Report on interventions
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Report on interventions

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Short Description	*Air pollution is an important environmental health problem in many cities in Europe. In recent years interest has gathered on passive control systems, as well as behavioural and engagement interventions as ways to reduce air pollution exposure further along with bringing a range of co-benefits. This report details the exposure impact assessment and the socio-economic impact assessment of the iSCAPE interventions and in this way contributes to an increased understanding of the benefits of using these interventions to mitigate air pollution exposure.*

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AADF – Annual Average Daily Flow
CFD – Computational Fluid Dynamics
CNG – Compressed Natural Gas
DALY – Disability Adjusted Life Years
DIE – Diesel
EEA – European Environmental Agency
ER – Emissions rate
ESS – European Statistical System
EU – European Union
GDP – Gross Domestic Product
GI – Green Infrastructure
GLA – Greater London Authority
GNH – Gross National Happiness Index
GPI – Genuine Progress Index
H – Height
LAD – Leaf Area Density
LBW – Low-Boundary Wall
LL – Living Lab
LPG – Liquid Petroleum Gas
OECD – Organisation for Economic Cooperation and Development
PCS – Passive Control System
PET – Physiologically Equivalent Temperature
PET – Petroleum
PPH – Petroleum Plugin Hybrid
RAD – Restricted Activity Days
RANS – Reynolds Averaged Navier-Stokes
W – Width
WP – Work Package

1 Executive Summary

Air pollution is one of the main environmental health problems in Europe and indeed globally. Despite substantial improvements in the European air quality since the 1970s, most member states are still not complying with EU air quality standards and implemented Air Quality Plans do often not deliver the expected results.

In the scientific literature, a range of air pollution exposure control approaches have been evaluated encompassing emission reductions, environmental legislation and personal protective equipment. In recent years, research interest has gathered around passive control systems, which acts between the source and the receptor of air pollution. Much research remains to be done on these technologies, and these are therefore the focus of the present report, and more generally of the iSCAPE project. This report explains the methodology and the results of the exposure impact assessment and the socio-economic impact assessment of the interventions as studied in the iSCAPE-project. The methodology and results of the exposure impact assessment reports:

- The effect of greening a street canyon in Bologna, Italy, by planting various kinds of trees in the street, was analysed through a CFD modelling study verified against field measurements carried out in two intensive experimental campaigns. The results show that the average concentrations can be reduced by up to 44% with the correct choice of tree type and vegetation geometry (distance between crowns) accounting for up to 22% variation in concentration reduction potential.
- The influence of a specific proposed urban development on the urban heat island was studied in Bottrop, Germany using the ENVI-met model. Changes were generally low and showed up to 0.3 °C temperature reduction and up to 12 °C reduction in physiologically equivalent temperature.
- The air pollution concentration reduction potential of a widespread deployment of low-boundary walls in Dublin, Ireland was analysed using linear statistical modelling. The results show a reduction potential of 12% for NO_x, 10% for $PM_{2.5}$, and 13% for PM_{10}.
- The effect of urban scale trees and grassland on the urban air quality was analysed for Guildford, UK using the ADMS Gaussian plume model for the year 2039. The results show that increasing the area of deciduous trees would lead to increases in PM_{10}, $PM_{2.5}$ and NO_x levels up to 2.7% and increasing the area of grassland would lead to increases of PM_{10}, $PM_{2.5}$ and NO_x concentrations up to 13.8%.

