Presenting air quality status through hot spot maps realized by using Kernel Density Estimation (KDE) - case study: Craiova, 2020/2021

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Abstract. As hot spot mapping has become an usual technique used worldwide in order to obtain a clearer view on the geographic incidence of several factors from the most diverse fields, this paper aims to present a case study (developed late 2020 and early 2021) regarding air quality status of Craiova – an important Romanian city – involving the most relevant three gaseous air pollutants. The study has been realized by using a modern technique for generating hot spot maps on grids, as smooth continuous surfaces, which is Kernel Density Estimation (KDE).

1 Introduction

The use of color codes in the transmitting information is an already usual practice, as it is proven that such a way of communication ensures a much higher efficiency of receiving information, compared to the transmission of inexpressive sets of data. Indeed, it is known that the more suggestive the way of transmitting is, the greater the impact on the central nervous system of the information receiver, so representations that involve and stimulate the activity of the visual cortex have been scientifically proven to be the most effective.

Therefore, it is effective to use the possibility of translating information into a language of colors, so that it gets not only quickly perceived, but also well understood and even often retained, because, as is well known, the human eye captures light by means of two types of photoreceptor cells located in the retina (named after their shape: rods and cones - the latter being the ones responsible for color vision, therfore transforming the light signal into an electrical one, which is conducted through the optic nerve to the visual cortex).

In practice, suggestive – and, implicitly, efficient – simultaneous transmission of large databases (to a more or less informed receiver) can be done by means of „heat" or „hot spot" type maps. The main difference between the two types of maps is that the „heat" type ones show the momentary, real concentration, on the respective area, of the points of interest, and the „hot spot" type ones show their statistical distribution on a certain grid [1].

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The colors used or the intensities of color could have various meanings, which must be specified, on a case-by-case basis, in the caption that necessarily accompanies the respective maps presented.

The idea for such representations came from an analogy with medical imaging, where, already, the „translation" into visual language of objective data collected from the body – for example, in thermography or interstitial electrosomatography.

Such maps („heat" or „hot spot") are used in situations that require the presentation of aspects related to meteorology, climatology, seismology, as well as in studies on air, water, soil quality [2], but also in many other situations (for example, information on the severity of a pandemic, on the stage of vaccination, etc.).

The present paper aims to present a modern way of monitoring the air pollution regarding the three main gaseous air pollutants: nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and carbon monoxide (CO), using the method of representing air pollution through color codes [3].

2 Theoretical considerations

2.1 Kernel Density Estimation (KDE)

Kernel Density Estimation (KDE) is a modern technique for generating „hot spot" maps on grids, as smooth continuous surfaces.

It has a great visual impact, as it presents continuous surface map showing gradients of variation in the intensity of events across the investigated areas without being limited to thematic boundaries.

Therefore, KDE appears to be different from the mapping methods in which the surface that is generated is exclusively based on a non-parametric estimate of the intensity function across cell grids, by using a weighting function based on a constant bandwidth or search radius. The bandwidth can be obtained through an analysis which will determine the smallest distance at which clustering of events is most intense and significant, therefore representing an appropriate scale of analysis. Obviously, selecting bigger bandwidths will increase the degree of smoothing.

Though KDE is a flexible approach for visualizing „hot spots" within a map [4], this technique is submitted to some limitations. As in thematic mapping, defining „hot spot" legend thresholds for KDE „hot spot" maps is a subjective process, which is affected by the experience of the researcher, therefore including a lot of trial and experimental error (as an alternative, standardization approaches could be used to develop more objective „hot spot" thresholds levels) [4].

KDE can be used as a local-scale operational air pollution model for estimating dispersion from point sources and area sources.

It can be applied to both urban and rural settings extending to distances up to approximately 20 km from the sources. Based on the original model, several model versions have been developed over the years to treat different regulatory aspects, including assessment of air pollution [1, 4-7].

2.2 Statistical analysis in simulating air pollutant dispersion

The results of statistical analysis have been applied to computer science, physics, ecology, economics, psychology and a number of other fields as a fundamental model for different processes in time.

In statistics, it is assumed that the dataset to be analyzed consists of a hierarchy of different populations whose differences relate to that hierarchy [8].

Within the present paper, equations are defined for air pressure, density, velocity and potential temperature, incorporating mass, momentum and energy conservation (the equations are not shown here).

