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EVALUATION OF THE MITIGATION EFFECTS OF VEGETATION ON AIR QUALITY IN THE FLORENCE METROPOLITAN AREA

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ABSTRACT

The work presented at this conference is aimed to evaluate the mitigation effects of a green area on the air quality in the Florence (Italy) metropolitan area. For the calculation of the dry deposition velocity for each involved specie a model based on the plant cover and on the vegetation structure (the so-called canopy) has been created. The dispersion process has been simulated using SAFE AIR. Simulations have been carried out for three scenarios. This work showed that an adequate localisation of a green area, with plant species effective in removing atmospheric pollutants, can play a determinant role for the improvement of the air quality in the considered area.

Key Words: Dispersion modelling, dry deposition, vegetation, mitigation, pollutant removal

1. INTRODUCTION

Vegetation in urban areas can affect air quality both locally and at regional level. Green areas can affect air quality in four main ways:

- temperature reduction and other microclimatic effects;
- direct atmospheric pollutants removal;
- volatile organic compounds (VOC) emission;
- and, energy consumption reduction.

Trees and their transpiration influence air temperature, radiation absorption, heat storage, wind velocity, relative humidity, atmospheric turbulence, surface albedo and mixing height. These micrometeorological modifications can sensibly affect pollutant concentration in urban areas. The main effect on the temperature is a reduction due the increased shadow and the transpiration. This enhances air quality because the emission of many pollutants, as well as ozone formation, is temperature-dependent. VOCs emission by vegetation can contribute to ozone and carbon monoxide formations. However, since VOCs production is temperature-dependent and temperature is decreased by the presence of the trees, also the VOC emission as well as ozone production are lower (Cardelino and Chameides, 1990). Trees also contribute to the buildings energy consumption reduction. This is due to the summer temperature reduction as well as to protecting buildings from the winds in winter (Heisler, 1986).

Vegetation contribute also directly to atmospheric pollutants removal by means of the leaves (see, e.g., Smith, 1990). Trees have direct effects also on the atmospheric particulate: a part of this is absorbed by the plant, but most of it is stored only temporary on the plant surface. The larger the canopy surface, the larger the increase of air quality.

In this paper only the latter effect has been taken into account. The work presented at this conference is aimed to evaluate the mitigation effects of a green area on the air quality in the Florence metropolitan area (Italy). The research has been performed in the framework of the VIS project (Health Impact Assessment applied to the Waste Management Plan of the Province of Florence), funded by the Province of Florence and the EU (LIFE 02 ENV/IT000018 "VISP project").

Pollutant removal models and dispersion models have been jointly applied to investigate on the effects of some mitigation scenarios.

2. POLLUTANT REMOVAL SIMULATION MODEL

For the calculation of the dry deposition velocity for each involved specie a model based on the plant cover and on the vegetation structure (the so-called canopy) has been created. In each model the canopy has been treated as single or multiple layer based on the complexity of the model.

The model has been implemented in visual basic. It starts from the definition of the deposition velocity V_d (Baldocchi et al.,1987, Nowak, 1994, Scott et al., 1998) as:

$$V_d^i = (R_a + R_b^i + R_c^i)^{-1} \tag{1}$$

where $R_a=u(z)/u_*^2$, u(z) is the wind speed at height z, and u_* is the friction velocity; the resistance of the boundary layer is described by the following function (Pederson et a.l, 1995):

$$R_b = 2(Sc)^{\frac{2}{3}}(\Pr)^{-\frac{2}{3}}(ku_*)^{-1} \tag{2}$$

where *Sc* is the Schmidt number and *Pr* is the Prandtl number. R_c, is the canopy resistance and it is the main descriptor of the deposition model based on vegetation. R_c is calculated as (Baldocchi 1988; Nowak, 1994):

$$1/R_c = 1/(r_s + r_m) + 1/r_t \tag{3}$$

r_m is the component of the resistance depending from the mesophyill, r_t is the value of the cuticular resistance. Both parameters depends from the pollutant studied. $1/r_s$

is the stomatal conductance and can be calculated following the so-called big-leaf models, starting from:

$$g_s = g(PAR)g(T)g(T)g(\psi)D_v / D_i \tag{4}$$

D_v e D_i are the molecular diffusivity of the water vapour and of the pollutant, respectively. The response of the stomatal conductance to the *PAR* (Photosynthetic Active Radiation) is assessed as:

$$g_s(PAR) = 1 / r_s(PAR) \tag{5}$$

where $r_s\ (PAR) = r_5$ (min) + $b_{r5}r_5$ (min) / *PAR*; r_s(min) is the minimum value of conductance in optimal conditions and b_{rs} is a constant. There are a number of published papers reporting the value of r_s(min) for many vegetal species (eg. Korner et al., 1979). The stomatal conductance of the canopy G_s is calculated as a PAR function:

$$G_s = (PAR) = \int_0^f df_{sun}(f)g[PAR_{sun}(f)] + df_{shade}(f)g[PAR_{shade}(f)]df \tag{6}$$

where f is the leaf area, df_{sun} e df_{shade} are the differences in leaf area in light (f_{sun}) and in shade (f_{shade}) between f and $f+df$. The PAR_{sun} and the PAR_{shade} are the densities of the fluxes for the lighted and shaded leaves, respectively. To calculate f_{sun}, df_{shade}, PAR_{sun} e PAR_{shade} a radiaction transfer model can be used:

$$f_{sun}(f) = [1 - \exp(-0.5 f / \sin(\beta))]2\sin(\beta) \tag{7}$$

where β is the sun elevation angle. The shaded leaf area is $f_{shade}(f) = f - f_{sun}$. The PAR_{sun} depends from the average angle between the leaf and the sun. The PAR flux inside the canopy is calculated from the radiation transfer model of Norman (1982):

$$PAR_{sun}(f) = PAR_{dir}\cos(\alpha) / sen(\beta) + PAR_{shade}(f) \tag{8}$$

where PAR_{dir} is the density of the flux of *PAR* over the canopy and α is the angle between the leaf and the sun. PAR_{shade} is calculate empirically from the following equation (Norman, 1982):

$$PAR_{shade}(f) = PAR_{dir}\exp(-0.5 f^{0.7}) + 0.07 PAR_{dir}(1.1 - 0.1 f)\exp(-\sin(\beta)) \tag{9}$$

The temperature dependence of the stomatal conductance (g) is calculated as $g(T) = [(T-T_{min})/(T_0-T_{min})][(T_{max}-T)/(T_{max}-T_0)]^{bt}$, where T_{min} e T_{max} are the maximum and minimum temperatures which are able to close the stomata. T_o is the best temperature for the stomatal functioning and b_t is defined as $b_t=(T_{max}-T_0)/(T_{max}-T_{min})$. The dependence of the stomatal conductance from the vapour pressure deficit (D) is linear: $g(D)=1-b_vD$, where b_v is a constant.

The water deficit can be quantified as leaf water potential (ψ). The stomatal conductance is relatively independent from (ψ) until a threshold value (ψ_0) after which g_s decrease rapidly. The function $g(\psi)$ is calculate following a linear model (Fischer et al., 1981): $g(\psi)=1$, if $\psi > \psi_0$, and $g(\psi)=a\psi+b_w$ if $\psi < \psi_0$, where a and b are constants. Thus, the stomatal resistance can be calculated be combining the previous equations: $R_5=1/[G_5(PAR)g(T)g(D)g(\psi)D_i/D_v]$.

3. DISPERSION MODEL

The dispersion process has been simulated using a three-dimensional new generation atmospheric dispersion model. The SAFE_AIR model (Simulation of Air pollution From Emissions _ Above Inhomogeneous Regions) has been implemented at the Department of Physics of the University of Genova (Italy), it simulates the transport and diffusion of airborne pollutants above complex terrain at local and regional scale (Canepa et al. 2003). SAFE_AIR II (the newest version of the model) is included in the Model Database of the European Topic Centre on Air Quality of the European Environment Agency (URL1 2005), while a previous version of the model has been selected by the Italian Agency for Environmental Protection and for Technical Support (APAT; URL2 2005) to be inserted in their list of air pollution models to be used in air quality evaluation. The main improvements of SAFE_AIR II concern its meteorological part and the algorithms to simulate diffusion of pollutants. However, during this world the old version has been applied.

