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Assessment of the ecological and social potential of the organization of ecological zones to ensure sustainable transport development of territories

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Abstract. The article presents the results of an assessment of the impact on the environment and public health of measures to prohibit entry into a certain territory of the city of cars belonging to low environmental classes ("ecological zone" or "ecozone"). When justifying the choice of the city on the example of which the research was conducted (Novosibirsk), both environmental and socio-economic aspects were taken into account. The assessment of the environmental impact of the ecozone organization consisted in modeling traffic flows on the road network before and after the organization of the ecozone, estimating the emissions of pollutants from the totality of traffic flows, calculating the maximum and average annual surface concentrations of the considered pollutants on the territory of the ecozone. Based on the calculated average annual concentrations of pollutants, characteristics of the population density living in the ecozone, and scenarios of its interaction with pollutants, public health risk assessments were carried out before and after the organization of the ecozone. Studies have shown that the change in gross emissions of major pollutants during the organization of the ecozone in Novosibirsk will be 40...60%. Ground-level concentrations of these pollutants will decrease by about the same amount. Carcinogenic and non-carcinogenic risks to the population will be reduced by about half.

1. Introduction

One of the mechanisms aimed at reducing the impact of the city's transport system on the environment and public health is the introduction of restrictions on the movement of cars of low environmental classes in a certain territory. Such territories are called "ecological zones" (German: Umweltzone) or "low-emission zones" (English: Low Emission Zone).

"Ecozones" are traffic management schemes designed to restrict vehicle access to certain urban areas based on their environmental characteristics. They are mainly organized in cities with a population of more than 200 thousand people. Usually, restrictions are based on the compliance of vehicles with a certain certification level (environmental class). In many cases, vehicles of lower environmental classes are allowed to enter ecozones if they are upgraded (for example, if diesel vehicles are equipped with soot filters). Vehicles that do not meet the established emission requirements may be banned from entering the ecozone, or they may be allowed to enter the ecozone for a fee.

Now ecozones operate in more than four hundred cities around the world. In particular, in Europe, they are organized in Germany, Austria, France, Belgium, Denmark and Spain.

Russian legislation provides for the powers of the constituent entities of the Russian Federation to impose restrictions on the movement of vehicles in localities, recreation and tourism areas, and specially protected areas in order to reduce the release of pollutants into the air. On the other hand, comprehensive action plans are currently being developed and implemented to reduce air pollution in major industrial centers, including Novosibirsk. Therefore, the question of the potential effectiveness of this measure in specific Russian conditions is very relevant.

2. Object of research

The following factors were taken into account when choosing a locality to evaluate the effectiveness of the ecozone organization. The organization of an ecozone makes sense in those localities where:

- there is a high degree of air pollution;
- there is a high contribution of motor transport to air pollution;
- a large number of people live;
- there is a high level of motorization;
- the urban planning structure and the structure of the road network allows you to select a zone with a high population density and the possibility of organizing a detour;
- public transport is well developed;
- it is possible to conveniently mark the boundaries of the ecozone for the administration of established restrictive measures;
- there is a favorable socio-psychological "background" that allows us to hope for the support of the organization of the ecozone from the majority of the population.

The following cities received the highest expert rating of desirability for ecozone organization: Moscow, Saint Petersburg, Novosibirsk, Samara, Omsk, Kazan, Yekaterinburg, Nizhny Novgorod, Voronezh, Ufa, Krasnodar, Krasnoyarsk, Vladivostok, Chelyabinsk, Perm.

Novosibirsk was chosen as an example from this list, since research for Moscow and St. Petersburg required significantly more labor. Therefore, any effective measures to improve the environment in the city center should be considered highly desirable.

The main source of emissions of polluting substances in atmospheric air in Novosibirsk and the region is road transport. However, its share in total emissions from all sources has tended to increase in recent years. In 2018, the share of emissions from road transport accounted for 68.5% [1].