The methodology and results of the socio-economic impact assessment reports:

- The social analysis of the Living Lab engagement activities was performed by using qualitative methods including surveys and a questionnaire. The results showed that LL engagement activities contributed - even though at different degrees - and raised awareness around urban air quality and the necessity for taking action to reduce air pollution across individuals, communities, and policy-makers.
- To analyse the market benefits of reducing air pollution via green infrastructure, a hedonic pricing analysis was carried out in Vantaa, Finland and Bologna, Italy. The results showed an added value of 39 €/m^2 for Vantaa and 112 €/m^2 for Bologna per microgram reduced $PM_{2.5}$. Likewise, an added value of 95 €/m^2 was shown for houses within 100 metres of green infrastructure for Vantaa, whereas in Bologna the benefits were 170 €/m2 and 37 €/m2 for a 10% increase in the land use share of urban green space and broad-leaved trees, respectively.
- The non-market benefits of low-boundary walls, photocatalytic coating, and green infrastructure were estimated with the Impact Pathway Approach and were compared to

the costs of these interventions. The benefits of installing low-boundary walls in the most polluted areas of Dublin were 4900 € on a regular footpath, and 24 000 € at cross-sections. The installation cost of a low-boundary wall was around 4500 €. The benefits of the photocatalytic coating were assessed in Bologna. They resulted from an estimated reduction of NO_2 concentration between 8-17%, corresponding to the expected economic benefits of 330 million € per year. The costs were assessed at 36 million € per year. The air-quality benefits of green infrastructure were assessed in Guilford. The benefits are a result of a reduction of the concentration of both $PM_{2.5}$ and NO_2. The expected benefits were 58 million € per year, or discounted to the average lifespan of a tree, 17 to 43 € per tree. However, it should be taken into account, that green infrastructure has many additional impacts to the associated air-quality benefits.

In this way, the iSCAPE-project has contributed to an improved understanding of the environmental and socio-economic benefits of passive control systems.

2 Introduction

Air pollution is one of the main environmental health problems in Europe (Annesi-Maesano, 2017) with more than 400,000 premature deaths caused per year (Guerreiro et al., 2018). Air quality in Europe has improved substantially since the 1970s due to technological and legislative measures (Turnock et al., 2016), but most member states are still not complying with the EU air quality standards, which are less stringent than WHO guidelines, and implemented Air Quality Plans often do not deliver the expected results (European Court of Auditors, 2018).

To alleviate this problem technological as well as legislative approaches can be taken, where the focus in the present report is on technological approaches:

1. Emission of air pollutants can be reduced through the implementation of cleaner technology in e.g. vehicles and industry, thus leading to lower concentrations.
2. Nature-based or man-made barriers can be inserted between the source and the receptor leading to lower personal exposure locally.
3. Personal protective equipment such as face masks can be used to protect the citizens e.g. when walking or bicycling.
4. Changing the behaviour of the citizens through the provision of information (e.g. in the form of route advise) can lead to lower personal exposure.

The focus in the present report, and more generally of the whole iSCAPE project, is on the second and fourth approaches since these have a shorter implementation time compared to the two other approaches. Besides, little research has been carried out on these approaches, and the aim of the present study, along with other iSCAPE deliverables, is thus to contribute to reducing the uncertainties surrounding their efficiency.

This report together with Deliverable 5.4 “Strategic Portfolio Choice” completes Task 5.3 of the fifth work package (WP) of the iSCAPE project. The title of WP5 is “Monitoring and evaluation of interventions”, and covers both air pollution and meteorological measurements, air pollution and climate modelling as well as socio-economic impact assessment of both physical (e.g. low-boundary wall and urban green infrastructure), behavioural (e.g. informational interventions) and engagement (e.g. Living Lab activities) interventions. Task 5.3 is entitled “evaluation of interventions” and consists of two parts:

- Environmental impact assessment, where cases with and without the interventions will be assessed using scenario modelling.
- Socio-economic impact assessment where the methodology developed in Task 5.5 (Definition of the socio-economic impact assessment methodology) will be applied to evaluate the interventions.

The exposure impact assessment is presented in Section 3, the socio-economic impact assessment in Section 4, followed by the conclusions in Section 5. Various approaches to exposure impact assessment have been used in various cities due to the nature of the interventions, and an overview is presented in Table 1. Likewise, various types of activities have been used in the respective Living Labs reflecting the various aims of the Living Labs and an overview is presented in Table 2.

