REDUCING THE POLLUTION OF THE AIRSPACE OF THE CITY'S MAIN HIGHWAY AREAS

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Abstract: The article deals with problems of air pollution in large cities and how to solve them. In Europe, road transport produces nearly half of NO_x emissions, which ensures urban air quality. Analysis of reference data has revealed scientists' active interest in reducing air pollution in large cities. However, since the objects of territorial planning continue to develop dangerously, one can speak of the absence of a sufficiently compelling concept of architectural and urban planning to ensure the environmental safety of the air basin of urban areas. Therefore, we propose to consider the object of the research and protection as systemic integrity of three entities: areas near trunk roads, air basins, and population. The paper presents an ER model of the research object and determines the main parameters of each entity, their interrelationships, and the action area. We propose an engineering and planning solution for installing special units to remove the most dangerous admixtures of nitrogen oxides and dust from the air basin near the city trunk roads through ozonation and absorption. The basis of the proposed treatment plant is a scrubber with combined processes of wet dust collection and ozonation characterized by high efficiency in removing fine dust and nitrogen oxides. The work presents a process flow diagram of purification and determines the operating conditions of the equipment. To substantiate the unit's operational safety in an emergency with ozone emission, we have simulated the process of ozone dispersion in the surrounding areas.

Keywords: Airspace, Air pollution, Engineering solution, Highway areas, Urban air quality, Urban planning.

1 Introduction

In 2015, environmental pollution caused approximately 9 million premature deaths worldwide (16% of all deaths), which is three times more than deaths from AIDS, tuberculosis, and malaria combined, and 15 times more than from all wars and other diseases [3]. Ukraine took 43rd place out of 92 countries provided official information in the World Air Quality Ranking $PM_{2.5}$ in 2020 [19].

In Europe, road transport produces almost half of NO_x emissions, so it plays a key role in ensuring air quality in cities [14]. The average annual values of nitrogen oxide concentrations in urban conditions are 20-90 μg/m^3, and the hourly maximums are in the range of 75-1015 μg/m^3, while at the intersections with heavy traffic during traffic jams NOx concentrations are several times higher (especially in ‘urban canyons’ where the road is narrow and buildings are tall). When exposed to sunlight, NO_x together with volatile organic compounds produces secondary pollutants that are more hazardous to health and the environment. The lifetime of NO_x is about a day. Some NO_x interacts with moisture and tu$_r$ns into HNO_3 producing acid precipitation. Some NO_x produces mineral salts in the form of dust with an aerodynamic diameter of fewer than 2.5 microns. The p$_{re}$sence of NO_x in the air is one of the main reasons for photochemical smog. Ozone and nitrogen oxides have poor solubility in the mucous membrane. Therefore, they are almost freely transported to the lower respiratory tract with the inhaled air, where they cause inflammation and oxidative stress.

To reduce damage to the natural environment due to eutrophication of water bodies, acidification of soils, the formation of ground-level ozone, and depletion of the stratospheric ozone layer, The United Nations Economic Commission for Europe signed The 1988 Sofia Protocol and The 1999 Gothenburg Protocol on the reduction of anthropogenic NO_2 emissions.

Analysis of reference data has revealed an active interest of scientists in the state of air quality and its relationship with health risks.

The authors of the article [9] have studied the level of air pollution with particulate matter in 56 largest cities of the world (with a total population of 608 million people) based on data from The WHO monitoring, atmospheric modelling, satellite remote sensing, and surface monitoring data. They have found out that at least 96% of the population of these cities are exposed to $PM_{2.5}$ in concentrations higher than those recommended by The WHO. Notably, cities with the highest levels of pollution are in low-income countries.

Spanish researchers note [10] that a high level of NO_2 is quite frequent in Spanish cities causing annual mortality (6085 deaths) due to natural causes. At the same time, the impact of NO_2 on daily mortality is three times higher than that of PM, and daily mortality associated with circulatory causes is twice as high as that from respiratory causes.

