Global Environmental Change 1994 **4** (3) 201–227

New data on air pollution in the former Soviet Union

Maria Shahgedanova and Timothy P Burt

The former Soviet Union was the world's second largest producer of harmful emissions. Total emissions in the USSR in 1988 were about 79% of the US total. Considering that the Soviet GNP was only some 54% of that of the USA, this means that the Soviet Union generated 1.5 times more pollution than the USA per unit of GNP. The governmental concerns about the size of USSR emissions were barely noticeable before the late 1980s; in the early 1990s the air pollution became an issue of great public attention – its economic priority, however, was changing slowly. This paper analyses the changes in fuel consumption by the Soviet industry during the last decade and makes available sets of data on air pollution in the former Soviet Union between 1980 and 1991. The temporal and spatial changes in emissions and ambient concentration of four major pollutants (suspended particles, sulphur dioxide, nitrogen oxides and carbon monoxide) are examined, and contributions of different branches of industry and transport are considered. The information was obtained from the State Committee on Hydrometeorology and Environment (Moscow). Summary data are presented in the main paper; full details are given in the accompanying appendix.

The authors are with the School of Geography, University of Oxford, Mansfield Road, Oxford, OX1 3TB, UK.

In recent years, environmental issues have become of increasing political importance in the former USSR as public awareness of the scope and effects of the problem has grown. Air pollution, being one of the major aspects of environmental degradation, is now receiving more and more attention from the scientific communities;[1] a growing number of publications document health problems in various cities which are believed to be connected with air quality.[2] Total emissions in the USSR in 1988 were about 79% of the US total. Considering that the Soviet GNP was only some 54% of that of the USA, this means that the Soviet Union generated 1.5 times more pollution than the USA per unit of GNP.[3]

Probably the best indicator of this critical environmental situation is the fact that 20% of the population of the former USSR lives in 103 cities where the level of at least one major pollutant has exceeded the national maximum permissible level by 10 times or more on at least one occasion during 1987–90.[4] Only 40% of the industrial sources of pollution are equipped with pollution abatement installations; 11% of these enterprises' emissions occur due to the improperly functioning or low-efficiency abatement equipment.[5]

The official Soviet approach meanwhile had been demonstrating a commitment to the protection of environment which resulted in the development of environmental legislation which did not compare unfavourably with the experience of Western industrialized nations. The first example of the Soviet air quality legislation was the 1949 resolution 'On Measures in the Struggle against Pollution of the Atmosphere and Improving the Sanitary-Hygienic Conditions of Populated Areas'; two years later, in 1951, the Air Quality Management Strategy for air pollution control was adopted. The most serious attempt to resolve pollution problems with the help of legislation was made in 1981, when the Air Quality Law – the first national law on air pollution, an analogue of the American Air Quality Act (1967) or the British Clean Air Act (1956) – was passed. The Law took a broad approach and quoted plans for 'protecting the air basin as part of the state plans for economic and social development of the USSR, by the exercise of the state control of air protection, and also by the establishment of ceilings on permitted discharges from the possible sources of pollutants.' These highly commendable provisions, however, were frustrated by the difficulty or impossibility of implementing them, caused by the vagueness of the laws

[1] A.R. Bond, (chairman), discussion 'Panel of the State of the Soviet Environment at the Start of the 1990s', *Soviet Geography*, Vol XXXI, No 6, pp 401–468; P.R. Pryde *Environmental Management in the Soviet Union*, Cambridge University Press, Cambridge, 1991; M. Fesbach and A. Friendly, 1992, *Ecocide in the USSR*, Aurum Press.
[2] Fesbach and Friendly, *op cit*, Ref 1.
[3] Bond, *op cit*, Ref 1.
[4] *Ibid.*

and underlying submission of environmental concerns to production quotas.[6] Another cause of the air pollution crisis was the diversity of environmental agencies. Before 1988, 15 agencies were set up to monitor and control the air quality;[7] coordination between the agencies was lacking. Moreover, before the mid-1980s, the enforcement of air pollution legislation often lay within the ministries which had largely been the cause of the problem in the first place. Thus, the Ministry of Non-ferrous Metallurgy was responsible both for production of the ferro-alloys on the one hand and for ensuring compliance with environmental standards on the other, the former issue being much more significant than the latter.[8] Twice, attempts were made to create a powerful environmental ministry following the experience of the US Environmental Protection Agency: in 1978, the coordination of the air pollution management was delegated to the State Committee on Hydrometeorology and the Environment; and a decade later the Ministry for Environmental Protection was set up. However, neither agency was given the necessary funding, authority and personnel to carry out its charges successfully.[9]

A rigorous analysis of the Soviet air pollution management was provided by the authors;[10] the purpose of this paper is to make available sets of data on air pollution with good geographical breakdown. The emissions and ambient concentration of four major pollutants (suspended particles, sulphur dioxide, nitrogen oxides and carbon monoxide) are analysed. The information was obtained from the State Committee on Hydrometeorology and Environment (Moscow), by whom one of the authors was previously employed; most of these data have not been freely available before. Summary data are presented in the main paper; full details are given in the accompanying appendix.

USSR fuel balance and shifts in fuel choice

A significant number of environmental issues – hazardous air pollution, ambient air quality, acid deposition, global climatic change – relate to energy production. Several analyses indicate that the share of emissions generated by fuel combustion is considerably higher than that generated by industrial processes.[11] Consumption of different types of fuel – solids (hard coal, lignite, peat and oil shale), liquids (crude petroleum and natural gas liquids) and gas – as well as the use of alternative types of energy production result in different consequences for ambient air quality and hazardous pollution, natural gas being known as the most 'environmentally friendly' type of fossil fuel.

In recent years, a considerable shift has occurred in fuel usage by West European and North American countries from traditional coal and oil consumption to alternatives which have much reduced emissions compared with coal and residual oil. The traditional Soviet fuel balance has also experienced notable alterations (Figure 1). Although the reasons for the shift towards natural gas were availability of very large supplies at reasonable costs [12] rather than the environmental characteristics of gas as a clean fuel, governmental policy in the last two decades has been to introduce use of natural gas in most sectors. Thus in 1955, the share of natural gas in the USSR fuel consumption was 2.4%; in 1987 it was 25%.[13] Electric power plants in the USSR have been the primary focus of the 'gas-for-oil' switch. In 1980–1991, most of the electricity used in the former Soviet Union was generated by large

[5]Ministry of the Environmental Protection and Rational Use of Natural Recources, *Proekt natsionalnogo doklada SSSR k konferentsii OON 1192 goda po okruzausei srede i razvitiyu*, Moscow, 1991, in Russian.
[6]M. Shahgedanova and T.P. Burt, 'Air pollution management in the former USSR', in J. Holder, ed, *Perspectives on the Environment*, Avebury, 1993.
[7]B. Jancar, *Environmental Management in the Soviet Union And Yugoslavia*, Duke University Press, Durham, NC, 1987.
[8]Shahgedanova and Burt, *op cit*, Ref 6.
[9]*Ibid.*
[10]*Ibid.*
[11]M. Amman, 'Recent and future development of emissions of nitrogen oxides in Europe', *Atmospheric Environment*, Vol 24A, No 11, 1990, pp 2759–2765.
[12]V.A. Shelest, 'Alternative sources of energy in the national economy of the Soviet Union', in P. Maillet, D. Hague, C. Rowland, eds, *The Economics of Choice Between Energy Sources*, MacMillan Press, London, 1982, pp 258–274.
[13]T.S. Khachaturov, *Ekonomika prirodopolzovaniya*, Moscow, 1991, in Russian.

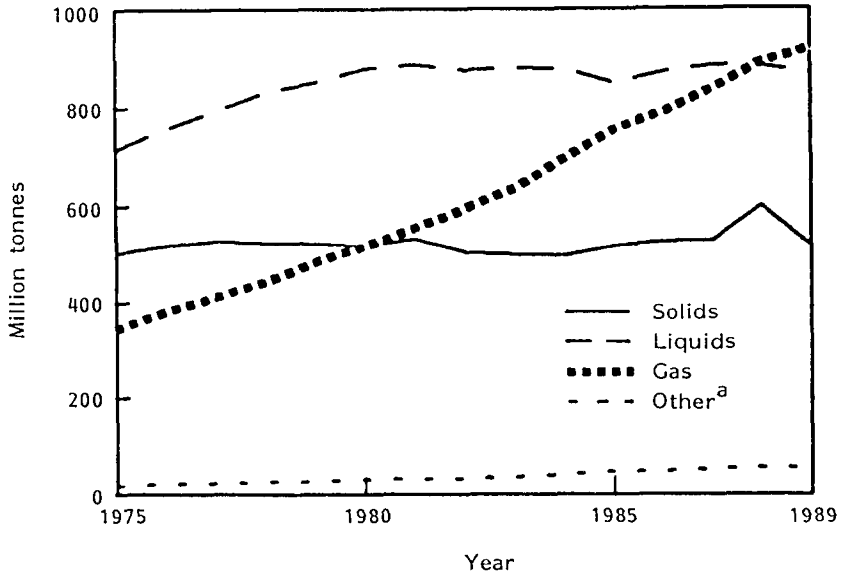


Figure 1. Fuels used for energy production in the USSR in 1975–89 (million tonnes coal equivalent).

Note: [a] Hydro, nuclear and geothermal electricity production.

Source: UN Energy Statistics Yearbooks for 1980, 1981, 1985, 1989.

central power plants, typically interconnected into regional grids and then to the all-union single electric power system, administered by the Ministry of Electric Power (Minenergo). Most of the generating capacity was made up of steam-generating plants that burn coal, gas, or oil. In 1980, natural gas represented only 24.2% of Minenergo fuel balance (Table 1) – coal was the most important fuel used by Minenergo's thermal stations, accounting for 37.3% of fuel inputs. Coal was followed closely by oil (mostly comprised of 'mazut' or residual fuel oil) at 35.7%. By 1985, natural gas consumption had nearly doubled – from 91.1 to 176.5 billion cubic metres,[14] making the share of natural gas in the fuel balance 40.3% and turning it into the most important fuel used by power plants. Oil consumption fell from 114.9 million tonnes to 94 million in 1985, causing oil's share of the fuel balance to decline from 35.7% to 25.9%. This strong penetration of natural gas into power plants' fuel balance, reducing the need for oil, continued in the late 1980s. Coal accounted for only 32.1% of the Ministry's fuel inputs in 1985. The actual amount of coal consumed by the power stations increased by only 3.6 million tonnes between 1980 and 1985; between 1985 and 1987 the consumption of coal by the electric power stations rose slightly, but declined in 1990. Emphasis has been put on the development of the vast open-pit excavations in the Kansk–Achinsk coal basin, located in the area between the Yenisey river and Lake Baikal in Eastern Siberia. Along with the considerably lower costs of Siberian coal in comparison with the traditional coal of the Donetskyi coal basin (Donbass) in the Ukraine or the brown coal of the Moscow coal basin, there is an environmental argument for Siberian coal which contains 0.2%–0.4% of sulphur while the sulphur content in the Donbass and Moscow coal ranges between 1.7% and 3.2%.[15]

[14]M. Sagers, 'Soviet atmospheric emissions from transportation and stationary sources', *Soviet Geography*, Vol XXXI, No 3, 1990, pp 224–234.
[15]Pryde, *op cit*, Ref 1.

Table 1. Fuel balance of Minenergo Power Stations in 1970–90 (%).

Fuel	1970	1975	1980	1985	1987	1990
Oil	23.4	29.5	35.7	25.9	17.4	17.2
Gas	23.8	22.0	24.2	40.3	48.0	50.4
Coal	47.5	44.5	37.3	32.1	33.0	30.6
Peat	3.4	2.1	1.0	–	–	–
Shale	1.8	1.9	1.8	–	–	–

Source: M. Sagers, 'Soviet atmospheric emissions from transportation and stationary sources', *Soviet Geography*, Vol XXXI, No 3, 1990, pp 224–234.

Not much information is available on the shift in fuels among power plants at the regional level. However, for the fuel-short European USSR, the shift was greater than for the country as a whole. The share of the natural gas in fuel balance of the regional power plants increased from 24.6% to 44.5% between 1980 and 1985. The major shift from mazut to gas occurred in the Volga region, in the Urals and Central Russia.[16] Thus, the share of gas at Tatarstan's electric plants rose from 45.6% to 80.3%.[17] In the Urals, despite a general increase in consumption, the share of mazut declined, and in Central Russia the share of petroleum fuels fell from 48% to 30%.[18] The share of gas in the overall fuel balance of power plants increased in the Central region from 27.3% to 54.3%; in the Urals from 31.1% to 55.2%; in the Ukraine from 20% to 30.8%; and in Belorussia from 5.9% to 22.5%.[19] Coal consumption by power plants declined relatively throughout the European USSR, and for most European regions an absolute decline has occurred. Between 1980 and 1985, in the Central region the share of coal fell from 22.5% to 14.7% of the fuel balance, in the Ukraine from 45.5% to 38.4%, and in the Urals from 40.4% to 33.5%.[20] In contrast, the electric stations of Kazakhstan, where the two main coal basins (Ekibastuzskyi and Karagandinskyi) are located, a 50% increase in consumption of coal was observed. There was also some increase in consumption of coal by electric stations in Siberia and the Far East.

Description of the data

This paper employs the data on emissions and ambient concentrations of four major pollutants (solid matter, sulphur dioxide, nitrogen oxides and carbon monoxide) published in the annual *Bulletins* by the State Committee on Hydrometeorology and the Environment.[21] The *Bulletins* have been regularly published between 1965 and 1991; however, before the early 1990s they were available only to a limited number of officials. To our knowledge, they comprise the most complete information on air pollution in the former USSR ever available both in the former Soviet Union and in the West. The period covered in this study is 1980–91.

The data on annual emissions from stationary sources are based on the reports of individual industrial enterprises which are verified by the officers of the local branches of the State Committee on Hydrometeorology and the Environment; the data on the transport emissions are estimated by the local statistical and/or environmental agencies on the basis of car fleet composition and types and volumes of fuel consumed. Information on both types of emission is then summarized by the State Committee on the Hydrometeorology and the Environment. It should be mentioned that a certain underestimation of the volume of emitted pollutants is very possible, since non-industrial stationary sources, stationary sources located outside urban areas and mobile sources other than automobiles are not included. Moreover, not all urban industrial enterprises send in their reports despite the obligation to do so. Thus in 1985, only 558 Moscow enterprises (including, however, the major polluters) reported their emissions, while the total number of enterprises was 2499.[22]

The ambient concentration data are of much greater reliability, as they are based on the data of an advanced monitoring network run by the Committee itself. In this paper, the results of regular monitoring at

[16]Sagers, *op cit*, Ref 14.
[17]A.A. Troitskiy, *Energetika v SSSR v 1986–1990 godakh*, Moscow, 1987, p 100, in Russian.
[18]*Ibid.*
[19]*Ibid.*
[20]*Ibid.*
[21]Annual Bulletins on Air Pollution in the USSR Cities and Industrial Centres, 1980–1990, Leningrad, in Russian.
[22]A.A. Bekker, ed, 'Okhrana okruzayusego vozdukha', unpublished paper, Moscow Institute of Applied Geophysics, Moscow, 1988, in Russian.

