrogen (sum of wet deposition of $N\_NO_3^-$ and $N\_NH_4^+$) amounted to 40 808 t in 2021, which is a decrease of 5 % compared to 2020 (42 999 t).

The highest values of wet deposition of oxidized forms of nitrogen (above 0.75 g·m^{-2}·year^{-1}) are recorded in the Jizerské hory, Orlické hory and Jeseníky, representing 0.9 % of the territory of the CR (Fig. IX.7). Wet deposition of reduced forms of nitrogen shows the highest values in the Jjizerské hory (0.102 % of the area of the CR, Fig. IX.8). The total wet deposition covers namely the Jizerské hory, Krkonoše, Orlické hory, and Jeseníky (8.901 % of the area of the CR, Fig. IX.9). Higher values of total dry deposition are observed locally within the entire CR, amounting to 0.41 % of the total territory (Fig. IX.10).

Table IX.2 Estimate of the total annual deposition in the Czech Republic (78 841 sq. km) in tonnes, 2021

	Deposition [t]		
	wet	**dry**	**total**
S	14 786	15 549	30 335
N (ox)	18 876	14 575	33 451
N (red)	21 932		
N (ox + red)	40 808		55 383
H$^+$	219	2 013	2 232
Cd	2.2	0.9	
Pb	34	19	

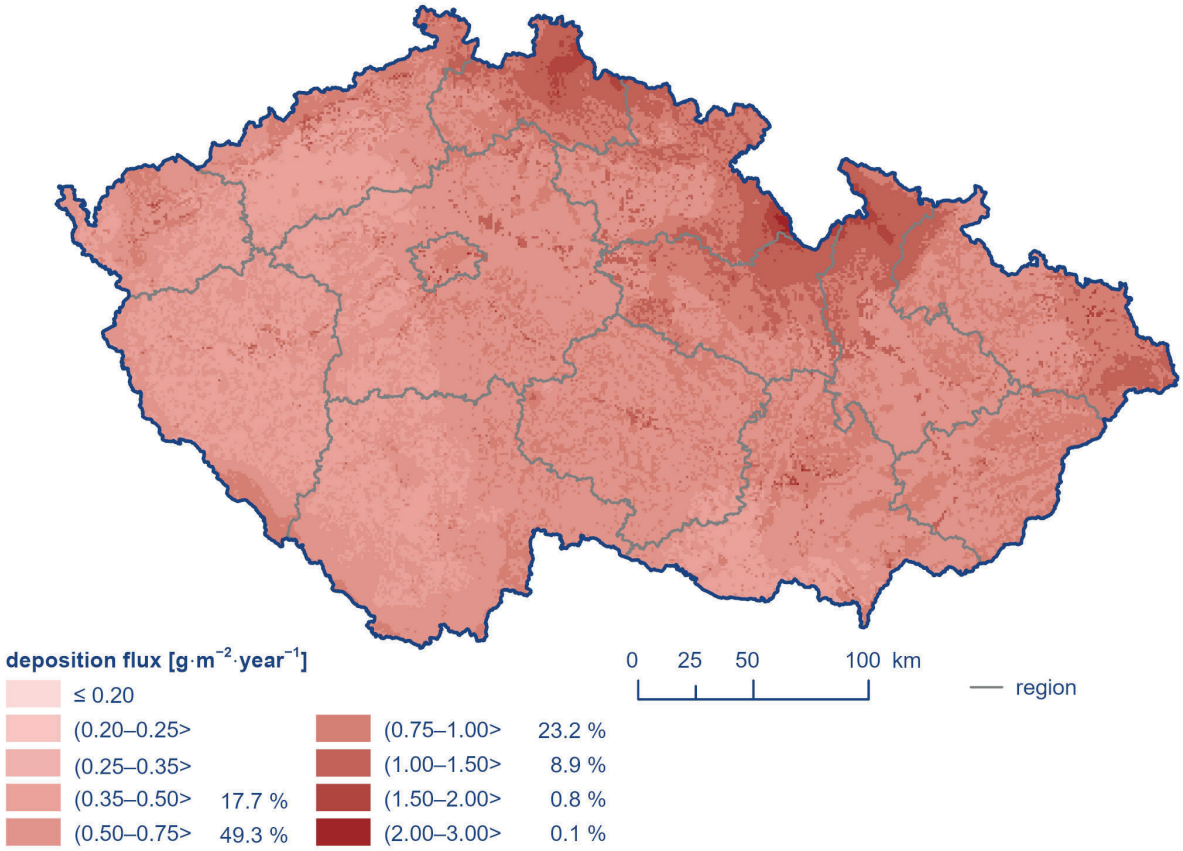


Fig. IX.6 Field of annual total deposition of nitrogen, 2021

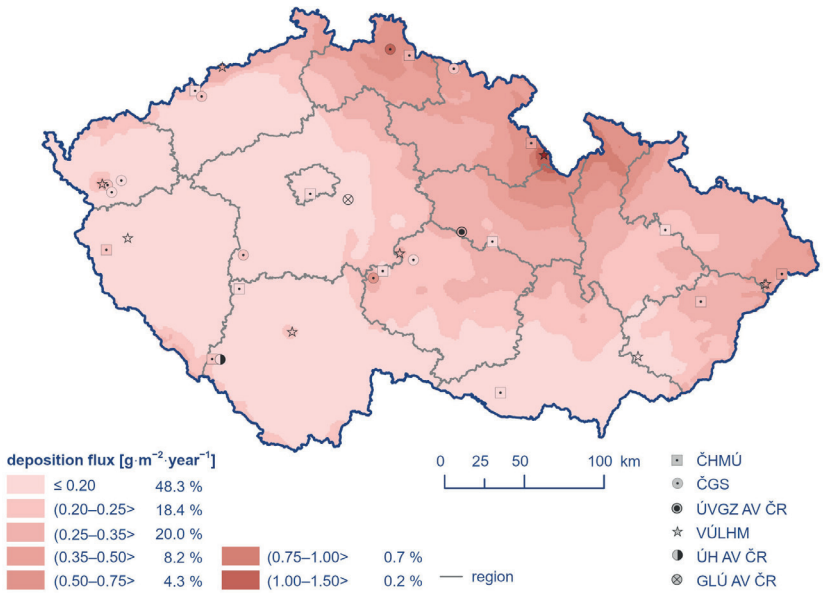


Fig. IX.7 Field of annual wet deposition of nitrogen ($N\_NO_3^-$), 2021

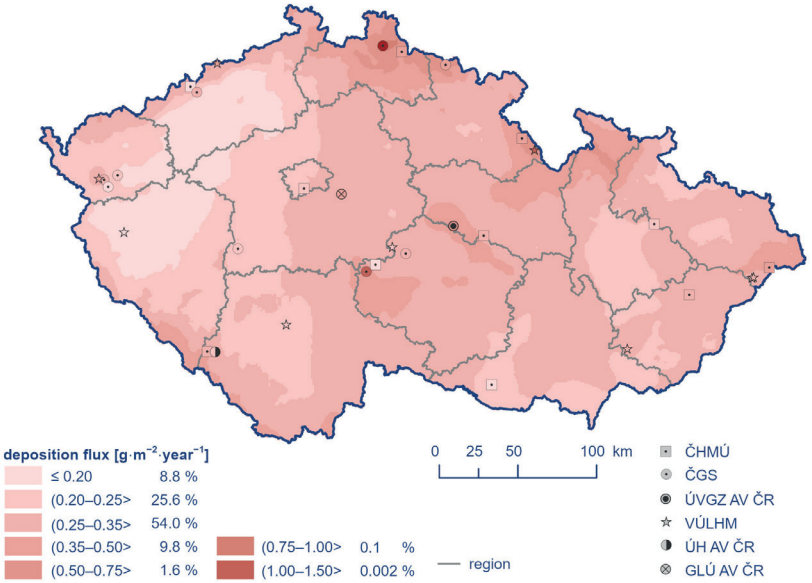


Fig. IX.8 Field of annual wet deposition of nitrogen ($N\_NH_4^+$), 2021

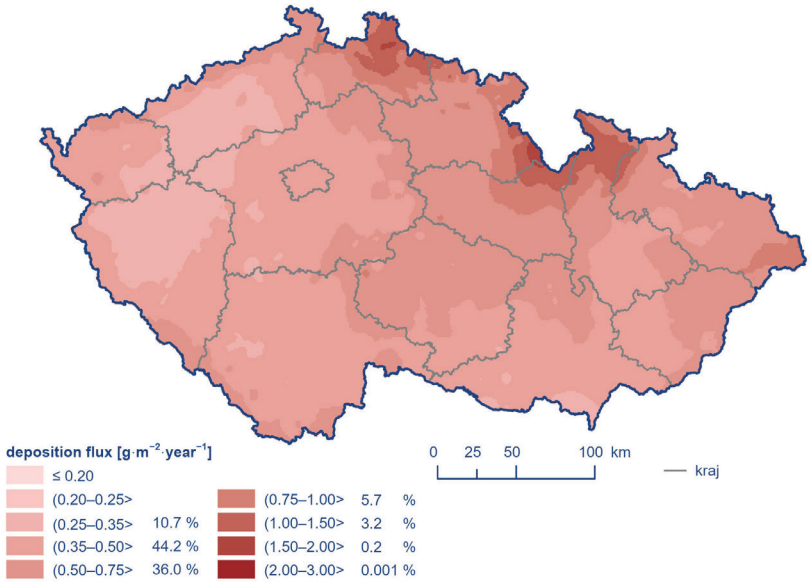


Fig. IX.9 Field of annual total wet deposition of nitrogen, 2021

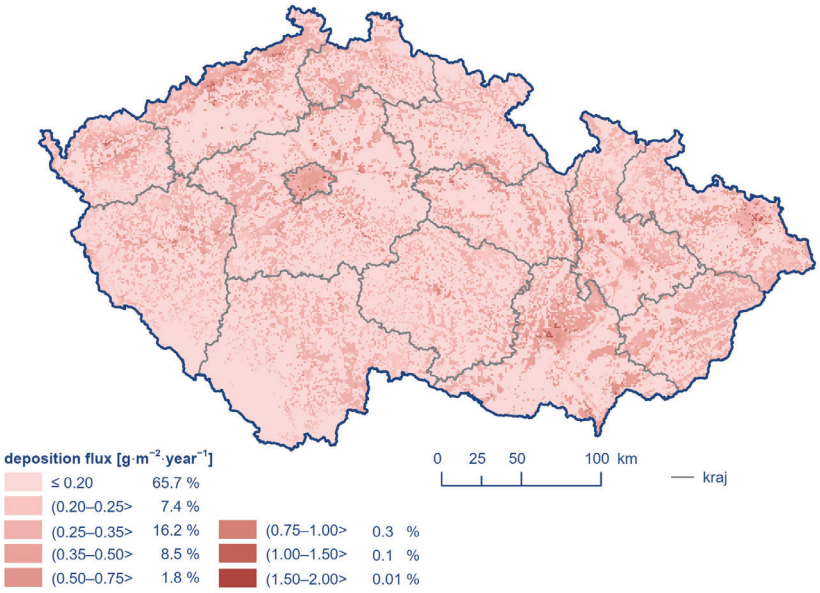


Fig. IX.10 Field of annual dry deposition of nitrogen (N_NO_x), 2021

Deposition of hydrogen ions

The average value of the hydrogen deposition flux in 2021 was, as in 2020, 28 mg·m^{-2}·year^{-1} (Tab. IX.1).

The total deposition of hydrogen ions on the area of the CR in 2021 was 2 232 t (Table IX.2). The year 2021 is thus comparable to the year 2020, when the value was 2 224 t. The partial components of hydrogen ion deposition are also comparable. The wet component reached 219 t in 2021, compared to 218 t in 2020, and the dry component was 2 013 t in 2021, compared to 2 006 t in 2020.

