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Planning Post Carbon Cities

Editors:
Jorge Rodríguez Álvarez
&
Joana Carla Soares Gonçalves

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The Green Breath of the City:

A Dynamic Approach for Air Purification through NbS in the City of Milan, Italy

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ABSTRACT: Air pollution is a worldwide issue and is considered one of the biggest urban challenges and the single largest environmental health risk in Europe. Exposure to Air pollution causes serious health problems and even mortality. In recent decades, cities recognise that nature can be part of the solution to air pollution reduction. By focusing on Milan as the case study and Nature-based Solutions (NbS) as the main framework, this research aims to present the most convenient time-dependent implementation strategies through a dynamic process, for maximising air purification through nature. The cycles of the city (mainly people movements) can benefit from optimizing the cycles of nature, which is here intended as a breathing system that purifies air at different rates and times of the day. Based on optimal targeting criteria, three target exposure areas have been recognized for three different timespans of the day. For the optimal selection strategy, Urban Green NbS and vegetation have been classified based on their appropriateness to different exposure time. This study aims to show that with consideration of time and locations, and by the optimal selection of Urban Green NbS and the vegetation species, air purification in all parts of the city can be maximised.

KEYWORDS: Air purification, Urban green Nature-based solution, Air pollution exposure, Optimal selection, Optimal targeting

1. INTRODUCTION

Air pollution is a worldwide issue and based on World Health Organization (WHO) is the single largest environmental health risk in Europe [1]. Clean air is considered a basic requirement for human health and well-being. By increased urban population and people activities, increasing outdoor air pollution is unavoidable. Studies about long-term exposure to air pollution demonstrate that people living in more polluted locations die prematurely, compared to those living in areas with lower levels of pollution [2].

Numerous programs and policies address air pollution direct and indirect impacts from the global level to the local scale. More recently, applying natural green elements is taken into consideration as a complementary strategy for air pollution removal due to its flexibility of implementation, multilateral benefits and efficiency.

2. HEALTHIER AIR BY APPLYING NATURE-BASED SOLUTIONS

Nature-based Solutions (NbS) are actions inspired by, supported by, or copied from nature, and that are designed to address a range of environmental challenges in an efficient and adaptable manner, while at the same time providing economic, social and environmental benefits [3]. "Green NbS" refer to those actions that address environmental challenges with green elements exclusively. In the case of air purification and reduction of exposure to air pollution, green air purifiers can be favourable solutions to improve air quality, because they provide additional benefits, like urban heat island mitigation, biodiversity increase, improved psycho-physiological well-being, among others.

3. THE CASE STUDY OF MILAN

Milan is a densely populated metropolitan city (over 3.2 million inhabitants) in Northern Italy, located in the heart of the Po Valley, is part of a flat, highly urbanized and industrialized area. Air quality is often poor due to relevant amounts of air pollutants released by transport, civil and industrial sectors [4]. Moreover, the geographical location protected by the Alps on the north side of the Lombardy Region, strongly limits natural ventilation. Hence, in Milan, as well as in large areas of the Lombardy Region and the Po Valley, air quality standards overcome the limits established by the EEA for fine atmospheric particulate matter (PM10 and PM2.5) [4] .

Table 1: comparison of standard levels of air pollutants and Milan Air pollutants, 2017

Pollutant	WHO guidelines	EU Ambient Air quality Directives	Main annual mean Value
PM 2.5	10	25	25-30
PM 10	20	40	30-43
O3	100	120	>140
NO2	40	40	64

Based on (Table 1) which is author's elaboration on the basis of [5], in Milan the levels of all pollutants is higher than average levels respecting WHO and EAP standards.

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3.1 Role of green elements in air quality management

Recently, Milan has implemented several urban green interventions, but mostly not with the direct scope of air pollution reduction. Mostly, greening strategies in Milan aim to improve landscape, protecting habitats, reducing soil consumption and increase biodiversity or changes in land use regulations.

It is evident that any green intervention will lead to improving air quality by consequences, but selecting green adequate measures by considering their location and the specific type of green species with the main aim of air pollution reduction, would lead to better results to tackle the problem of air pollution and its impact on population's health.

4. THE PROPOSED METHODOLOGY: THROUGH A DYNAMIC PROCESS

This study suggests implying Urban Green NbS in parallel to other mitigation measures in Milan to purify the air. The main concept of this proposal is to provide a dynamic approach for tackling air purification, by including the time variable at the urban scale.