Table 2. Comparison of atmospheric emissions in the USSR (1988) and the USA (1987) (million tonnes).

Country	Suspended particles	CO_2	NO_x	CO
Stationary sources:				
USSR	14.7	17.7	4.5	14.9
USA	5.6	19.5	11.1	51.2
Transport:				
USSR	–	–	1.8	28.4
USA	1.4	0.9	8.4	7.2

Source of data for the US emissions: as for Table 1.

stationary sites are used. The number of sites is different for each city and depends on population, size of an urban area, character of relief, and degree of urbanization. The number of sites may be increased in areas of complicated terrain, high numbers of sources or for locations within an urban area of special natural, historical or cultural significance for which the ambient air quality is essential. The effect of changing site locations is minimized by maintaining a basic sub-network, which includes not less than a third of all monitoring sites which cannot be replaced and whose location is designed to represent a fixed set of surroundings (living area, industrial area, roads, etc) over a long period of operation. Measurements are taken according to one of the three approved programmes: the complete programme (sampling at 1am, 7am, 1pm, and 7pm local time), non-complete (samples taken at 7am, 1pm, and 7pm), and shortened (samples taken at 7am and 1pm). The number of cities presenting information on emissions ranged between 534 in 1980 and 600 in 1990; the information on ambient concentrations was provided by 442 cities in 1980 and 579 in 1990.

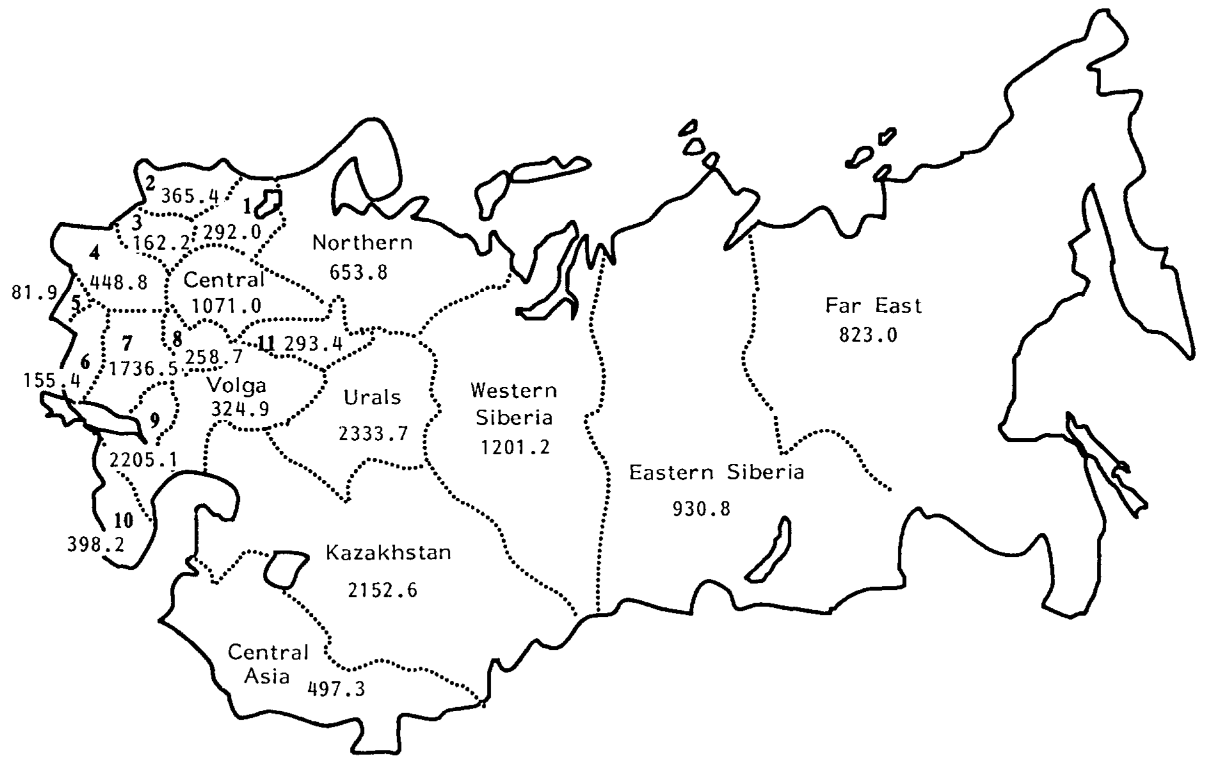
Pollution by suspended particles

Pollution by suspended particles presents one of the most serious problems for the Soviet cities. Suspended particles emissions from stationary sources totalled 14.7 million tonnes across the country in 1988, exceeding those in the USA by a factor of 2.6 (Table 2). Stationary sources provide a much higher share of emissions in the USSR than in the USA – 24% in the USSR in 1988 compared to 5.4% for the USA in 1987.[23] The high amount of particulate emissions in the USSR is probably due to the still widespread use of solid fuels such as coal (particularly lignite), peat and shale. For example, although the USA consumed 752 million tonnes of coal in 1987, only 9% consisted of lignite; in comparison, the USSR consumed 708 million tonnes, but about 25% was lignite.[24] The limited amount of pollution abatement equipment at factories and power plants also adds to the large volumes of emitted suspended particles.

Energy production remains the main contributor to suspended particle pollution, 34% of total particulate emissions in 1988. However, a decrease in emissions from power plants has been registered since 1985; in 1988, it contributed 21% compared to 1985. Energy production is followed by ferrous metallurgy, contributing up to 14% of the emitted matter, and construction materials production, which provided 9% of the total in 1988. The share of 'trapped' emissions (those removed before emission to the atmosphere) normally varies between 98% and 71%, being considerably lower at oil refineries (only 40%) and gas processing plants (about 34%).

In regional terms, the Urals, Kazakhstan and Donetsk–Dniepr region

[23]Sagers, *op cit*, Ref 14.
[24]*Ibid.*



••••• -Regional borders; 1-North-Western region, 2-Baltic States, 3-Belorussia, 4-South-Western region, 5-Moldova, 6-Southern region, 7-Donetsk-Dniepr region, 8-Black Soils region, 9-Northern Caucasus, 10-Transcaucasia, 11-Volgo-Vyatsky region

Figure 2. Emissions of suspended particles from stationary sources in 1988 (thousand tonnes).

experience the biggest suspended particles emissions – approximately 2 million tonnes per year (Figure 2). In Kazakhstan, where the solid matter makes approximately 41% of the total, the main input comes from energy production, which contributed about half of the Republic's particulate emissions in 1988. The highest emissions of solid matter were 490 000 tonnes in 1988, in the Kazakh city of Ekibastuz, at the centre of the mining area, these coming mostly from power generating plants burning coal (Figure 3). However, it is not only the type of fuel that contributes to the high pollution level, since 70 of 77 dust-capturing installations were out of order at the local power plants. It should also be mentioned that these figures do not include emissions coming directly from coal mining or from transportation of coal by heavy lorries.

In Donetsk–Dniepr region the high solid-matter emissions are contributed by energy production (32%) and ferrous metallurgy (39%) in nearly equal proportions. A certain decrease of emissions was found between 1985 and 1988 both at steel mills (due to the increase of gas share in fuel balance and replacement of old abatement equipment) and power plants (mainly due to the decrease of energy production and shifts in fuel balance). In such highly polluted cities as Kryvoi Rog, Zaporozh'ye, Maryupol' and Dnepropetrovsk, the reduction in suspended particles emissions was from 7% (Kryvoi Rog) to 26% (Zaporozh'ye) in 1988 compared to 1985.

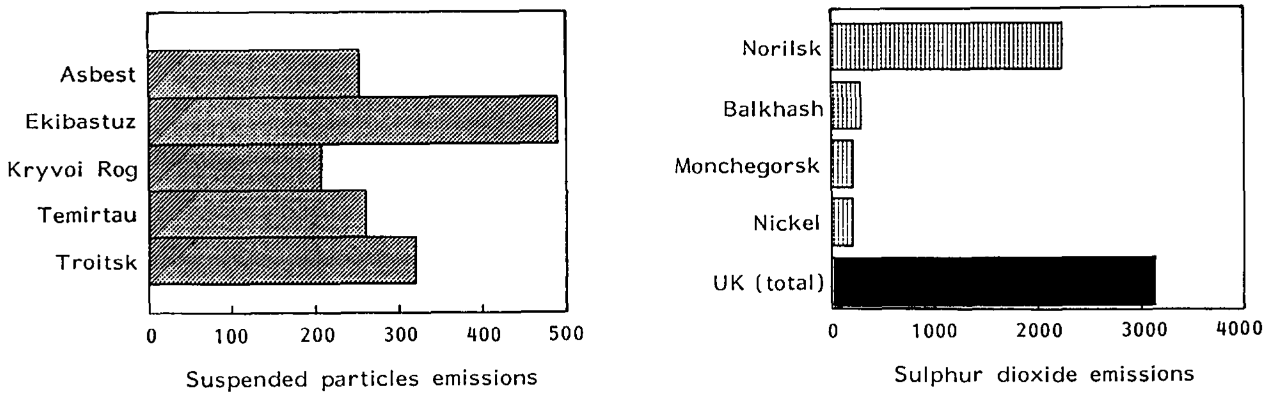


Figure 3. Soviet cities with maximum emissions of suspended particles and sulphur dioxide in 1988 (thousand tonnes a^{-1}).

In the Urals, the emissions of suspended particles remain mainly stable. However, in one of the Urals' industrial centres, Asbest (Ekaterinburg district), there was an enormous 30% increase in emissions between 1985 and 1988, comprising partly the extremely dangerous pollutant asbestos.

The average annual ambient concentration of suspended particles estimated for 440 cities was 210 μgm^{-3} in 1990, exceeding the specified daily USSR limit (Table 3) by a factor of 1.4. Average concentrations taken for the whole country are decreasing; the reduction was 32% in 1990 compared to 1981, which is a higher rate than that for suspended particle emissions (Figure 4). The difference may have been caused by the reduction of dust emissions coming from heavy lorries, due to the use of more efficient diesel trucks from the Kama Truck Plant and greater use of newer cars. Another reason for the decrease in suspended particles pollution may be the construction of orbital roads around urban areas which keep the heavy vehicles away from city centres and residential areas.

Table 4 presents cities with the highest levels of suspended particle pollution. In 1990, the highest annual concentrations – 1250 μgm^{-3} – were found in Kutaysi (Georgia), its truck factory and that producing construction materials being the main contributors. The construction materials plant as well as the local refiner are also known not to possess any abatement equipment. Concentrations of 1030 μgm^{-3} resulting from cement production were registered in the city of Bezmein (Turkmenistan). In five more cities, the annual means exceeded 800 μgm^{-3}, the high concentrations being produced mainly by construction mate-

Table 3. Environmental quality standards for air (μgm^{-3}).

Pollutant	**EEC** **Period**	**Concentration**	**USA** **Period**	**Concentration**	**USSR** **Period**	**Concentration**
Smoke	Yearly median of daily values	80			Daily arithmetic mean	50
	Winter median of daily values	130				
SO_2	Yearly median of daily values	80–120	Annual arithmetic mean	80	Daily arithmetic mean	50
	Winter median of daily mean	130–180				
Particulates			Annual geometric mean	75	Daily arithmetic mean	150
CO			8-hour limit	10000	Daily arithmetic mean	300
Ozone			1-hour	240	Daily arithmetic mean	30
NO_x			Annual arithmetic mean	80	Daily arithmetic mean	40 (NO_2), 60(NO)
Formaldehyde					Daily arithmetic mean	3
Benzo(a)pyrene					Daily arithmetic mean	$3.6^* 10^{-3}$
Phenol					Daily arithmetic mean	3

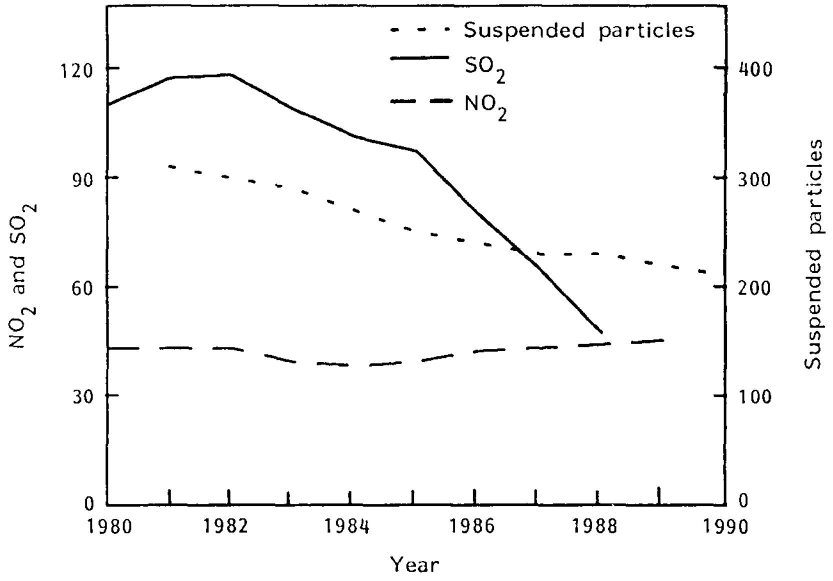


Figure 4. Concentrations of suspended particles, SO_2 and NO_2 averaged over the USSR urban areas (μgm^{-3}).

rials production (Ashkhabad, Rustavi) and metallurgy (Rustavi, Blagoveshensk). The average concentration of suspended particles estimated for cities manufacturing cement, asbestos, and similar materials significantly exceeds the average national level, being approximately 350 μgm^{-3}. They are followed by the centres for ferrous metallurgy, where the average level is about 290–300 μgm^{-3}.

The regional distribution of suspended particles pollution is influenced not only by the location of polluting enterprises but also by the natural climatic conditions. Very high dust concentrations are found in cities located in desert or semi-desert areas: in Central Asia (as far as republican averages are concerned), the highest concentrations in 1990 were found in Turkmenistan – about 580 μgm^{-3}, and Armenia. To a large extent, such concentrations are a natural extension of wind impacts on desert soils, but are exacerbated by anthropogenic activities which disturb the soil surface or interfere with the natural environment. Thus in Central Asia, the number of days with dust storms can reach 100; an annual mean of 30–50 days is registered at many weather stations.

Figure 5 demonstrates the pattern of suspended particle pollution throughout the whole USSR in 1990. High concentrations of suspended particles are found in the Donetsk–Dniepr region, in the Southern Urals and in Southern Siberia, where the contributions of metallurgy and coal

Table 4. Pollution by suspended particles in Soviet cities in 1990 (μgm^{-3}).