Chinese scientists have summarized the publications of different authors on the impact of air pollution on public health by analysing space-time series, cohort, panel, and cross-sectional studies. They have concluded [1] that most of the data show a positive relationship between the concentrations of PM, SO_2, NO_2 and an increased risk of mortality. SO_2 and NO_2 in the environment may be high-risk factors for sudden infant death syndrome. NO_2 is the cause of hospitalization because of respiratory and cardiovascular diseases with exacerbation of asthma in children. There is also a clear impact of NO_2 on the frequency of viral infections among asthmatics. Children, the elderly, asthmatics, and people with chronic obstructive pulmonary disease are more sensitive to the effects of ozone. However, risk assessment of ozone-related mortality is higher in the warm season.

The article [12] assesses the risks of threats to the health of the population of Kyiv from 2005 to 2017 based on the developed modelling software complex for solving the problems of environmental pollution in the technogenic-loaded territories. Risk analysis has shown that most of the territory of Kyiv is characterized by increased values of risks (both chronic intoxication and reflex effects) that differ across city districts indicating the instability of the atmospheric air quality in Kyiv. At the same time, the lowest risk values have been found on the territory of Hydropark (park complex), and the highest have been observed on the Bessarabska Square and Maidan Nezalezhnosti (the city centre with heavy traffic).

The work [2] has studied the level of pollution with the main pollutants (NO_x, O_3, SO_2, CO, PM_{10}, $PM_{2.5}$, C_6H_6 over five years in 5 cities (> 50,000 inhabitants), five towns (5,000-50,000 inhabitants) and five villages (<5000 inhabitants) in Central Europe based on data from 15 automatic stations. The authors have found out that air quality varies greatly for different settlements, for different seasons, and during the day from 08:00 to 09:00 a.m.

The studies [11] carried out in India have shown that there are distinct seasonal variations in the concentrations of O_3 and NO_x with a maximum observed in winter and a minimum during the rainy season. As for daily variations, the concentration is higher at night than during the day. In this case, the correlation coefficient of 0.52 for the O_3 and $[NO_2]/[NO]$ ratio indicates the role of photolysis of NO_2 producing ozone in this place.

Chinese scientists [17] note that seasonal and average daily variation of NO_x concentration in Changchun has a bimodal distribution, which is higher in autumn and winter than in spring and summer. The daily change in NO_x concentration peaks first at 07:00–08:00 a.m. and then between 8:00 and 10:00 p.m. At the same time, there is a positive correlation of NO_x concentration with NO_2, NO, $PM_{2.5}$, PM_{10}, CO, and pressure, while a significant negative correlation is with O_3, temperature, wind speed, and humidity.

Work [13] assesses the concentration of NO_2 and NO_x on roads using data from the monitoring network of adjacent roads. Average and maximum NO_2 concentrations on roads are 33 and 105 ppb, respectively, with higher concentrations with winds perpendicular to the road rather than parallel. The NO_2/NO_x ratios ranged from 0.25 to 0.35, which is significantly higher than the expected tailpipe emission ratios.

Thus, due to the increasing negative anthropogenic impact of urbanization on people taking into account the concept of zero pollution within the framework of the EU's Circular Economy Action Plan by 2050 [6], the issues of environmental protection of the urban environment and natural ecosystems are becoming increasingly acute indicating the importance and relevance of the problem raised.

2 Materials and Methods

A scrubber is the main equipment. It is a device for wet air purification, which structurally consists of a section for contaminated air inlet, a working chamber, a nozzle block, a recirculation system, a cuttings chamber, and a gas removal section.

The main gases used as a working medium are nitrogen monoxide, nitrogen dioxide, and ozone.

Nitric oxide (NO) is a colourless, odourless, and tasteless gas, non-flammable, and with low water solubility (4.6 ml/100 ml of water at 20°C) that oxidizes to NO_2 in air. The melting point is 164.4°C; the boiling point is 152.2°C. Vapours are heavier than air. It is very toxic when inhaled and absorbed through the skin. The low odour threshold is 0.36 mg/m^3; the strong odour threshold is 1.2 mg/m^3.