SAFE_AIR consists mainly of two parts: a meteorological pre-processor (WINDS, Wind-field Interpolation by Non Divergent Schemes, Release 4.2) and a model which simulates the airborne pollutant transport and diffusion (P6, Program Plotting Paths of Pollutant Puffs and Plumes, Release 2.1). In the newest version II there is also another meteorological pre-processor (ABLE, Acquisition of Boundary Layer parameters, Release 1.2) capable of calculating the horizontal distribution of relevant boundary layer parameters like mixing height h , Monin -Obukhov length L , friction velocity $u*$, convective velocity scale $w*$ starting from routinely measured meteorological variables.

WINDS (Georgieva et al. 2003) is a diagnostic mass-consistent model which reconstructs the 3D wind field in complex terrain at mesoscale using available wind data. Release 4.2 of the model incorporates advances in numerical formulation. In fact, besides the SOR (Successive Over-Relaxation) iterative method, the ADI (Alternating Direction Implicit) iterative method has been implemented in order to achieve a non-divergent flow field. The ADI method is much more effective than the SOR method as far as converge of the code is concerned. It reduces up to 30 times computational time, especially for stable cases.

P6 (Canepa and Ratto 2003) is a Lagrangian multi-source model that make use of both Gaussian plume segments and puffs to simulate airborne pollutant dispersion, in such a way it allows to deal with numerical simulation of both non-stationary and inhomogeneous conditions. The dispersion parameterisation in P6 has been recently improved with the implementation of new advanced sets of dispersion σ-functions.

4. CASE STUDY

The studied area is 8 km x 8 km and is located in the Florence metropolitan area, approximately 8.5 km north-west from the city centre. The dispersion model has been applied using the climatologic method, that is applying a simplified average meteorology by means of the Joint Frequency Functions (JFF) calculated using a large amount of meteorological data (measures from a meteorological station for a period of 4 years). Simulations have been carried out for an hypothetical waste-to-energy plant to be constructed in the area, as well as for other pollution sources (line sources, the two highways in the area, A1 and A11; and point sources, the main industrial stacks in the area). For the green area, two different scenarios have been studied. The first one is referred to as "mitigation", while the second one involves a larger area and has been called "improvement" (see map in figure 1). Two different location for the waste-to-energy plant have been studied (referred to in the map as CP and OSM).

Tree and shrubs species used for the study, both evergreen and deciduous, were selected among the most popular species growing in the study area provided they were well-adapted to the environment, fast growing, if possible, and with a big LAI (Leaf Area Index). Following these criteria species such as *Quercus robur*, *Populus alba*, *Populus nigra*, *Fraxinus ornus*, *Fraxinus oxycarpa*, *Ulmus minor*, *Carpinus betulus Salix alba Euonymus europaeus*, *Ligustrum vulgare*, *Viburnum opulus* , etc., were selected.