City	C_{mean}	σ	C_{max}	Source of pollution
Ashkhabad (Turkmenistan)	840	0.72	4 800	Construction materials production
Achinsk (Eastern Siberia)	630	0.49	6 700	Non-ferrous metallurgy
Bezmein (Turkmenistan)	1 030	0.83	5 600	Cement production
Blagoveshensk (Far East)	900	0.60	4 300	Power plants
Kirovokan (Armenia)	630	0.49	3 800	Car plant, petrochemical industry
Kutaysi (Georgia)	**1 250**	–	**14 800**	Truck plant, construction material production
Novotroitsk (East of European Russia)	700	0.50	2 400	Ferrous metallurgy
Svetlovodsk (Ukraine)	950	0.43	2 800	Power plants
Rustavi (Georgia)	820	0.68	12 700	Ferrous metallurgy, construction materials production

C_{mean} – mean annual concentration– σ – standard deviation; c_{max} – absolute maximum concentration.

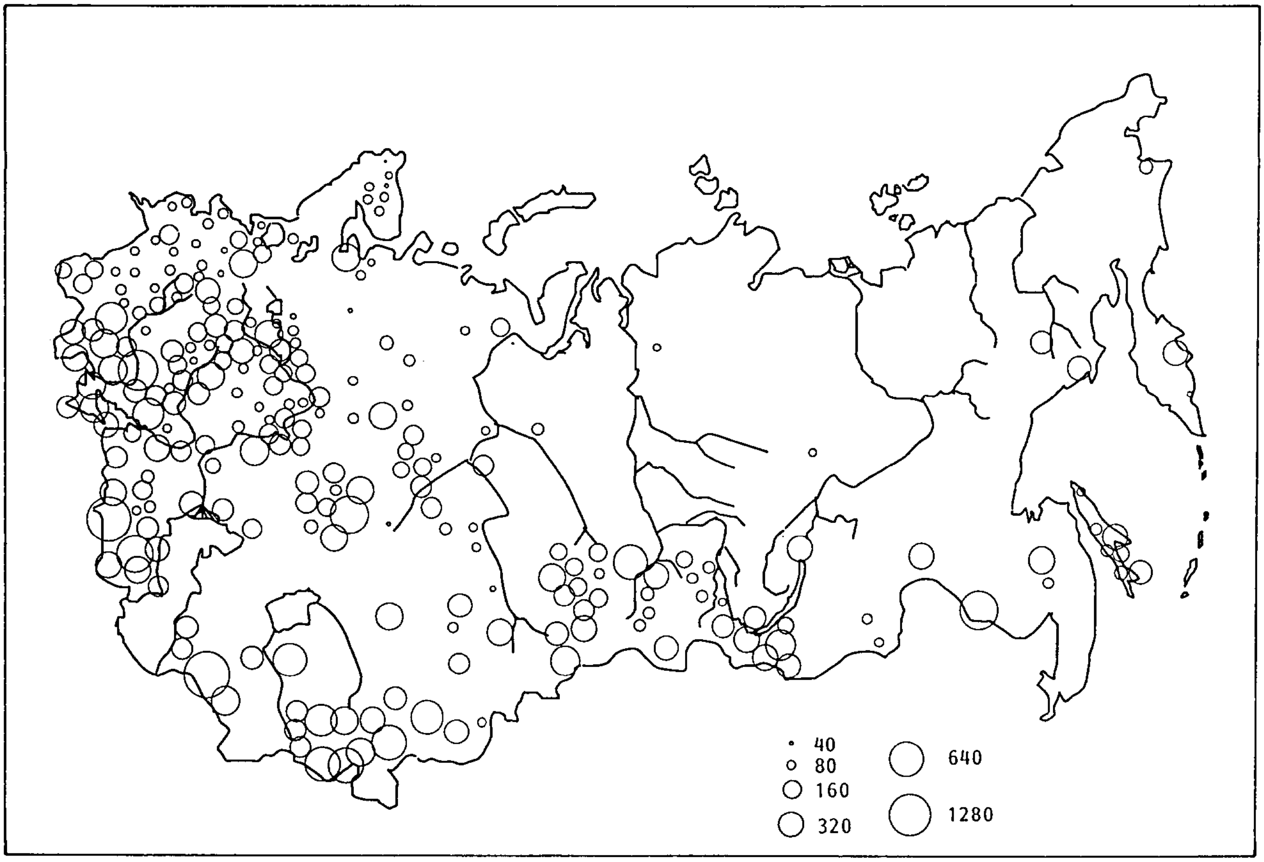


Figure 5. Annual mean concentrations of suspended particles in Soviet cities in 1990 (μgm^{-3}).

mining are strengthened by natural conditions favourable to the strong entrainment by wind of dust and soil.

Pollution by sulphur dioxide

The total figure for SO_2 industrial emissions (including electricity generation by power plants) in 1988 was 17.7 million tonnes. Sulphur dioxide is the only oxide of sulphur reported by the Soviet Union, unlike the USA which reports both sulphur oxide and sulphur dioxide, the last one being, however, the major component. For this united category in 1988, the US emissions exceeded SO_2 emissions of the USSR by only about 9% (Table 2). However, the systematic neglect of small boilers and furnaces by official Soviet inventories may result in an approximately 30% underestimation of sulphur dioxide emissions.[25]

Sulphur dioxide forms the largest category of gaseous emissions in the USSR (38% of total gaseous emissions in 1988). The main source of SO_2 is electricity generation (ie power plants), providing 43% of the total. It is a comparatively low share; for example, in the UK power plants burning fossil fuel contributes up to 71% of the industrial emissions of SO_2.[26] A 30% decrease in SO_2 emissions coming from power plants was registered between 1980 and 1988; that is a significant reduction, as in the UK the decrease of SO_2 emissions coming from power plants was only 13% during the same period.

After electricity generation, the next most important source of SO_2 is metallurgy. In 1988, non-ferrous metallurgy accounted for about 25% of

[25]A. Ryaboshapko, 'Emissions of pollutants in the USSR and their environmental effects', paper presented at 'Power Plant and Environment 90: the Greenhouse Effect and the Regional and the Global Effects of Emissions', Tampere, Finland, 31 October–2 November 1990.

[26]*Digest of Environmental Protection and Water Statistics*, No 12, Department of Environment, London, 1989.

the USSR total, although on average 44% of the sulphur was removed from waste gases at non-ferrous smelters, a very high share compared to other branches of industry. The peak of SO_2 emissions from non-ferrous metallurgy was observed in 1983; by 1988, the emissions had declined by 13%. It may be suggested that the large volume of sulphur dioxide emissions in the USSR reflects the lack of abatement equipment on major sources such as power plants (the share of captured sulphur emissions is about 1.5–2%) and the large amount of non-ferrous metals produced. Thus, in 1990 the USSR was significantly ahead of the USA in production of nickel (230 000 tonnes in the USSR compared to 3 700 tonnes in the USA), zinc (920 000 tonnes compared to 358 000 tonnes), cadmium (2.4 million tonnes compared to 1.7 million tonnes) and slightly ahead in production of copper (1.3 million tonnes against 1.2 million tonnes).[27] Compared to the emissions from power plants, total industrial emissions of sulphur dioxide in 1988 only dropped by 12% compared to 1980, a significantly lower rate compared to the UK where, according to the Department of Environment data,[28] the emissions from large combustion plants (power stations and industry combined) in 1988 were 21% below the 1980 baseline.

In terms of the regional distribution of SO_2 emissions, Eastern Siberia, the Urals and the Donetsk–Dniepr region are the main areas (Figure 6a). In terms of SO_2 emissions per unit of the territory, the European part of the USSR is far ahead of the Asian section. The Donetsk–Dniepr region – the centre for metallurgy and coal production – is the worst case, with Moldova, Estonia, Lithuania, Belorussia and the Urals following it (Figure 6b). During the 1980s a steady decrease in SO_2 emissions was observed in the North-Western, Central and the Black Soils regions. As the main source of SO_2 in all three areas is energy production, the decrease was clearly linked to the decreased use of 'mazut' fuel. Thus in Moscow, the share of 'mazut' decreased by 60% in 1988 compared to 1987, resulting in a 51 000 tonnes decrease of harmful emissions. In the Volga region, the strong introduction of cleaner fuel into power plants was compensated by the increase of emissions from the petrochemical industry and from gas processing. The most notable growth of sulphur dioxide emissions was registered in the Far East; the emissions in 1988 compared to 1980 were 34% higher.

In 1988, emissions of sulphur dioxide exceeded one thousand tonnes a year in 27 towns. Emissions from stationary sources in Noril'sk, a city of over 180 000 population on Eastern Siberia's Taimyr peninsula, were reported to have reached 2.2 million tonnes – 12.4 tonnes per capita. These SO_2 emissions come from the copper–nickel smelters, part of the Noril'sk Mining and Metallurgical Combine, established between 1932 and 1936 and expanded in the early 1970s, which process the local ores containing up to 25% of sulphur.[29] Noril'sk is followed by three other centres of non-ferrous metallurgy (Figure 4). In Balkhash (Kazakhstan), 290 000 tonnes of SO_2 were emitted in 1988 by the lead smelter; in Monchegorsk the major ore processor on the Kola peninsula, smelting local ores containing 5% of sulphur and ores transported from Noril'sk,[30] emitted 212 000 tonnes of SO_2. Although emissions of SO_2 were reported to have decreased in this city by about 19% during 1983–88, many opportunities to reduce the output of noxious gases were lost, as more than half (85 of 132) of the waste-gas cleaning installations were out of order in 1988. The third centre is Nickel (Kola peninsula), where 211 000 tonnes were emitted by non-ferrous smelters in 1988. In

[27]*Metal Statistics 1981–1991*, Metallgesellschaft Frankfurt-on-Main, 1992.
[28]*Op cit*, Ref 26.
[29]Laurila T. Tuovinen, H. Lattila, A. Ryaboshapko, P. Brukhanov, S. Korolev, 'Impact of the sulphur dioxide sources in the Kola Peninsula on air quality in northernmost Europe', *Atmospheric Environment*, Vol 27A, No 9, 1993, pp 1379–1395.
[30]*Ibid*.

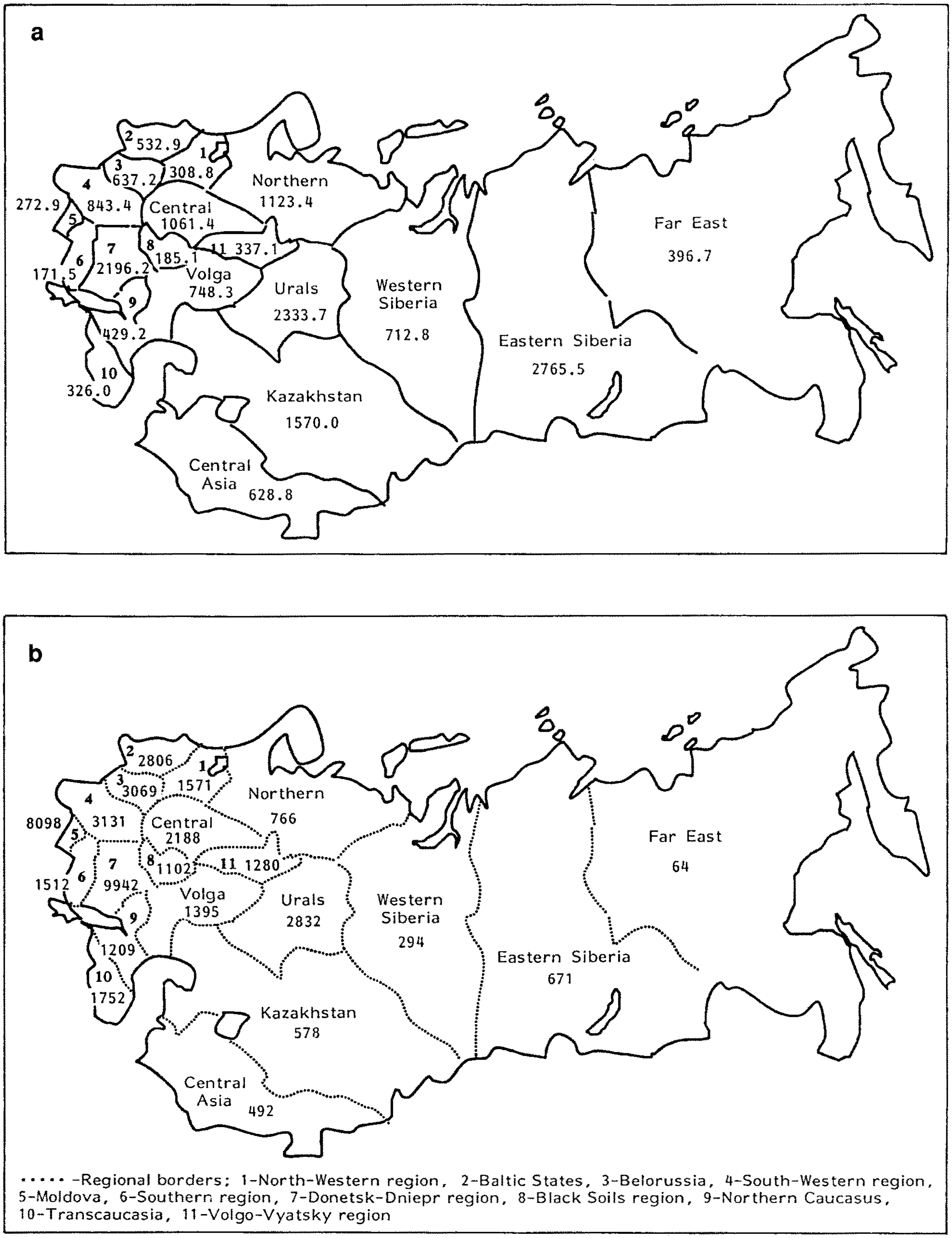


Figure 6. (a) Emissions of sulphur dioxide from stationary sources in 1988 (thousand tonnes); (b) Emissions of sulphur dioxide from stationary sources in 1988 (kg km^{-1}).

Table 5. Pollution by SO_2 in Soviet cities and industrial areas in 1990 (μgm^{-3}).