The total deposition of hydrogen ions in most of the CR territory (99.8 %) reaches values between 10 and 100 mg·m^{-2}·year^{-1}. Higher values are observed in the Krušné hory, the Ostrava area, and locally in the Brno area (Fig. IX.11). Wet deposition amounts to a maximum of 10 mg·m^{-2}·year^{-1}, while the highest values above 5 mg·m^{-2}·year^{-1} are recorded in the upper parts of the Krušné hory, Jizerské hory, Krkonoše, Jeseníky and Moravian-Silesia Beskydy (4.6 % of the CR; Fig. IX.12). Dry deposition is comparable to total deposition (Fig. IX.13).

Deposition of cadmium, lead, nickel and chloride ions

Wet deposition of cadmium reached 2.2 t in 2021, which is comparable to 2020 (2.0 t). Dry deposition in 2021 (0.9 t) was the same as in 2020 (Tab. IX.2). The highest values (above 0.05 mg·m^{-2}·year^{-1}) have been reached by cadmium deposition in the Jablonec area, Orlické hory, and Moravian-Silesia Beskydy (4.8 % of the CR area; Fig. IX.14). Dry deposition has reached values higher than 0.05 mg·m^{-2}·year^{-1} almost exclusively in the Liberec region, in the Krkonoše mountain area and Krkonoše foothills, and partly in the Ostrava area (0.8 % of the CR; Fig. IX.15).

Wet deposition of lead in 2021 (34 t) was comparable to 2020 (31 t). Dry deposition was also comparable, reaching a value of 19 t in 2021, while it was 17 t in 2020 (Tab. IX.2). The highest values of led wet deposition (over 0.7 mg·m^{-2}·year^{-1}) have been reached in the upper parts of the Jizerské hory, Orlické hory, and the Moravian-Silesia Beskydy (4.7 % of the CR; Fig. IX.16). The highest values of dry deposition have then been reached in the Příbram and Ostrava areas (3.5 % of the CR; Fig. IX.17).

Wet deposition of chloride ions, similar to other monitored substances, acquires higher values (above 0.5 mg·m^{-2}·year^{-1}) within the CR primarily in mountainous areas, especially in the Jizerské hory and Orlické hory (0.5 % of the CR; Fig. IX.18).

The annual wet deposition of nickel ions reaches the highest values at the locations Uhlířská, Salačova Lhota, Červík (Fig. IX.19).

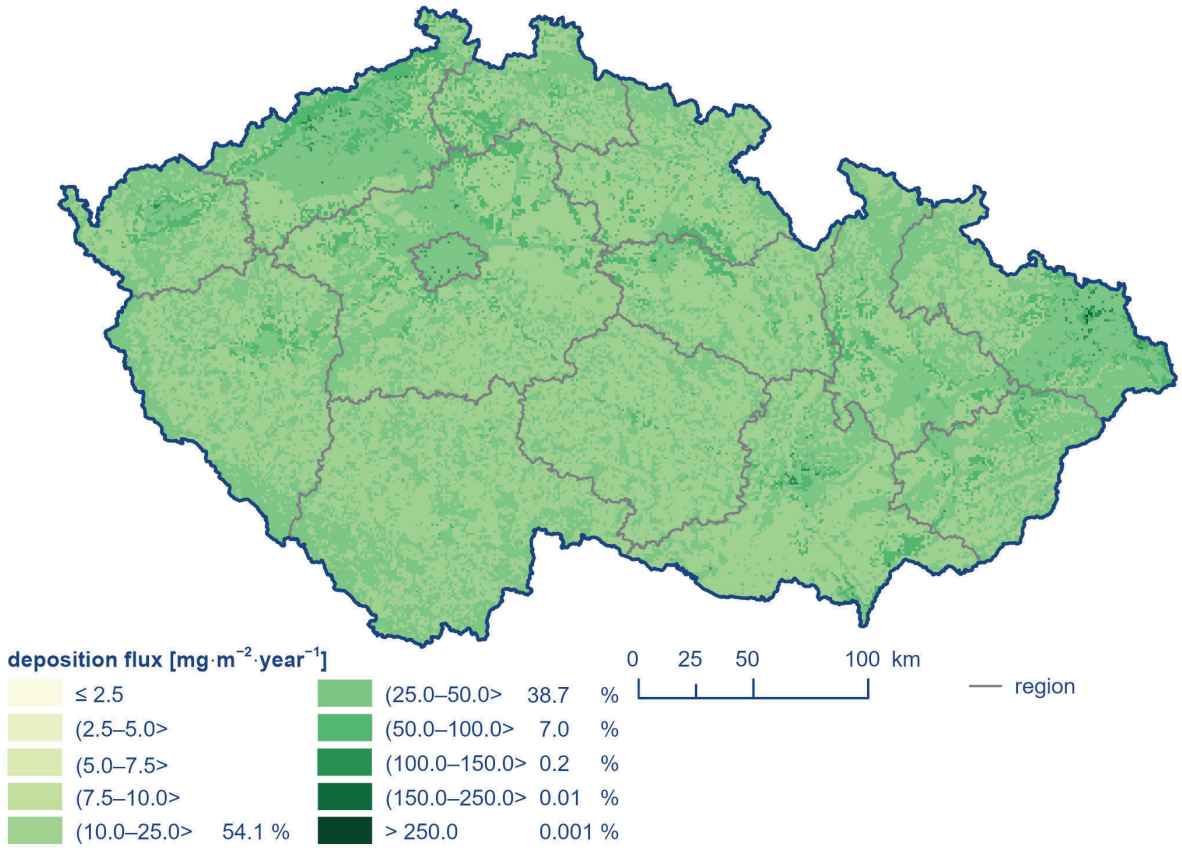


Fig. IX.11 Field of annual total deposition of hydrogen ions, 2021

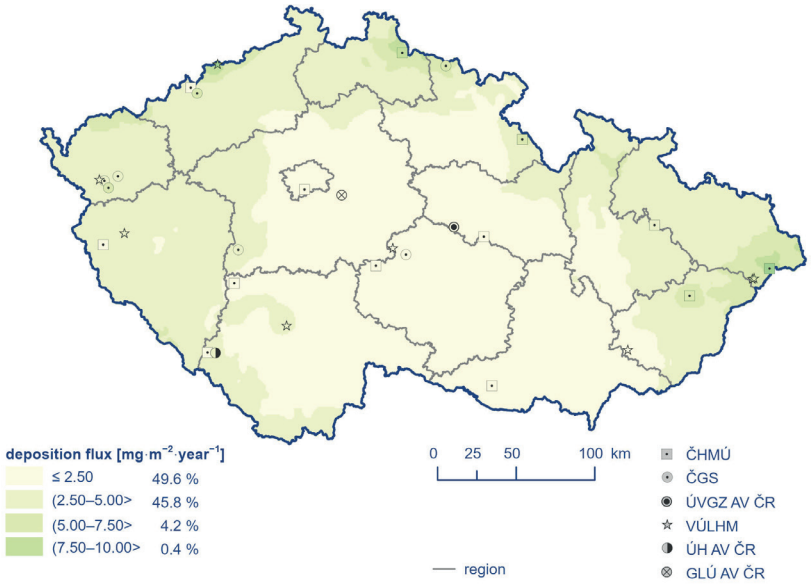


Fig. IX.12 Field of annual wet deposition of hydrogen ions, 2021

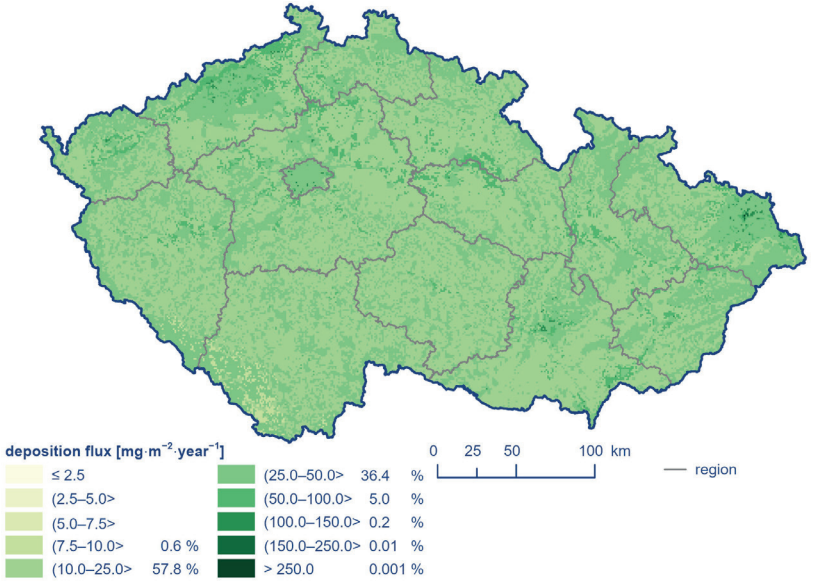


Fig. IX.13 Field of annual dry deposition of hydrogen ions corresponding to SO_2 and NO_x gas deposition, 2021