4.1 Framework of the Dynamic Process

This research is divided in two main steps. In the first step, an analysis has been carried out to clarify the issue by assessing two main elements, namely the hazard of pollution flows and the exposed population, taking into account the different times of the day. This step presents a dynamic process of optimal targeting of population concentration and pollution concentration to identify the locations of the highly exposed areas at different periods of the day in Milan. The second step refers to the optimal selection of NbS types by evaluating the extent of solutions for the most suitable measures to be implemented, based on the specific location and time of exposure of the identified hotspots. Optimal selection is about answering to the question of 'what' or finding the best NbS to maximise air purification at specific timespans. Using this concept, air purification is enhanced by maximising the ability of green elements in absorbing pollutants at different times of the day.

4.2 Optimal targeting

To identify target areas of exposure, three different timespans have been defined based on general air pollution and population distribution patterns in Milan. Three timespans included: Rush hours; Middle hours; and Night-time of regular working days. Since commonly people follow more unified patterns during weekdays due to their day today activities like work and education, hence, regular working days have been selected in this study.

4.2.1 Population

In this research two types of population have been defined: passive and active population. Passive population refers to 'night population', mostly residents, derived from national and local statistical data [6,7]. Active population refers to 'day population' and is divided in two main categories of Rush hours and Middle hours. Analysing and mapping mobility requires the integration of traditional data and new sources of information, closer to city users, such as the tracking of mobile phone data activity or geo-located activity [8]. Tracking people based on their mobile phone devices enables to map the exact location of city users at different times of the day. Data generated from previous research has been used [9].

4.2.2 Air pollution

The second dynamic element mapped in this research is the hazard, i.e. air pollution. Air pollution is a transboundary feature, and it cannot be captured and stopped locally. Acquiring data about the location of pollution emission sources is crucial for deriving the hazard map. In this study, traffic congestion and the vehicular flows as the main sources of air pollution have been considered according to the same three timespans identified above. Due to the limitations of this study, other sources of pollution (mainly residential heating and industry) have not been accounted. However, the main concern is air pollution sources at the ground level where people use public space and interact with the street level.

To obtain air pollution data for different times of the day, besides considering the general traffic trend in Milan, the origin-destitution (O/D) data released by Agenzia Mobilità Ambiente e Territorio (AMAT) [10] and traffic data from Google Maps for different times of the day have been used.

4.3 Optimal selection

As it has been discussed above, the two components of hazard (pollution) and exposure (population) have been assessed taking into account both the spatial and the temporal dimensions. For answering the identified dynamic phenomena, we argue that the solutions should also be responsive and adaptable to air pollution flows. Proper design and location of plantings could mitigate the local concentration in pollution hotspots, hence reducing the health risk for people [11].

In particular, optimal selection is about recognising which specific actions (what) can maximise air purification and, as a consequence, minimise negative health impact of exposure to air

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pollution in designated areas. Hence, it is essential to select the suitable NbS types and species to maximise the air purification process. Due to the various factors involved in the selection among all possible solutions, finding the most suitable measure is a complex procedure.

Selecting the best urban green actions, and also assigning the best vegetation species to these actions are the two steps to perform. NbS can take various forms, but these can be mainly summarised into two categories of blue and green solutions. Green NbS refer to those actions that solve environmental issues with green elements. In the case of purifying air and reducing the exposure impact of air pollution, Urban Green NbSare the right option. In this study, the aim is to understand which NbS actions are the best response to different times of exposure.

(Fig. 1) is a simplified category of Urban Green NbS: distinguishing these categories and their subdivisions have been adapted from various relevant sources.

Green Urban NbS	
Forms of Green NbS	**Subdivision of Green NbS**
External Green buildings	Green Roof - Living Walls Green Façade- Green Balcony School Ground- House Gardens
Internal green buildings	Indoor Vertical Greeneries Potted Plants
Green landscape and public green surfaces	Urban Forest -Parks and Urban Green Areas- Pocket Parks Green Play Ground- Afforestation Green Corridors
Green areas for water management	Water Park
Social Garden	Allotments - Community Garden
Street level green	Street Trees- clustered trees Eco-urban Furniture

Figure 1: Forms of Urban Green NbS

One of the critical components in sustainable urban greening is the selection of plants and planted spaces [12]. Plants have a major role in removing air pollution and with the correct selection, air pollution purification can be maximised. The criteria of this study for selecting the best vegetation specie are based on their ability to absorb air pollution and purifying the air.

Selecting the right vegetation based on the ability of absorption helps us to have better results and outcomes within the same space and budget availability. Selecting the right vegetation can maximise air purification. Direct consideration for vegetation selection is mostly related to environmental factors of the city and the ability of green element in general to absorb different pollutants.