City	C_{mean}	σ	C_{max}	Source
Almalyk (Usbekistan)	87	0.18	1870	Ferrous metallurgy, chemical industry
Gorlovka (Ukraine)	70	0.032	460	Ferrous metallurgy, chemical industry, coal mining
Dzerzinsk (Ukraine)	82	0.029	320	Ferrous metallurgy, coal mining
Zapolyarny (Kola)	73	0.168	1240	Non-ferrous metallurgy (copper–nickel smelters)
Zyryanovsk (Kazakhstan)	70	0.020	250	Non-ferrous metallurgy (lead smelter)
Mozyr' (Belorussia)	80	0.050	810	
Noril'sk (Eastern Siberia)	**140**	**0.513**	**8400**	Non-ferrous metallurgy (copper–nickel smelters)
Saransk (Volga)	73	0.043	640	Power plants
Simferopol' (Crimea)	76	0.066	500	Power plants
Stepnoe (Volga)	126	0.611	8890	Gas processing
Tallinn (Estonia)	82	0.068	1370	

C_{mean} – mean annual concentration– σ – standard deviation; c_{max} – absolute maximum concentration.

response to Finnish protests over what is believed to be a significant Soviet contribution to Finland's acid rain problem, the USSR Ministry of Non-ferrous Metallurgy has been instructed to reduce sulphur dioxide emissions from nickel smelting operations on the Kola peninsula to about 200 000 tonnes annually. A number of nickel-smelting complexes at the Kola peninsula require immediate reconstruction. Thus, the Pechenega complex, acquired from Finland at the end of the second world war, is now undergoing expansion and modernization in conjunction with an agreement by which a Finnish company delivers a number of sections including control systems.[31] Research on meteorological patterns in high latitudes has led to the suggestion that the smelters of the Kola peninsula and Noril'sk, which emit sulphur and suspended particles mostly at a height above 100 m,[32] so facilitating transport of pollutants over long distances, might be a possible source of the Arctic Haze – the increase of sulphate and aerosols concentrations recorded in Alaska and Canada.[33]

Ambient SO_2 concentrations peaked in the USSR in the early 1980s, when the mean annual concentration estimated for the industrial areas reached 118 μgm^{-3}, significantly exceeding the recognized limit (according to the US standards, the annual mean should not exceed 80 μgm^{-3}). By 1988, the annual average had dropped to 47 μgm^{-3} (Figure 4). After this, the method of SO_2 pollution measurement was changed so that precise comparison is impossible; however, given an annual mean of 30 μgm^{-3} in 1990, the tendency for declining SO_2 pollution is clear.

Although throughout the country as a whole a decrease in SO_2 pollution has been found, in a large number of industrial cities the level of ambient sulphur dioxide concentrations remains high. Thus in 1990, in 10 cities the annual limit of 80 μgm^{-3} was exceeded (Table 5), the highest concentrations being registered in Noril'sk – 140 μgm^{-3} for the annual mean, the daily means reach 1300 μgm^{-3}. To make things worse, residential areas in this city could be located only in one place due to the complicated local topography; almost all are located downwind of the smelter, so experiencing the worst pollution.[34] Not only is the air quality within the city extremely poor, but ecosystems show damage at a considerable distance from the smelter. The damage to forests, unique for their northernmost location, is growing: in 1970 the area covered by completely dead forests was 6 000 hectares; in 1988 it was 382 000 hectares.[35] Noril'sk is followed by the small town of Stepnoe (the Volga delta) where the Astrakhan Gas Condensate Complex is situated. The SO_2 annual mean in 1990 was 126 μgm^{-3}; the complex is known not to provide any cleansing of the waste gases.

[31]M. Sagers, 'Air pollution at Monchegorsk continues', *Soviet Geography,* Vol XXX, No 3, 1989a, pp 253–262.
[32]Laurila *et al*, *op cit*, Ref 29; *ibid.*
[33]A.K. Rahn, 'Progress in Arctic air chemistry', *Ambio*, Vol 19, 1985, pp 1987–1994.
[34]Sagers, *op cit*, Ref 31.
[35]Shahgedanova and Burt, *op cit*, Ref 6.

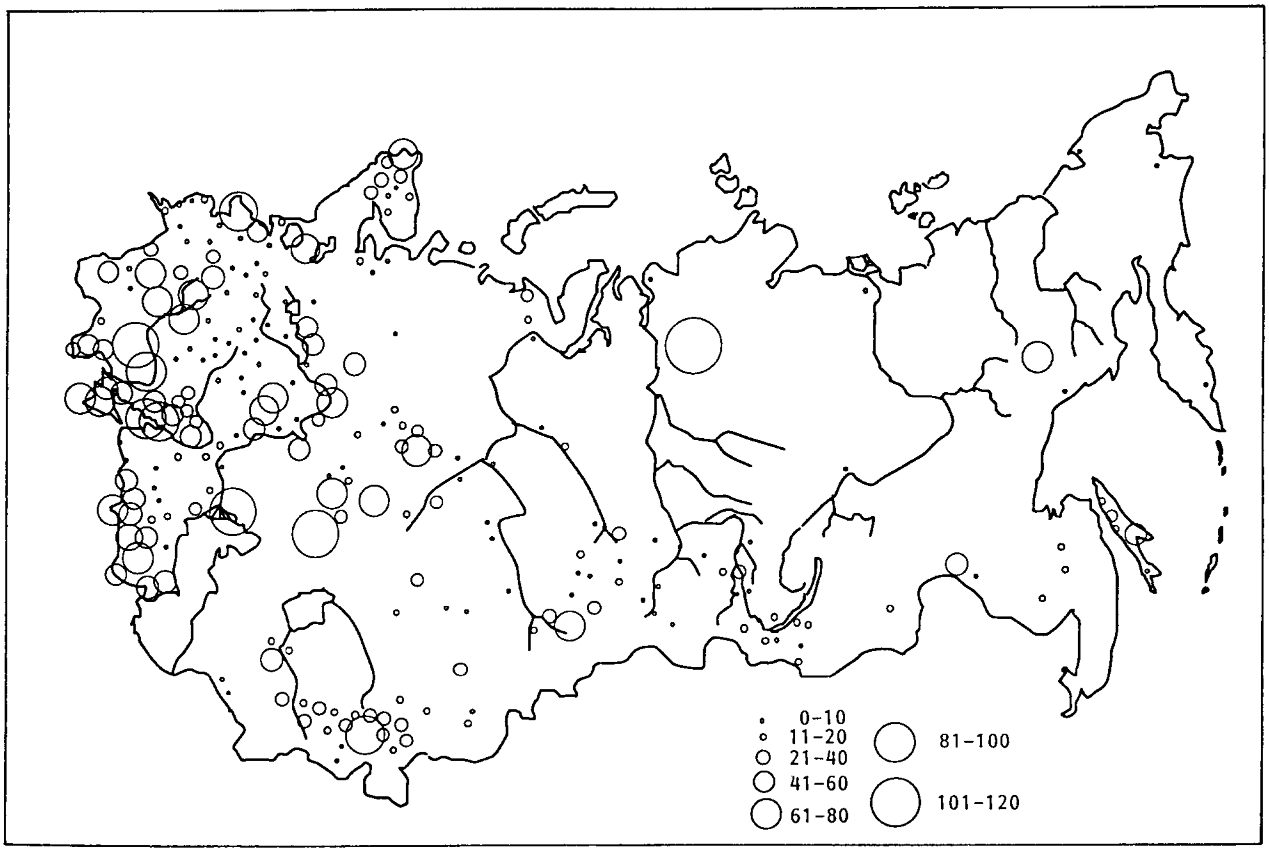


Figure 7. Annual mean concentrations of sulphur dioxide in Soviet cities in 1990 (μgm^{-3}).

In regional terms, the highest annual means of 50–80 μgm^{-3} are observed in the Urals and the Donetsk Coal Basin areas (Donbass) (Figure 7). A cluster of coal and steel producing towns situated rather near to each other makes Donbass the worst area in the former USSR in terms of SO_2 pollution, being very similar to the notorious Katowice region in Poland. The industrial areas of the Volga region and the Urals also have high levels, being subject to frequent temperature inversions and rather long periods of calm weather together with high sulphur emissions from metallurgical and petrochemical plants and oil refineries. Annual means of 50–80 μgm^{-3} are registered in north-eastern Estonia and some districts of Belorussia. The extremely high emissions from nickel–copper smelters result in local annual means of 25–30 μgm^{-3} in the Kola peninsula. According to the research conducted by Polish scientists,[36] the level of emissions at which coniferous forests (dominant in this area) begin to show damage from sulphur air pollution is roughly 5–7 tonnes per km^2 per year, corresponding to an annual mean concentration of SO_2 of 20 μgm^{-3}. The following framework to evaluate the effects of SO_2 on coniferous forests is suggested: 20 μgm^{-3} – slight damage; 41–60 μgm^{-3} – moderate damage; 60 μgm^{-3} – severe damage.[37] According to this, a large part of the Kola peninsula can be identified as a zone where wild life may be threatened. As in similar environments in Eastern Canada and Scandinavia, coniferous forest communities in the Kola peninsula have developed podzolic soils derived from crystalline bedrock, and thus have little natural 'buffer'

[36] S.J. Kabala, 'The economic effects of sulphur dioxide pollution in Poland', *Ambio*, Vol 18, No 4, 1989, pp 250–251.
[37] *Ibid.*

against acid rain or solid compounds which are converted to acids on assimilation by plant tissues or contact with soil water.[38] At present, the ecological impacts documented at Monchegorsk involve either the disappearance of plant species in conjunction with the alteration of community structure (severe impact), or disappearance of particular species only (moderate impact). In the zone of severe impact, an area of 17.3 km^2, sulphur dioxide absorption has reduced vegetation cover density sufficiently to produce a serious soil erosion problem; in the zone of moderate impact, some 240 km^2, sulphur pollution has resulted in the disappearance of certain species of mosses and lichens, reduced tree stand density, and heightened soil acidity.[39] These detrimental effects have been cumulative, as the emissions have been considerable since the 1940s.[40] Similar pollution damage has been reported around the Sudbury copper–nickel smelter in northern Ontario, Canada.[41]

Pollution by nitrogen oxides

The total sum of NO_x emissions from stationary sources was 4.5 million tonnes in the Soviet Union in 1988; that is, about 2.5 times less than in the USA.[42] The share of NO_x is also less in the USSR, about 9% of gaseous emissions, while in the USA it is about 17% of the total, due to the higher level of urbanization and industrialization there. However, between 1980 and 1988, a considerable 20% growth of NO_x emissions from stationary sources was registered in the USSR, which is different, for example, from the UK, where NO_x emissions from stationary sources in 1988 were 20% less compared to the peak of 1979. Energy production is the main contributor to NO_x pollution in the Soviet Union, being 60% of the total. However, the increase of NO_x emissions from power plants was less than the average growth, only 10% in 1988 in comparison with 1981.

In regional terms, the Urals and the Donetsk–Dniepr region experience the highest NO_x emissions from industry (Figure 8a); the amount of nitrogen oxides emitted per unit of territory in these regions was 1 t km^{-2} and 2.5 t km^{-2} in 1988 (Figure 8b). In the Donetsk–Dniepr region some decline in levels has been found: compared to the worst year of 1983 levels had declined by 15% by 1989. A steady growth of NO_x emissions has been registered in Kazakhstan: in 1989, the annual amount was twice as big as in 1980.

NO_x emissions from cars contributed about a third of the total (automobiles plus industry) in 1988. Figure 9 presents the national NO_x emissions from transport between 1980 and 1988 for the USSR and the UK. In both countries emissions have increased: 22% in the UK between 1980 and 1988, and 58% in the Soviet Union, where the number of privately owned cars increased from about 8.2 million in 1980 to 11.0 million in 1984,[43] and reached 15 million in 1988.[44] Freight traffic by trucks increased by 17.6% between 1980 and 1988, and passenger traffic by buses increased by 23.2%.[45] As no special measures to reduce NO_x emissions have been adopted, this increase in emissions seemed likely to continue, though a temporary reduction is now evident as fuel prices have been steadily growing since 1990 with the result that there has been a considerable reduction of fuel consumption by private vehicles.

In 1988, NO_x emissions from transport dominated those from industry in 135 cities. The list includes four of the 15 capitals of the former

[38]A.V. Doncheva, V.N. Kalutskov, 'Predicting the environmental impact of mining and metallurgy in the Taiga zone with special reference to Monchegorsk and Sadbury', *Soviet Geography*, Vol 18, No 4, 1977, pp 223–229.
[39]*Ibid.*
[40]Laurila *et al*, *op cit*, Ref 29
[41]T.C. Hutchinson and L.M. Whitby, 'The effects of acid rainfall and heavy metal particulates on a boreal forest ecosystem near the Sudbury smelting region of Canada', *Water, Air and Soil Pollution*, No 7, 1977, pp 421–428.
[42]M. Sagers, 'Differences in emissions of pollutants and inferred air quality among Soviet cities', *Soviet Geography*, Vol XXX, No 6, 1989b, pp 512–521.
[43]*Ekonomika i organizatsiya promyshlennogo proizvodstva*, No 5, 1985, pp 102–105.
[44]M. Sagers, 'Geography of the private car ownership in the USSR", *Soviet Geography*, Vol XXXII, No 1, 1991, pp 61–65.
[45]*Op cit*, Ref 43.

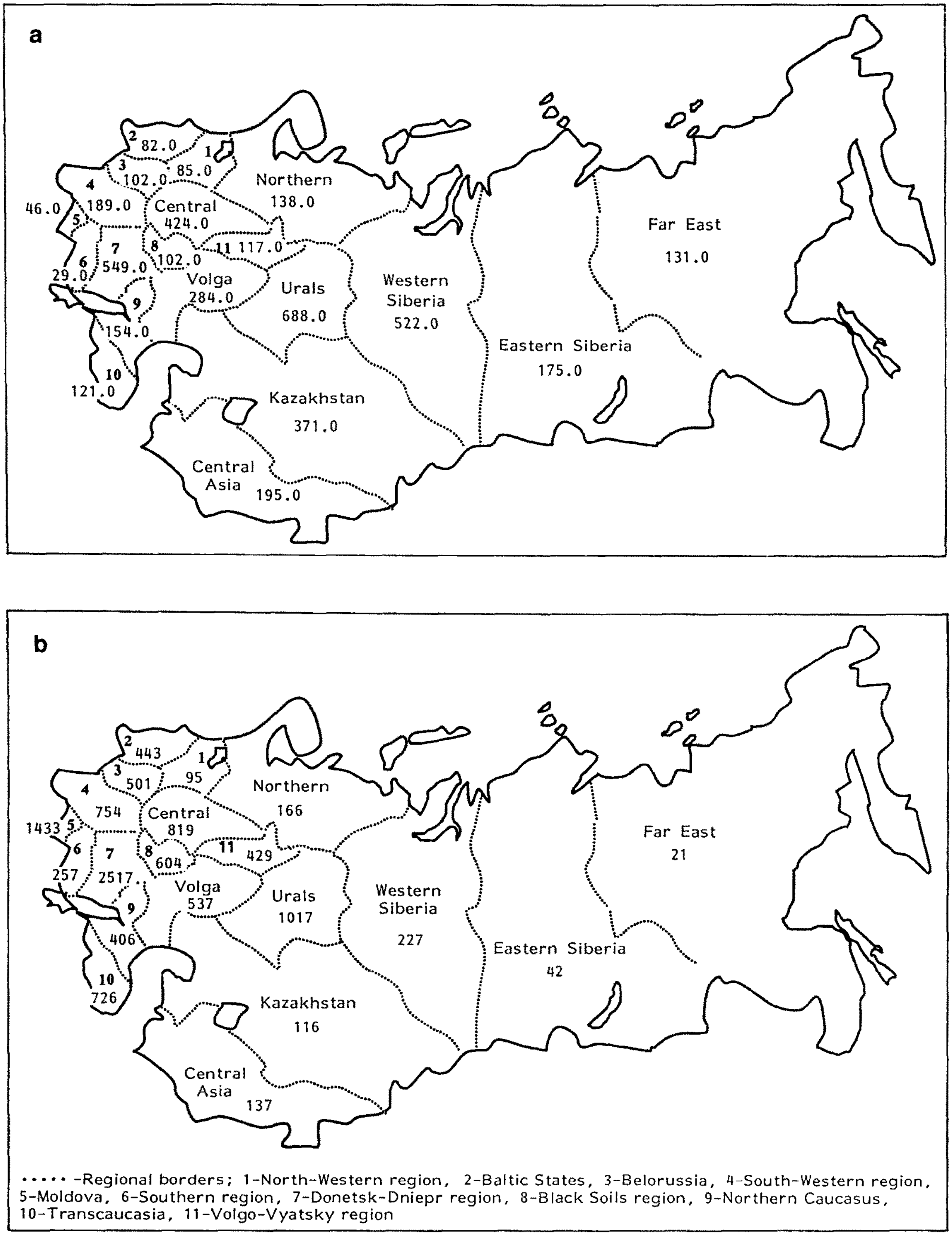


Figure 8. Emissions of nitrogen oxides from stationary sources in 1988 (thousand tonnes); (b) Emissions of nitrogen oxides from stationary sources in 1988 (kg km^{-1}).