The movement of a passive particle in a turbulent flow is described by the system of equations below, and the particles' positions and velocities are computed on the three axes as follows:

$$x(t + dt) = x(t) + dt\,(u(t) + u^*(t)) \tag{1}$$

$$y(t + dt) = y(t) + dt\,(\mathrm{v}(t) + \mathrm{v}^*(t)) \tag{2}$$

$$z(t + dt) = z(t) + dt\,(\mathrm{w}(t)\mathrm{w}^*(t)) \tag{3}$$

Continuous emissions of air pollutants are described by the release of the symbol particles.

The distributions of these particles in space and time constitute the picture of air pollutant distribution.

The track of every particle is divided by some discrete sections in the grid, and the particles in every section go through the same time step. In every time step, the horizontal and vertical velocities can be computed, and every velocity consisted of the average velocity and the fluctuating velocity.

At every step,

$$V = \overline{V} + V^* \tag{4}$$

where V represents the u, v and w velocities on the three chartesian axes, $\overline{V}$ represents the average velocity and V^* represents the fluctuating velocity.

The fluctuating velocity $V^*(t + \Delta t)$ at the time $t + \Delta t$ is expressed as:

$$V^*(t + \Delta t) = V^*(t)R(\Delta t) + U(t + \Delta t) \tag{5}$$

where $R(\Delta t)$ represents the Lagrangian self-relative coefficient, which is expressed by:

$$R(\Delta t) = \exp(-\Delta t/T) \tag{6}$$

where T is a Lagrangian time scale, and $U(t + \Delta t)$ being a log-normal variable with a random distribution with a zero mean and σ standard deviation.

The σ parameter is expressed as:

$$\sigma = (\overline{V^{*2}})^{\frac{1}{2}}[1 - R^2(\Delta t)]^{\frac{1}{2}} \tag{7}$$

where σ represents σ_u, σ_v or σ_w (σ_u, σ_v are the standard deviations of the horizontal velocity distribution and σ_w is the standard deviation of the vertical velocity distribution). The values of σ_u, σ_v and σ_w are obtained from empirical relations, they being related to the meteorological conditions [8].

2.3 Drawing the grid and specifying boundary conditions

The altitude for the normal model region must be selected, and the thermal boundary layer is included and simulated by this altitude.

The grid is drawn, so a fine horizontal grid resolution is developed to explain the air flow pattern that forms the basis for the reproduction of the development and spatial variations of the parameters.

A three-dimensional spatial structure of the boundary layer evolution can be simulated.

The altitude must also be selected, and the thermal boundary layer is included and simulated by this altitude.

The grid is divided by horizontal and vertical lines, in order for a fine linear grid resolution to be developed for explaining the air flow pattern that forms the basis for the reproduction of the development and planar variations of the parameters, so a two-dimensional spatial structure of the boundary layer evolution can be simulated [1].

Boundary conditions must be taken into account.

Boundary conditions include: zero lateral gradient for all variables with the exception of out-flowing normal velocity (the condition for velocity has been chosen so the gravity waves are inhibited to reflect in the domain); a domain ceiling, limiting vertical velocity to zero (reflections of vertically propagating gravity waves are eliminated at the ceiling by introducing a Rayleigh friction layer in the upper region of the domain); zero tangential and normal velocity at the lower boundary.

In the simulation area, the concentration in every grid is a direct proportion to the sum of the particles passing through this grid [1, 4-7].

Considering the grid position at the *x* horizontal and *y* vertical away from the source, its volume is $dx \cdot dy \cdot dz$, and *dx, dy* are equals to the unit length. If n_j *is the* number of particles passing through the grid, the number of air pollutants in the grid is:

$$\frac{Qdxdy}{N}\sum_{i=1}^{n_j}\frac{1}{|u_j|} \tag{8}$$

where *Q* is the source quantity, so that the concentration profile is:

$$c(x,z)=\frac{Q}{Ndz}\sum_{i=1}^{n_j}\frac{1}{|u_j|} \tag{9}$$

The results generally show that using a „hot spot" study is beneficial, as it can be used to investigate planned or unplanned release of air pollutants.

3 Air quality within Craiova – the area subject to the study

3.1 General information about Craiova

Craiova is located in South-western Romania (within the 4th region, named „South-west Oltenia"), being one of the most developed cities of the country. Craiova is the capital of Dolj county (abbreviation: DJ).