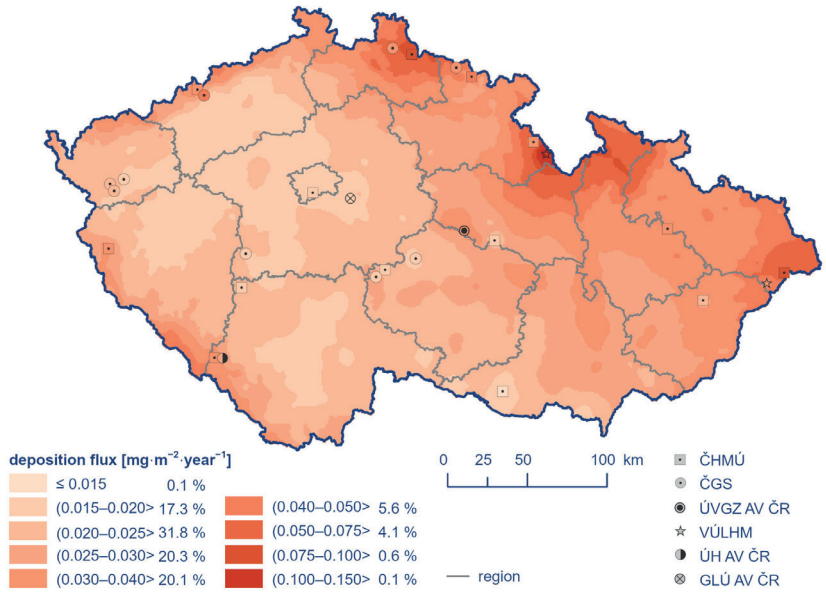


Fig. IX.14 Field of annual wet deposition of cadmium ions, 2021

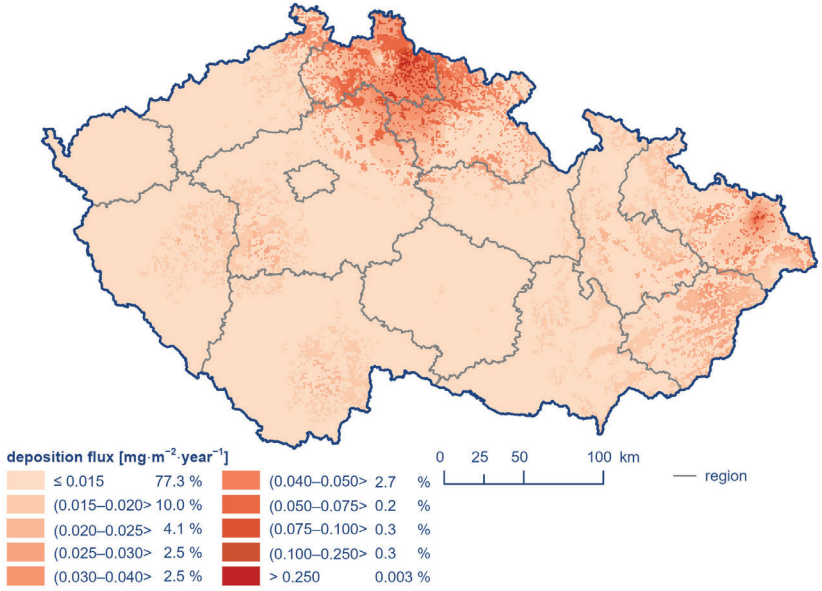


Fig. IX.15 Field of annual dry deposition of cadmium, 2021

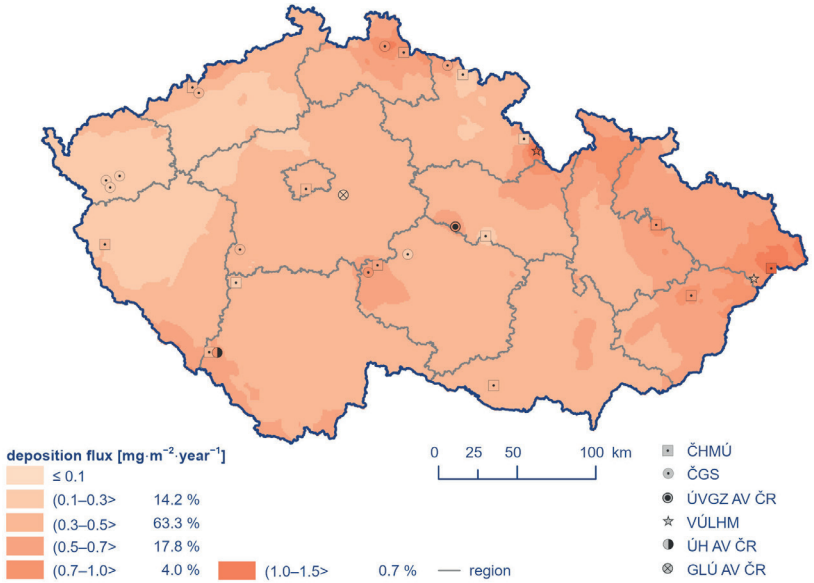


Fig. IX.16 Field of annual wet deposition of lead ions, 2021

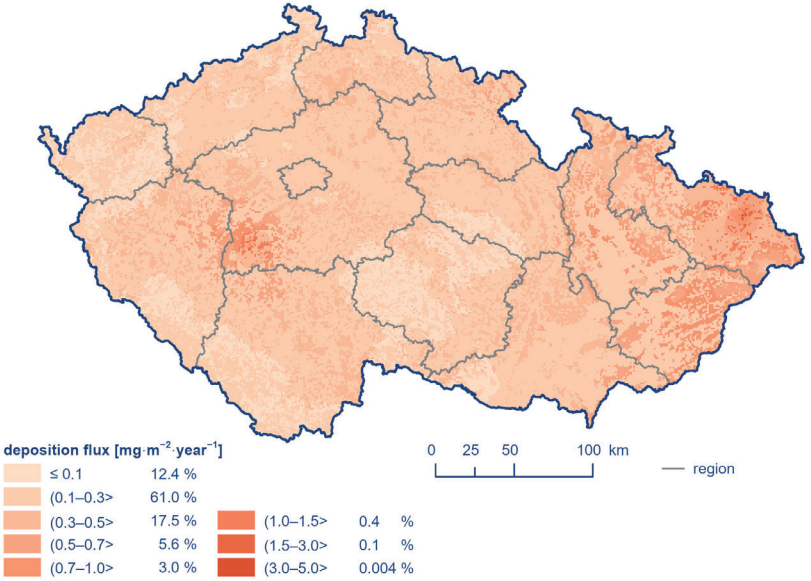


Fig. IX.17 Field of annual dry deposition of lead, 2021

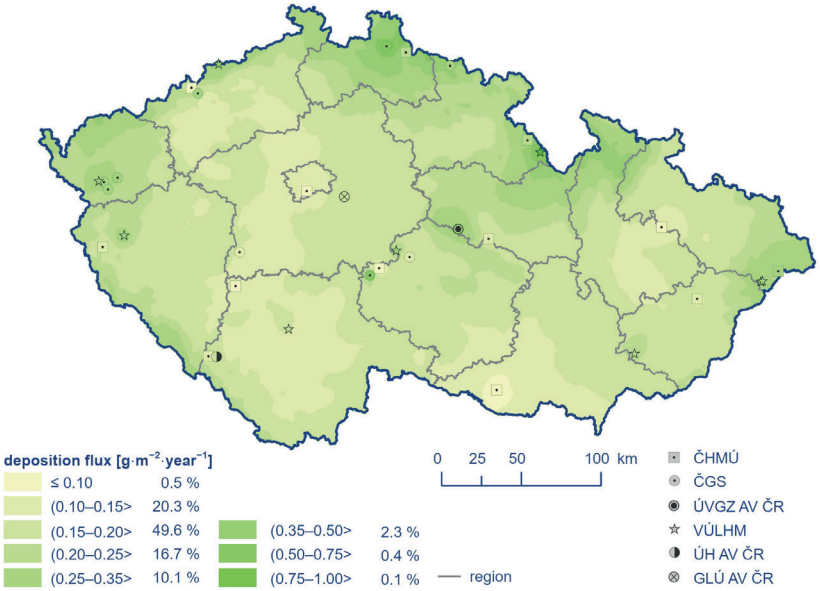


Fig. IX.18 Field of annual wet deposition of chloride ions, 2021

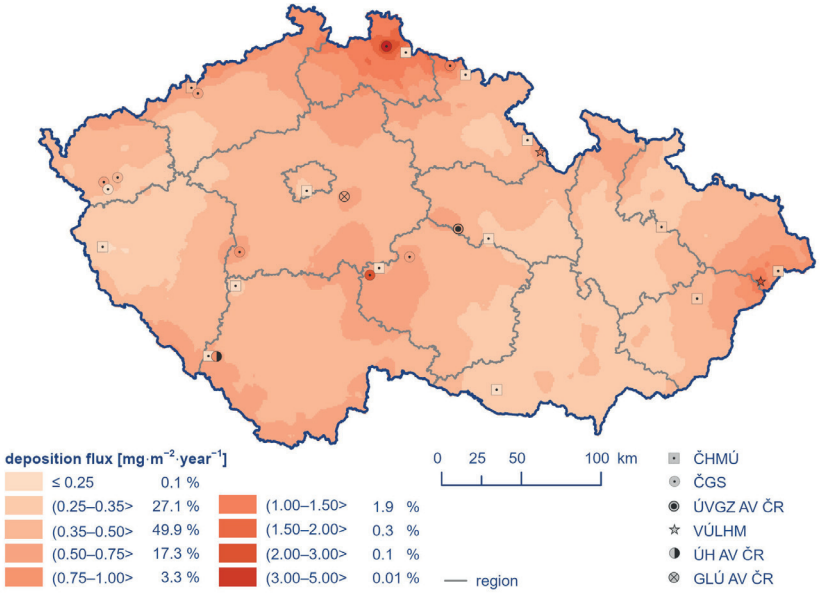


Fig. IX.19 Field of annual wet deposition of nickel ions, 2021

Trends in deposition

Since 2002, a decrease in the total annual sulphur deposition can be observed (Fig. IX.20). In the years 2002–2006, the total deposition was higher than 65 000 t, except for 2003 (51 510 t), the year significantly below normal in terms of precipitation (516 mm, i.e., 77 % of the long-term normal). Since 2015, the total deposition has been below 40 000 t over the area of the CR with constant or slightly decreasing values, corresponding to the level of SO_2 concentration in the ground layer of the atmosphere. In 2021, the lowest value of total annual sulphur deposition was reached in the period from 2002. In comparing the wet and dry components of deposition, the wet component prevailed until 2009, again except for 2003. Since 2010, the dry component has slightly prevailed. The exceptions are the years 2011 and 2021, when the ratio is balanced.

Since 2002, the annual deposition of sulphur on the forested surface of the CR (26 428 km^2), as well as the throughfall deposition of sulphur, have shown a decrease with considerable fluctuations (Tab. IX.3). In 2021, the total deposition on the forested surface of the CR reached the second lowest value since 2002, while the lower deposition was only in 2016. The throughfall deposition of sulphur reached, in 2021, the lowest value since 2002. Until 2016, the values of throughfall deposition are higher than total deposition values, except for 2014, and since 2017, the total deposition has been higher. In the long term, higher values of throughfall deposition are observed especially in some mountainous areas, which can be attributed to the contribution of deposition from fog, low cloud cover and rime frost (horizontal deposition). Total sulphur deposition is calculated as a sum of vertical wet and dry deposition from SO_2, while horizontal wet deposition is not included in the total deposition due to uncertainties.

The total annual deposition of nitrogen in the years 2002–2013 ranged from 40 000 to 50 000 t (Fig. IX.21). A slight decrease can be observed since 2012, with occasional fluctuations in 2017 and 2021. The value of total annual nitrogen deposition in 2021 was the third lowest since 2002, with lower values recorded in 2019 and 2020, corresponding to NO_x concentrations. Until 2010, the wet component of oxidized forms of nitrogen prevailed. Since 2011, the dry component has slightly prevailed, except for 2013 and 2016 with both components balanced. Since 2017, the wet component of deposition has again prevailed, but only very slightly.

Together with the variation of deposition of nitrogen and sulphur (Hůnová et al. 2014), variation can be seen in the mutual ratio of these two elements in atmospheric precipitation, related to trends in emissions of particular compounds. A slight, although not steady, increase in the ratio of nitrates to sulphates could have been observed at selected CHMI stations (wet-only) since 2000 (Hůnová et al., 2017). In 2002 and 2003, sulphates dominated

Table IX.3 Estimate of the total annual deposition of sulphur on the forested part of the Czech Republic (26 428 sq. km) in tonnes, 2001–2021

	deposition [t]	
	total	troughfall
2001	27 894	36 899
2002	25 984	31 011
2003	21 306	26 818
2004	23 247	32 835
2005	22 855	26 461
2006	21 975	25 660
2007	17 445	29 279
2008	15 528	30 197
2009	16 590	26 193
2010	17 621	27 944
2011	15 118	18 691
2012	15 311	19 079
2013	16 530	19 723
2014	16 810	12 836
2015	13 294	16 044
2016	12 625	19 724
2017	14 621	12 608
2018	14 870	14 002
2019	13 133	10 707
2020	13 057	7 492
2021	12 757	7 174

atmospheric precipitation. Until 2011, the ratio was quite even, except for 2009, and since 2012 nitrates have clearly predominated. In 2021, the second highest value of the ratio (1.46) was reached since 2002, while the highest value (1.58) occurred in 2017 (Fig. IX.22).

The total deposition of hydrogen ions has been ranging between 2 500 and 5 000 t since 2012. Since 2013, a decreasing trend of the deposition is evident, with the second lowest value recorded in 2021, after 2020. The dry component significantly dominates the deposition of hydrogen ions, while the proportion of the wet component has been decreasing since 2007 (Fig. IX.23).

The total deposition of cadmium ions has been ranging from 6 to 12 t since 2013, except for 2011. There is a noticeable decrease in deposition from 2014, followed again by an increase from 2019. In 2021, the fifth lowest value of total deposition was reached, with the lowest value recorded in 2018. The wet component predominates in the deposition of cadmium ions, with a ratio of about 70:10. The only exception is 2018, when both components had equal proportion (Fig. IX.24).

The total deposition of lead ions ranged between 150 and 200 t until 2006. Since 2007, a slight decrease in deposition is noticeable with deviations in 2012 and 2015. In 2021, the third lowest annual value since 2002 was reached, with lower values occurring in 2019 and 2020 only. As with the deposition of cadmium ions, the wet component prevails in a ratio of approx. 70:10. The exception is 2012, when the proportion of both components is similar (Fig. IX.25).