City	Modelling approach	Type of PCS/intervention	Research objectives
Bologna	CFD modeling	Trees at neighborhood scale (street canyon)	Effect of trees on air quality and air temperature
Bottrop	ENVI-met modeling	Designations on Building Structure	Effects of building a structure on small scale city-climate; Planning alternatives to be preferred from these points of view
Dublin	Statistical Modeling	Low-Boundary Walls	Effects of LBWs on reducing personal exposure of air pollution in the built environment.
Guildford	Gaussian plume modelling	Trees and grass at the urban scale	Effects of trees and grass on urban air quality
Lazzaretto (outskirts of Bologna)	CFD modeling	Photocatalytic coating at a neighborhood scale (street canyon)	Effect of photocatalytic coating on air quality
Vantaa	ENVI-met modeling	Trees and green roofs at building block scale	Effect of trees and green roofs on local air quality

Table 1 Overview of the modelling approaches used for exposure impact assessment in the various cities.

City	Type of activities	Living Lab aim
Dublin	Workshops and meetings	To raise the citizen's awareness about air quality using low-cost sensing technology and to engage the citizens and the stakeholders in the co-create and co-design of the passive control system.
Bologna	Workshops and meetings	To raise citizens' awareness of air pollution and climate change issues; engage and co-create passive control systems to tackle those issues.
Bottrop	Workshops and meetings	To raise citizens' awareness of air pollution, urban heat and the quality of stay
Guildford	Workshops	To raise citizens' awareness about air quality and the impact of green infrastructure to reduce air pollution and improve health and well-being.
Vantaa	Workshops and meetings	Engage and co-create with urban planners and to raise awareness of air quality issues.

Table 2 Overview of the aim and type of activities carried out in the respective Living Labs that form the basis of the socio-economic impact assessment.

As seen from Table 1, the scale of the intervention is determining for which modelling approach has been used with street scale interventions assessed using street scale models and urban scale interventions assessed using urban scale models. Table 2 shows that all the living labs are using similar engagement approaches towards different aims.

3 Exposure impact assessment

This section will describe the methodologies and results for exposure impact assessment in the iSCAPE target cities.

3.1 Bologna

The pilot in Bologna is specifically devoted and focused on investigating the effectiveness of trees in modifying air ventilation and improving thermal comfort at neighbourhood and urban scales. To this aim, two intensive experimental field campaigns were conducted in two parallel street canyons, i.e. Marconi and Laura Bassi Sts., characterized by variation in the presence of vegetation. While the campaigns are thoroughly described in D5.2 (first and update version), here it is worth to mention that data gathered during these campaigns serve to verify the model setup of the CFD simulations which are presented in the following sections. Briefly, the CFD simulations setup at neighbourhood level in one of the two street canyons (in particular, the one without trees) were first verified in the base case scenario (i.e., without trees); after that, model scenarios adding different types of trees and/or with different crown distances will be evaluated and compared with the outputs obtained in the reference case. This will be used to derive the impact of trees on local circulation. Specifically, here we will focus on Marconi street, a major arteria in the core of the business area of the city centre of Bologna (Italy). In this area, there are a few major streets (Marconi street, Riva Reno street, Ugo Bassi street), with smaller alleys between the major streets. Marconi street is characterized by a high packing density of the buildings (i.e. buildings are very close and generally tall; Kanda, (2006) and has a street canyon configuration with an aspect ratio (H/W, where H is the height of the buildings and W is the width of the street) H/W equal to 1.65. It is one of the most polluted sites in the town, with an average NO_2 concentration of 94 µg m^{-3} in 2014, according to the ARPAE (Emilia Romagna Environmental Protection Agency) measurements (as from the urban air quality station located in the nearby San Felice street). An overview of the study area is shown in Figure 1.