It is situated at 44°20′ North latitude and 23°49′ East longitude.

Craiova metropolitan area is composed of 24 localities: one municipality (Craiova), two cities (Filiași and Segarcea), as well as 21 communes.

3.2 Monitoring and communicating air quality in Craiova

Air quality in Craiova urban area (including its surrounding suburban zone) is continuously monitored.

The concentrations of different air pollutants are recorded by five modern monitoring stations provided by the European Community [9], which are denoted by: DJ1, DJ2, DJ3, DJ4, DJ5 (as previously stated, DJ is the abbreviation for Dolj county).

The aspect of such a station is presented in Fig. 1, where the meaning of the Romanian words written on the front plexiglass panel is: „Craiova automatic air quality monitoring network".

Near the city hall, there is an electronic display panel exhibiting information about the general air quality index, for which a color code is used, corresponding to the scale of the air quality states, as follows: 1) excellent – color: deep green; 2) very good – color: green; 3) good – color: yellowish green; 4) medium – color: yellow; 5) bad – color: orange; 6) very bad – color: red. This electronic display panel is shown in Fig. 2.

Moreover, all the data are included in the Monthly Report on the Environment State in Dolj County [10], being also published on the site of the local environmental agency, APM DJ [11], which is linked to the site of the national environmental agency, ANPM [12].

Fig. 1. One of the five monitoring stations in Craiova – Dolj County.

Fig. 2. Electronic display panel exhibiting information about the general air quality index in Craiova.

In addition to mobile sources of pollution (road traffic), major stationary sources of pollution in Craiova are represented by economic operators, of which the most representative were located on a map, for their better spatial visualization. This map (which was taken over from the local environmental agency, APM DJ [11]) is revealed in Fig. 3.

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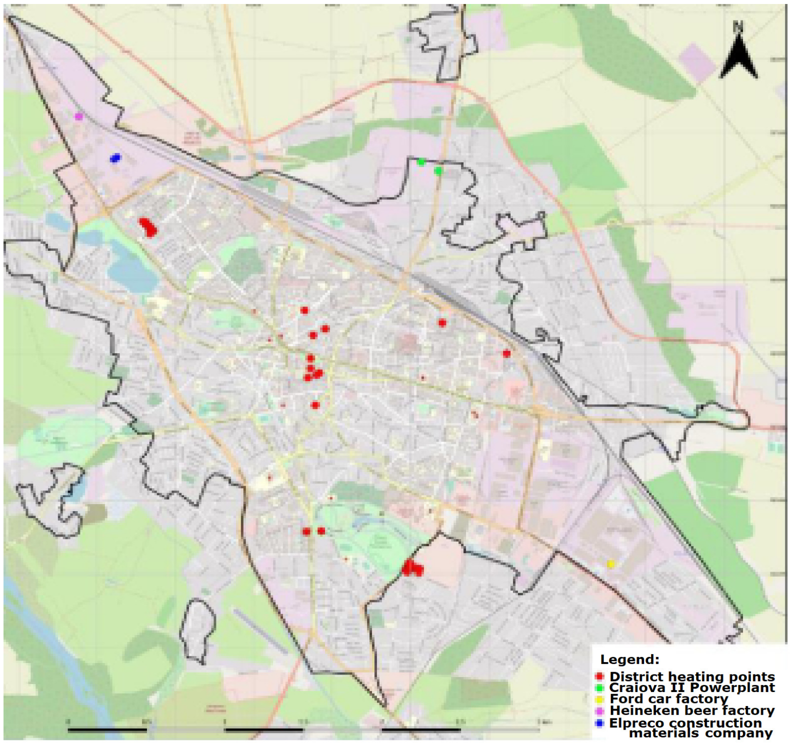

Fig. 3. Major stationary sources of pollution in Craiova.

4 Case study: Craiova „hot spot" maps revealing air quality status

4.1 Concentrations of the main gaseous air pollutants in the monitored period

Results recorded by the first two of the five stations mentioned above, between November 1st, 2020 and April 30th, 2021 were taken into account.

Obviously, the concentrations are proportional to the quantities of the air pollutants [13].

The concentrations of the main gaseous air pollutants (namely: NO_2, SO_2 and CO) during the monitored period are presented in Fig. 4-6.