Nitrogen dioxide (NO_2) is a reddish-brown highly toxic gas with a sweetish, pungent odour. The melting point is 11.2°C; the boiling point is 21.2°C. It reacts with water. The low odour threshold is 2.0 mg/m^3; the strong odour threshold is 10.0 mg/m^3.

Ozone (O_3) is an explosive pale blue gas with a characteristic pleasant odor that resembles chlorine at high concentrations. The boiling point is 112°C; the melting point is 193°C. The smell is noticeable even at a dilution of 1:100,000.

Oxidation of nitric oxide by ozone proceeds completely according to the reaction (1)

$$NO + O_3 = NO_2 + O_2, \quad (1)$$

followed by chemisorption by irrigated water according to the reaction (2)

$$3NO_2 + H_2O = 2HNO_3 + NO, \quad (2)$$

where the degree of interaction is 90%.

In modelling ozone dispersion profiles, the Gaussian mixture model algorithm is used, which is the most common in air dispersion analysis modelling. It is based on the assumption that the pollutant will spread according to a normal statistical distribution. When implementing the model, some simplifications have been made, i.e., the emission concentration does not affect the rarefied flow; molecular diffusion and longitudinal diffusion (along the wind direction) are negligible; turbulent flows are linear; lateral average wind speed and vertical wind speed are zero, ideal for an underlying surface.

3 Results

Under modern economic conditions, many large cities are unable to quickly and effectively improve the quality of atmospheric air by re-planning territories (e.g., building interchanges, bypass roads, redesigning cities as for landscaping, arranging pedestrian zones, bicycle paths, etc.) or adopting unpopular decisions (bans or restrictions on traffic in the city centre, penalties, etc.), since this requires large investments in urban transport infrastructure and hinders the sustainable existence and development of society. In addition, the transition to green energy and the use of electric vehicles cause difficulties and high economic costs.

Currently, there are different proposals for protecting the air basin, especially in large cities. The authors of [7] consider the possibilities of promising architectural design of highly urbanized areas using TiO_2 nanoparticles as a component of construction materials such as concrete and gypsum, or a component of active membrane tissues. They are activated by UV radiation and neutralize various atmospheric pollutants, especially acidic gases due to photocatalysis. However, this is applicable for newly built communities and does not fully solve the problem of air purification.

An article by Korean researchers [5] describes the development of a system of artificial soil-plant and electrostatic filters for air purification from fine particulate matter in the urban environment, especially in hot spots. Due to plant leaves, the filter based on multi-layered different artificial soils has an efficiency of 78.5% for $PM_{2.5}$ and 47% for PM_{10} at the incoming airspeed of 0.15 m/s.

The modern European market has ready-made solutions for removing pollutants and viruses from urban and indoor air using biotechnology, fine filtration, UV irradiation, and air ionization.

For example, U-Earth [https://www.u-earth.eu/products] has developed a bioreactor that neutralizes viruses, volatile organic compounds, and fine particles. However, such an air purifier needs to be refilled every 30 days with a special mixture of biotechnological bacteria and enzymes.

ENS has developed the Clean Air technology [https://www.ens-cleanair.com] to remove dust, soot, and other contaminants from the air without using filters. In this system, fine dust particles are positively charged and move to the negatively charged collector plate, where they adhere to the surface. Unfortunately, this solution does not solve the problem of removing gas pollutants from the air.

The British company Airlabs [https://www.airlabs.com] offers devices based on a chemically modified nanocarbon filter for capturing and destroying ozone, nitrogen oxides, and volatile organic compounds. However, it operates in confined spaces (premises, transport).

The German developer Purevento [https://www.purevento.com] offers mobile containers for removing fine particles and nitrogen oxides in a synchronized four-stage filter element treating up to 60,000 m^3 of air per hour with an efficiency of 85%. This solution requires replacement and disposal of filters.