Trends in wet deposition at selected CHMI stations

For the assessment of wet deposition, five CHMI stations were selected, with “wet-only” sampling. These are the Praha-Libuš, Svratouch, Košetice, Souš, and Přimda stations. Wet deposition is largely affected by meteorological and climatic conditions and emission sources, therefore deposition values are highly variable from year to year. When evaluating the aforementioned stations, it can be observed that the highest wet deposition values are reached at the Souš station, while the lowest at the Košetice station.

Since 2002, a decrease in wet deposition of sulphate ions (SO_4^{2-}) has been observed, with deviations depending on meteorological conditions. Compared to 2020, the Souš and Svratouch stations show a significant increase in 2021, while the Košetice and Přimda stations show a decrease. The deposition at the Praha-Libuš station remains the same (Fig. IX.26). As with the deposition of SO_4^{2-}, a decrease with significant fluctuations is observed for the deposition of nitrate ions (NO_3^-). Compared to 2020, the Souš, Přimda and Praha-Libuš stations show an increase in 2021, while the Košetice station, on the contrary, shows a decrease. Deposition at the Svratouch station remains the same (Fig. IX.27). The trend of the deposition of ammonium ions (NH_4^+) in the years 2002–2021 is highly variable depending on meteorological conditions and the amount of emission sources. Compared to 2020, the deposition at the Souš station in 2021 remains at the same level, while it decreases slightly at the other stations, except for the Košetice station, where the decrease is significant (Fig. IX.28). The development of hydrogen ion deposition is highly variable, however, a decreasing trend can be identified, particularly at the Souš station. Compared to 2020, the Souš and Přimda stations showed an increase in 2021, while the values at the Praha-Libuš, Svratouch, and Košetice stations decreased (Fig. IX.29).

The deposition of cadmium ions decreased until 2013, and then stagnated at values below 0.2 $mg \cdot m^{-2}$ from 2014. The higher cadmium deposition at the Souš station corresponds to the long-term high pollution burden of this area. Compared to 2020, deposition values are comparable in 2021, except for the Přimda station, where there is a slight increase, and the Souš station, where, on the contrary, there is a decrease (Fig. IX.30). In 2016, the lead ion deposition values showed a significant increase in wet deposition at all stations, up to a value of 7 $mg \cdot m^{-2}$ at the Souš and Svratouch stations. Since 2014, deposition values have stagnated below 1 $mg \cdot m^{-2}$. Compared to 2020, deposition values in 2021 are comparable at the Praha-Libuš and Souš stations, lower at the Svratouch station and, conversely, higher at the Košetice and Přimda stations (Fig. IX.31).

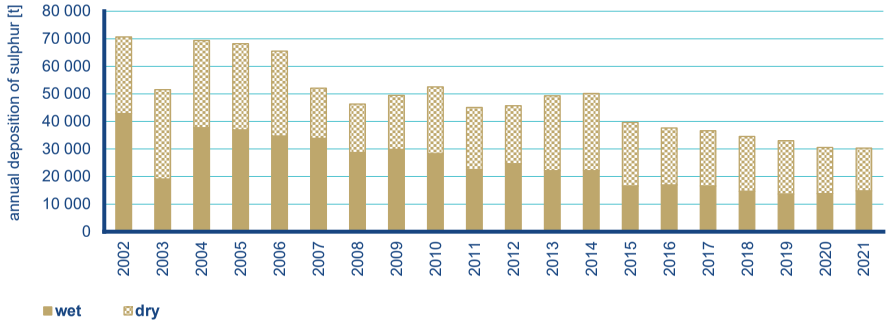


Fig. IX.20 Annual deposition of sulphur ($S\_SO_4^{2-}$, S_SO_2) on the area of the Czech Republic, 2002–2021

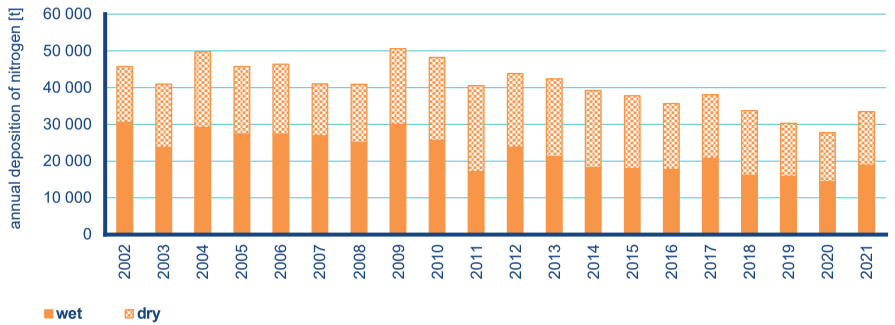


Fig. IX.21 Annual deposition of oxidized forms of nitrogen ($N\_NO_3^-$, N_NO_x) on the area of the Czech Republic, 2002–2021

Fig. IX.22 Ratio of nitrate to sulphate concentrations in atmospheric deposition (expressed as $\mu eq \cdot l^{-1}$) at the CHMI localities, 2002–2021

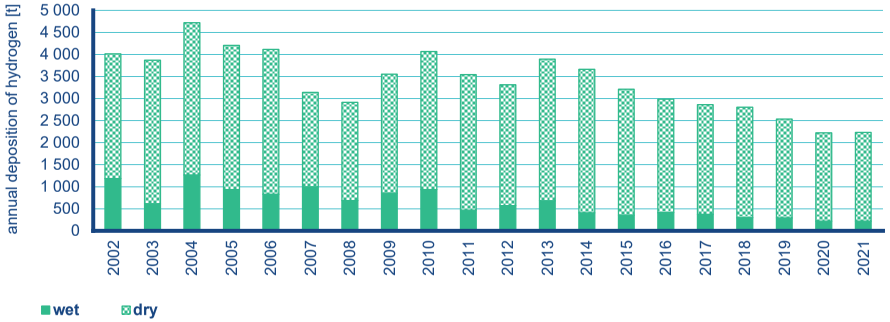


Fig. IX.23 Annual deposition of H^+ on the area of the Czech Republic, 2002–2021

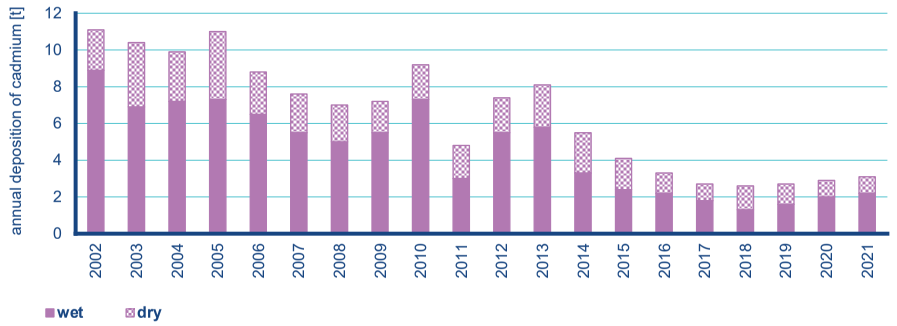


Fig. IX.24 Annual deposition of Cd^{2+} on the area of the Czech Republic, 2002–2021

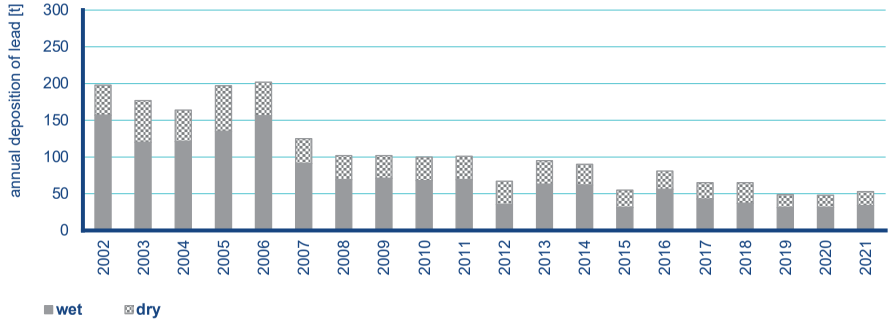


Fig. IX.25 Annual deposition of Pb^{2+} on the area of the Czech Republic, 2002–2021