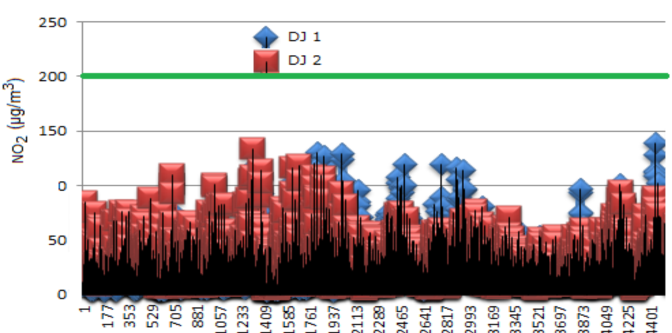

Fig. 4. Concentrations of nitrogen dioxide (NO_2) recorded in Craiova during the monitored period.

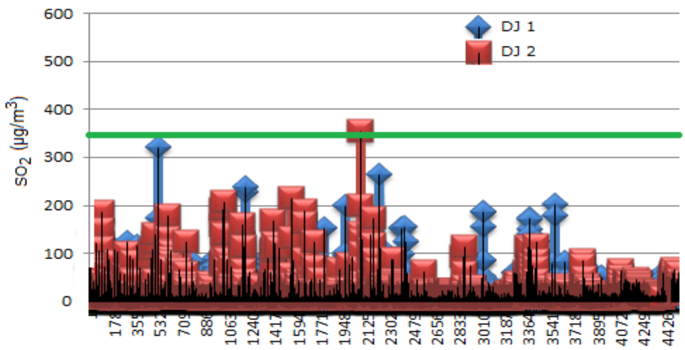

Fig. 5. Concentrations of sulfur dioxide (SO_2) recorded in Craiova during the monitored period.

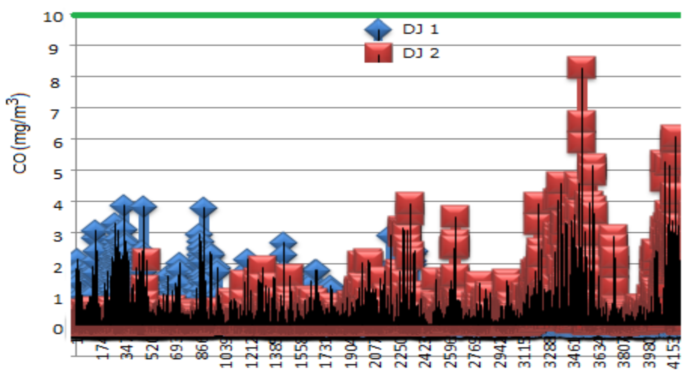

Fig. 6. Concentrations of carbon monoxide (CO) recorded in Craiova during the monitored period.

4.2 The grid realised for Craiova metropolitan zone

Initial conditions of the model are: temperature, humidity and wind profiles, as functions of height above ground level. The region submitted to study was divided into an array of cells.

The grid (Fig. 7) was realised by taking into account the entire metropolitan zone (all the twenty-four localities: the municipality, two cities and twenty-one communes) [1].

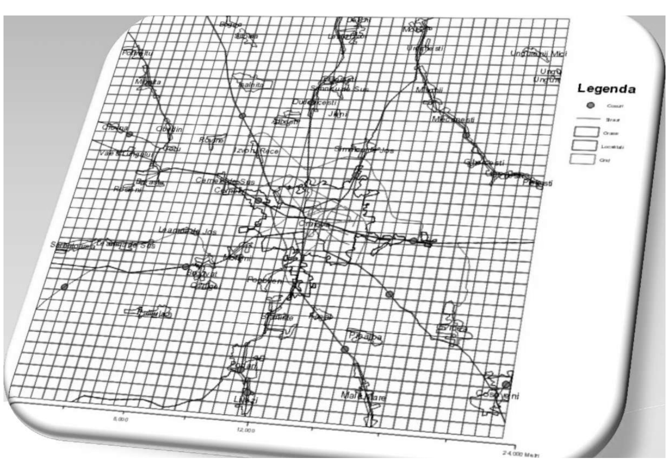

Fig. 7. The grid realised for Craiova metropolitan zone.