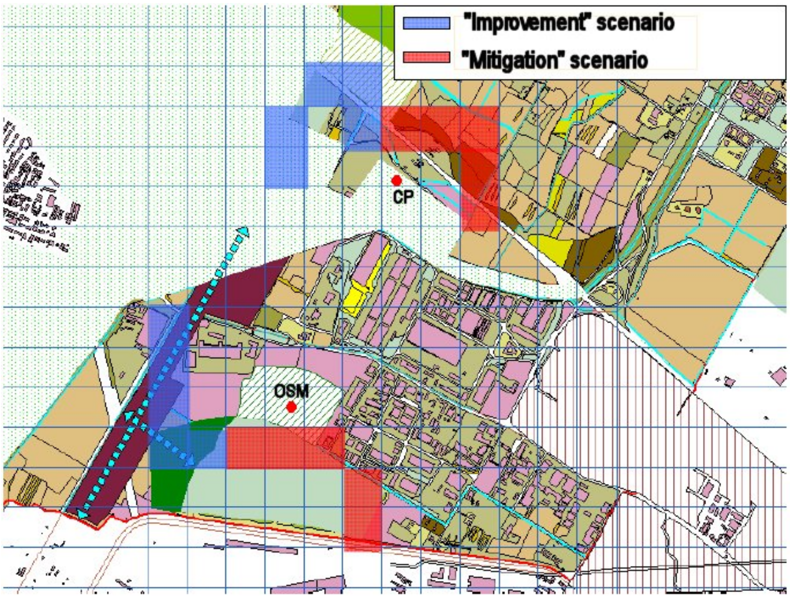

Figure 1. Map of the studied area showing the mitigation scenarios and the two locations for the waste-to-energy plant.

Simulations have been carried out for the three scenarios (scenario 0, businnes as usual, BAU; scenario 1, mitigation; scenario 2, improvement), using the dry deposition velocities previously calculated. Results take into account for the effects on the three sources systems (waste-to-energy plant, main line sources and main point sources) for the five pollutants studied (NO_2, SO_2, PM_{10}, Cd and Pb).

5. RESULTS

Some of the results are showed in figures 2-8, just as examples.

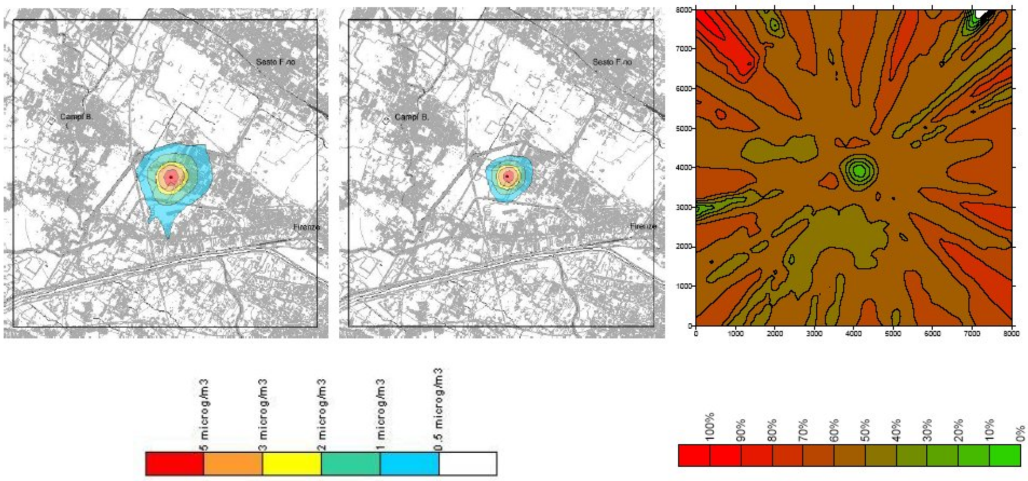

Figure 2. Annual mean concentration map of NO_2 for the scenario 0 (left) and the scenario 1 (centre); Contour map of the relative difference between the two scenarios (right). Emission from the waste-to-energy plant at OSM.