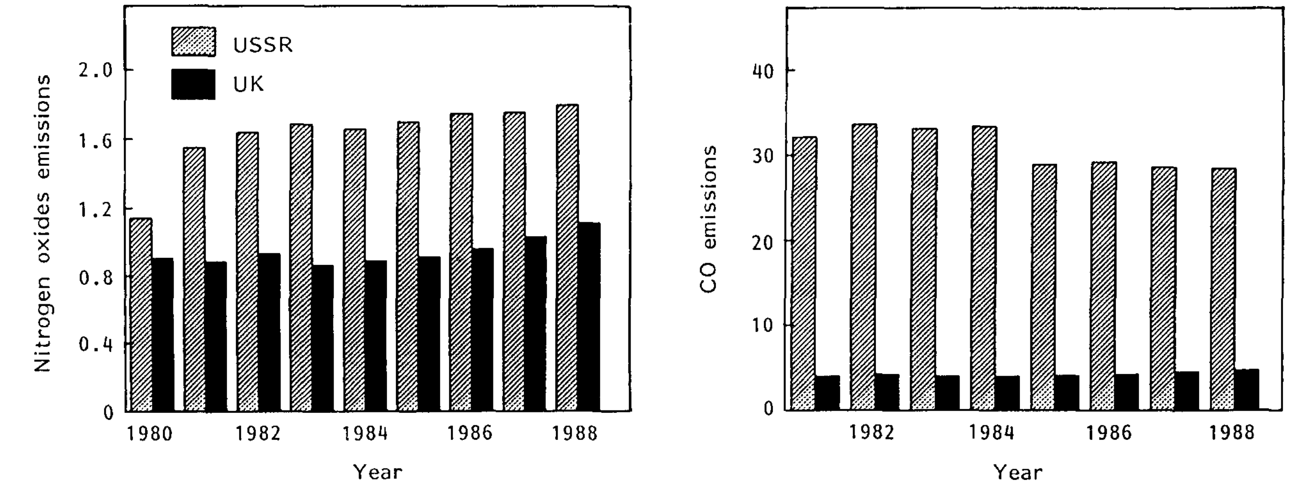


Figure 9. NO_x (million tonnes a^{-1}) and CO (thousand tonnes a^{-1}) emissions from road transport in the USSR and the UK.

union republics (Alma-Ata, Ashkhabad, Baku, Tbilisi), and a large number of important administrative centres (eg L'vov, Rostov, Voronez). Table 6 lists cities with relatively high (over 8 000 tonnes in 1988) volumes of NO_x emissions from road transport. The biggest city – Moscow – is at the top of the list, NO_x emissions from transport being 42 000 tonnes in 1988. The most dramatic growth was seen in Tashkent, Baku, Tbilisi, and Fergana; in Tbilisi NO_x emissions from road transport were nearly 5 times higher than in 1980; in Baku and Tashkent they nearly doubled over the same period. The increase in NO_x emissions was mainly due to the increase in private automobile ownership: in 1988, the number of private cars in the Northern Caucasus, Transcaucasia and Central Asia ranged between 23 and 34 per 100 families compared to 2–3 in 1970, while the average the increase throughout the USSR during the same period was from 2 to 17.[46]

The national annual mean for nitrogen dioxide ambient concentrations in 1990 was 45 $\mu g m^{-3}$ (Figure 4), although according to the Soviet standards a daily mean should not exceed 40 (Table 3). NO_2 annual mean concentrations exceeded 100 $\mu g m^{-3}$, the US limit for annual mean concentrations of nitrogen oxides, in 10 cities. The maximum annual mean – 146 $\mu g m^{-3}$ – was registered in Yerevan (Table 7); this was caused by high volumes of emissions from transport strengthened by unfavourable meteorological conditions. In Yerevan, the high NO_2 concentrations together with the high values of solar radiation cause the formation of high ozone concentrations, resulting in photochemical

[46]Sagers, *op cit*, Ref 44.

Table 6. Soviet cities with the highest NO_x emissions from road transport (thousand tonnes a^{-1}, % of the total NO_x emissions).

City	1980	1985	1988
Moscow (Central Russia)	**76.2 (34)**	**64.7**	**41.7 (30)**
St Petersburg (North-Western Russia)	31.0 (36)	54.0	21.1 (31)
Tashkent (Usbekistan)	9.3 (35)	17.1	26.8 (48)
Baku (Azerbaidzan)	14.2 (38)	26.8	28.2 (63)
Tbilisi (Georgia)	3.8 (58)	15.9	18.7 (84)
Kiev (Ukraine)	–	11.1	11.9 (35)
Yerevan (Armenia)	13.4 (43)	–	8.8 (49)
Alma-Ata (Kazakhstan)	11.9 (62)	–	11.2 (78)
Minsk (Belorussia)	8.1 (35)	–	8.7 (33)
Fergana (Usbekistan)	1.9 (17)	–	11.0 (54)
Novosibirsk (Eastern Siberia)	11.8 (24)	17.9	5.6 (15)

Table 7. Soviet cities with the highest levels of NO_2 pollution in 1990 (μgm^{-3}).

City	C_{mean}	σ	C_{max}	Source
Yerevan (Armenia)	**146**	**0.08**	**980**	Non-ferrous metallurgy, chemical industry, power plants, transport, climatic conditions
Gorlovka (Ukraine)	125	0.06	660	Ferrous metallurgy
Grozny (Chechnya)	100	0.09	840	Petrochemical, chemical industry
Lubertsy (Moscow suburb)	100	0.08	700	Chemical industry
Makeevka (Ukraine)	110	0.07	420	Ferrous metallurgy
Magnitogorsk (Urals)	118	0.09	1 970	Ferous metallurgy, transport
Odessa (Ukraine)	103	0.04	420	Chemical and petrochemical industry, ferrous metallurgy, transport, climatic conditions
Poronaisk (Sakhalin)	125	0.07	380	Pulp and paper mills, construction materials production
Volzsky (Volga)	107	0.09	1 870	Chemical, petrochemical industry
Zyryanovsk (Kazakhstan)	120	0.02	250	Non-ferrous metallurgy, climatic conditions

C_{mean} – mean annual concentration– σ – standard deviation; c_{max} – absolute maximum concentration.

smog. Metallurgical or/and chemical plants are located in the majority of cities with high NO_2 pollution levels; in some (Tashkent, Vladivostok) power plants are responsible. The maxima in 1990 were 1 970 μgm^{-3} in Magnitogorsk (centre for ferrous metallurgy) and 1 910 μgm^{-3} in Tashkent (electricity generation).

Figure 10 indicates that the industrial areas of the south-east of European Russia, eastern and southern Ukraine, the Caucasus, the southern Urals and Central Asia are the most polluted zones for NO_x; this results both from location of the most polluting industries in these regions and from higher rate of transformation of nitrogen oxide to nitrogen dioxide as result of photochemical processes, influenced by the amount of incoming solar radiation.[47] Figure 11 presents the mean NO_2

[47]E.Y. Bezuglaya, *Meteorologicheskyi potentzial i klimaticheskie osobennosti zagryaznenyia vozduha gorodov*, Leningrad, 1980, in Russian.

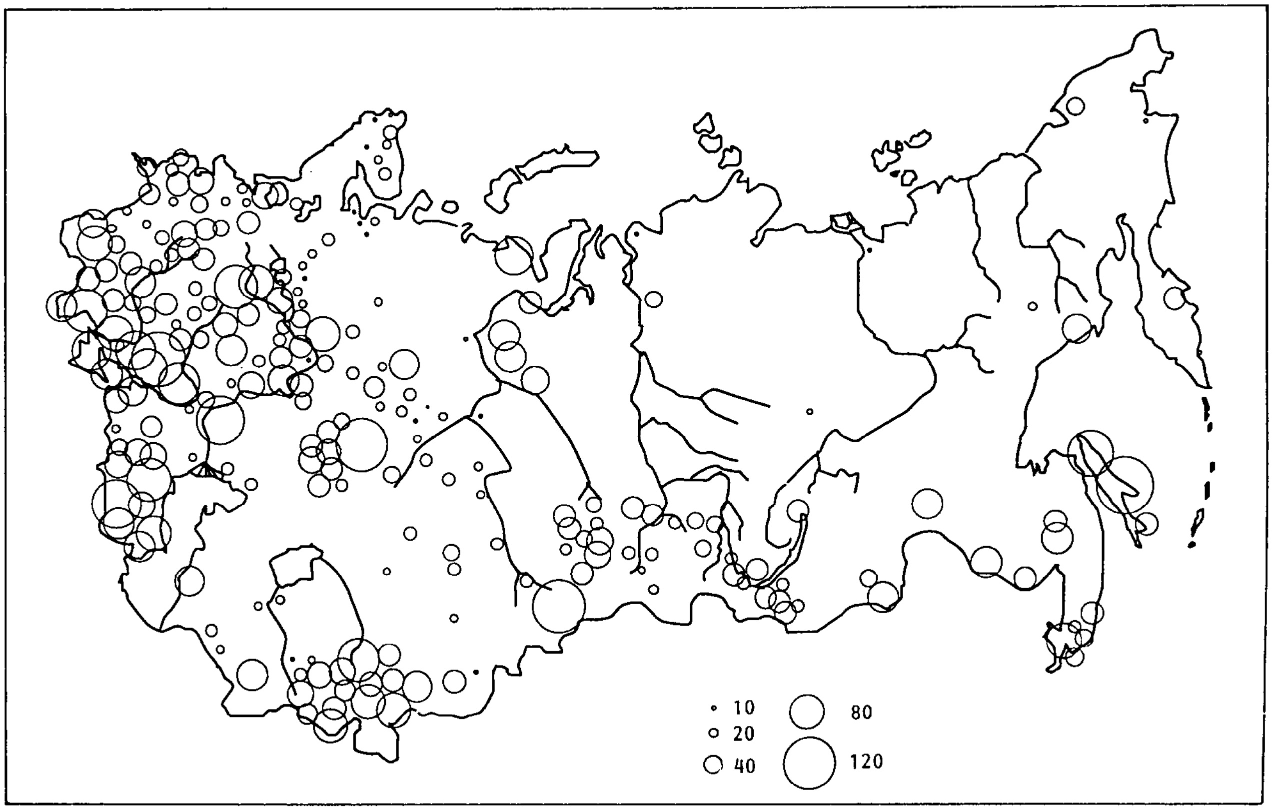


Figure 10. Annual mean nitrogen dioxide concentrations in Soviet cities in 1990 (μgm^{-3}).

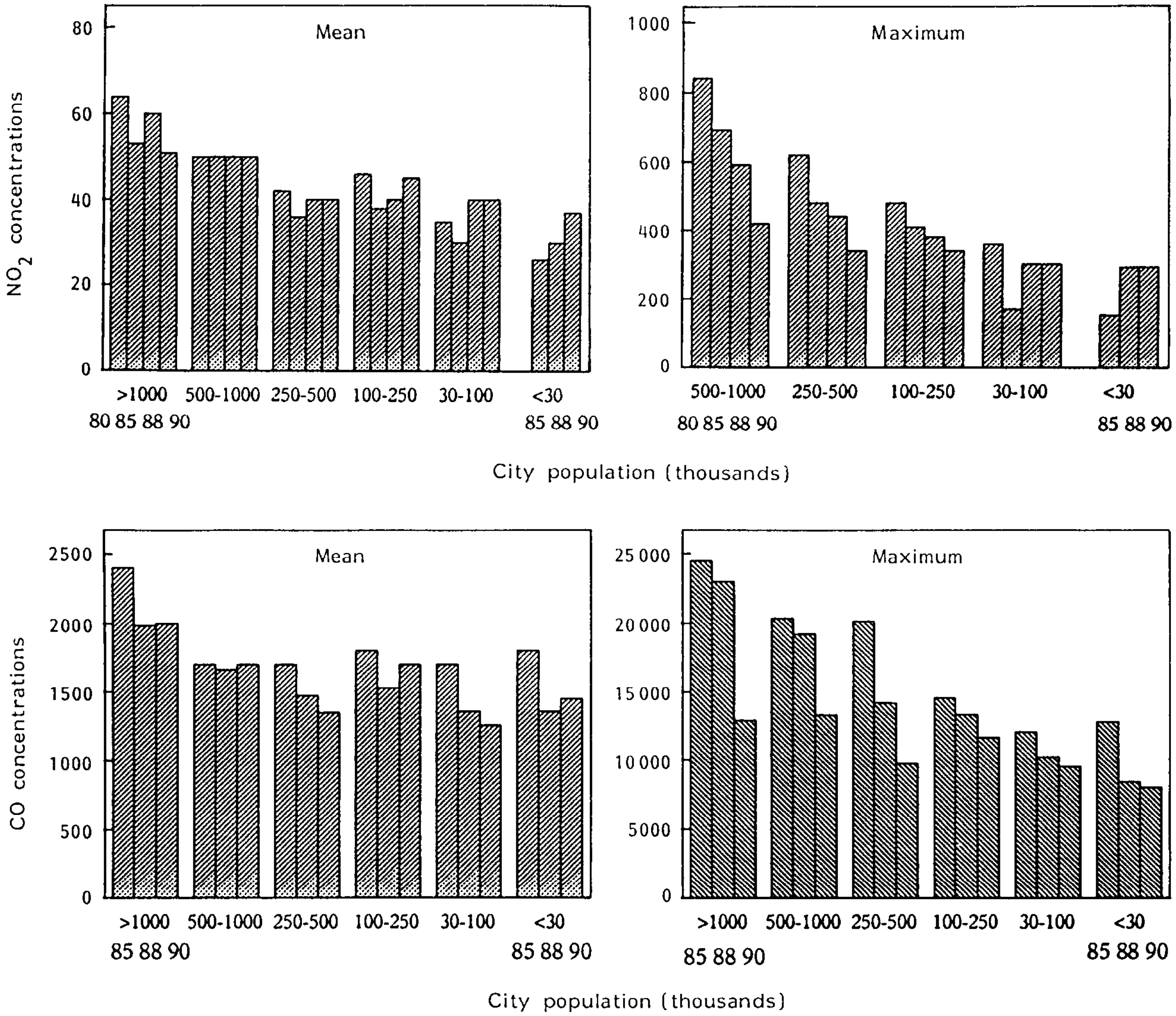


Figure 11. NO_2 and CO pollution in Soviet cities with different populations (μgm^{-3}).

concentrations for different size groups of cities. The highest levels are registered in cities where population exceeds one million people, reflecting the influence of transport on NO_2 pollution. A smaller peak of NO_2 concentrations is registered in cities whose population is in the range 100–250 thousand: the type of urban areas in which heavy industry enterprises are usually located.