The Italian company Is Clean Air [https://www.iscleanair.com] has presented the APA technology to reduce industrial emissions, which can be used outdoors and indoors to remove particulate matter, heavy metals, hydrocarbons, pollen, spores, NO_x, SO_x, CO_2 from the air within a radius of 25 m. It uses centrifugal force and water in combination with UV treatment with consequent water-based waste. Compared to other systems, filterless technology significantly reduces the cost of production and system maintenance.

Another Italian company Airlite [https://www.airlite.com] offers interior and exterior paints that use photocatalytic properties of mineral components to neutralize pollutants such as formaldehyde and nitrogen oxides (88% efficiency) when exposed to light, and to prevent the growth of bacteria, mold, and spores. At the same time, the produced salts are fixed on walls. However, reactions only take place on the surface leaving contaminants in the air.

The Dutch project (see the following link on the project: https://www.studioroosegaarde.net/project/smog-free-tower) called The Smog Free Tower is a 7-meter high aluminium tower with positive ionization technology that purifies 30,000 m^3/h of air and uses a small amount of green energy. This project has already been launched in China, South Korea, the Netherlands, Mexico, and Poland.

However, despite the variety of treatment facilities and protective materials, many problems of maintaining clean air have not been resolved yet. Therefore, they require an urgent solution to reduce the negative impact of urban road transport emissions on the health of population of urbanized areas and the environment. We propose a conceptual model of the transition to clean air in urbanized areas shown in Figure 1, according to which it is necessary to solve the triune problem of coexistence and protection of:

- A person who seeks to live comfortably that requires constant progress, and at the same time preserve their main treasure, i.e. health;
- Transport, which is associated with the need to quickly move goods and services requiring sustainable economic development and leading to climate change;
- The environment, the state of which is deteriorating against the background of intensification of natural disasters due to anthropogenic influence.

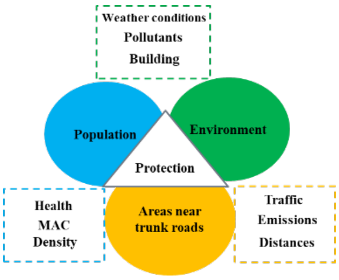

Figure 1. Conceptual Model of the Transition to Clean Air in Urbanized Areas

The research objective was the systemic integrity of three entities, namely, areas near trunk roads, air basin, and population.

The purpose of the work is to propose an engineering and planning solution for purifying the air basin in areas near trunk roads of large cities within the framework of the conceptual model of the transition to clean air in urbanized areas.

The basis of the proposed treatment plant is a scrubber with combined processes of wet dust collection and ozonation characterized by high efficiency of removing fine dust up to 2 microns in size. It operates using the principle of dust particle settling on the surface of droplets under inertial forces or Brownian motion, and nitrogen oxides (acid gases). It is a vertical, hollow stainless steel unit with a grate at the bottom. A layer of nozzles is laid on it to uniformly distribute the gas flow over the cross-section of the unit and to increase the degree of absorption. A mist extractor is placed in the upper part of the unit to avoid drop entrainment. Purified air enters the atmosphere at a height of over 3.5 m. The irrigation water is supplied in the counter-current to the gas flow by means of several rows of radially placed nozzles. Ozonized air is supplied through the side connection. Filters for coarse air purification are placed on the air intake connections. The body is made with noise reduction, lightning and vandalism protection.

The scrubber works periodically, turns on automatically when the sensor is triggered indicating that the NO_x concentration in the air exceeds The WHO recommended value [18], or it can be controlled remotely upon request.

In the place of direct installation of the unit, access to tap water, power supply, and sewerage is required.

Absorption is highly effective for purifying gases with a noticeable concentration but it is also possible for gases at low concentrations, when a gas is highly soluble in the absorbent. Since purified air is a gas with low concentration and low oxidation (NO content is up to 80-90%), it is poorly absorbed. To ensure better absorption of NO_x, it is necessary to oxidize NO to NO_2 by at least 55%. Therefore, ozone is supplied to the scrubber.