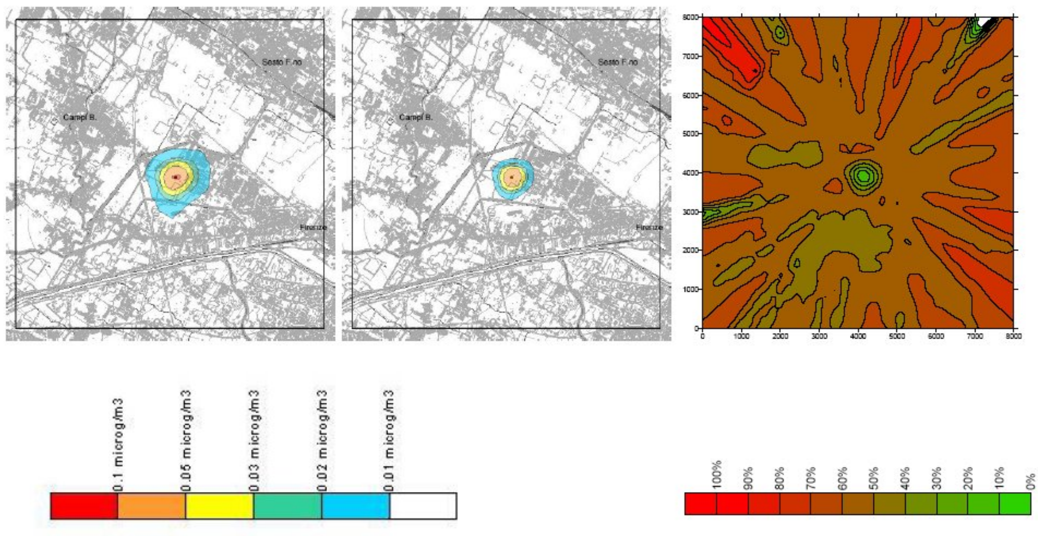

Figure 3. Annual mean concentration map of PM_{10} for the scenario 0 (left) and the scenario 1 (centre); Contour map of the relative difference between the two scenarios (right). Emission from the waste-to-energy plant at OSM.

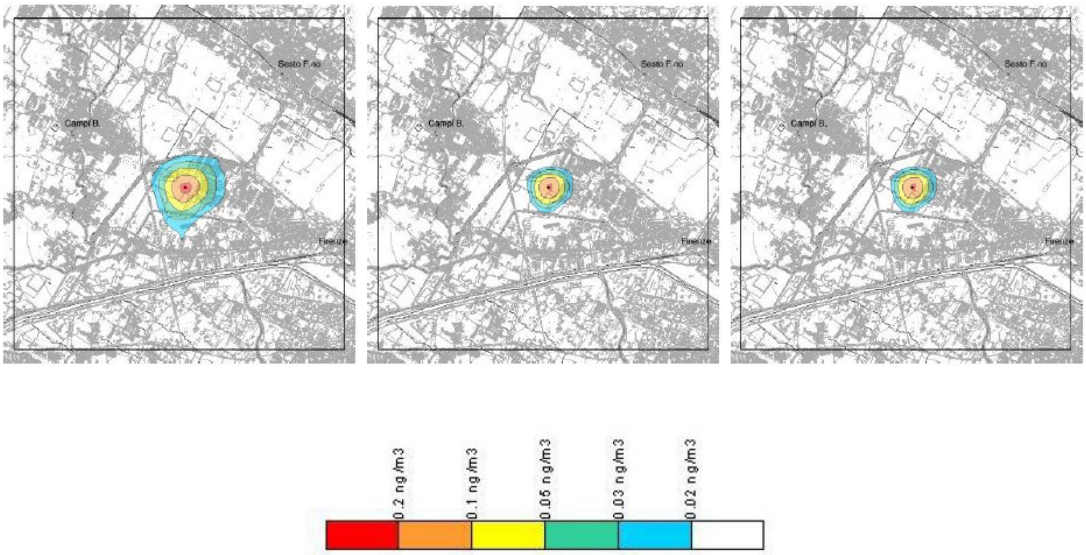

Figure 4. Annual mean concentration map of Cd for the scenario 0 (left), the scenario 1 (centre) and the scenario 2 (right). Emission from the waste-to-energy plant at OSM.