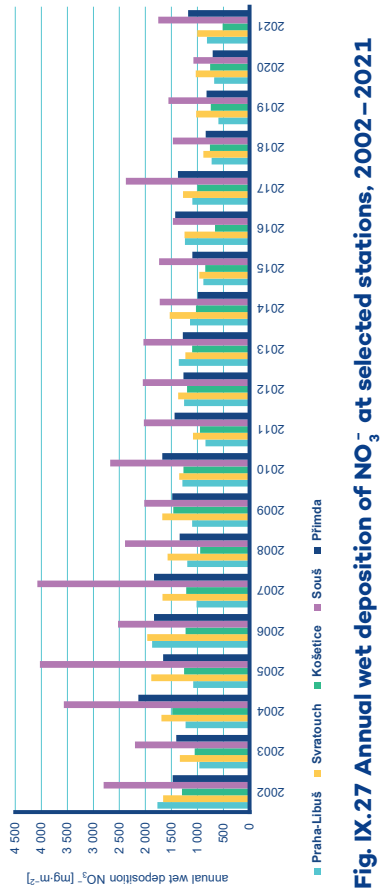


Fig. IX.27 Annual wet deposition of NO_3^- at selected stations, 2002–2021

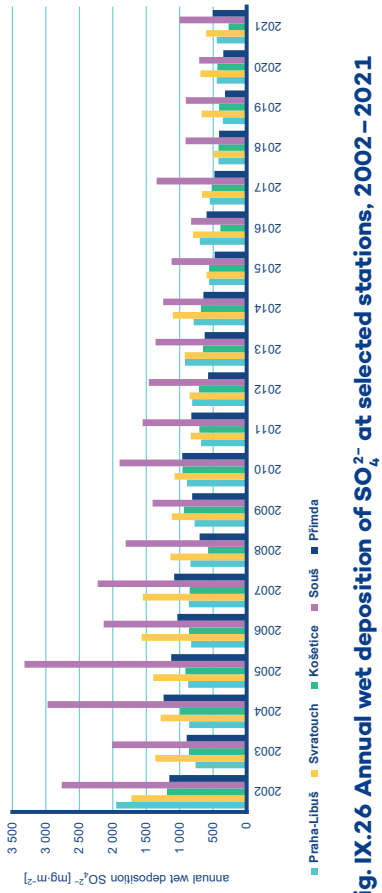


Fig. IX.26 Annual wet deposition of SO_4^{2-} at selected stations, 2002–2021

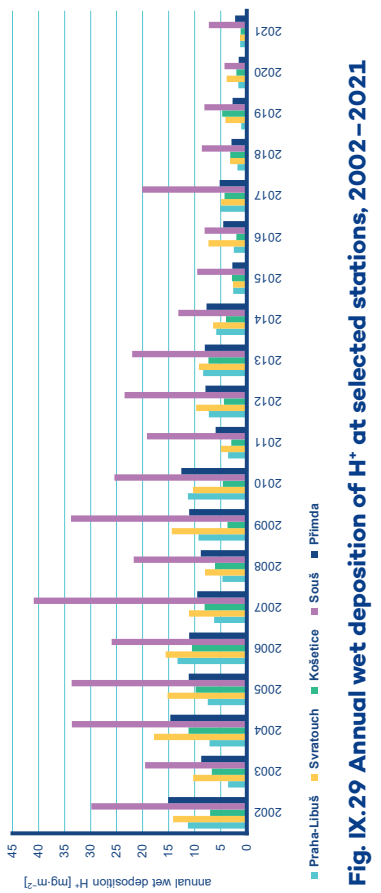


Fig. IX.29 Annual wet deposition of H^+ at selected stations, 2002–2021

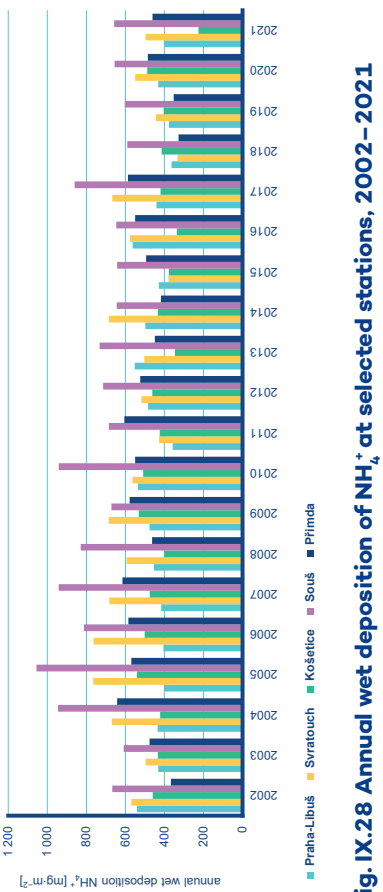


Fig. IX.28 Annual wet deposition of NH_4^+ at selected stations, 2002–2021

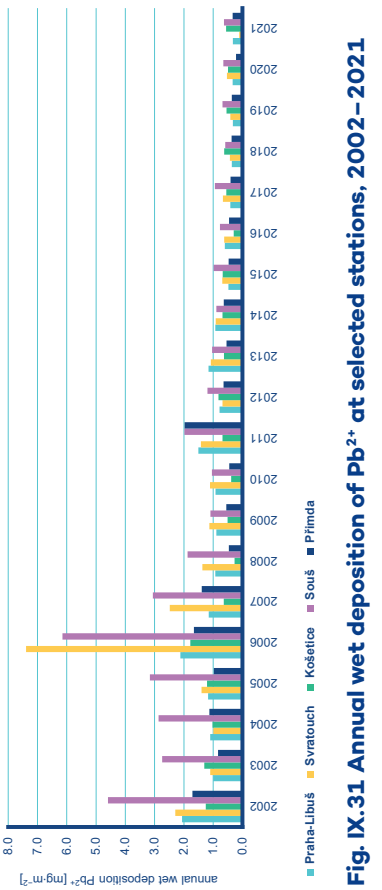


Fig. IX.31 Annual wet deposition of Pb^{2+} at selected stations, 2002–2021

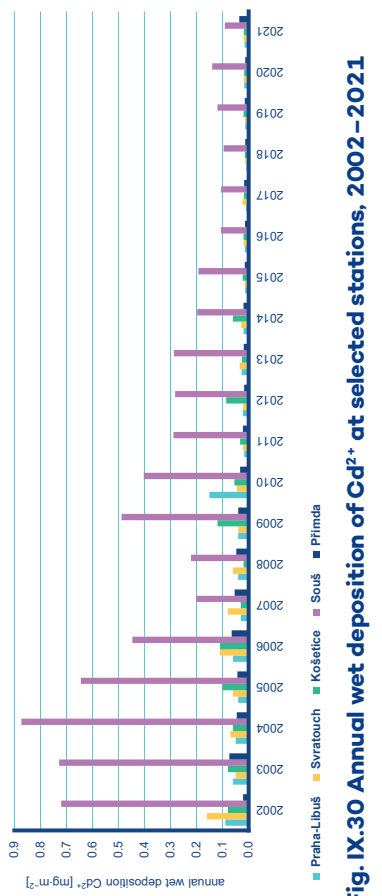


Fig. IX.30 Annual wet deposition of Cd^{2+} at selected stations, 2002–2021

X. GREENHOUSE GAS EMISSIONS

Greenhouse gases form a part of the Earth's atmosphere and contribute to the so-called greenhouse effect. They are produced not only by natural processes, but also by human activities. Monitoring of these so-called anthropogenic greenhouse gas emissions is carried out within the inventory of greenhouse gas emissions and removals. More about the processing methodology and reporting obligations can be found under the reference CHMI (2022d).

Total greenhouse gas emissions including removals from the Land Use, Land Use Change and Forestry (LULUCF) sector, expressed in carbon dioxide equivalent (CO_2 eq.), decreased in the Czech Republic (CR) from 190 million tonnes in 1990 to 126 million tonnes in 2020 (Tab. X.1). Emissions alone (excluding LULUCF) decreased from 199 million tonnes to 113 million tonnes, a decrease of 43 % compared to the 1990 reference year. The Czech Republic has thus complied with the second commitment period of the Kyoto Protocol; to reduce emissions by 20 % by 2020 compared to the base year 1990. The proportion of particular sectors in total emissions in CO_2 eq. over the years is shown in Fig. X.1.

The proportion of CO_2 emissions in total greenhouse gas emissions in CO_2 equivalent (excluding LULUCF) was 81 % in 2020, the proportion of CH_4 emissions reached 10 % and the proportion of N_2O emissions 5 %. The proportion of fluorocarbons in CO_2 eq. in 2020 was 4 % (CHMI 2022c).

The emissions trading system (ETS) is an important source of data for preparation of background data for the inventory of greenhouse gas emissions (CHMI 2022c). Emissions reported under the EU ETS in 2020 reached 54.6 Mt CO_2, representing 59 % of the total CO_2 emissions of the CR (Tab. X.2).

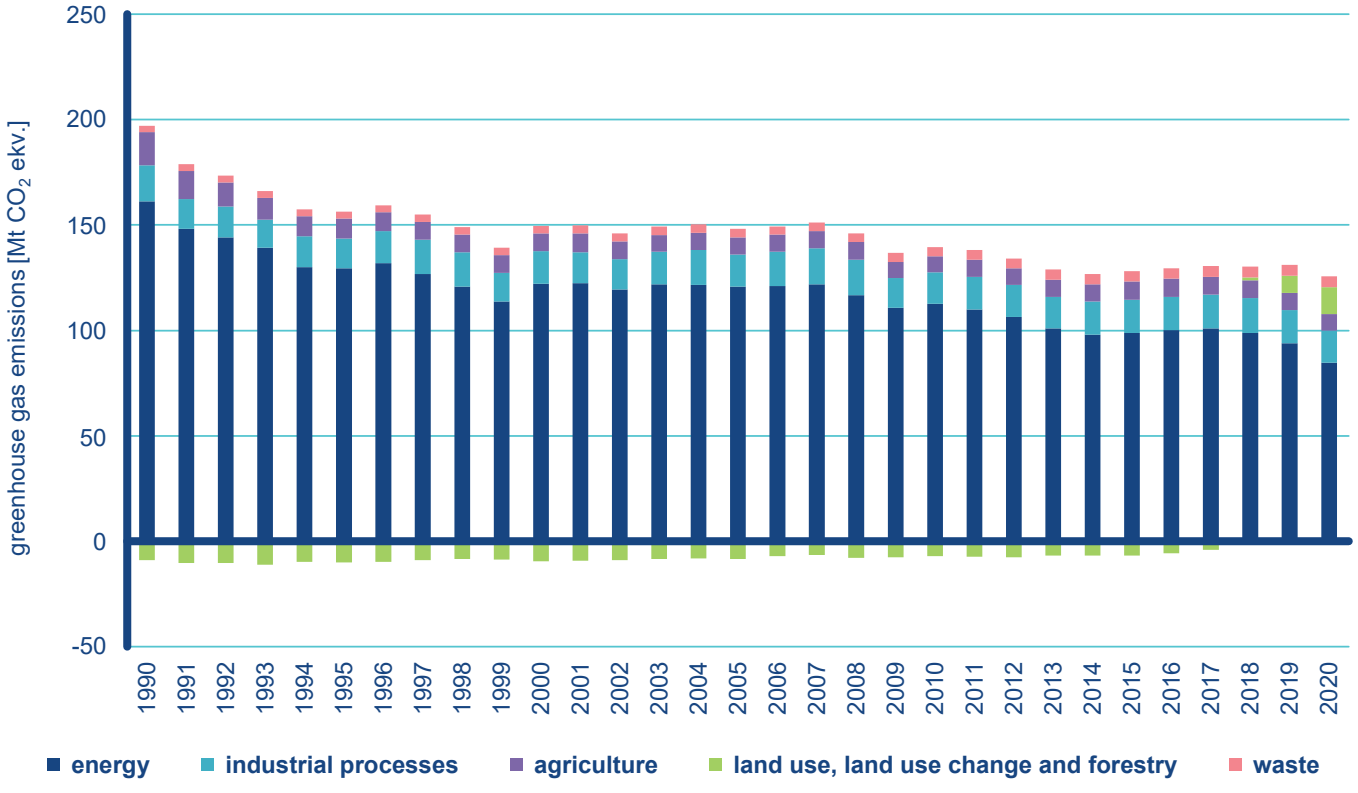


Fig. X.1 Share of individual sectors on total greenhouse gas emissions for 1990–2020 time-series

Tab. X.1 Trend in greenhouse gas emissions for 1990-2020 time-series

	CO_2 excl. net CO_2 from LULUCF	CO_2 excl. net CO_2 from LULUCF	CH_4	N_2O	F-gases	Sum emissions incl. LULUCF	Sum emissions excl. LULUCF
	Mt	Mt	Mt (CO_2 ekv.)	Mt (CO_2 ekv.)	Mt (CO_2 ekv.)	Mt (CO_2 ekv.)	Mt (CO_2 ekv.)
1990	157	166	23	9	0	190	199
1991	140	151	22	8	0	170	180
1992	137	147	20	7	0	165	175
1993	131	142	20	6	0	157	168
1994	124	134	18	6	0	149	159
1995	123	133	18	7	0	148	158
1996	126	136	18	6	0	151	161
1997	123	132	17	6	1	148	156
1998	118	127	17	6	1	142	150
1999	109	118	16	6	1	132	140
2000	119	128	15	6	1	141	151
2001	119	128	15	7	1	142	151
2002	116	125	15	6	1	138	147
2003	120	129	15	6	1	142	150
2004	121	129	14	6	2	143	151
2005	118	127	15	6	2	141	149
2006	120	128	15	6	2	143	151
2007	123	129	14	6	2	146	152
2008	116	124	14	6	2	139	147
2009	108	116	14	6	3	130	138
2010	111	118	14	5	3	133	141
2011	109	116	14	6	3	132	139
2012	105	112	14	6	3	128	135
2013	101	108	13	6	3	123	130
2014	98	105	13	6	3	121	128
2015	99	106	13	6	4	122	129
2016	102	107	13	6	4	124	130
2017	104	108	13	6	4	127	131
2018	108	107	12	6	4	131	129
2019	110	102	12	6	4	132	124
2020	105	92	12	5	4	126	113

Tab. X.2 Trend in greenhouse gas emissions in emission trading scheme for 2010–2020 time-series

	Combustion of fuels	Refining of mineral oil	Production of pig iron or steel	Production of cement clinker, lime, or calcination of dolomite/magnesite	Manufacture of glass and mineral wool	Manufacture of ceramics	Production of pulp, paper and cardboard	Total CO_2 in EU ETS	Total CO_2 in the Czech Republic	Share of CO_2 from EU ETS
	Mt CO_2	Mt CO_2	Mt CO_2	Mt CO_2	Mt CO_2	Mt CO_2	Mt CO_2	Mt CO_2	Mt CO_2	%
2010	62.53	1.05	6.08	3.35	0.67	0.41	0.65	75.26	118.47	63.53
2011	61.12	0.99	5.92	3.74	0.63	0.44	0.59	73.82	116.15	63.55
2012	56.73	0.95	5.86	3.40	0.65	0.42	0.59	68.94	112.20	61.44
2013	55.06	0.82	5.91	3.12	0.64	0.39	0.50	67.50	107.53	62.77
2014	53.65	0.91	5.90	3.35	0.67	0.39	0.48	66.44	105.05	63.24
2015	53.63	0.93	5.70	3.46	0.72	0.38	0.48	66.37	105.79	62.73
2016	54.20	0.71	6.06	3.70	0.73	0.40	0.46	67.31	107.42	62.67
2017	53.88	1.00	5.45	3.82	0.75	0.41	0.46	66.84	108.47	61.62
2018	53.22	0.92	5.79	4.15	0.74	0.43	0.48	66.80	107.03	62.41
2019	49.28	0.98	5.29	4.14	0.73	0.45	0.52	62.43	101.67	61.40
2020	41.96	0.80	5.36	3.92	0.72	0.41	0.51	54.60	92.40	59.09

Carbon dioxide

CO_2 emissions originate mainly from the combustion of fossil fuels. Other contributing processes include, in particular, desulphurisation, decomposition of carbonates in the production of lime, cement and glass, and metallurgical and chemical production. Emissions and removals (CO_2 absorption) occur in the LULUCF sector. As shown in Fig. X.1, CO_2 sinks from LULUCF prevailed until 2017, but since 2018, emissions have already predominated. This was caused by a bark beetle calamity, which required logging in forests that would have otherwise captured CO_2. In other areas, such as industrial processes, CO_2 capture is not yet registered in the CR. CO_2 emissions from combustion processes arise mostly from the combustion of solid fuels, and to a lesser extent from the combustion of liquid and gaseous fuels. In the last years, there have been changes in the structure of fuel use, with the proportion of natural gas and biomass combustion increasing and the use of coal fuels declining. Even so, lignite and other coal fuels still predominate in the CR (CHMI 2022c) (Fig. X.3).