4.3 Monitoring air quality in Craiova

By using this grid and the graphs previously obtained for the concentrations of the main gaseous pollutants (Fig. 4-6), their „hot spot" dispersion maps were drawn [1], by means of the appropriate dispersion model mentioned above (KDE).

They are presented in Fig. 8-10.

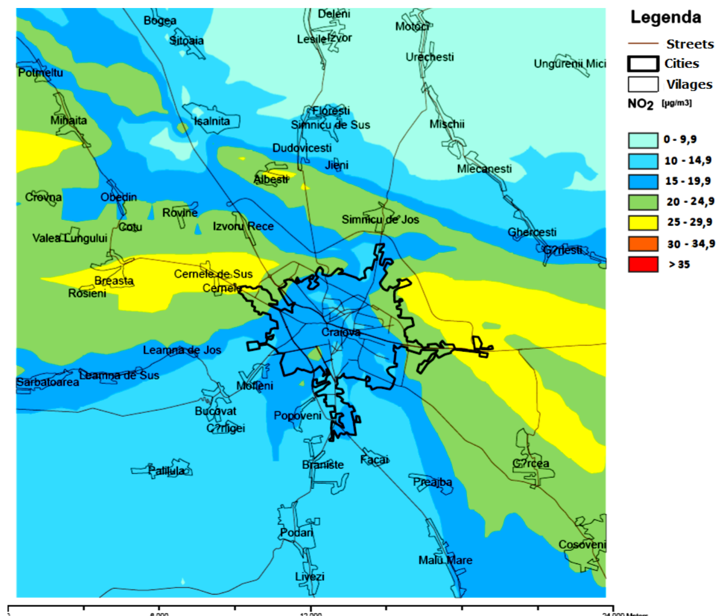

Fig. 8. „Hot spot" map indicating the mean concentration of NO_2 over Craiova metropolitan zone.

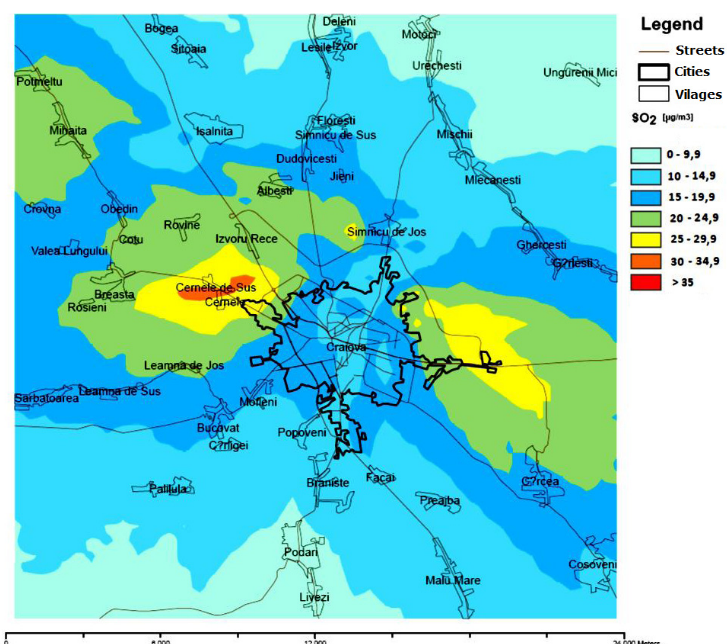

Fig. 9. „Hot spot" map indicating the mean concentration of SO_2 over Craiova metropolitan zone.