The criteria for selection of vegetation are based on Milan's geographic location and the ability of certain types of vegetation in absorbing air pollution. This selection has been mainly done based on the data available on the I-tree® tool [13].

5. POPULATION AND POLLUTION DISTRIBUTION PATTERNS BASED ON THREE TIMESPANS

Target areas are those places with high concentration of people (residents and city users) and pollution. Based on the dynamic capturing of population and pollution methodology, which has been explained above, risk maps for different timespans are presented in this section.

Three timespans are included: rush hours which refer to two timespans in the morning (from 8 a.m. to 10 a.m.) and in the evening (from 7p.m to 9p.m). These timespans refer to periods when people are moving or commuting between origins and destinations. From home to work, school, and vice versa. The second period refers to middle hours of the day (from 10 a.m. to 5 p.m.) and after work (from 5 p.m. to 7 p.m.). Since these two timespans follow the same patterns and are contiguous, we consider them as one whole time period. Finally, the third time span is Night-time (from 8 p.m. to 2 a.m.). This timespan can be mainly identified as passive hours, when people spend more time at residences.

5.1 Target areas: Risk maps

Target areas for different timespans have been determined by considering data and overlapping maps of population density and traffic situation in specific periods.

Refer to (Fig. 2), high level of risk intensity in Rush hours mostly emerges around the second ring of the city, where the main transportation hub stations of the city like (e.g. Central Railway Station) are located. Also the highest level of traffic in this time span mainly occurs around the main roads and along the highways.

Refer to (Fig. 3), the most active districts in Middle hours can be observed in the historical central core, retail districts and between the first and second ring of the city. Also, the concentration of people in a big zone in the east-north part of Milan (Bicocca district) is considerable. Traffic trend in this time span shows a moderate traffic along the first and the second ring of the city.

Refer to (Fig. 4), high levels of risk in Night-time can be identified in the residential districts with the highest population in Milan. In addition, a very low level of traffic along the second and third ring of the city can be observed.

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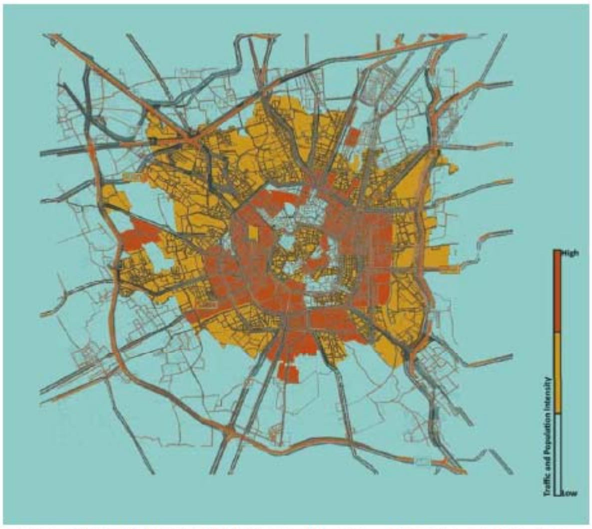

Figure 2: Rush hours' risk map (8 a.m. - 10 a.m. and 7 p.m. – 9 p.m.)

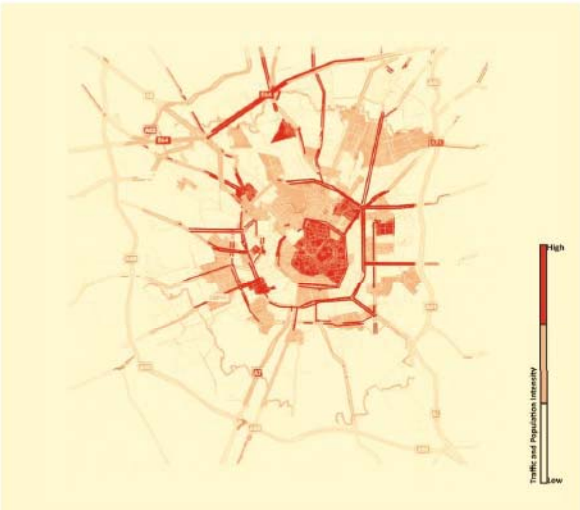

Figure 3: Mid-hours risk map (10 a.m. - 7 p.m.)