Between 1990 and 2020, CO_2 emissions decreased by 44 % (Fig. X.2). This was mainly due to a decrease in the Energy sector – the production of electricity and heat for production plants and services, households and other consumers. The decrease in combustion emissions in manufacturing companies in the early 1990s was a result of the slowdown and restructuring of some industries; at the end of the period, the decrease in emissions was due to savings and the introduction of new technologies. Reductions in emissions from services and households can be attributed to more economical use of energy (increasing energy efficiency, especially thermal insulation of buildings, and more economical energy management). On the contrary, the opposite trend is evident in transport, namely in the increase of emissions. However, this has ceased in recent years and emissions have tended to fluctuate, which is due to the generally more efficient options for combustion processes and also to changes in the composition of fuels burned. As already mentioned, the LULUCF sector (CHMI 2022c) has also contributed to CO_2 emissions since 2018.

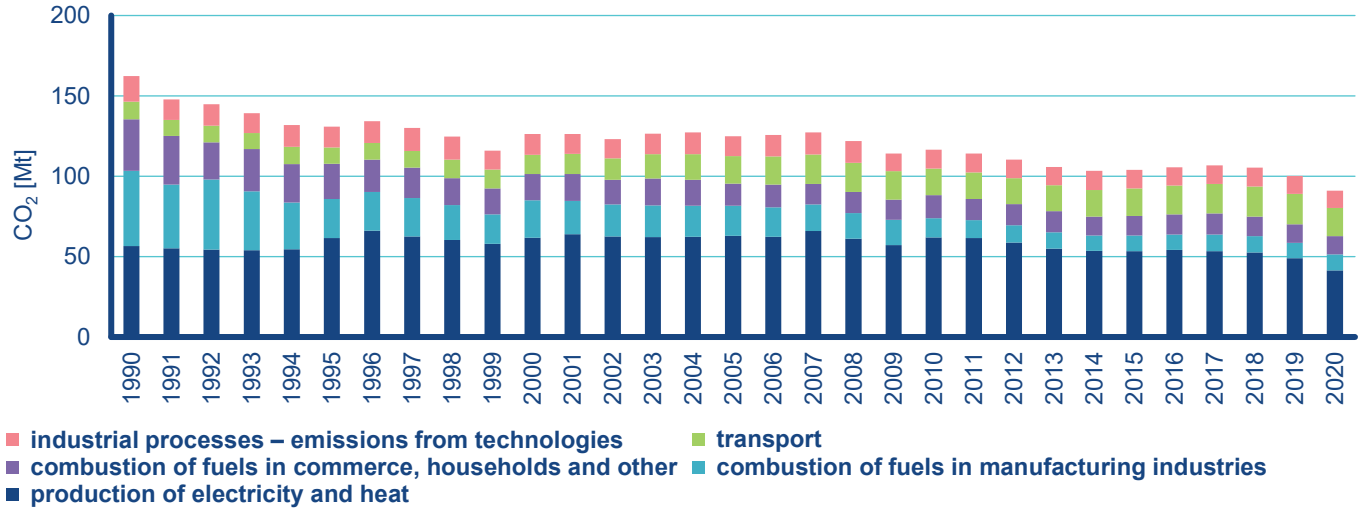


Fig. X.2 Share of individual sectors on total CO_2 emissions for 1990–2020 time-series

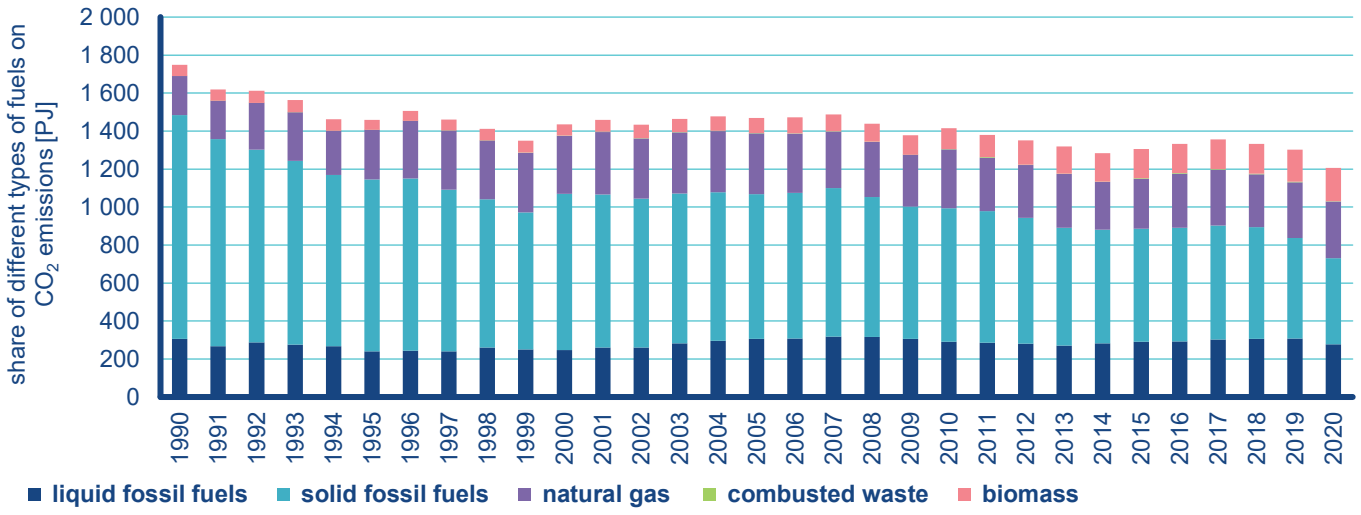


Fig. X.3 Share of different types of fuels combusted for 1990–2020 time-series

Methane

In terms of production, methane (CH_4) is the second most important greenhouse gas in the CR. Anthropogenic emissions of CH_4 in the Czech Republic come mainly from mining, and treatment and distribution of fuels; these types of emissions are classified as fugitive emissions (emissions freely escaping into the atmosphere). Animal breeding, anaerobic decomposition of biological waste in landfills and wastewater treatment are further important sources of CH_4 emissions. In the breeding of animals, this gas is generated during digestive processes (especially in cattle) and the decomposition of excrement of animal origin. Changes in these areas are also reflected in trends in CH_4 emissions; in recent years, for example, there has been a noticeable change in fugitive emissions from the extraction and processing of fuels in connection with the closure of some mines in the Ostrava region (CHMI 2022c).

In the 1990–2020 period, CH_4 emissions were reduced by 51 % (Fig. X.4), particularly as a consequence of reductions in coal mining and livestock numbers, and to a lesser extent by reduced solid fossil fuel consumption in households. The increase in emissions in the Waste sector was mitigated by the utilisation of landfill gases and biogas for energy production purposes.

Nitrous oxide

The greatest amounts of nitrous oxide (N_2O) emissions originate from agricultural activities, especially the denitrification of nitrogen added to the soil in the form of artificial fertilizers or organic material. Other important sources are the production of nitric acid and other chemical industries, and to a lesser extent transport (vehicles with catalytic converters) (CHMI 2022c).

There was a reduction in N_2O emissions by 43 % in the 1990–2020 period (Fig. X.5), particularly as a consequence of the reduced use of artificial fertilizers in agriculture, a reduction in livestock numbers, and recently also as a result of the targeted introduction of technologies to eliminate nitrous oxide emissions in the production of nitric acid.

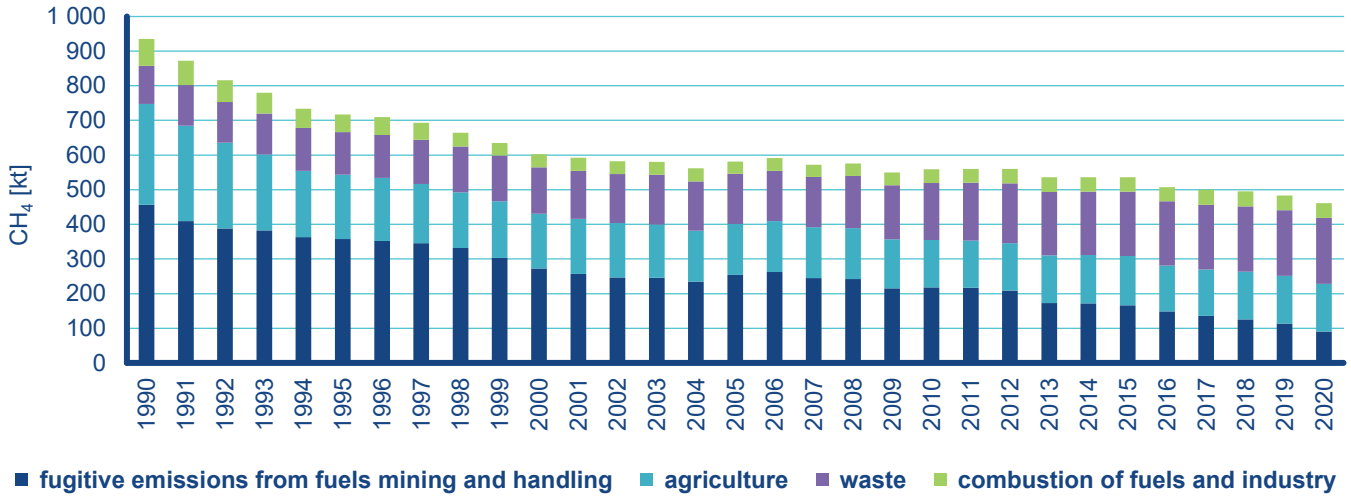


Fig. X.4 Share of individual sectors on total CH_4 emissions for 1990–2020 time-series

