Assessment of air pollution trends in Krasnoyarsk using indicators of sustainable development

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Abstract. This paper studies the state of atmosphere in Krasnoyarsk (Russia) in terms of sustainable development indicators based on data from State reports ‘On the state and protection of environment in the Krasnoyarsk Territory’ for the period from 2007 through to 2018. Gross emissions, their structure and dynamics as well as atmospheric pollution indexes are analyzed.

1. Introduction
The atmospheric air is an essential component of the environment. As a result of industrial activities large quantities of pollutants are dumped into the atmosphere causing environmental problems. About 7 million people died worldwide from air pollution in 2012 [1], which proves air pollution to be the world's largest environmental health risk. Pollution of urban atmosphere is widely discussed globally. In Israel identifies the most suitable and economically feasible policy measures to reduce concentrations of particulate matter and ozone [2]. It describes a comprehensive methodology that takes into account the effects of PM and O₃ and describes the overall costs and benefits expected from their reduction. In China computes [3] the efficient air pollution abatement ratios of 30 regions during the period 1996–2002. Three air emissions (SO₂, soot and dust) are considered. Investigates the environmental risk in Xiamen caused by the emission of pollutants into the atmosphere from urban energy consumption in cities [4]. The first occurrence of smog was recorded over London in December 1952 [5]. In today’s situation smog occurs in many cities around the world.

On the whole in Russia [6], total emission of air pollutants in 2017 changed slightly compared to 2010 (a decrease within 1%). Since 2012, there has been a redistribution of emissions: emissions from stationary sources have dropped by 11 % while those from mobile sources have increased by 14%. Among the administrative-territorial subjects, the highest emission from stationary sources was registered in the Siberian Federal District, which in 2017 amounted to 5762 thousand tons (33% of the all-Russian indicator).

2. Object of study
The city of Krasnoyarsk is one of the largest cities in Russia with a population of more than 1 million people. It is located in the center of Russia, on both banks of the Yenisei River at the junction of the West Siberian Plain, the Central Siberian Plateau and the Sayan Mountains. The relief of the city is hilly with lowlands. Krasnoyarsk is a developed center of industry of Russia, more than 17 thousand enterprises, organizations, institutions are located in the city. The climate of Krasnoyarsk is continental, softened by large masses of water (Krasnoyarsk Reservoir), ice-free Yenisei River in winter and the surrounding mountains [7].
The city is the largest transport hub in Eastern Siberia; the presence of a number of large enterprises in the metallurgical, engineering and chemical industries exacerbates the environmental situation. The main substances that create very high or simply high levels of atmospheric pollution are benz(a)pyrene, formaldehyde, suspended solids and nitrogen dioxide [8].

3. Research methods and instruments
Sustainability indicators provide a display of the state or change of economic, social or environmental variables. The main purpose of introducing indices is to assess a situation or event to predict the development of the current situation and develop solutions to existing problems [9]. To study the state of atmosphere, we employ the UN sustainable development indicators [10] along with the indicators developed in individual countries of the world. The UN indicators of sustainable development take into consideration such aspects as input influence, air pollution state and management, including:

- greenhouse gas emissions (CO₂, CH₄, N₂O), t/year;
- sulphur oxide (SOₓ) and nitrogen oxide (NOₓ) emissions; t/year/person;
- consumption of ozone-depleting substances, t/year;
- concentration of pollutants in the city atmosphere (O₃, CO, particulate matter, SO₂, NO₂, NO), mg/m³;
- air pollution abatement costs, USD.

The source data on the level of air pollution in Krasnoyarsk were borrowed from State reports on the state of the environment [8].

4. Results
Gross emission of pollutants is an aggregate characteristic of the amount of pollutants emitted into atmosphere per year.

Figure 1 shows the dynamics of gross emissions from stationary and mobile sources into atmosphere of Krasnoyarsk over the period from 2007 to 2018. Since 2013, an amended method of assessment of emissions from motor transport is applied, which has yielded almost 50% lower indicators (Order of the Federal Service for the Supervision of Natural Resources of November 1, 2013, No. 6-p).

During the period from 2007 to 2018, gross emissions from stationary sources were decreasing virtually all the time by approximately 4 thousand tons a year whereas emissions from motor vehicles were linearly growing at the rate of about 3 thousand tons a year. In 2018, emissions from mobile sources accounted for about 40% of the total emissions.
Figure 2 presents the structure of emissions of various pollutants from stationary sources in the atmosphere of Krasnoyarsk over the years 2007-2018. Carbon monoxide accounts for about 50% of emissions. Nitrogen oxide emissions remain at approximately one and the same level during the period under review.