The automobile fleet of Novosibirsk as of July 1, 2019 totaled 449.8 thousand vehicles, the population was 1618 thousand people, the level of motorization – 278 cars per thousand inhabitants, which is slightly lower than the national average (306 cars per thousand people) [2].

3. Description of the method

The assessment of the ecological and social effect of the ecozone organization in this work was of a predictive nature. This imposed specific conditions on the selection and formation of initial data, and, accordingly, on the methods used for evaluating intermediate and final results.

The environmental and social performance of the ecozone organization was evaluated in the following sequence:

1. Based on the analysis of urban planning information, the structure of the road network and transport characteristics, the territory that is potentially suitable for organizing an ecozone was selected.
2. The structure of the road network used for modeling traffic flows was formed for the selected city territory. In this work, the simulation was performed using the PT VISUM software.
3. Based on transport modeling, the maximum intensity of traffic flows was determined for all elements of the road network that is part of the ecozone.
4. The composition of traffic flows (i.e., the distribution of vehicles by type and environmental class) was determined based on the assumption that the composition of traffic flows is identical to the average composition of the car fleet in the region. The average composition of the fleet was determined based on the processing of traffic police data in the interpretation of the analytical Agency "AUTOSTAT".
5. The average coefficients of run-through emissions of pollutants for the traffic flow of a given composition were calculated. For this purpose, COPERT software was used, which

implements the standard pan-European method of inventory of vehicle emissions EMEP/EEA [3].

6. Based on the assumption that the composition of traffic flows on the entire road network in the ecozone is identical, the maximum single (g/s) and gross (kg/h) emissions of pollutants on each segment of the road network were calculated.

7. Gross emissions were added up for all sections of the road network to obtain total emissions for the entire ecozone.

8. Maximum one-time emissions were used as input data for modeling the dispersion of pollutants in the atmosphere to estimate the emerging surface maximum one-time concentrations throughout the ecozone. In this work, the unified program for calculating atmospheric pollution "ECO CENTER" was used for this purpose. The obtained surface maximum single concentrations were compared with the hygienic standards of air quality in populated areas in order to analyze their compliance on the territory of the ecozone.

9. The calculated maximum one-time concentrations (at several characteristic points located throughout the ecozone) were converted to average annual values based on the time heterogeneity of transport flows and climatic characteristics.

10. Average annual concentrations of pollutants were used as input data for assessing public health risk indicators.

11. Several possible scenarios for changing the initial data after the ecozone was established were developed, and one of them was selected as the most likely one to be used for further assessments.

12. For the selected scenario, paragraphs 3.10 were performed, taking into account changes in the initial data describing the intensity and composition of traffic flows associated with the organization of the ecozone.

13. A comparative analysis of the results obtained was carried out to determine the environmental performance indicators of the ecozone organization, and conclusions were formulated.

4. Features of estimation of average annual concentrations of pollutants
In this paper, the average annual concentrations were estimated as follows:

- several calculation points located near the largest residential areas were selected within the ecozone territory;
- at these points, the maximum single concentrations of pollutants that characterize the most unfavorable conditions were calculated both by the power of emissions (maximum traffic intensity on the entire road network within the ecozone) and by meteorological conditions (adverse weather conditions: calm + inversion);
- according to expert given variations in traffic density during the day, days and weeks per year was calculated the coefficient of reduction in average concentration caused by the change of intensity of a transport stream within a year;
- based on the analysis of publicly available weather parameters in the city under consideration (Novosibirsk) [4] were determined: a) the number of cases of adverse weather conditions in the year and b) the average duration of adverse weather conditions;
- based on these data, the coefficient of decrease in the average annual concentration was determined due to the probabilistic nature of the formation of adverse meteorological conditions;
- the total value of the average annual concentration was calculated as the product of the maximum single concentration and the two coefficients described above.

The first coefficient quite adequately corrects the change in concentration, since the relationship between traffic intensity, emissions, and concentration is linear in the first approximation. Although the second coefficient introduces an error (it seems to underestimate the results, since the binary model "there is an inversion – no inversion" is used), it allows us to take into account the very complex influence of weather parameters on the result.