To make quantitative calculations of the process, including the consumption coefficients for ozone and water (per one m3 of purified air), the concentration of NO_x in the atmospheric air is considered in the range of 0-1 mg/m^3 [16]. The share of NO_2 in NO_x emissions is usually up to 20% [8]. The purifying efficiency in the ozonized scrubber reaches 75-80%, the productivity is 2500 m^3/h, and the residence time in the unit is 6-7 seconds [15]. The volume of water supplied for irrigation is determined taking into account the dilution of the produced nitric acid to pH = 5.5, which makes it possible to send wastewater to the city sewage system according to the rules for receiving wastewater into it.

Figure 2 shows the dependences of the amount of ozone required for NO oxidation and water for irrigation of the scrubber on the initial content of nitrogen oxides in the purified air.

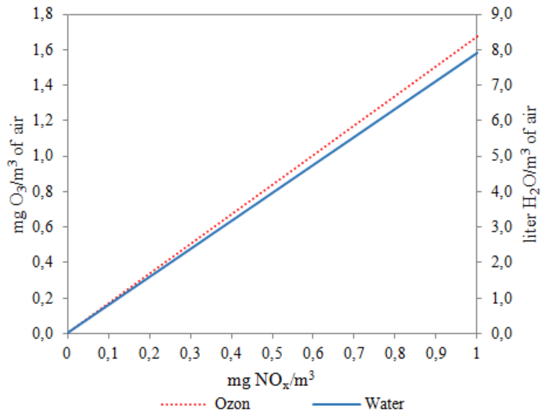

Figure 2. Consumption of Ozone and Water Depending on the Content of NO_x in one m^3 of Purified Air

To purify air with an initial NO_x concentration of 0.5 mg/m3, about 2.1 g of O_3/h is required, which is provided by an ozone generation unit with a capacity of 3 g/h. Unreacted ozone will reach 0.9 g/h, 0.279 g/h of which will dissolve in the irrigation water (solubility coefficient is 0.31 at 20ºC [4]). The rest will be carried away by exhaust air. To ensure the concentration of ozone at the level of standard values, a catalytic ozone destruction unit is placed in the gas outlet pipe at the scrubber outlet. The hourly water consumption will be about 10 m^3.

Recycling can be used to reduce water consumption. Automatic control of the supply of material flows (air, ozone, and water) according to a specific local pollution scenario will reduce consumption expenditures. Depending on the degree of air pollution in the predetermined urban locations, it is planned to place units of various capacities.

Thus, the proposed engineering and planning solution for the use of special units will allow purifying the air basin near the city trunk roads by removing the most dangerous admixtures of nitrogen oxides and dust by physicochemical methods. It should be noted that, in comparison with the known analogues, the unit is not difficult to maintain with sufficiently effective air purification in a short period. The economic efficiency of using purification plants in urban systems will be primarily manifested in reducing medical costs for the treatment of vulnerable groups of the population (children, the elderly, as well as people suffering from asthma, allergies, and immune system disorders).

4 Discussion

The objects of territorial planning continue to develop dangerously; therefore, one can speak of the absence of a sufficiently effective concept of architectural urban planning to ensure the environmental safety of the air basin of urban areas. Therefore, we propose an ER model consisting of three entities, namely, areas near trunk roads, air basin, and population. Table 1 presents its infological model. For each entity, the main parameters, their interrelationships, and the action area are determined. The main parameters for areas near trunk roads are the number of vehicles moving along this road, emissions of harmful substances into the environment, and the distance from the treatment plant to the trunk road, from the trunk road to the building. These parameters are linked to other parameters by basic links such as displacement, dispersion, and arrangement. Air basin and large cities are the main areas for using protective structures.