Marconi street is a four-lane restricted traffic zone where from 7:00 to 20:00, every day, the movement of motor vehicles is restricted, characterized by a considerable transit of buses (almost all bus lanes pass from this street). It is characterized by the presence of portici (arcades), which are not modelled in these simulations, and therefore also by high pedestrian traffic. Marconi street is almost completely free from trees and GI (green infrastructure), apart from the first part of the street. The street is oriented about 20° to East from North-South direction. Riva di Reno street, oriented in East-West direction in Figure 1, is a two-lane road characterized by intense car and bus traffic (Prandini et al., 2018). For more details and pictures of the area, the reader is referred to as D5.2 (“Air pollution and meteorology monitoring report”).

Figure 1 Overview of Marconi street and surrounding area (left) and Marconi street canyon view (right) (source: Google Earth):

The objective of the CFD (Computational Fluid Dynamics) simulations setup in Bologna is to evaluate the effectiveness of trees in modifying the flow dispersion impacting on the air pollution, and in ameliorating the urban thermal comfort. As such, and to better evaluate the influence of different types of trees introduced in a real urban environment as Marconi street we have firstly chosen two different types of trees ('Populus tremula' and 'Fagus sylvatica'), and after that we have ideated five scenarios in which these trees were inserted at different distances in the middle of Marconi street canyon. The motivation for the different scenarios is presented in Section 3.1.1.3.

3.1.1 Modelling methodology

The CFD code CD-adapco STAR-CCM+ 12.02.10 has been employed to solve the steady-state Reynolds-averaged Navier–Stokes (RANS) equations with realizable k-ε turbulence model. The buoyancy thermal effects have been considered in this work.

The transport equations for kinetic energy k and the turbulent dissipation rate ε are:

$$\frac{\partial}{\partial t}(\rho k) + \nabla \cdot (\rho k u) = \nabla \cdot [(\mu + \frac{\mu_t}{\sigma_k})\nabla k] + P_k - \rho(\varepsilon - \varepsilon_0) + S_k \quad (1)$$

And

$$\frac{\partial}{\partial t}(\rho \varepsilon) + \nabla \cdot (\rho \varepsilon u) = \nabla \cdot [(\mu + \frac{\mu_t}{\sigma_\varepsilon})\nabla \varepsilon] + \frac{1}{T_\varepsilon} C_{\varepsilon 1} P_\varepsilon - C_{\varepsilon 2} f_2 \rho (\frac{\varepsilon}{T_\varepsilon} - \frac{\varepsilon_0}{T_0}) + S_\varepsilon \quad (2)$$

Where:
u is the average velocity, μ is air dynamic viscosity, σ_k, σ_ε, $C_{\varepsilon 1}$, and $C_{\varepsilon 2}$ are model coefficients, P_k and P_ε are production terms, whose formulation depend on the k-ε model variant, f_2 is a damping function that mimics the decrease of turbulent mixing near the walls, enforcing realisability, S_k and S_ε are used specific source terms, ε_0 is the ambient turbulent dissipation rate value in the source

terms, T_ε is the large-eddy time scale, T_0 the specific time-scale related to ambient turbulent source term. Mean flow, turbulence, energy and dispersion equations were discretized using a second order scheme and the Semi-Implicit Method for Pressure Linked Equation (SIMPLE) scheme was used for pressure-velocity coupling. The contribution to turbulence induced by traffic has been neglected, according to the literature (see, for instance, Buccolieri et al., 2018).

3.1.1.1 Heat transfer model

The buoyancy forces have been considered under the Oberbeck-Boussinesq approximation, i.e. in Navier-Stokes equation, the mass density is constant in all the terms with exception of in the gravitational body force term. The local momentum balance equation then gives:

$$\rho(\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j}) = \rho g_i - \frac{\partial p}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_j} \quad (3)$$

where the density ρ is assumed to be a function of temperature and pressure in accordance with the ideal gas law:

$$\rho(T, p) = \frac{p}{RT}. \quad (4)$$

Where R is the specific gas constant, with R_0=8314.4621 (J kmol K^{-1}) and M is the gas molecular weight.