5. Features of public health risk assessment

The public health risk assessment was carried out in accordance with the guidelines 2.1.10.1920–04 on public health risk assessment for exposure to chemicals that pollute the environment [5], which provides for the unification of methods and criteria for risk assessment.

To assess the exposure, the average characteristics of the population group exposed to traffic flow emissions in the ecozone under study were selected (table 1).

Table 1. Recommended standard values for exposure factors

Exposure factor	Value
Lifetime exposure (carcinogens)	70 years
Life expectancy	70 years
Exposure frequency, residential area scenario	350 days/year
The period of averaging of exposure, years	carcinogens: 70 years
The speed of the inhalation, adult, General characteristics	20 м^3/ day
Body weight, adult, 18 years or more	70 kg

The amount of chemical intake into the human body was calculated using the formula:

$$LADD = \frac{C \cdot IR \cdot ED \cdot EF}{BW \cdot AT \cdot 365} \tag{1}$$

where   LADD – average daily dose during life, mg/kg × day;
            C – concentration of the substance in the air, mg /м^3;
            IR – average daily volume of inhaled air, m^3/day;
            ED – duration of exposure, years;
            EF – frequency of exposure, days/year;
            BW – human body weight, kg;
            AT – the period of averaging of exposure, years;
            365 – number of days per year.

The carcinogenic risk was calculated using the formula:

$$ICR = LADD \times SFi, \tag{2}$$

where   LADD – average daily dose during life, mg/kg × day;
            SFi – carcinogenic potential factor.

When exposed to multiple carcinogens, the total carcinogenic risk for this route of entry (inhalation) is calculated using the formula:

$$CR_T = \Sigma\ CR_j, \tag{3}$$

where CR_T – total carcinogenic risk for the route of entry of T;
            CR_j – carcinogenic risk for the *j*-th carcinogenic substance.

Additionally, we calculated the:
Cri = LADD × SFi × 1 000 000 – carcinogenic annual population risk (per 1 million people).
Cri = LADD × SFi × 1 000 000 / 70 – carcinogenic annual population risk during life (per 1 million people).

Assessment of non-carcinogenic risk is carried out by calculating the hazard coefficient

$$HQ_i = \frac{c_i}{RfC} \tag{4}$$

where HQ_i – hazard ratio of substance i;
            C_i – level of exposure to the substance i, mg/m^3;

RfC – safe exposure level, mg/m^3.

If the calculated hazard coefficient (HQ) of a substance does not exceed one, then the probability of developing harmful effects in a person with daily intake of the substance during life is insignificant and such an impact is characterized as acceptable. If the hazard ratio exceeds one, the probability of harmful effects in humans increases in proportion to the increase in HQ, but it is impossible to specify the exact value of this probability.

In case of combined intake of several substances in any way, the hazard coefficients are added together and the total hazard index is calculated, which should also not exceed one.