Table 1: ER Model of the Research Object

Object	Parameters		Action	Area
	Name	Description		
Areas near trunk roads	Traffic	the number of vehicles moving along the given trunk road	Displacement	Large cities
	Emissions	release of harmful substances into the environment	Dispersion	Air basin
	Distances	the distance from the treatment plant to the trunk road, from the trunk road to the building	Arrangement	Large cities
Air basin	Weather Conditions	a short-term special combination of meteorological factors	Displacement	Air basin
	Pollutants	an anthropogenic agent that enters the environment in quantities exceeding the values established by The WHO	Dispersion	Air basin
	Building	arrangement of buildings and structures	Arrangement	Large cities
Population	Health	a natural state of the body characterized by its balance with the environment	Displacement	Air basin
	MAC	maximum allowable concentrations	Dispersion	Air basin
	Density	the number of inhabitants per 1 km² of the territory	Arrangement	Large cities

A process is shown on flow diagram of the polluted air purification consisting of four steps, at each of which the main components are determined in Figure 3. Atmospheric air monitoring to determine the content of pollutants (nitrogen oxides and dust) and environmental parameters is carried out continuously. If the specified values are exceeded, the next step takes place, i.e., chemical and mechanical air purification is started, material flows are supplied. The main components of this step are the site of the treatment plant location, the treatment equipment. The third step is the disposal of wastewater into the sewerage with the determination of the pH scale to control the disposal. The final step is the control of the exhaust air with the determination of the content of ozone and nitrogen oxides. The process is automatic and regulated by the level of air pollution.

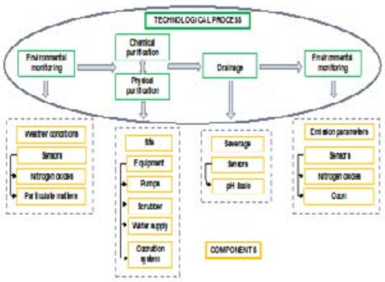

Figure 3. A Process Flow Diagram of Purifying the Air Basin of Areas near Trunk Roads with the Corresponding Components

The main conditions for the operation of the treatment plant (including restrictions) have been determined:

- The level of air pollution exceeds the maximum allowable concentrations;
- Availability of utilities such as power supply network, water supply, sewerage;
- Urban planning indicators, namely, building lines, planning requirements at different types of intersections;
- Weather conditions such as low temperatures, strong wind, rain, thunderstorm, snow;
- The ozone concentration level at the outlet exceeds the maximum allowable concentrations.

To take into account the emergency with ozone emission from the unit, we have carried out the modelling of ozone dispersion in the surrounding area shown in Figure 4. The following parameters have been taken into account during modelling:

- Emission height is 3.5 m;
- Wind speed is 1.25 m/s;
- Background pollution is conventionally assumed to be zero;
- The OX axis is oriented in the direction of the wind, the OY axis is perpendicular to the OX axis;
- Mass of ozone emitted into the atmosphere is 3 g/h.

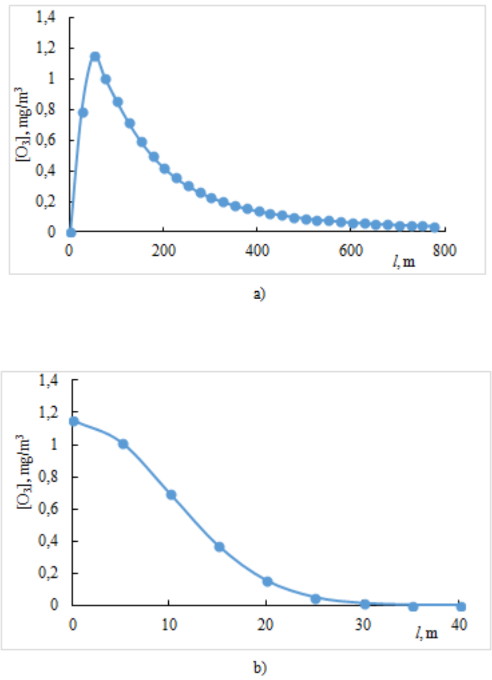

Figure 4. Ozone Dispersion Profiles in the Surrounding Area: a) along the OX Axis; b) along the OY Axis

When there is one source of emission, the main parameter is the calculated maximum concentration, which is predicted for cases where a dangerous wind speed is expected in the lower atmosphere. The obtained dispersion profiles make it possible to optimally determine the rational and most economical set of measures that ensure the necessary purity of the air basin, to establish the measurement of the emission parameters, the concentration field.