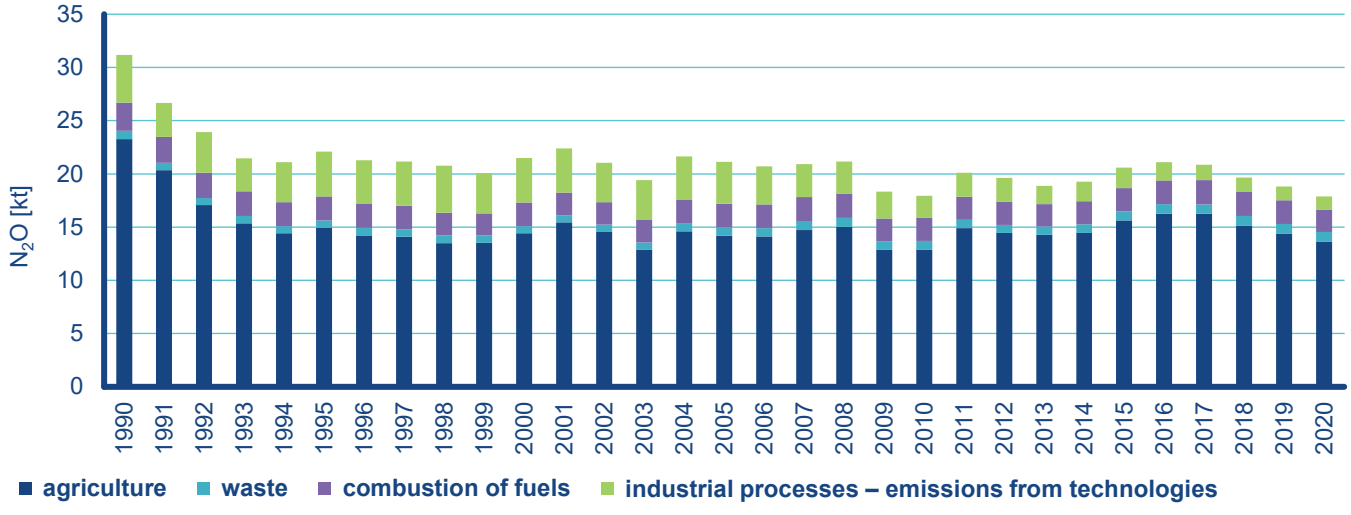


Fig. X.5 Share of individual sectors on total N_2O emissions for 1990–2020 time-series

Fluorinated gases

Emissions of fluorinated gases increased from 184 kt CO_2 eq. in 1995 to 4 088 kt CO_2 eq. in 2020 (Fig. X.6). Consequently, the contribution of fluorinated gases to the total aggregate emissions from industrial processes also increased (from 1.3 % in 1995 to 26.8 % in 2020). These substances are not manufactured in the CR and are imported for all uses. They are used mainly in refrigeration and air conditioning technologies (namely HFCs), in electrical engineering (namely SF_6, and newly since 2010 also NF_3) as well as in a number of other areas (e.g. in plasma etching, filling of fire extinguishers, aerosol propellants, and blowing agents). The emissions are generated mainly by releases from the equipment in which they are used. The increase in these emissions is caused by their use as replacements for substances that deplete the Earth's ozone layer (CFC, HCFC — mainly as refrigerants), the increased use of modern technologies (air conditioning) and the manufacturing focus of the CR (production of cars and air conditioning units) (CHMI 2022c). The rapid increase of fluorinated gas emissions in the context of their higher global warming potential (GWP) has led globally to increased attention on monitoring their emissions levels and consequently to their regulation. These regulations deal mainly with applications for which there are available alternative technologies that are more effective in terms of economy and have lower or no impact on the Earth's climate system. Thus, in recent years, high GWP fluorinated gases have been replaced by low GWP gases. Thanks to legislative measures, fluorinated gases are also no longer used in insulating glass windows, blowing agents or as refrigerants in household refrigeration technologies. Nevertheless, their emissions to the atmosphere still continue, due to long lifetime of the related equipment.

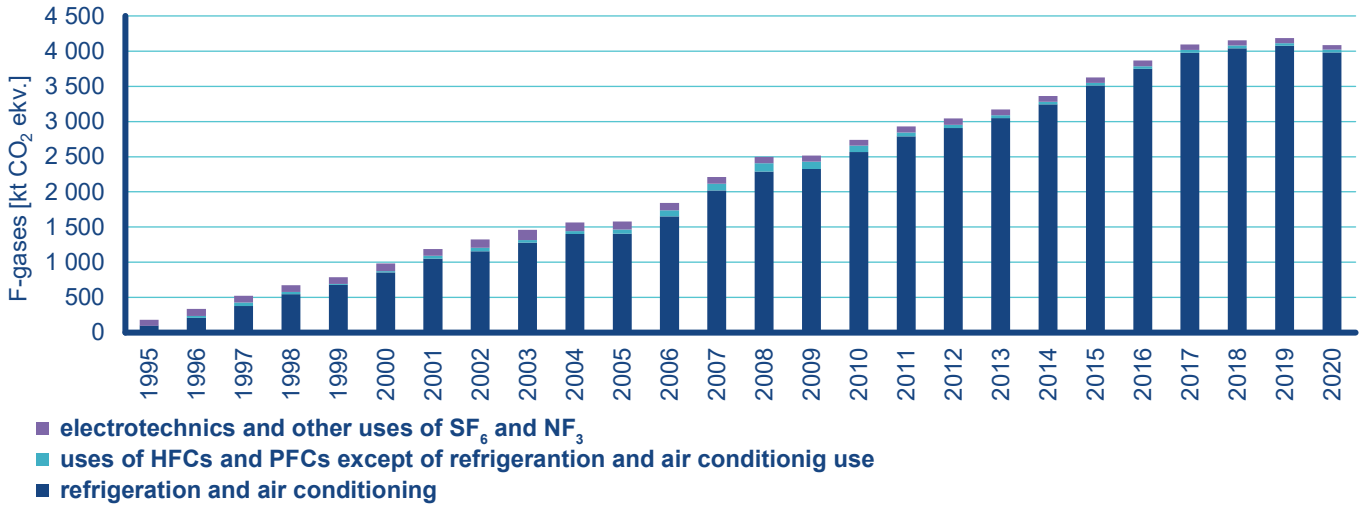


Fig. X.6 Share of individual sectors on total F-gas emissions for 1995–2020 time-series

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LIST OF ABBREVIATIONS

a. s.	joint-stock company
ACTRIS	Aerosols, Clouds and Trace gases Research InfraStructure
AOT40	Accumulated Ozone Exposure over a Threshold of 40 ppb
ASKPCR	Association of the Glass and Ceramic Industry of the
AV ČR	Czech Academy of Sciences
BaP	benzo[*a*]pyrene
BC	black carbon
CENIA	Czech Environmental Information Agency
CFC	chlorofluorocarbon
CLRTAP	Convention on Long-range Transboundary Air Pollution Coll.
CEZ	Czech Energetic Work
CGS	Czech Geological Survey
CHMI	Czech Hydrometeorological Institute
CR	Czech Republic
CSO	Czech Statistical Office
D21	degree-days
LTO	long-term objective
EC	elemental carbon
EC	European Commission
EC	European Community
EEA	European Environment Agency
EMEP	Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmissions of Air Pollutants in Europe
EoI	Council Decision 97/101/EC on exchange of information
ESFRI	European Strategy Forum on Research Infrastructures
ETC/HE	European Topic Centre for Human health and the environment
EU	European Union
EU ETS	European Union Emissions Trading Systém
GAW	Global Atmosphere Watch
GLÚ AV ČR	Institute of Geology of the Czech Academy of Sciences of the Czech Republic
GWP	Global Warming Potential
HBÚ AV ČR	Institute of Hydrobiology of the Academy of Sciences of the Czech Republic
HCB	hexachlorbenzene
HCFC	hydrochlorofluorocarbons
HFC	hydrofluorocarbons
PLA	protected landscape area
IARC	International Agency for Research on Cancer
ICOS	Integrated carbon observation systém
AQI	Air Quality Index
LV	limit value
IPCC	Intergovernmental Panel on Climate Change
IPH	informative threshold value

ISPOP	System of the Fulfilling Reporting Obligations
LRTAP	Convention on Long-range Transboundary Air Pollution
LULUCF	Land Use, Land-Use Change and Forestry
MHMP	Prague City Hall
MOE	Ministry of Environment
NAOK	National Atmospheric Observatory Košetice
NFR	Nomenclature for Reporting Codes
NMVOC	non-methane volatile organic compounds
NO_X	NO_X (as NO_2) – nitrogen oxides expressed as NO_2
NP	national park
O/K/F-M	Ostrava/Karviná/Frýdek-Místek
OC	organic carbon
OECD	Organisation for Economic Cooperation and Development
UN	United Nations
PAH	polycyclic aromatic hydrocarbons
PCB	polychlorinated biphenyls
PM_{10}	particulate matter fraction < 10 μm
$PM_{2.5}$	particulate matter fraction < 2.5 μm
POP	persistent organic pollutants
PZKO	Air Quality Improvement Program
REZZO	Register of Air Pollution Emissions Sources
DC	dispersion conditions
RPH	regulatory threshold value
Coll.	Collection of Laws
CET	Central European Time
SELČ	Central European Summer Time
SO_X	SO_X (as SO_2) –sulphur oxides expressed as SO_2
SPE	summary operating records
SWRS	Smog Warning and Regulation System
SZÚ	National Institute of Public Health
TAČR	Technology Agency of the Czech Republic
TC	total carbon
TSP	total suspended particulates
UCR	Unit Carcinogenic Risk
ÚCHP AV ČR	Institute of Chemical Process Fundamentals of the CAS
UN-ECE	United Nations Economic Commission for Europe
ÚVGZ AV ČR	Global Change Research Institute CAS
VI	ventilation index
VOC	volatile organic compounds
VPH	alert threshold value
VŠB TU	Technical University of Ostrava
VÚLHM	Forest Management and Gamekeeping Research Institute
WAM	with additional measures
WEM	with existing measures
WHO	World Health Organization
WMO	World Meteorological Organization
ZABAGED	Fundamental Base of Geographic Data of the Czech Republic
ZÚ	Institute of Public Health

ANNEX I

Detailed specifications of the presented pollution level maps

Spatial maps are constructed from the results of measurements at individual locations, using and combining a wide range of information (CHMI 2022d). Uncertainties of individual maps depend mainly on the density of the network of monitoring stations and the uniformity of coverage of the national territory by these stations, as well as on the uncertainties of individual measurements, model inputs, model calculations and the methods used in constructing the spatial maps. Maps have the least uncertainty near measuring stations. Although the uncertainties of some particular maps are quite high, these are associated with estimates of the air pollution field that adequately correspond to the background data used and the state of current knowledge. The uncertainties of maps must be taken into account when interpreting them.

The following paragraphs describe the background sources used for construction of the air pollution maps for 2021 and the specifications of the individual maps presented in this yearbook.

1. Data employed

a. Measured air pollution data. The annual characteristics of the measured data from the AQIS database are used.

b. Outputs from dispersion models. Outputs from the following models are used:

CAMx — Eulerian model, resolution 2.3 × 2.3 km, 2021:

- meteorology: ALADIN 2021 model in 2.3 × 2.3 km resolution
- anthropogenic emissions for the territory of the CR for 2020, unless otherwise stated: REZZO 1 and 2 stationary sources — reporting for 2020 updated by reporting for 2021 available as of 3 April 2022; REZZO 3 areal sources — local heating (background data 2020, degree-days 2021), agriculture — breeding (2019 and 2020) and agriculture activities, brown coal and black coal mines (2021), quarries — surface mining, fugitive emissions from production of coke, iron and steel, foundries and other resources, landfills, construction activities, use of solvents; REZZO 4 mobile sources — road transport according to the Road and Motorway Directorate census (2016), off-road transport, Václav Havel Airport in Prague (2016, updated for 2021 according to CO_2 emissions ratio for the Czech Republic (EUROCONTROL 2022)), other international airports (2020, updated for 2021 according to CO_2 emission ratio for the Czech Republic (EUROCONTROL 2022))
- anthropogenic emissions for Poland for 2019: Central emission database for air quality modelling in Poland (KOBiZE 2022)
- anthropogenic emissions outside the CR and Poland: basic substances – CAM S-REG-AP v4.2-ry[1] for 2019 (Kuenen et al. 2021); benzo[*a*]pyrene, cadmium, and lead (2019) (EMEP/CEIP 2022; these cadmium and lead emissions were also used for the territory of Poland)
- biogenic VOC emissions from plants and NO from soil: the MEGAN v2.1 model (GUENTER et al. 2012)
- boundary conditions – in time and space, variables from the global WACCM model (NCAR 2022)

SYMOS — Gaussian model, resolution 1 × 1 km (reference points in a 250 × 250 m grid in built-up areas and a 500 × 500 m grid outside built-up areas, averaged into a grid of 1 × 1 km); outside the CR 1 × 1 km, 2021 (meteorology: wind roses 2021 from the ALADIN model in the 2.3 × 2.3 km grid and at 120, 330, 500, and 700 m height levels according to the effective height of the source, anthropogenic emissions: as for the CAMx model (except for emissions from the EMEP/CEIP database)). For $PM_{2.5}$, the model was smoothed in a 3 × 3 km grid.