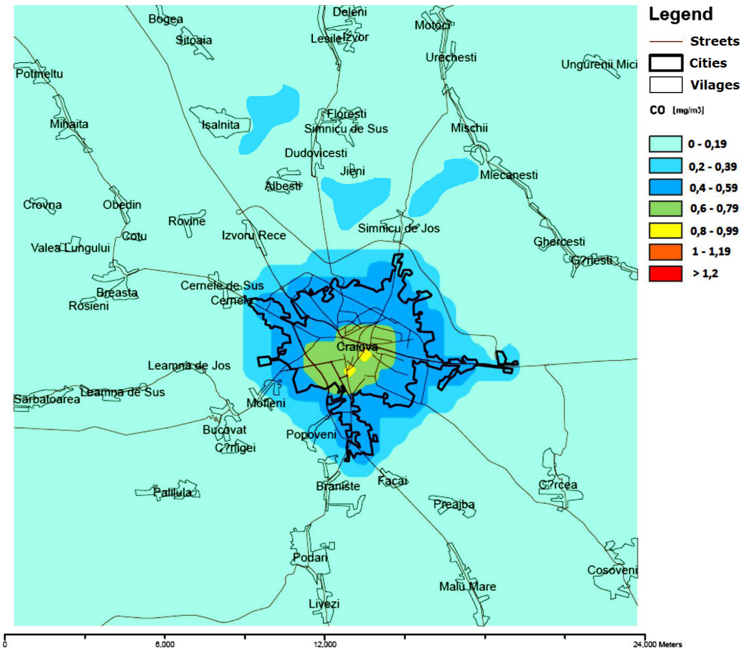

Fig. 10. „Hot spot” map indicating the mean concentration of CO over Craiova metropolitan zone.

Every map shows a mean of a statistical distribution with a continuous random variable (pollutant concentation), also called the expected value, obtained by integrating the product of the variable with its probability, as defined by the distribution [8].

4.4 Pollutants dispersion

As far as pollutants dispersion is concerned, it is obviously important to know the way in which they are dispersed, since there are a lot of dwellings in the studied arrea, as well as various economical agents and institutions.

As is well known, the movement of pollutants in the atmosphere is caused by transport, dispersion and deposition („transport” is a movement caused by time-averaged wind flow, „dispersion” results from local turbulence, whereas „deposition” includes precipitation, scavenging and sedimentation, causing some downward movements of pollutants in the atmosphere, which ultimately remove them to the ground surface) [14].

Generally, pollutant concentrations decrease with distance away from the pollution source, although the degree of this decrease varies (traffic activity, wind speed and wind direction having a big influence on the dispersion manner). For example, the highest concentrations of roadway pollutants occur on or just downwind of a road way and decrease to ground levels within 150-200 m, pollutant concentrations tending to be higher when winds blow from the road and also when wind speeds are low [15].

4.5 Comparison between the results obtained and the ones from similar studies

We have compared our own results with some similar environmental research developed worldwide.

Thus, we have comparatively analysed research findings referring to areas from different countries, namely: Israel [4], India [6], Slovenia [16], Kuwait [17], Spain [18], Romania [19], Italia [20] and China [5, 21-23].

This comparison leads to the conclusion in Craiova metropolitan area is not an alarming one. However, the local competent authorities, as well as the main economic agents that generate pollution (namely: Craiova II Powerplant, Ford, Heineken, Elpreco – which were presented in Fig. 3) [11] must consider the necesity of diminishing air pollution, in order to meet the environmental requirements imposed at European [9] and global level [15].

5 Conclusions

From the present study, whose main purpose was examinating the spreading of the main gaseous air pollutants over Craiova metropolitan area during a certain period of time, one may observe that the concentrations of the three main air pollutants taken into acount (namely: NO_2, SO_2 and CO) did not exceed in an alarming manner the main limitation imposed for these pollutants by Law no. 104/2011 on ambient air quality, which refers to their hourly values (*i.e.*, an average of 200 μg/m^3 per hour for NO_2, an average of 350 μg/m^3 per hour for SO_2 and an average of 10 mg/m^3 within eight hours for CO.

More precisely, one can see that the regulated limit-value for NO_2 was not reached at all during the experiment, and neither was the regulated limit-value for CO. The only pollutant for which the regulated limit-value was reached – and also other quite high values were recorded – was SO_2, which most probably mainly occured because of the central heating, specific to the winter time.

However, we might conclude that neither of the „hot spot" dispersion maps – realised by using KDE statistical model – show an alarming pollution of the air for Craiova metropolitan zone, during the case study period, namely from November 1st, 2020 until April 30th, 2021.

As a result of the comparisons to other similar studies, we could draw the conclusion that the air pollution within Craiova metropolitan zone is not alarming compared to other areas of the globe.

However, there are still some measures to be taken, which the competent authorities, together with the main economic agents generating pollution, are already dealing with (for example, in order to reduce sulfur dioxide emissions, the thermal powerplant – Craiova II – takes measures to improve the quality of the filters used at the exhaust stacks; on another side, for reducing the negative effects of the road traffic, *i.e.*, in order to reduce nitrogen dioxide and carbon monoxide emissions, the municipality already purchased fully electric buses).

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