Pollution by carbon monoxide

In 1988, the share of carbon monoxide emitted by stationary sources (14.9 million tonnes) represented 32% of Soviet gaseous emissions, about the same as in the USA. However, in tonnage, US carbon monoxide emissions were about 33% higher those than in the USSR (21 *v* 15.3 million tonnes in 1987), evidently due to the considerably greater consumption of fossil fuels in the USA (about 32 million barrels per day of oil equivalent for the US in 1986 *v* about 25 million for the USSR).[48] Ferrous metallurgy has remained for years the main CO emitter in the

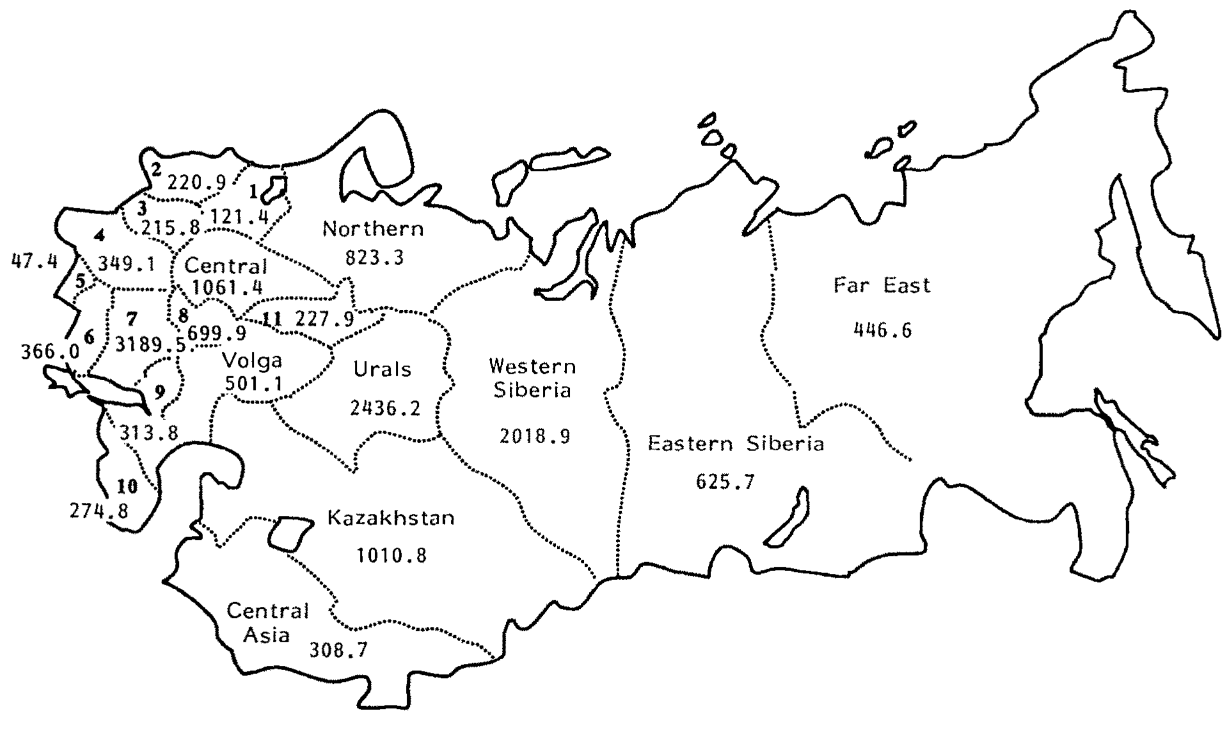
[48]Jancar, *op cit*, Ref 7.

Table 8. Soviet cities with the highest CO emissions from road transport (thousand tonnes a^{-1}).

City	1980	1985	1990
Moscow (Central Russia)	**984.9**	**731.6**	**633.4**
Leningrad (North-Western Russia)	404.4	453.8	290.9
Tashkent (Uzbekistan)	123.7	203.1	277.0
Baku (Azerbaidzan)	188.6	234.4	226.6
Tbilisi (Georgia)	48.1	195.2	224.6
Kiev (Ukraine)	–	183.0	194.0
Yerevan (Armenia)	165.6	–	138.9
Omsk (Western Siberia)	153.5	184.4	121.7

USSR, producing 45% of all stationary-source CO emissions in 1988. Other industries are far behind (oil refining and petrochemical industry following ferrous metallurgy with inputs of 7% and 5% of the total).

In regional terms, the Donetsk–Dniepr region with 3.2 million tonnes emitted in 1988 and the Urals with 2.4 million tonnes are far ahead of the other regions (Figure 12). In the Donetsk–Dniepr region, where CO emissions come mainly from steel and iron mills (73% of the regional CO stationary-source emissions), a 21% decline was observed in 1988 compared to 1981, when the maximum was registered. In 1988, the considerable increase in emitted CO was found in Kazakhstan. The most dramatic growth has been registered in Western Siberia, where in 1988 it was 72% higher than in 1981, mainly due to the new oil wells which started operating during this period, and to some extent because of the absence of environmental protection. The share of 'trapped' CO



••••• -Regional borders; 1-North-Western region, 2-Baltic States, 3-Belorussia, 4-South-Western region, 5-Moldova, 6-Southern region, 7-Donetsk-Dniepr region, 8-Black Soils region, 9-Northern Caucasus, 10-Transcaucasia, 11-Volgo-Vyatsky region

Figure 12. CO emissions from stationary sources in 1988 (thousand tonnes).

Table 9. Soviet cities with the highest levels of CO pollution in 1990 (μgm^{-3}).

City	C_{mean}	σ	C_{max}	Source
Andizan (Uzbekistan)	3 250	3	25 000	Transport
Bishkek (Kirghizstan)	4 000	3.6	39 000	Power plants, transport, climatic conditions
Irkutsk (Eastern Siberia)	4 000	2.4	33 000	Power plants, climatic conditions
Yerevan (Armenia)	**6 000**	**3.6**	**46 000**	Transport, climatic conditions
Gorlovka (Ukraine)	4 000	1.0	10 100	Ferrous metallurgy
Kommunarsk (Ukraine)	4 000	1.2	12 000	Ferrous metallurgy
Kyrovokan (Armenia)	–	–	45 000	Transport
Kyahta (Eastern Siberia)	4 000	3.0	24 000	Transport, climatic conditions
L'vov (Ukraine)	3 500	1.0	7 000	Transport
Marneuly (Georgia)	5 000	2.0	9 000	Ferrous metallurgy
Nikolaev (Ukraine)	3 500	2.0	22 000	Ferrous metallurgy
Rustavi (Georgia)	3 500	1.0	8 000	Ferrous metallurgy
Sumgait (Azerbaidzan)	4 000	3.2	24 000	Chemical industry
Sukhumi (Georgia)	3 500	1.0	8 000	Transport
Ulan-Ude (Eastern Siberia)	3 600	2.3	25 000	Transport, power plants, climatic conditions
Vladivostok (Far East)	3 600	2.3	25 000	Transport
Zestaphoni (Georgia)	4 750	1.0	15 000	Ferrous metallurgy

C_{mean} – mean annual concentration; σ – standard deviation; c_{max} – absolute maximum concentration.

emissions in 1988 dropped in the oil-producing industry almost to zero, compared to 21% in 1987).

As far as individual cities are concerned, Kryvoi Rog heads the list with 900 thousand tonnes of CO emitted by steel mills in 1988 (Table 9). Although there was a slight decrease in emissions – 4% in 1988 compared to 1986, it is most likely that this occurred due to the cutting of steel production, rather than because of environmental concerns.

28.4 million tonnes of carbon monoxide were emitted by automobiles in 1988. Unlike the NO_x, a decline in CO emissions was found during the 1980s; in 1988 it was 15% less compared to 1982 (Figure 9). It seems difficult to believe that automobile emissions would be declining in the Soviet Union; however, this may be due to the introduction of newer car designs and the growth of diesel fuel consumption. Carbon monoxide forms the major part of emissions from transport – 80% in 1988 (the total comprises emissions of carbon monoxide, nitrogen oxides and hydrocarbons). The share of pollutants from transport in the USSR is substantially different from that in the USA where CO was only 30% of the total transport emissions. This probably reflects the lower octane rating in Soviet fuel mix, the generally lower temperatures and much longer idling times for the Soviet vehicles. Table 8 presents the list of Soviet cities where CO emissions from transport exceeded 100 thousand tonnes in 1988. Moscow heads the list with CO automobile emissions of 633 thousand tonnes in 1988. Although this figure is still extremely high, there has been a decline of 36% since 1980.

The average level of CO pollution across the country was estimated to be 1620 μgm^{-3} in 1990; that is 10% less than in 1985. Despite this reduction the general level of pollution remains high; in 40 cities the annual mean in 1990 was above 3000 μgm^{-3}, the national limit for the CO daily mean (Table 3). The maximum level of carbon monoxide pollution was in Yerevan (Armenia), where it was 6000 μgm^{-3} in 1990 (Table 9). Yerevan's CO emissions do not place it among the worst cases, but its location in a deep basin subject to protracted periods of stagnant air, results in extremely poor air quality. The maximum concentration in 1990 reached 46 000 μgm^{-3}, exceeding the Soviet maximum permissible level by the factor of 15, and the US 8-hour limit by a factor of 5. Yerevan is followed by two iron and steel producing cities: Marneuly (5000 μgm^{-3} in 1990) and Zestaphoni (4750 μgm^{-3}),

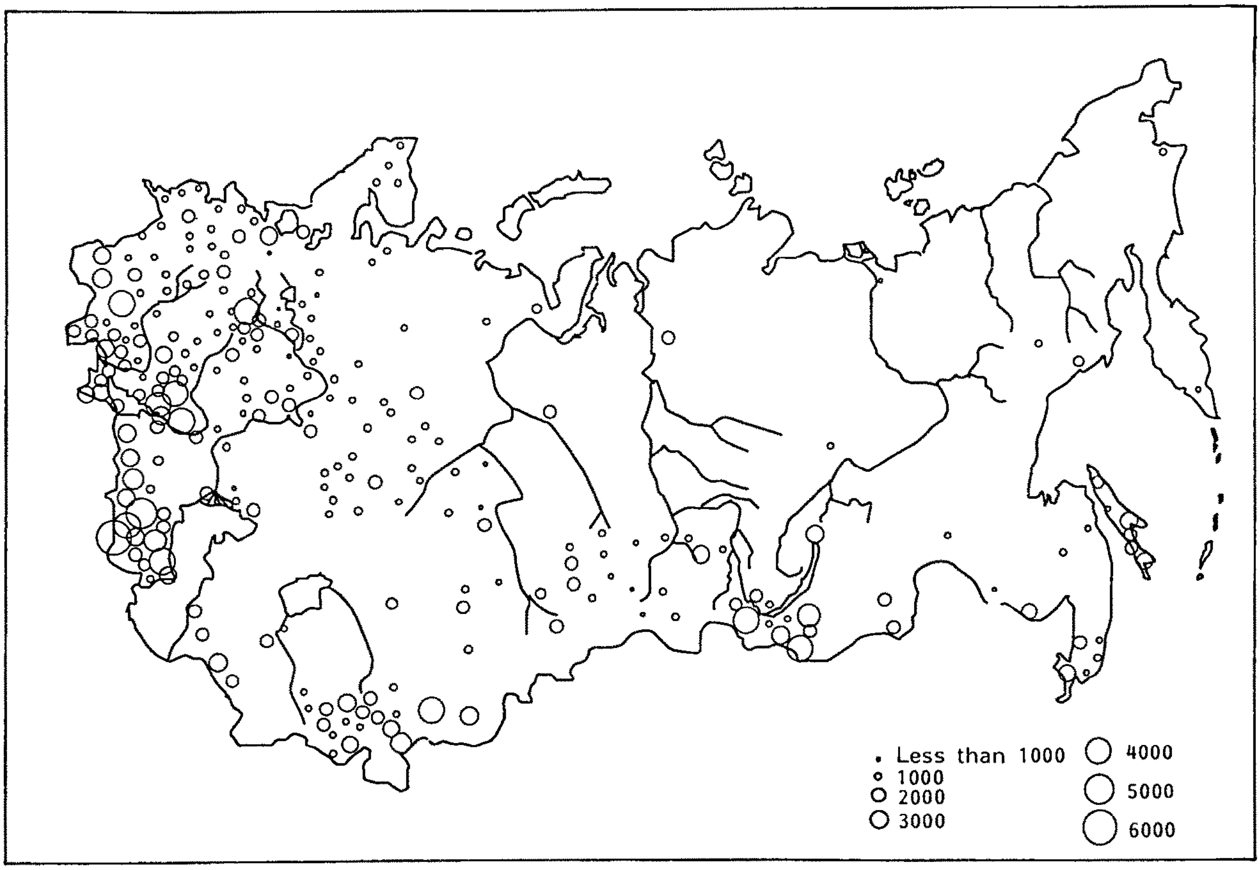


Figure 13. Annual mean concentrations in Soviet cities in 1990 (μgm^{-3}).

both located in Georgia. The average annual mean estimated for the 28 cities specializing in ferrous metallurgy was 1870 μgm^{-3}, that is higher than the general average figure. For comparison, in the USA by 1991, only in two areas – around a Wisconsin engine factory and in Steubenville, Ohio – did carbon monoxide from stationary sources violate the air quality standards.[49]

The highest ambient CO levels are registered at cities with a population of over 1 million as a result of CO emissions from transport. In 1990, the average annual mean for such cities was 2000 μgm^{-3}, 17% lower than in 1985 (Figure 11). However, in some cities, for example in St Petersburg, the level of CO pollution is growing, probably because of the growth of industrial pollution in this particular city.