6.Results and Discussion

Using the developed methodology, the ecozone configuration for the city of Novosibirsk was developed. The most heavily trafficked Central historical part of the city was taken as a basis, including all or part of the borders of Pisarev street, Hippodromskaya, Kamenskaya highway, Kirov street, Voskhod, Ob river embankment to the railway line.
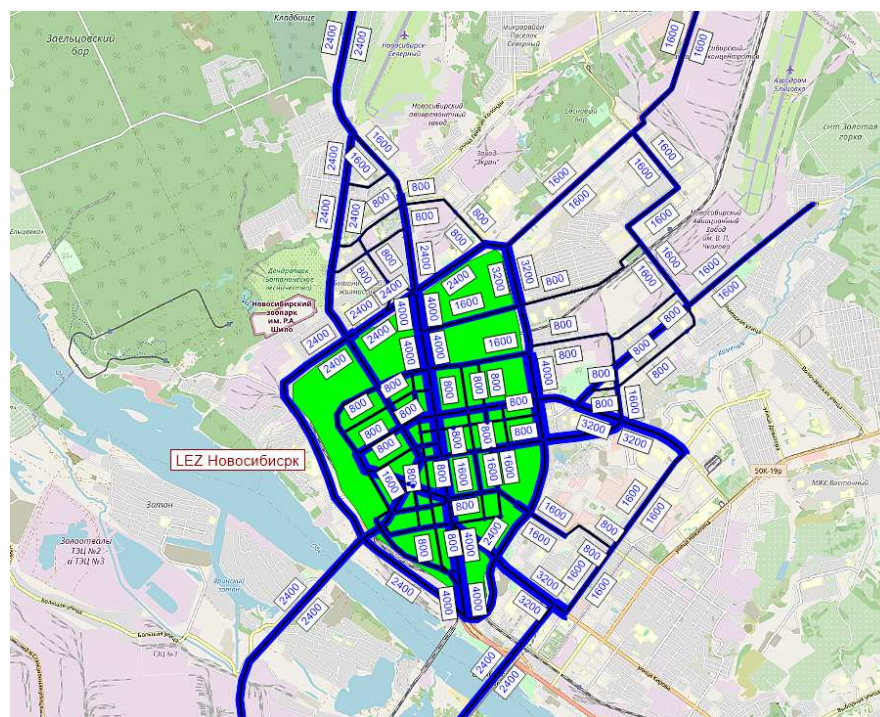

Figure 1. Configuration of the road network in the Novosibirsk ecozone

Description of the basic scenario: the structure of the vehicle fleet was adopted according to expert data processed by the traffic police for Novosibirsk. For vehicles that do not comply with Euro-3, it was 44.2%. The output coefficient for vehicles of environmental classes Euro-0 and Euro-1 is adopted in the range of 0.4...0.8, for vehicles of other environmental classes – the output coefficient is equal to 1. The coefficient of production of cars of ecological classes Euro-0 and Euro-1 was assigned by experts based on a visual analysis of the structure of real traffic flows on the street and road network of Novosibirsk. Traffic flow rates are assumed to correspond to the maximum capacity of network sections (saturation mode, typical for peak time intervals).

Description of the forecast scenario **«Prohibition of vehicles less than Euro-3»**: the share of buses in the traffic flow increased by 1%, which is enough to compensate for the ban on entry into the ecozone of passenger vehicles of environmental classes Euro-0...Euro-2; coef. output for vehicles of Euro-0 environmental classes... is reduced by 95% compared to the basic version, their share is reallocated to higher environmental classes in proportion to the existing structure of the vehicle fleet; traffic intensity on the road network has not changed.

Changes in gross emissions of major pollutants during the organization of an ecozone in Novosibirsk are shown in table 2.

Table 2. Changes in gross emissions of major pollutants during the organization of an ecozone in Novosibirsk

Pollutant	Emissions reduction, %
CO_2	2,3
CO	65,4
VOC	57,2
NMVOC	58,5
HC_4	34,5
NO_x	40,1
NO_2	20,6
NO	41,8
TSP	12,6
PM_{10}	17,0
$PM_{2,5}$	25,9
BC	50,3
OC	70,4
N_2O	37,5
NH_3	79,7
SO_2	1,4

Note: NMVOC – non-methane volatile organic carbons; TSP – total amount of suspended solids; BC – soot; OC – organic dispersed particles.