3.1.1.2 Species transport model

In this work, CO has been used as tracer pollutant for all simulations. In turbulent flows, STAR-CCM+ computes the mass diffusion as:

$$J = -(\rho D + \frac{\mu_t}{Sc_t})\nabla c. \quad (5)$$

where D is the molecular diffusion coefficient for the pollutant in the mixture, $\mu_t = \rho(\frac{c_\mu k^2}{\varepsilon})$ is the turbulent viscosity, Y is the mass fraction of the pollutant, ρ is the mixture density.

$Sc_t = \frac{\mu_t}{\rho D_t} = 0.7.$ is the turbulent Schmidt number, where D_t is the turbulent diffusivity.

The pollutant sources have been simulated by separating volumes of section 0.5 m x 0.5 m. Four linear sources have been created in Marconi street canyon: two simulating the car traffic and two simulating the public bus traffic. The emissions rate (ER) was set using emissions previously derived and illustrated in D6.2 (‘Microscale CFD evaluation of PCS impacts on air quality’) with the methodology outlined above and by splitting the values equally into the linear sources.

3.1.1.3 Modelling momentum sink induced by vegetation

The representation of vegetation in the simulations is crucial to capture its effects on wind flow in urban areas. In this work, trees have been modelled as sources and sinks of momentum, heat, turbulence kinetic energy and turbulent dissipation rate. As done in other recent works on urban CFD vegetation (Jeanjean et al., 2017), the inertial drag has been parameterized in terms of leaf area density or *LAD* (Leaf Area Density; m^2 m^{-3}) of the vegetation to describe the interactions between foliage and atmosphere, by means of a momentum sink term (*Su_j*) in the momentum equations (one for each velocity component) as:

$$S_{U_j} = -\rho LADC_d U u_j \quad \text{(Pa m}^{-1}\text{)} \tag{6}$$

where ρ is the air density (kg m^{-3}), u_j is the j wind velocity component (m s^{-1}), U is the average wind speed (m s^{-1}) and C_d is the sectional drag for vegetation (dimensionless). The sectional drag is a constant related to aerodynamic features of vegetation. In this work we assume C_d =0.2, while the value of LAD for Populus tremula has been taken equal to 2.03 (m^2 m^{-3}) and the value of LAD for Fagus sylvatica has been taken equal to 0.97 (m^2 m^{-3}), according to the value found in literature (Breuer et al., 2003). Figure 2 shows the leaves shapes of the two species.

Figure 2 Leaves shape for Populus tremula (left) (source:http://www.altovastese.it/flora-2/la -neve-dei-pioppi-le-4-specie-presenti-in-italia) and for Fagus sylvatica (right) (source:https:// nelboscodelladea.com/tag/cibo).

3.1.1.4 Modelling of turbulence modifications and pollutant removal by vegetation

The vegetation also modifies the mean flow motion into wake turbulence. Then, this process is usually parametrized as the source and sink terms of turbulent kinetic energy or TKE (Turbulent Kinetic Energy; k) and turbulent dissipation rate (ε) as follows:

$$S_k = \rho LADC_d(\beta_p U^3 - \beta_d U k) \quad \text{(kg m}^{-1}\text{ s}^{-3}\text{)} \tag{7}$$

$$S_\varepsilon = \rho LADC_d(C_{\varepsilon 4}\beta_p \frac{\varepsilon}{k} U^3 - C_{\varepsilon 5}\beta_d U \varepsilon) \quad \text{(kg m}^{-1}\text{ s}^{-4}\text{)} \tag{8}$$

where $0 \le \beta_p \le 1$ is the fraction of mean kinetic energy converted into TKE by means of drag, β_d is the dimensionless coefficient for the short-circuiting of the turbulence cascade; $C_{\varepsilon 4}$ and $C_{\varepsilon 5}$ are model constants. Several values of these parameters can be found in the literature; in this work, we have used β_p=1 , β_d=4 and $C_{\varepsilon 4}$=$C_{\varepsilon 4}$=1.5, following Buccolieri et al. (2018) and Amorim et al. (2013).