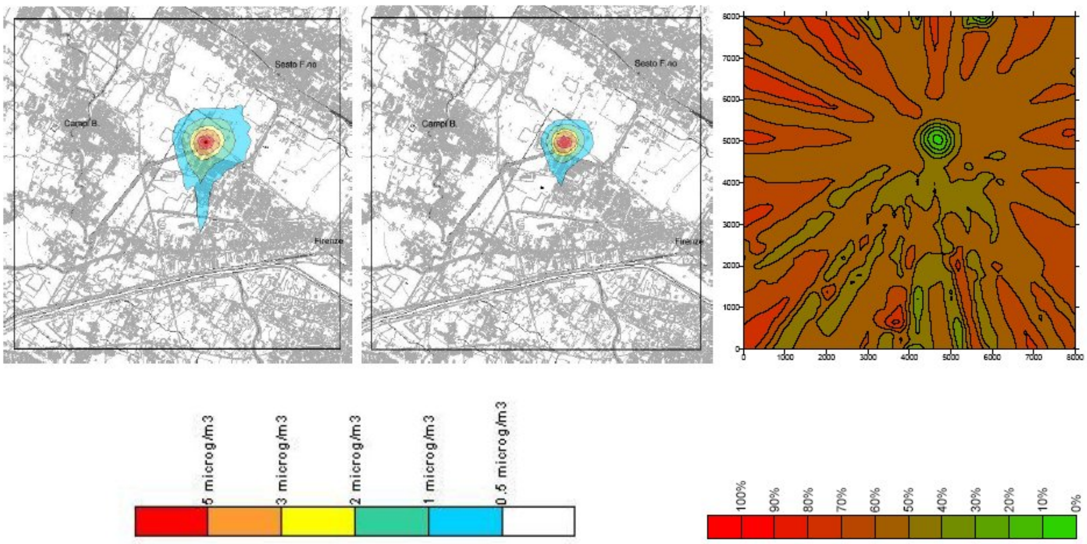

Figure 5. Annual mean concentration map of NO_2 for the scenario 0 (left) and the scenario 1 (centre); Contour map of the relative difference between the two scenarios (right). Emission from the waste-to-energy plant at CP.

For the simulations relative to the waste-to-energy plant, the results show an average reduction of the pollutants concentration between 50% and 90% for the scenario 1. The scenario 2 does not seem to add further advantage to the situation, with a marginal impact on the concentration reduction. This is probably due to the location of the added green area, rather far from the considered stack.

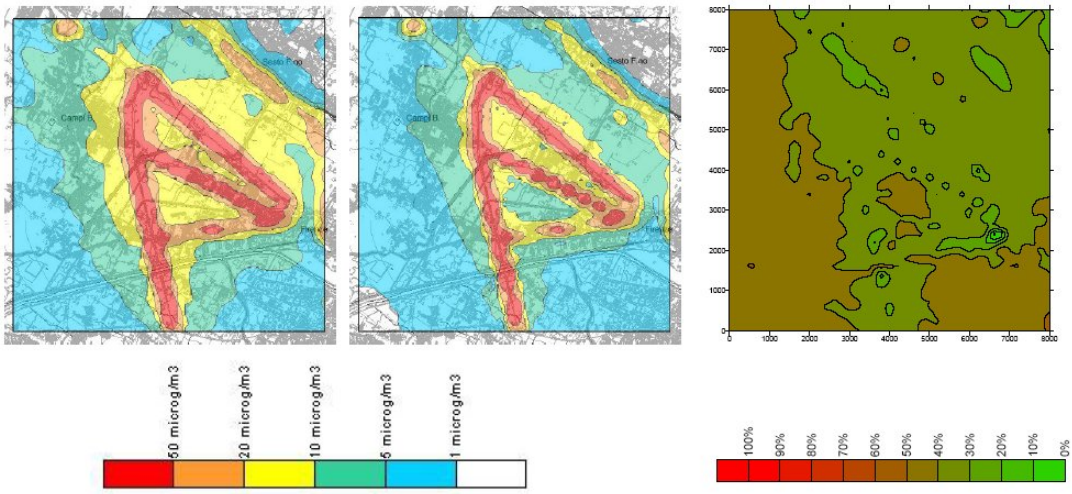

Figure 6. Annual mean concentration map of NO_2 for the scenario 0 (left) and the scenario 1 (centre); Contour map of the relative difference between the two scenarios (right). Emission from the main line sources.