The results of calculating surface concentrations before and after the ecozone organization showed a decrease in CO by 65% (Figures 2 и 3), NO_2 – by 40%, polycyclic aromatic hydrocarbons (for benzo(a)pyrene) – on 7%, aldehydes (for formaldehyde) – on 31%, aromatic hydrocarbons (for benzene) – on 66%, persistent organic pollutants (by dioxins) – on 42%.
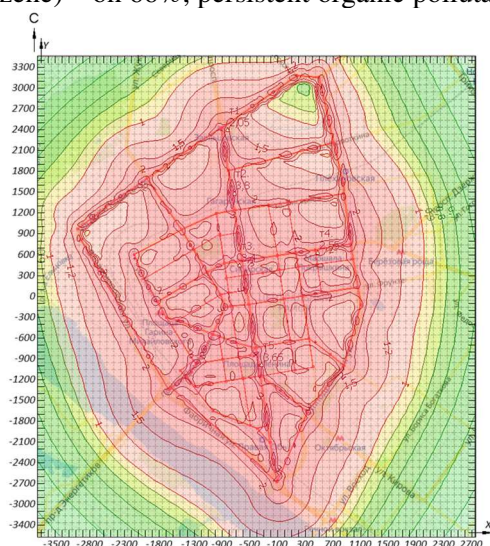
Figure 2. Estimated surface CO concentration (in fractions of the maximum permissible concentration) before the ecozone is established
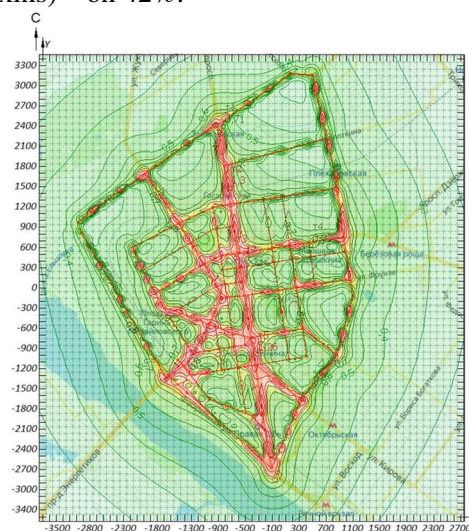
Figure 3. Estimated surface CO concentration (in fractions of the maximum permissible concentration) after the ecozone organization

A comparison of the results obtained for the baseline scenario and monitoring data [6] shows a satisfactory adjustment of the calculated models, with the exception of benzo(a)pyrene, for which monitoring shows significantly higher values. Apparently, this is due to the decisive contribution of stationary sources to atmospheric pollution with this substance, which were not taken into account in this work.

The organization of an ecozone is most effective in reducing emissions of those pollutants whose emissions are more determined by the availability and efficiency of exhaust gas treatment systems. These substances include CO, VOC, NO_x, $PM_{2.5}$, BC, OC, NO_2 и NH_3. Those substances whose emissions depend on both the efficiency of exhaust gas treatment systems and tire and brake wear (TSP, PM10) show a moderate decrease. Emissions of CO_2 and SO_2, which are largely determined by fuel consumption, are practically not reduced, since transport flows remain unchanged.

The obtained values of the maximum single concentrations of pollutants were recalculated to the average annual values using the approach described above. The resulting conversion coefficient (0.174) was slightly higher than the recommended value of 0.1 in [7] for the case of simplified estimation.

The calculation of the average carcinogenic risk for the Novosibirsk ecozone shows that this indicator will decrease from a value of $3.7 \cdot 10^{-5}$ (or 4 cases per 100 thousand population) to a value of $1.7 \cdot 10^{-5}$ (or 2 cases per 100 thousand population).

The results of calculating the total hazard index (non-carcinogenic risk) show a decrease in risk from the average current value (2.14) to a low value (1.08) after the organization of the ecozone.

7. Conclusion

Studies have shown that the change in gross emissions of major pollutants during the organization of the ecozone in Novosibirsk will be 40...60%. The ground-level concentration of these pollutants will decrease to about the same extent.

The results of the carcinogenic risk assessment show that the risk fluctuates close to the acceptable limits. The organization of the ecozone led to a noticeable decrease in the carcinogenic risk for all substances except benzo(a)pyrene, which is associated with a slight change in its concentrations.

The results of the assessment of the total hazard index (non-carcinogenic risk) show a decrease in risk from the average current value to a low value after the organization of the ecozone.

Thus, the study showed a fairly high ecological and social potential of the organization of ecological zones. Therefore, this measure of traffic management can be recommended for other large cities in Russia with a high share of motor transport in the structure of air pollution.

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