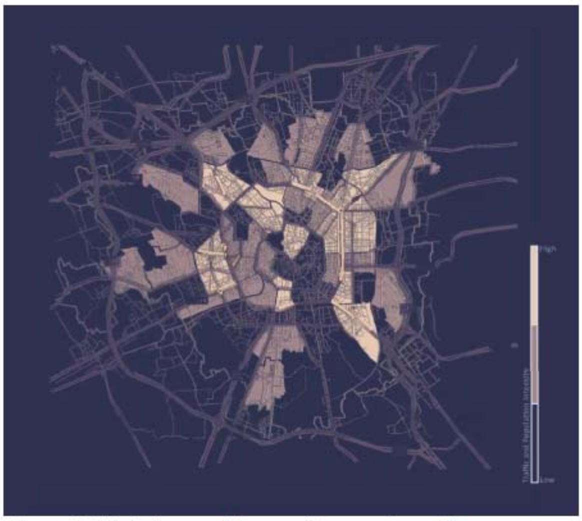

Figure 4: Night hours risk map (8 p.m. -2 a.m.)

6. TIME DEPENDENT STRATEGY

6.1 Urban Green NbS taxonomy based on time

NbS are relevant solutions for addressing air pollution problems at the urban scale. We divided Urban Green NbS based on their adjustability and suitability to different times of the day. Besides time, three main categorizations were elaborated for considering and selecting suitable NbS types based on: budget, space availability and technical complexity of implementation (Fig. 5).

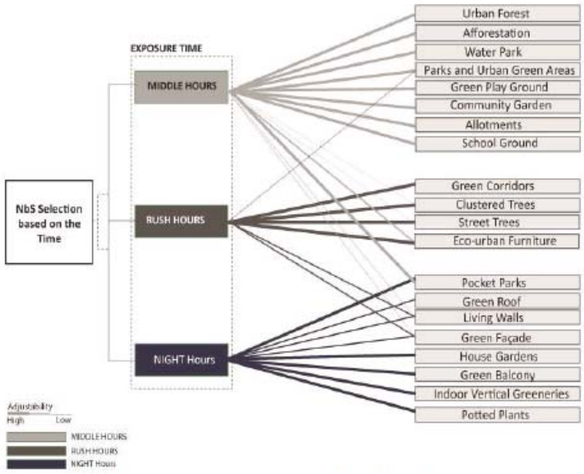

Figure 5: NbS categorization based on the time

This categorization and the assignment of specific actions to specific timespans aims at maximizing the efficacy of air purification, as presented below.

Generally, Rush hours characterised by movement of people by vehicular means. The best green actions for reducing the impact of exposure in this period, are those which can implemented in street areas (Table2).

Middle hours are considered as active hours of a typical weekday. In this period, people have more time to spend in green spaces around workspaces and schools. Recommended actions for this time span, are those which can implemented in bigger areas (Table2).

The night hours are the periods when people spend most of their time in their homes. They are not exposed to the traffic-related air pollution, but there is still a significant amount of air pollutes which are stagnant. While purifying the air at home and in residential areas, these solutions should be reasonable also in terms of scale and budget (Table2).

6.2 Green species selection based on time

Evergreen species absorb air pollution in all seasons, evergreen species with long longevity are more favourable in comparison to other species.

By considering the fact that related actions for rush hours are more on street levels, selected trees should not be higher than 15 meters. The best size for street trees is between 9 to 15 meters. By considering

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this fact, trees with these sizes are suitable options for target areas in this timespan (Table2).

Bigger trees with more leaves have stronger capacity in air pollution absorption. By considering this fact and also considering the scale of Middle hours' recommended actions, bigger trees should be considered for target areas in this timespan (Table2).

Since Night hours' actions are more at building scale, suggested vegetation for this timespan should be suitable for smaller spaces. For this time span considering plants with the ability of Crassulacean Acid Metabolism (CAM) is significant. This ability of vegetation helps them to absorb CO_2 even during night hours (Table2).

7. CAPACITY OF MAXIMIZING AIR PURIFICATION

By integrating all timespans and looking to the city as a 24 hours cycle, we present a time-dependent risk map of the whole city of Milan for a complete working day (Fig. 6).