According to the obtained profiles of the dispersion of ozone leaving the unit, one can see that the maximum concentration along the OX axis (the wind flow) will be at a distance of 50 m from the emission source decreasing to the permissible value at distances of about 500 m. At the same time, with transverse dispersion along the OY axis (perpendicular to the wind flow) the standard value is at a distance of 30 m.

We should note that dispersion of the maximum possible ozone emission in case of an emergency, shown in Fig. 4, does not take into account the active rapid decay of ozone and its interaction with air impurities. In addition, the unit is equipped with an ozone concentration sensor, and if the standard values are exceeded, the ozone generator turns off.

5 Conclusion

The objects of territorial planning continue to develop dangerously; therefore, one can speak of the absence of a sufficiently effective concept of architectural urban planning to ensure the environmental safety of the air basin of urban areas. We propose to consider the object of research and protection as a systemic integrity of three entities, namely, areas near trunk roads, air basin, and population. The paper presents an ER model of the research object and determines the main parameters, their interrelationships, and the action area for each entity.

Based on the conducted studies, we propose an engineering and planning solution for using special facilities for removing the most dangerous impurities of nitrogen oxides and dust from the air basin near the city trunk roads through ozonation and absorption. The research determines the operating conditions of the unit and presents a process flow diagram of purification. To take into account the emergency of ozone emission, we have carried out the modelling of ozone dispersion in the city.
At this stage, the proposed solution for non-regenerative air purification in urbanized areas requires small investments and fits into the linear economy model. However, according to the Concept of Zero Pollution by 2050 within the framework of the EU's Circular Economy Action Plan, such an approach is undoubtedly promising.

Literature:

1. Chen, B., & Kan, H. (2008). Air pollution and population health: a global challenge. Environmental Health and Preventive Medicine, 13(2), 94–101. DOI: https://doi.org/10.1007/s12199-007-0018-5.
2. Cichowicz, R., & Stelęgowski, A. (2019). Average Hourly Concentrations of Air Contaminants in Selected Urban, Town, and Rural Sites. Archives of Environmental Contamination and Toxicology, 77(2), 197–213. DOI: https://doi.org/10.1007/s00244-019-00627-8
3. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. (2021). Pathway to a Healthy Planet for All. EU Action Plan: "Towards Zero Pollution for Air, Water and Soil". Document 52021DC0400. Available at: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52021DC0400.
4. Egorova, G.V., Voblikova, V.A., Sabitova, L.V., et al. (2015). Ozone Solubility in Water. Moscow Univ. Chem. Bull., 70, 207–210. DOI: https://doi.org/10.3103/S0027131415050053.
5. Elkamhawy, A., & Jang, C. (2020). Performance Evaluation of Hybrid Air Purification System with Vegetation Soil and Electrostatic Precipitator Filters. Sustainability, 12(13), 5428. DOI: https://doi.org/10.3390/su12135428.
6. European Commission. (2020). Circular economy action plan. For a cleaner and more competitive Europe. Available at: https://op.europa.eu/en/publication-detail/-/publication/45cc30f6-cd57-11ea-adf7-01aa75ed71a1/language-en/format-PDF/source-170854112#.
7. Januszkiewicz, K., & Kowalski, K.G. (2019). Air Purification in Highly-Urbanized Areas with Use TiO2: New Approach to Design the Urban Public Space to Benefit Human Condition. IOP Conf. Ser.: Mater. Sci. Eng., 603, 052071. DOI: https://doi.org/10.1088/1757-899X/603/5/052071.
8. Kiesewetter, G., Borken-Kleefeld, J., Schoepp, W., Heyes, C., Bertok, I., Thunis, P., Bessagnet, B., Terrenoire, E., et al. (2013). Modelling compliance with NO2 and PM10 air quality limit values in the GAINS model. TSAP Report #9, V1.0, DG-Environment of the European Commission, Belgium. Available at: https://ec.europa.eu/environment/air/pdf/TSAP-Report-.pdf.
9. Krzyzanowski, M., Apte, J.S., Bonjour, S.P., et al. (2014). Air Pollution in the Mega-cities. Curr. Envir. Health Rpt., 1, 185 191. DOI: https://doi.org/10.1007/s40572-014-0019-7.
10. Linares, C., Falcón, I., Ortiz, C., & Díaz, Ju. (2018). An approach estimating the short-term effect of NO2 on daily mortality in Spanish cities. Environment International, 116, 18-28. DOI: https://doi.org/10.1016/j.envint.2018.04.002.
11. Nishanth, T., Satheesh Kumar, M.K., & Valsaraj, K.T. (2012). Variations in surface ozone and NOx at Kannur: a tropical, coastal site in India. J. Atmos. Chem., 69, 101-126. DOI: https://doi.org/10.1007/s10874-012-9234-5.
12. Popov, O., Iatsyshyn, A., Kovach, V., Artemchuk, V., Kameneva, I., et al. (2020). Risk Assessment for the Population of Kyiv, Ukraine as a Result of Atmospheric Air Pollution. Journal of Health and Pollution, 10(25), 200-303. DOI: https://doi.org/10.5696/2156-9614-10.25.200303.
13. Richmond-Bryant, J., Owen, R. C., Graham, S., Snyder, M., McDow, S., Oakes, M., & Kimbrough, S. (2017). Estimation of on-road NO2 concentrations, NO2/NOx ratios, and related roadway gradients from near-road monitoring data. Air Quality, Atmosphere, & Health, 10(5), 611–625. DOI; https://doi.org/10.1007/s11869-016-0455-7.
14. Sundvor, I., Balaguer, N.C., Viana, M., Querol, X., Reche, C., Amato, F., Mellios, G., & Guerreiro, C. (2012). Road traffic's contribution to air quality in European cities. ETC/ACM Tech. Pap., 2012/14. Available at: https://acm.eionet.europa.eu/reports/docs/ETCACM_TP_2012_14_traffic_contribution_city_aq.pdf.
15. Tatarchenko, H.O., Biloshytskyi, M.V., Tatarchenko, Z.S., & Biloshytska, N.I. (2020). Volodymyr Dahl East Ukrainian National University, assignee. Sposib ochyshchennia zabrudnenoho povitria urbanizovanykh terytorii [The method of cleaning polluted air in urbanized areas]. Ukraine patent, UA 147495. 2020, Dec. 15. (in Ukrainian).
16. Tatarchenko, G.O., Kravchenko, I.V., Pysarenko, M.V., & Porkuian, S.L. (2019). Doslidzhennia zabrudnennia atmosfernoho povitria vidpratsovanymy hazamy avtotransportu v miskomu seredovyshchi [The study of air pollution by exhaust gases of vehicles in urban environment]. Visnik of the Volodymyr Dahl East Ukrainian National University, 8(256), 99–104. DOI: https://doi.org/10.33216/1998-7927-2019-256-8-99-104.
17. Wang, L., Wang, Ju, Tan, X., & Fang, C. (2020). Analysis of NOx Pollution Characteristics in the Atmospheric Environment in Changchun City. Atmosphere, 11(1), 30. DOI: https://doi.org/10.3390/atmos11010030
18. WHO Air Quality Guidelines for Europe Air quality guidelines. (2005). Global update 2005. Particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Available at: https://www.euro.who.int/__data/assets/pdf_file/0005/78638/E90038.pdf.
19. World Air Quality Report. (2020). Region & City PM2.5 Ranking. Available at: https://www.iqair.com/world-most-polluted-countries.

Primary Paper Section: J

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