In regional terms, southern areas (Southern and South-eastern Ukraine, the Caucasus, Southern Kazakhstan and Central Asia, Baikal region) experience higher CO pollution (Figure 13). This can be explained by three main factors: concentration of polluting industries in these areas (as in the South-eastern Ukraine, Georgia and Azerbaidzan); the larger number of private vehicles (Caucasus, Ukraine, Southern Russia); and unfavourable climate (Armenia, the Baikal region).

The most problematic areas

The ten top cities in terms of total emissions in 1988 are presented in Table 10. Six of the ten are major centres for iron and steel production,

[49]Fesbach and Friendly, *op cit*, Ref 1.

Table 10. Soviet cities with the highest emissions in 1988 (thousand tonnes a^{-1}).

City	Emissions Total	Industry	Transport	Population (thousands)	Main source
Noril'sk (Eastern Siberia)	2 368.1	2 343.6	24.5	181.0	Non-ferrous metallurgy
Krivoy Rog (Ukraine)	1 328.2	1 252.7	75.5	683.6	Ferrous metallurgy
Moscow	1 113.1	311.4	801.3	8 614.0	Transport
Temirtau (Kazakhstan)	936.6	917.6	19.0	288.2	Ferrous metallurgy
Novokuznetsk (Western Siberia)	888.8	833.0	55.8	589.0	Ferrous metallurgy
Magnitogorsk (Urals)	873.7	849.0	24.7	429.8	Ferrous metallurgy
Mariupol' (Ukraine)	813.9	777.6	36.3	522.2	Ferrous metallurgy
Ekibastuz (Kazakhstan)	765.3	744.1	21.2	141.0	Power plants
Lipetsk (Central Russia)	745.3	684.5	60.8	513.8	Ferrous metallurgy
Baku (Azerbaidzan)	718.9	421.1	297.8	–	Petrochemical industry

showing that ferrous metallurgy is one of the country's worst polluters. Thus, two large combines in Novokuznetsk (Kuznetskyi and West Siberian) themselves produced per capita 12 times more pollution than industry and transport did in the biggest Soviet city, Moscow. Many of the steel mills date back to the 1930s, like the steel complex at Magnitogorsk where open-hearth furnaces are still in use[50] and only 50% of emissions were filtered in 1990; others were constructed in 1941–42 as the result of the evacuation of Soviet industry from Central Russia and Ukraine, and are desperately in need of modernization. Polymetallic ore smelting, with which a number of problematic areas particularly in the Arctic are associated, threatens people's health and contributes to environmental degradation most dramatically in Noril'sk, where about 13 tonnes of pollutant per capita were emitted in 1988. Compared to the population of Dudinka, a non-industrial town 60 miles away, the population of Noril'sk is twice as likely to suffer from prolonged upper respiratory tract infections; the risk for children under 14 is more than 2.5 times as high as in Dudinka.[51]

Petroleum refining and the petrochemical industry are the other sectors creating serious environmental problems. Baku refineries are particularly bad, being the oldest in the country. The advanced age of the equipment is reported to be a significant factor in the high level of emissions and the rapid growth of expenditures on pollution abatement in recent years.

The high concentration of industry in certain cities has resulted in the creation of vast areas where the air quality may only be described as calamitous. Though it is quite difficult to estimate which regions experience the poorest air quality, the following may be identified as particularly bad: the Donetsk–Dniepr region, the Moscow district, the Sea of Azov coast, the northern Caspian coast, the Northern Caucasus, the Urals, Usbekistan, Kazakhstan, and the Kuznetskyi coal basin. As far as single cities are concerned, Table 11 presents those where the annual levels of three or more pollutants exceeded the 24-hour limit in 1990. The most disturbing feature is the presence in the urban atmosphere of highly toxic contaminants such as benzo(a)pyrene, phenol and formaldehyde, a problem which has been almost overcome in the USA and West European cities.[52] The annual mean concentration of benzo(a)pyrene – a carcinogenic coal-tar by-product – averaged over 203 cities was 3.6×10^{-3} $\mu g m^{-3}$ in 1989, exceeding the 24-hour limit by 3.6 times.[53] Maximum concentrations in 1990 reached 0.11 $\mu g m^{-3}$ in the Siberian cities of Bratsk, Zima and Chita where pollution from industrial sources is made even worse by extremely unfavourable weather

[50] *Ibid.*
[51] *Ibid.*
[52] *Ibid.*
[53] E.Y. Bezuglaya, A.B. Shchutskaya, I.V. Smirnova, 'Air pollution index and interpretation of measurements of toxic pollutant concentrations', *Atmospheric Environment*, Vol 27A, 1993, pp 773–779.

Table 11. Soviet cities with the poorest air quality[a] in 1990.

City	Main pollutants	Source of pollution
Angarsk (Eastern Siberia)	Benzo-(a)-perene, formaldehyde, SP	Petrochemical, medical and biological industries, power plants
Berezniky (Urals)	CS_2, H_2SO_4, NO, NO_2	Chemical industry, fertilizers production
Bishkek (Kirghizstan)	Benzo-(a)-perene, formaldehyde, NO	Power plants, transport
Bratsk (Eastern Siberia)	Benzo-(a)-perene, formaldehyde, CS_2, HF	Non-ferrous metallurgy, pulp and paper mills, power plants
Volzskyi (Volga region)	Formaldehyde, metilmercaptan, NO_2, CS_2	Petrochemical and chemical industries
Gubakha (Urals)	Sterene, benzo-(a)-perene, formaldehyde	Chemical industry, power plants
Yerevan (Armenia)	Benzo-(a)-perene, SP, NO, NO_2	Chemical industry, power plants, non-ferrous metallurgy, transport
Kemerovo (Western Siberia)	Benzo-(a)-perene, formaldehyde, CS_2	Fertilizers production, chemical industry, non-ferrous metallurgy
Kiev (Ukraine)	Benzo-(a)-perene, formaldehyde, NH_3	Chemical and petrochemical industries, construction materials production
Komsomol'sk-na-Amure (Far East)	Benzo-(a)-perene, formaldehyde, NH_3, lead	Ferrous metallurgy, power plants, petrochemical industry
Krasnoyarsk (Eastern Siberia)	Benzo-(a)-perene, formaldehyde, SP	Chemical industry, non-ferrous metallurgy, construction materials production, transport
Kutaisy (Georgia)	Benzo-(a)-perene, phenol, SP	Chemical and petrochemical industries, truck plant, transport
Magnitogorsk (Urals)	Benzo-(a)-perene, sterene, CS_2, NO_2	Ferrous metallurgy
Mogilev (Belorussia)	Benzo-(a)-perene, CS_2, NO_2	Chemical industry, ferrous metallurgy
Novokuznetsk (Western Siberia)	Benzo-(a)-perene, HF, NO_2	Metallurgy, coal mining, power plants
Novosibirsk (Western Siberia)	Benzo-(a)-perene, formaldehyde, NO_2, NH_3	Transport, power plants, construction materials production
Novocherkassk (Southern Russia)	Benzo-(a)-perene, formaldehyde, SP	Metallurgy, petrochemical industry, power plants
Khabarovsk (Far East)	Benzo-(a)-perene, formaldehyde, phenol	Power plants, construction materials production, petrochemical industry, road and railway transport

[a] The annual mean of three or more pollutants exceeded the 24-hour national limit.

conditions such as prolonged inversions and periods of anticyclonic stagnation. It is no surprise that the study of health effects of air pollution in the cities of Eastern Siberia found 'increased illness and shortened life expectancy due to the intensive industrial exploitation of the region'.[54]

Conclusions

The most dramatic change in environmental affairs in the former USSR during recent years has been the expansion of information available to the public about the actual condition of the environment. Whereas previously data about pollution levels and the health effects of pollution were available only to scientists and governmental officials, now they are widely published in the mass media. The economic priority of environmental concerns, meanwhile, has not experienced much change. A number of comprehensive proposals have been designed by Soviet scholars for environmental revival; however, they require tremendous investment. The well known Russian environmentalist Yablokov stated that 'in order to improve the quality of the environment what must be spent in the USSR is no less than 5% of GNP. We are still spending around 1%'.[55] The scarce financial resources available for attaining these environmental goals are a factor that will be in effect for a rather long time. The more urgent problems, such as housing, the health service, and food supply take precedence; when the traditional argument 'employment-versus-environment' is used, the decision is still normally not in favour of the environment. The collapse of the Soviet Union has aggravated these environmental problems, many of which have now become international. Numerous political and ethnic conflicts, and further decreases in industrial production suggest that, in the face of other serious economic problems, the capability to address environmental problems effectively may not be improving.

[54]Fesbach and Friendly, *op cit*, Ref 1.
[55]S.B. Lavrov, 'Regional and environmental problems in the USSR: a synopsis of views from the Soviet parliament', *Soviet Geography*, Vol 31, No 7, 1990, pp 477–499.

Appendix

Table A1. Emissions of suspended particles in various regions of the Soviet Union in 1980–88 (thousand tonnes a^{-1}).

Region	80	81	82	83	84	85	86	87	88
Russia									
Northern	–	–	761.2[a]	777.5	815.3	740.2	689.0	696.0	653.8
North-Western	1117.1	1115.4	344.22	339.5	341.2	310.4	310.1	316.9	292.0
Central	1481.4	1355.4	1292.9	1228.7	1177.1	1197.9	1099.8	1007.4	1071.0
Volga-Vyatsky	303.6	309.6	301.3	324.5	294.2	353.8	290.0	297.1	293.4
Black Soils	384.8	448.9	428.4	407.8	412.0	379.7	353.3	257.1	258.7
Volga	475.5	465.2	391.5[b]	360.8	378.0	359.3	364.6	374.5	324.9
Northern Caucasus	294.8	353.5	339.2	341.9	340.7	346.7	317.9	306.9	306.6
Urals	2340.7	2249.0	2297.2	2373.4	2286.2	2364.2	2316.2	2266.3	2205.1
Western Siberia	1389.2	1411.8	1304.8	1330.3	1233.3	1216.2	1160.3	1303.1	1201.2
Eastern Siberia	1132.6	1154.4	1176.5	1234.6	1114.1	1187.5	1050.8	1015.0	930.8
Far East	726.9	718.9	711.0	685.6	704.5	708.9	809.8	872.2	823.0
Ukraine									
Donetsk–Dniepr	2425.6	2226.2	2285.6	2184.2	2118.4	2037.8	1937.1	1919.0	1736.5
South-Western	468.7	442.1	424.9	426.7	426.4	437.2	471.2	492.0	448.8
Southern	149.0	158.9	175.4	200.4	262.6	213.4	184.0	156.1	155.4
Baltic States	560.1	528.1	589.8	485.6	472.0	472.9	405.8	395.4	365.4
Lithuania						53.1	50.4	48.7	
Latvia						58.1	45.0	42.2	
Estonia						269.1	275.0	253.5	
Transcaucasia	512.9	506.4	540.3	510.0	531.1	443.2	503.9	459.9	398.2
Georgia						170.0	157.7	146.2	
Azerbaidzan						272.8	247.8	210.9	
Armenia						61.1	54.4	40.8	
Central Asia	577.5	658.1	523.9	576.9	582.0	620.9	634.5	567.3	497.3
Usbekistan						415.8	355.5	286.8	
Kirgizstan						63.0	61.3	61.9	
Tadzikistan						59.6	57.5	53.3	
Turkmenistan						96.1	93.0	95.3	
Kazakhstan	1465.4	1469.4	1540.8	2023.6	2393.6	2904.1	3027.7	2416.0	2152.6
Belorussia	214.9	191.6	186.2	189.1	182.4	172.5	166.4	164.3	162.2
Moldova	112.2	126.7	106.7	107.2	98.1	96.2	85.7	85.9	81.9

[a] In 1982 the North-Western region was divided into the North-Western and the Northern; [b] Bashkiria was transmitted from the Volga region to the Urals region.

Table A2. Emissions of suspended particles[a] from various branches of industry in the Soviet Union (thousand tonnes a^{-1}) and percentage of trapped emissions[b] in 1980–88.

Industry	80	81	82	83	84	85	86	87	88
Energy generation	6096.3	5244.4	5311.3	5695.6	5919.2	6274.8	6192.7	5455.7	4943.2
					93.5	93.2	93.1	94.1	94.4
Ferrous metallurgy	2865.5	2707.7	2778.3	2685.9	2605.9	2405.9	2364.3	2183.7	2024.7
					85.7	86.5	86.7	87.2	88.4
Construction materials production	1925.6	2218.3	1945.5	2088.3	2095.7	2082.1	2042.0	1848.1	1278.4
					92.9	92.0	92.1	93.3	95.3
Non-ferrous metallurgy	890.2	885.6	965.1	959.4	891.7	838.4	815.4	742.9	760.2
					97.4	97.5	97.5	97.6	97.7
Agriculture									546.3
									71.4
Timber, pulp, paper production	284.2	634.7	580.0	571.0	561.7	555.8	564.2	523.7	473.2
					83.2	83.2	83.2	85.0	86.8
Coal mining	643.1	464.2	434.2	409.3	426.7	405.3	386.2	380.1	352.3
					87.3	88.3	88.4	91.0	91.7
Oil production	15.3	85.2	45.8	53.0	61.9	64.9	33.1	262.0	232.8
					75.6	63.5	79.6	78.2	40.1
Fertilizer production	–	205.3	188.7	187.4	169.6	129.7	147.2	137.2	108.4
					97.7	97.0	97.9	97.8	97.9
Chemical	392.8	268.5	207.1	181.4	169.6	129.7	147.2	137.2	108.4
					91.1	93.2	92.4	93.3	94.8
Gas processing	5.6	5.5	5.3	6.4	7.5	6.1	7.3	4.7	6.0
					36.1	36.5	46.1	48.8	34.4
Petrochemical	140.3	121.0	126.7	129.8	119.0	116.2	124.8	117.7	109.9
					85.0	83.6	83.4	84.0	84.2
Total	16210.4	15722.9	15973.0	16391.9	16524.2	16565.1	16499.2	15721.8	14675.1

[a] Figures quoted as 'emissions of suspended particles' represent suspended particles emissions entering the atmosphere; [b] Figures quoted as 'percentage of trapped emissions' are estimated as a share of the total suspended particles emissions produced.

Table A3. Emissions of sulphur dioxide in various regions of the Soviet Union in 1980–88 (thousand tonnes a^{-1}).