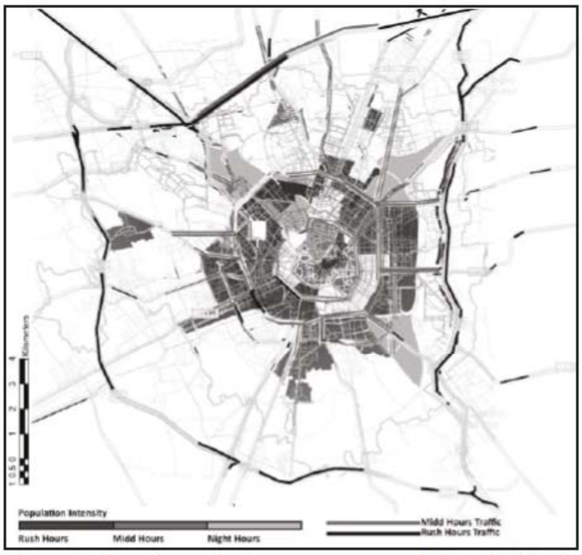

Figure 6: time-dependent exposure map of City of Milan for a complete working day

Figure 7: Rush hours' Exposure Map

Figure 8: Mid-hours 'Exposure Map

Figure 9: Night hours 'Exposure Map

Recommended Nbs actions	Recommended green species
Rush hours (Figure 7) (8 a.m. - 10 a.m.) and (7 p.m. - 9p.m.)	
• Green corridors • Clustered trees • Street trees • Green walls • Eco-urban furniture	India, Tamarind, Swamp Bay, Cinnamon, Leyland Cypress, California Peppertree, Italian Cypress, and Carrot wood, Silk Bay, Leyland Cypress- Willow- Norfolk Island Pine, Bahama, Lysiloma, Seaside Mahoe, White Kauai Rosemallow, Canela, Lingue, Norway Maple, Toog, Raulí-Largeleaf Rosemallow, and Evergreen Ash.
Mid-hours (Figure 8) (10 a.m. - 5 p.m.)	
Recommended Nbs actions	***Recommended green species***
• Urban Forest • Afforestation • Parks and green areas • Green playground • Community garden • Allotments • Pocket parks • School grounds	Coast Redwood, Slash Pine, Australian Pine, Longleaf Pine, Sydney Blue GUM, Tanoak, Belah, Ribbon Gum Eucalyptus, Ribbon Gum Eucalyptus, Southern Magnolia, Southern Magnolia, California Laurel, Corsican Pine, Bunya Bunya, Canary Island Pine, Balata, Tilia Tuan, Sweetwood, Wild Tamarind, Redbay, Wild Chestnut, Bunya Bunya, Silk Oak.
Night hours (Figure 9) (8 p.m. -2 a.m.)	
Recommended Nbs actions	***Recommended green species***
• Pocket parks • Green roofs • Green walls • House gardens • Green balconies • Indoor vertical greeneries • Potted plants	Dracaena, Areca Palm, Neem Tree, Bamboo Palm, Dragon Tree, Barberton Daisy, Rubber plant, Orchid, Spider Plant, Peace Lily, Devil's Ivy, Gerbera , Weeping Fig, Peepal Tree, Rama Tulsi, Gerbera (Orange), Rama Tulsi, Chrismas Cactus, Schlumbergeras, Lady Palm, Flamingo Lily, English Ivy

Table2: Recommended actions and Recommended green species for different time spans

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8. CONCLUSION

By increasing urban population, related air quality and quality of life challenges are also increasing. This research has focused on how to exploit Urban Green NbS to purify air. With a case-study application in Milan, a city that dramatically suffers of bad air quality, this study has proposed a dynamic approach towards achieving cleaner air, introducing the metaphor of a living green breathing. . In particular, this study establishes a taxonomy of Urban Green NbS and vegetation species based on their capacity to purify air in different urban places and times of the day.

This research provides a novel attempt for capturing pollution exposure through a dynamic process. Firstly, an attempt has been made to map risky areas through an optimal targeting of solutions. Three exposure patterns for the different timespans of a regular working day have been identified as optimal targets (Fig.7), (Fig. 8), (Fig. 9). These patterns show the spatial distribution of population and pollution during three timespans of 'Rush hours – Middle hours and Night hours. Hence, on the basis of time, places and people presence, we categorize the most relevant and suitable Urban Green NbS and species for these target areas.

Finally, by integrating all times and looking to the city as a 24 hours cycle pulsing organism, we present a time-dependent risk map of the whole city of Milan depicting a complete working day. Introducing flexible solutions at the urban scale, to be adjusted to changing conditions is an added value in urban green planning and can be easily replicated to other cities.

Considering the rhythm of the city and nature at the same time, we finally take into consideration also people's biological rhythms, thus contributing to improve quality of life.

Since this research introduces a new methodology, the main limitation encountered was the lack of site-specific data, both referring to species capacity to purify air, and to people's flow patterns during the day.. To achieve our desired result, we combined different data derived from several studies and databases. Future work will seek to measure the contribution of the green NbS and specific vegetation on air purification for each vulnerable areas by quantifying the CO2 absorption rates.

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