![Figure 2](image_url)

**Figure 2.** Dynamics and structure of emissions of various pollutants from stationary sources.

The population of the city is constantly growing at a speed of 16 thousand people a year. Table 1 shows the dynamics of gross emissions per person. The amount of gross emissions per person for each pollutant is continuously reduced throughout the entire period.

| Year | Population (*10^3) | Specific gross emission (kg/person/year) | Specific emissions (kg/person/year) |
|------|---------------------|----------------------------------------|-----------------------------------|
|      |                     | PM | SOx | CO | NOx |
| 2007 | 932.5               | 36.8 | 30.0 | 89.0 | 16.6 |
| 2008 | 948.5               | 30.5 | 30.1 | 78.4 | 16.4 |
| 2009 | 963.2               | 28.4 | 29.2 | 75.3 | 17.0 |
| 2010 | 979.6               | 27.2 | 29.0 | 72.6 | 16.6 |
| 2011 | 979.6               | 25.4 | 26.4 | 71.7 | 15.1 |
| 2012 | 1017.2              | 25.6 | 29.4 | 68.6 | 16.1 |
| 2013 | 1036.6              | 21.3 | 26.1 | 66.7 | 22.7 |
| 2014 | 1053.2              | 19.0 | 25.0 | 62.1 | 13.4 |
| 2015 | 1066.9              | 18.8 | 25.0 | 58.6 | 13.7 |
| 2016 | 1082.9              | 18.1 | 23.5 | 56.6 | 16.4 |
| 2017 | 1090.8              | 15.9 | 20.8 | 53.9 | 15.1 |
| 2018 | 1096.1              | 13.6 | 18.3 | 52.1 | 14.5 |

In Russia, an atmospheric pollution index (API) is used to assess the level of long-term pollution in a city. In actual fact, two pollution indexes are employed: API for an individual pollutant and an aggregate API-5 over 5 primary city pollutants [11]. An aggregate API is found by a special formula taking into account the annual average concentration of a pollutant, its daily average maximum permissible concentration and a coefficient describing the degree of harmfulness of the pollutant.

Annual dynamics of the atmospheric pollution index in Krasnoyarsk is given in Table 2, where BP stands for benz(a)pyrene, F – formaldehyde, PM – particulate matter, NO_2 – nitrogen dioxide, NH_3 – ammonia, and EB for ethylbenzene. It is important to emphasize that the drastic decrease in the assessed
air pollution level in 2014 was due to the revised daily average maximum permissible concentration of formaldehyde (Order of the Sanitary Physician-in-Chief of the Russian Federation of April 7, 2014, No 27). During the period under review, the level of pollution remained consistently very high, the major contributors to the aggregate pollution index being benz(a)pyrene, formaldehyde, particulate matter, nitrogen dioxide, and ammonia.

Table 2. Dynamics of atmospheric pollution index API-5.

| Year | API-5 | Pollutants | Pollution level |
|------|-------|------------|-----------------|
| 2007 | 14.66 | BP, F, PM, NO₂ | Very high |
| 2008 | 15.31 | BP, F, PM, NO₂, NO | Very high |
| 2009 | 18.56 | BP, F, PM | Very high |
| 2010 | 21.86 | BP, F, PM, NO₂ | Very high |
| 2011 | 23.75 | BP, F, PM, NO₂, NH₃ | Very high |
| 2012 | 22.93 | F, BP, PM, NO₂ | Very high |
| 2013 | 17.05 | F, BP, PM, NO₂ | Very high |
| 2014 | 17.48 | F, BP, EB | Very high |
| 2015 | >7 | F, BP, PM, NO₂, NO | High |
| 2016 | >14 | BP, F, NH₃, NO₂, PM | Very high |
| 2017 | >14 | BP, F, NH₃, NO₂, PM | Very high |
| 2018 | >14 | PM, NO₂, NH₃, F, BP | Very high |

5. Conclusion
The paper describes the state of atmosphere in the city of Krasnoyarsk in terms of sustainable development indicators. Our analysis is based on the data from State reports ‘On the state and protection of environment in the Krasnoyarsk Territory’ for the years 2007 through to 2018.

The gross indicators suggest that the air pollution level in Krasnoyarsk over the period 2014-2018 slightly decreased and yet remained consistently high compared to other cities in Russia. The observed mitigation of pollution is associated with the improved dust and gas removal systems introduced at large industrial enterprises. Gross emissions from stationary sources in 2018 accounted for 60% and from mobile sources – for 40%. The structure of emissions from stationary sources in 2018 was as follows: carbon monoxide – 49%, sulfur dioxide – 17%, particulate matter – 13%, nitrogen oxides – 14%. It should be noted that specific emissions per person for all pollutants were decreasing during the entire period under review.

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