Region	80	81	82	83	84	85	86	87	88
Russia									
Northern	–	–	1122.6[a]	1200.4	1208.4	1213.3	1193.4	1204.2	1123.4
North-Western	1468.9	1420.0	352.0	359.0	347.1	366.5	349.9	361.5	308.8
Central	2167.7	1970.0	1965.7	1829.3	1794.5	1562.8	1330.3	1195.2	1061.4
Volga-Vyatsky	347.2	365.5	393.3	401.9	404.4	430.4	365.1	348.8	337.1
Black Soils	267.8	251.8	253.8	245.4	238.6	246.4	214.4	218.6	185.1
Volga	1612.3	1616.6	880.3[b]	844.9	737.9	728.4	651.1	661.3	748.3
Northern Caucasus	472.0	481.8	469.5	508.3	477.9	459.7	469.3	487.8	429.2
Urals	2608.5	2465.7	3080.5	3053.6	2795.4	2719.4	2618.7	2585.8	2333.7
Western Siberia	616.6	637.6	659.6	693.8	735.7	770.2	741.1	765.3	712.8
Eastern Siberia	2217.6	2536.6	2796.4	3154.6	3081.5	3028.4	2868.1	2863.8	2765.5
Far East	296.0	333.4	346.3	327.5	345.4	354.4	383.5	393.8	396.7
Ukraine									
Donetsk–Dniepr	2533.3	2353.7	2343.0	2399.2	2357.1	2369.8	2367.1	2207.4	2196.2
South-Western	1171.2	992.4	916.6	927.4	915.5	898.5	839.7	872.0	843.4
Southern	144.2	145.9	167.7	171.9	197.3	194.9	186.2	184.1	171.5
Baltic States	978.3	806.8	615.5	587.5	584.1	557.9	550.9	572.4	532.9
Lithuania						215.6	238.7	209.0	
Latvia						67.9	66.5	63.9	
Estonia						207.4	206.8	205.6	
Transcaucasia	319.4	352.6	348.0	360.9	336.6	363.8	378.1	371.1	326.0
Georgia						102.7	110.8	93.7	
Azerbaidzan						164.2	149.6	128.2	
Armenia						111.2	110.6	104.1	
Central Asia	373.0	634.5	716.4	780.9	681.1	698.6	633.4	725.3	628.8
Usbekistan						529.2	616.4	523.5	
Kirgizstan						70.1	73.1	64.8	
Tadzikistan						17.2	21.4	19.6	
Turkmenistan						16.9	14.4	20.9	
Kazakhstan	1606.6	1381.6	1387.1	1409.3	1479.2	1612.5	1550.1	1566.9	1570.0
Belorussia	739.9	731.3	711.8	708.5	649.4	699.3	706.6	695.8	637.2
Moldova	289.9	304.9	287.3	283.9	270.7	271.7	297.7	317.2	272.9

[a] In 1982 the North-Western region was divided into the North-Western and the Northern; [b] Bashkiria was transmitted from the Volga region to the Urals region.

Table A4. Emissions of sulphur dioxide[a] from various branches of industry in the Soviet Union (thousand tonnes a^{-1}) and percentage of trapped emissions[b] in 1980–88.

Industry	80	81	82	83	84	85	86	87	88
Energy generation	10728.6	10008.0	9860.1	9708.1	9157.9	8732.8	8431.9	8134.2	7549.1
					1.4	1.4	1.5	7.2	1.5
Non-ferrous metallurgy	4112.5	4368.4	4614.8	5121.9	4956.0	4974.9	4642.9	4653.8	4482.2
					35.2	37.4	41.3	42.1	44.2
Ferrous metallurgy	1381.0	1148.2	1156.0	1226.4	1257.2	1242.1	1208.5	1143.3	1081.3
					6.8	5.2	6.1	6.8	7.2
Agriculture									554.5
									0.2
Petrochemical	585.1	563.6	576.3	540.0	568.1	587.5	570.7	570.9	518.7
					4.6	2.2	2.6	2.6	2.0
Gas processing	73.3	330.0	369.3	399.7	307.7	305.4	314.4	381.0	505.2
					5.3	8.1	8.8	13.0	12.4
Coal mining	543.5	456.7	426.3	402.9	470.1	460.2	409.7	409.3	393.2
					1.1	0.7	0.7	0.8	0.9
Timber, pulp, paper production	322.8	356.6	330.1	329.8	338.3	331.5	353.3	332.2	315.0
					26.7	34.4	34.3	26.7	28.4
Construction materials production	288.4	290.3	358.5	411.4	456.9	425.5	411.0	433.7	265.8
					1.6	2.3	1.0	4.3	1.2
Fertilizer production		244.4	213.4	191.6	186.6	200.1	193.6	192.2	166.6
					40.2	30.0	32.6	41.0	39.0
Chemical	387.1	165.0	161.4	144.5	164.9	142.9	146.9	144.9	124.4
					7.7	14.9	11.2	15.4	17.4
Oil production	46.4	46.5	41.7	41.3	48.2	47.4	42.6	56.0	59.5
						68.3	68.2	65.8	16.7
Total	20000.0	19530.7	19832.4	20264.4	19737.0	19548.4	18684.7	18598.4	17651.3

[a] Figures quoted as 'emissions of sulphur dioxide' represent sulphur dioxide emissions entering the atmosphere; [b] Figures quoted as 'percentage of trapped emissions' are estimated as a share of the total sulphur dioxide emissions produced.

Table A5. Emissions of nitrogen oxides in various regions of the Soviet Union in 1980–89 (thousand tonnes a^{-1}).

Region	80	81	82	83	84	85	86	87	88	89
Russia										
Northern	–	–	139.9[a]	142.1	133.3	133.3	134.6	144.9	139.0	138.0
North-Western	220.0	464.1	486.7	473.6	428.6	416.2	439.2	441.4	397.1	424.0
Volga-Vyatsky	74.8	72.3	78.7	74.3	79.9	90.2	98.2	102.6	112.9	117.0
Black Soils	44.8	54.1	64.6	66.9	77.8	80.7	77.1	78.8	101.5	102.0
Volga	298.2	288.6	231.6[b]	225.3	236.5	243.2	276.9	285.5	288.2	284.0
Northern Caucasus	123.9	124.9	125.4	127.1	114.0	117.3	139.6	141.5	144.1	154.0
Urals	539.5	546.9	659.0	653.5	635.4	670.8	665.6	715.2	700.5	688.0
Western Siberia	426.9	362.2	–	487.1	368.8	372.6	544.3	601.1	552.1	552.0
Eastern Siberia	174.3	173.9	187.7	191.2	205.1	187.2	176.6	176.2	172.6	175.0
Far East	173.4	111.0	99.6	99.5	101.8	96.4	103.8	118.3	129.2	131.0
Ukraine										
Donetsk–Dniepr	619.1	626.8	630.4	643.1	594.5	537.8	574.4	554.5	556.1	549.0
South-Western	186.8	156.4	174.6	173.5	184.2	187.6	196.8	211.5	203.1	189.0
Southern	34.6	34.6	34.7	31.0	40.4	28.4	28.8	29.3	29.2	29.0
Baltic States	89.3	90.4	86.2	82.9	73.2	79.4	80.7	87.8	84.2	82.0
Lithuania						41.2	47.3	44.5	–	
Latvia						11.7	12.7	12.0	–	
Estonia						23.6	23.3	23.4	–	
Transcaucasia	105.6	108.4	102.7	113.3	114.2	131.2	146.8	133.6	135.4	121.0
Georgia						28.8	40.9	37.8	–	
Azerbaidzan						66.8	64.5	72.4		
Armenia						31.2	28.2	25.2	–	
Central Asia	110.9	126.5	158.7	186.6	152.7	164.1	175.9	183.5	174.5	195.0
Usbekistan						117.1	121.3	114.1	–	
Kirgizstan						11.0	11.7	12.2	–	
Tadzikistan						8.7	8.3	8.2	–	
Turkmenistan						39.1	42.2	40.0		
Kazakhstan	169.1	185.1	190.2	205.2	225.3	220.6	229.5	247.0	315.8	371.0
Belorussia	97.9	90.5	90.6	85.4	86.6	84.0	103.2	106.2	104.0	102.0
Moldova	51.4	56.9	50.3	42.4	43.7	42.1	49.7	47.6	48.3	46.0

[a] In 1982 the North-Western region was divided into the North-Western and the Northern; [b] Bashkiria was transmitted from the Volga region to the Urals region.

Table A6. Emissions of nitrogen oxides from various branches of industry in the Soviet Union (thousand tonnes a^{-1}) and percentage of trapped emissions[b] in 1980–88.

Industry	80	81	82	83	84	85	86	87	88
Energy generation	2418.7	2325.2	2383.9	2426.8	2439.7	2474.1	2516.4	2573.6	2668.4
Ferrous metallurgy	455.6	479.3	465.8	470.8	475.2	464.6	458.2	436.5	455.0
Gas processing	226.6	229.1	230.7	242.1	233.8	232.4	230.8	297.6	245.0
Construction materials production	128.9	132.2	139.5	139.3	141.5	143.8	145.4	142.1	123.9
Agriculture	–	–	–	–	–	–	–	–	88.5
Timber, pulp, paper production	97.7	94.0	86.2	93.2	93.8	91.1	92.9	85.1	79.4
Fertilizer production	–	–	–	–	–	–	70.6	82.8	65.8
	–	–	–	–	–	–	80.4	69.3	73.1
Non-ferrous metallurgy	85.0	81.2	81.3	81.8	81.4	78.5	72.7	74.4	61.5
Oil production	–	–	40.1	39.4	39.7	40.5	40.4	82.8	54.0
Petrochemical	49.7	44.0	41.9	48.8	48.4	51.1	57.2	48.5	49.6
	–	–	–	–	15.8	16.3	15.8	18.8	20.8
Chemical	–	–	23.7	24.9	21.6	18.2	19.1	27.7	25.9
	–	–	–	–	63.5	67.0	74.2	66.5	70.6
Coal mining	37.9	35.6	37.2	38.6	32.9	31.0	30.0	24.4	24.1
Total	3675.9	3736.4	4149.8	4189.2	3994.7	3981.6	4332.1	4497.9	4492.3
Transport (million tonnes)	1.4	1.55	1.64	1.69	1.66	1.70	1.75	1.76	1.80

Table A7. Emissions of carbon monoxide at various regions of the Soviet Union in 1980–88 (thousand tonnes a^{-1}).

Region	80	81	82	83	84	85	86	87	88
Russia									
Northern	–	–	891.9[a]	843.7	817.9	815.2	303.0	831.1	823.3
North-Western	890.2	1025.4	125.6	129.8	138.2	155.3	143.1	134.3	121.4
Central	811.9	788.8	706.0	752.3	808.8	813.7	774.9	738.5	675.5
Volga-Vyatsky	223.7	253.4	190.7	201.7	189.3	188.2	205.6	213.9	227.9
Black Soils	840.1	826.6	807.8	801.3	756.9	767.3	713.5	717.8	699.9
Volga	750.9	802.0	739.6[b]	578.3	459.8	474.6	497.8	484.5	501.1
Northern Caucasus	508.1	431.6	468.8	401.7	413.6	356.5	338.8	334.2	313.8
Urals	2373.5	2452.2	2388.0	2422.1	2348.6	2305.9	2390.2	2516.4	2436.2
Western Siberia	1349.9	1171.4	1292.8	1344.6	1356.3	1389.8	1632.3	2044.4	2018.9
Eastern Siberia	881.8	850.3	806.4	816.6	758.2	727.9	696.0	680.3	625.7
Far East	594.0	475.9	463.7	446.1	471.2	481.7	580.7	484.8	446.6
Ukraine									
Donetsk–Dniepr	3968.6	4046.5	3833.3	3813.8	3887.7	3604.2	3500.3	3314.6	3189.5
South-Western	377.4	395.7	399.5	397.0	390.4	377.1	378.1	358.1	349.1
Southern	635.6	655.5	556.0	536.7	507.0	501.6	459.1	418.0	366.0
Baltic States	161.9	161.1	168.7	172.7	164.7	173.2	223.9	228.5	220.9
Lithuania						97.0	100.3	101.2	
Latvia						47.2	46.0	42.0	
Estonia						56.7	60.8	58.1	
Transcaucasia	400.0	350.2	343.1	316.5	322.4	325.4	291.5	272.1	274.8
Georgia						159.9	150.4	152.7	
Azerbaidzan						103.6	94.5	97.6	
Armenia						28.0	27.2	24.5	
Central Asia	240.3	342.2	394.6	376.8	421.4	470.9	399.9	333.9	308.7
Usbekistan						220.3	152.5	151.3	
Kirgizstan						35.0	36.6	34.5	
Tadzikistan						55.3	56.2	55.9	
Turkmenistan						89.3	88.6	67.0	
Kazakhstan	1377.0	723.6	928.7	966.5	997.2	992.6	983.2	956.4	1010.8
Belorussia	221.2	241.4	279.9	305.5	315.1	308.1	251.2	235.1	215.8
Moldova	54.2	62.3	55.5	49.2	47.8	49.0	62.1	53.2	47.4

[a] In 1982 the North-Western region was divided into the North-Western and the Northern; [b] Bashkiria was transmitted from the Volga region to the Urals region.

Table A8. Emissions of carbon monoxide[a] from various branches of industry in the Soviet Union (thousand tonnes a^{-1}) and percentage of emissions trapped[b] in 1980–88.

Industry	80	81	82	83	84	85	86	87	88
Ferrous metallurgy	7363.8	7369.2	7336.2	7307.7	7423.8	7266.5	7115.1	6975.8	6714.1
					36.2	40.3	41.9	43.8	46.1
Oil production	318.0	78.5	102.1	98.2	117.2	105.6	272.1	880.5	988.4
					8.9	11.2	6.5	20.8	0.0
Petrochemical	1254.7	1168.5	1267.8	1065.3	979.8	853.1	822.8	748.3	676.6
					62.9	64.9	66.8	69.7	71.9
Coal mining	1045.8	903.2	847.6	825.3	797.3	373.1	708.3	652.4	614.3
					2.8	0.8	0.7	0.2	0.3
Gas processing	313.2	266.8	266.1	254.7	304.1	355.9	553.1	564.8	560.5
					0.7	0.6	–	0.4	0.4
Non-ferrous metallurgy	1088.1	918.8	826.7	831.2	798.0	745.9	690.7	693.2	540.9
					3.1	3.6	3.3	16.2	18.7
Agriculture									448.1
									0.6
Construction materials production	843.4	781.2	788.6	854.5	897.7	684.3	678.7	672.8	406.2
					23.0	26.1	27.4	26.8	27.9
Timber, pulp, paper production	136.1	314.8	311.3	308.1	342.0	337.1	382.8	364.1	356.1
					1.4	1.4	1.2	1.2	1.3
Chemical	558.5	298.9	270.3	278.1	278.9	275.2	291.3	307.0	305.0
					34.6	36.5	38.5	44.8	46.0
Energy generation	–	349.5	293.7	311.7	238.4	238.7	197.7	374.0	175.2
					0.6	0.6	0.6	0.4	0.8
Fertilizer production	–	170.1	182.2	203.1	217.0	179.2	156.6	146.2	147.1
					73.5	71.3	72.2	76.8	76.0
Total	–	15610.4	15855.6	15686.1	15645.8	15257.7	15305.2	15350.0	14938.0
Transport (million tonnes)	–	32.1	33.6	33.09	30.39	28.89	29.19	28.59	28.43

[a] Figures quoted as 'emissions of suspended particles' represent CO emissions entering the atmosphere; [b] Figures quoted as 'percentage of trapped emissions' are estimated as a share of the total suspended particles emissions produced.