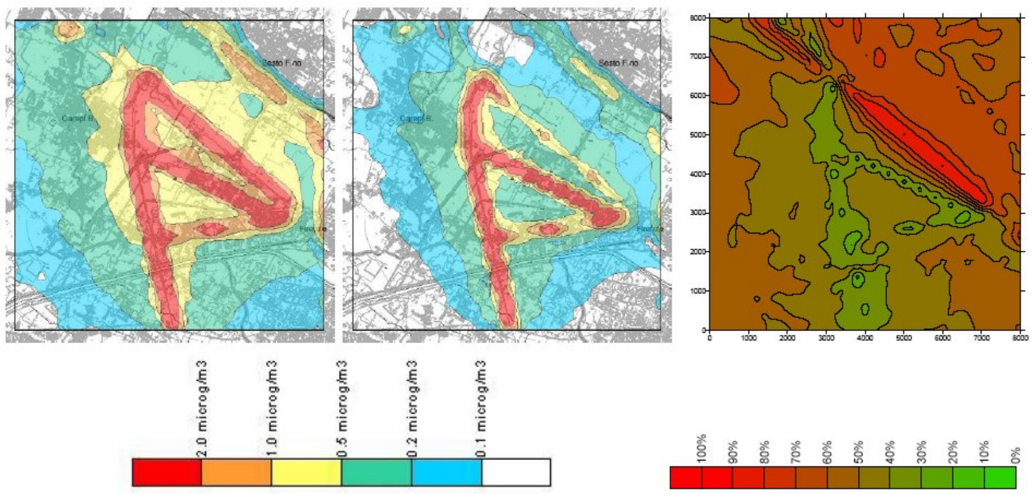

Figure 7. Annual mean concentration map of PM_{10} for the scenario 0 (left) and the scenario 1 (centre); Contour map of the relative difference between the two scenarios (right). Emission from the main line sources.

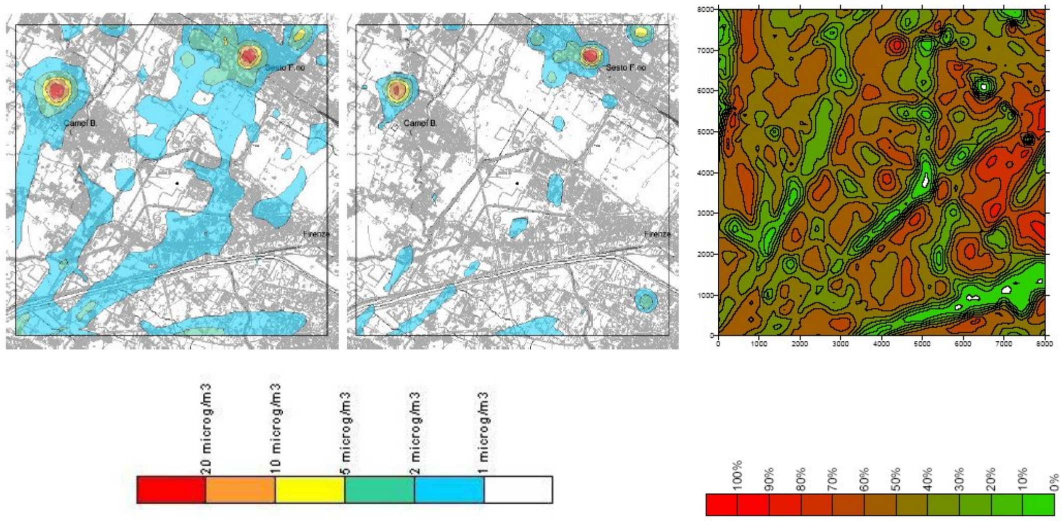

Figure 8. Annual mean concentration map of SO_2 for the scenario 0 (left) and the scenario 1 (centre); Contour map of the relative difference between the two scenarios (right). Emission from the main point sources.

Similarly, for the main line sources and the main point sources, the simulations show a pollutants concentration reduction in the scenario 1 between 30% and 60%, with maxima of 80-90% for some pollutants. Also in this case the scenario 2 does not add further advantages.

6. CONCLUSION

In conclusion it can be stated that an adequate localisation of a green area of 2 km^2 (scenario 1), with plant species effective in removing atmospheric pollutants, can play a determinant role for the improvement of the air quality in the considered area. They are capable of effectively reducing the impact of the waste-to-energy plant, with a considerable effect on the existing pollutant sources as well.

7. ACKNOWLEDGEMENTS

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