CAMS ensemble forecast[2] – median of the Eulerian model ensemble, resolution 0.1 x 0.1°, year 2021 (meteorology: ECWMF 2021, emission: CAMS-REG-AP; see COPERNICUS (2022) for details)

The most recent outputs that were available from particular models at the time of preparing the yearbook were always used.

c. Emissions from traffic: resolution 1 × 1 km, source: the Road and Motorway Directorate census (2016)

d. Elevation: resolution 1 × 1 km, source: ZABAGED, SALSC.

e. Population density: resolution 1 × 1 km, source: CSO.

1 https://permalink.aeris-data.fr/CAMS-REG-AP
2 https://www.regional.atmosphere.copernicus.eu/

2. Estimates of uncertainty

The uncertainty in relation to the relevant map was assessed using the cross-validation method; see Horálek et al. (2007). Estimations of the concentrations at measuring sites was always created by leaving out the given measurement using the other data, thus objectively estimating the quality of the map outside the measuring site. This approach was used repeatedly for all the measuring sites. The estimated values were compared with the measured values using the root-mean-square error (RMSE) or the relative root-mean-square error (RRMSE).

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(\dot{Z}(s_i) - Z(s_i))^2}$$

$$RRMSE = \frac{RMSE}{\frac{1}{N}\sum_{i=1}^{N} Z(s_i)} \cdot 100$$

Where $Z(s_i)$ is the measured value of the concentration at the i^{th} point,
$\dot{Z}(s_i)$ is the estimate at the ith point using the other data,
N is the number of monitoring stations.

For calculation reasons, the estimate of the uncertainty was calculated only for interpolation of the residuals; thus the overall uncertainty of the map is generally somewhat greater. It should also be noted that this is the median uncertainty of the whole map; the spatial distribution of the uncertainty was not estimated.

3. Parameters of the individual maps

For the maps of the individual pollutants, the Tables 1–8 below present the supplementary quantities used in the linear regression model and their parameters (c, a1, a2, ...), the interpolation parameters using kriging (range, nugget, partial sill), the inverse distance values (IDW — inverse distance weighted), and for most maps the root-mean-square of the error (RMSE) in the map is also given. These parameters are always given for the individual pollution layers (rural, urban, traffic).

a. **Suspended particulate matter PM_{10}:** The maps were constructed using 55 rural (without distinguishing background and industrial), 87 urban and suburban background and 27 traffic stations. The results of measurements at six urban and suburban industrial stations were taken into account only in their immediate vicinity (Tab. 1, Annex 1).

b. **Suspended particulate matter $PM_{2.5}$:** The maps were constructed using 29 rural (without distinguishing background and industrial), 52 urban and suburban background and 19 traffic stations. The results of measurements at seven urban and suburban industrial stations were taken into account only in their immediate vicinity. The uncertainty in the map was not calculated because of the mapping methodology (Tab. 2, Annex I). This is because PM_{10} maps were used as supplementary quantities — due to the strong regression relation between PM_{10} and $PM_{2.5}$ the uncertainty estimates would be underestimated.

c. **Benzo[*a*]pyrene:** The maps were constructed using 11 rural, and 42 urban and suburban stations (without distinguishing background, traffic, and industrial ones), which were supplemented by eight rural and eight urban and suburban stations whose values were estimated using the measured values of previous years. Concerning the city and rural map layers, an exponential interrelation with the $PM_{2.5}$ city and rural map layer, respectively, was applied. Due to the low number of measuring stations in small settlements, the estimation of uncertainty in rural areas is only indicative (Tab. 3, Annex I).

d. **Nitrogen dioxide and nitrogen oxides:** The maps for NO_2 were constructed using 31 rural (without distinguishing background and industrial), 48 urban and suburban background and 22 traffic stations. The results of measurements at 4 urban and suburban industrial stations were taken into account only in their immediate vicinity. The maps for NO_x were constructed using 29 rural, 46 urban and suburban background and 22 traffic stations (Tab. 4, Annex I).

e. **Tropospheric ozone:** The maps of the 26 highest maximum daily 8-hour running averages were constructed on the basis of 24 rural and 29 urban and suburban stations. The measurement results of 3 transport and 2 urban and suburban industrial stations were taken into account only in their immediate vicinity. The maps for AOT40 were constructed using 27 rural and 34 urban and suburban background stations (Tab. 5, Annex I).

f. **Benzene:** The maps were constructed using 6 rural, and 24 urban and suburban background stations. The results of measurements at 2 industrial and 6 traffic stations were taken into account only in their immediate vicinity (Tab. 6, Annex 1).

g. **Heavy metals:** The maps for arsenic were constructed using 16 rural and 40 urban and suburban stations (without distinguishing between background, traffic and industrial stations). The cadmium map was constructed using 56 stations (without distinguishing according to type). The high relative uncertainty of the cadmium map is related to the low cadmium values over most of the territory (Tab. 7, Annex I).

h. **Sulphur dioxide:** The map of the 4 highest 24-hour concentrations was constructed using 29 rural (without distinguishing background and industrial) and 30 urban and suburban background stations. The results of measurements at 3 traffic and 3 industrial stations were taken into account only in their immediate vicinity. The maps of the annual or winter averages were constructed using 38 and 35, respectively, rural (without distinguishing background and industrial) and 30 urban and suburban background stations. The results of measurements at 3 and 2, respectively, traffic stations and 3 industrial stations were taken into account only in their immediate vicinity (Tab. 8, Annex I).

Tab. 1 PM_{10} map parameters

Linear regression model + interpolation of residuals	Annual average			36th highest daily average		
	rural areas	urban background	traffic	rural areas	urban background	traffic
c (constant)	3.5	13.9	10.7	−5.0	24.2	18.6
a1 (model CAMx)	1.72	0.69	0.88	1.82	0.61	0.73
a2 (altitude)	-0.0055	-0.0073			-0.0139	
range [km]	45	90	5	47	25	5
nugget	0	4.6	0	0	19.0	0
partial sill	2.9	2.2	4.5	11.6	1.3	13.8
weight IDW		1			1	
RMSE [µg·m^{-3}]	**1.8**	**2.7**	**2.3**	**4.2**	**5.2**	**3.5**
relat. RMSE [%]	**11**	**14**	**10**	**14**	**15**	**9**

Tab. 2 $PM_{2.5}$ map parameters

Linear regression model + interpolation of residuals	Annual average		
	rural areas	urban background	traffic
c (constant)	0.7	−2.4	−2.1
a1 (rural map of PM_{10})	0.62		
a2 (urban background map of PM_{10})		0.86	
a3 (traffic map of PM_{10})			0.79
a4 (model SYMOS)	0.95		
range [km]	10	100	2
nugget	0	1.1	0
partial sill	1.2	0.2	1.9
weight IDW		1	

The numbers of stations also include foreign (German and Polish) stations that were used in the creation of some maps.

The urban and rural layers were combined using the limits of the classification intervals (CHMI 2022d): $\alpha 1 = 200$ inhabitants·km^{-2}, $\alpha 2 = 1000$ inhabitants·km^{-2}. The background and traffic layers were combined using the limits of the classification intervals (CHMI 2022d): $\tau 1 = 3$ t·km^{-2}·year^{-1}, $\tau 2 = 8$ t·km^{-2}·year^{-1} (for PM_{10} and $PM_{2.5}$ maps), or $\tau 1 = \tau 2 = 10$ t·km^{-2}·year^{-1} (for NO_2 and NO_x maps), where the PM_{10} and $PM_{2.5}$ maps were based on SPM emissions, while the NO_2 and NO_x maps were based on NO_x emissions[3].

3 For the spatial maps of NO_2 and NO_x, the traffic layer was used only in cities, while outside of cities in territories with $NO_x > 5$ t·km^{-2}·year^{-1} the layers were used from all the urban, suburban, rural and traffic stations.

Tab. 3 Benzo[*a*]pyrene map parameters

Linear regression model + interpolation of residuals	Annual average	
	rural areas	urban background
c (constant)	0.1	0.1
b1 (constant)	0.2	
b2 (constant)		0.2
a1 (exp(b1*rural map $PM_{2,5}$))	0.04	
a2 (exp(b2*urban map $PM_{2,5}$))		0.03
range [km]	30	6
nugget	0	0
partial sill	0.02	0.25
RMSE [µg·m^{-3}]	**> 0.3**	**0.5**
relat. RMSE [%]	**> 30**	**35**

Tab. 4 NO_2 and NO_x map parameters

Linear regression model + interpolation of residuals	NO_2 – annual average			NO_x –annual average		
	rural areas	urban background	traffic	rural areas	urban background	traffic
c (constant)	8.0	16.7	18.8	8.9	25.7	31.3
a1 (model SYMOS NO_2)	4.43	1.50				
a2 (model SYMOS NO_2 – REZZO4)			2.75			
a3 (model SYMOS NO_x)				2.35	0.62	
a3 (model SYMOS NO_x – REZZO4)						1.93
a4 (altitude)	-0.01	-0.01		–0.01	-0.03	
weight IDW	1	1	1	1	1	1
RMSE [µg·m^{-3}]	**1.1**	**2.4**	**5.5**	**2.3**	**5.2**	**16.3**
relat. RMSE [%]	**14**	**16**	**22**	**22**	**23**	**34**

Tab. 5 Ground-level ozone map parameters

Linear regression model + interpolation of residuals	26th highest maximum daily 8-hour average		AOT40 exposure index	
	rural areas	urban background	rural areas	urban background
c (constant)	111.7	23.0	16146	8114
a1 (model CAMS)		0.90		0.84
a2 (altitude)	0.01		1.12	
weight IDW	1	1.1	1	1
RMSE [µg·m^{-3}]	**4.0**	**4.2**	**2727**	**2617**
relat. RMSE [%]	**3**	**4**	**16**	**16**

Tab. 6 Benzene map parameters

Linear regression model + interpolation of residuals	Annual average	
	rural areas	urban background
c (constant)	−1.2	−1.1
a1 (model CAMx)	6.87	7.15
weight IDW	1	1.6
RMSE [µg·m^{-3}]	**0.1**	**0.3**
relat. RMSE [%]	**16**	**22**

Tab. 7 Arsenic and cadmium map parameters

Linear regression model + interpolation of residuals	Arsen – annual average		Kadmium – annual average
	rural areas	urban background	whole map
c (constant)	−0.8		0.1
a1 (rural map PM_{10})	0.109		
a2 (model CAMx)			1.68
range [km]	130	10	16
nugget	0	0	0
partial sill	0.2	0.4	0.1
RMSE [µg·m^{-3}]	**0.3**	**0.6**	**0.2**
relat. RMSE [%]	**38**	**47**	**88**

Tab. 8 SO_2 map parameters

Linear regression model + interpolation of residuals	4th highest daily average		Annual average		Winter average	
	rural areas	urban background	traffic	rural areas	urban background	traffic
c (constant)	0.4	5.6	1.1	2.5	1.2	2.0
a1 (model CAMx)	0.99	0.46	0.89	0.40	0.71	0.43
weight IDW	1.5	1.7	1	1	1	1
RMSE [µg·m^{-3}]	**4.7**	**6.3**	**1.1**	**1.5**	**1.2**	**1.0**
relat. RMSE [%]	**43**	**45**	**31**	**35**	**31**	**22**

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