The pollutant flux S_d (g m^{-2} s^{-1}) is calculated as the product of the dry deposition velocity V_d (cm s^{-1}) and pollutant concentration c (g m^{-3}):

$$S_d = -LADV_d c \tag{9}$$

3.1.1.5 Modelling of transpirational cooling due to vegetation

The transpiration cooling of vegetation has been recently included in thermal CFD simulations to evaluate the impact on temperature. In order to account for the effect of vegetation on air temperature, Gromke and Blocken (2015) employed a volumetric cooling power P_c (W m^{-3}) per unit volume vegetation as a function of LAD. In this work, we adopted the same approach.

The basic principle is that when air flows through vegetation it gets cooled by transpiration mainly from the leaf surfaces. The heat *H* (J) required to change the temperature of an object can be calculated according to Incropera et al. (2006):

$$H = mc_p \Delta T \tag{10}$$

with c_p the specific heat capacity (J K^{-1} kg^{-1}), *m* (kg) the mass of the object and ΔT the change in temperature (K). Since the volumetric cooling power P_c is understood as the transfer of heat per time *t* (s) and volume *V* (m^3), the equation can be rearranged to obtain:

$$\frac{H'}{V} = P_c = c_p \Delta T \frac{1}{V} \rightarrow \Delta T = P_c V \frac{1}{m'} \frac{1}{c_p} \tag{11}$$

with *H* the heat transfer rate (W) and $\dot{m}$ the mass flow rate (kg s^{-1}).

The right part of the last equation states that the change in temperature ΔT when air flows through vegetation is proportional to the cooling power P_c and the volume of the vegetation *V* and inversely proportional to the air mass flow through the vegetation volume $\dot{m}$ and the specific heat capacity c_p of air. The equation is based on the simplified assumption that the heat and mass transfer at the leaf surface is not a function of the flow regime and the corresponding heat transfer coefficient. A similar model has been recently applied by Moradpour et al. (2017). Gromke and Blocken (2015) and Moradpour et al. (2017) obtained the best agreement with experimental air temperature in different validation studies for a volumetric cooling power of 250 W m^{-3} per unit of LAD.

3.1.2 Model input

The description of the sources, temporal and spatial resolution for the model input is thoroughly described in D6.2, while the instrumental setup deployed as part of the intensive field experimental campaigns in the two Bologna street canyons is extensively described in D3.3 ('Report on footprint of Passive Control Systems') and D5.2 ('Air pollution and meteorology monitoring report', first and update version) . The five scenarios that we created and are described in the following in this work are based on the results obtained considering one particular simulation chosen among the 26 reported in D6.2 obtained from the measurements in the Marconi St. canyon. In the scenario considered in D6.2 for Marconi St, we simply added a row of different types of trees along the Marconi street, choosing one summer case among all the 26 simulation cases (13 of which referred to Marconi street); as such, for the five scenarios evaluated in this Deliverable we have adopted the same setting and boundary conditions (obtained from measurements) of that selected case (Table 3 and Table 4).

Table 3 shows the observations corresponding to that case used to set the velocity boundary conditions.

Day	UTC time	Wind direction (°) – wind velocity (m s^{-1})	u_* (m s^{-1})	z_0 (m)
22/08/2017	12:00	93º-4.4	0.54	3.0

Table 3 Wind data used for setting the boundary conditions in the five scenarios evaluated in this deliverable.

Table 4 shows the values obtained from the intensive thermographic campaign with the thermal camera, used to set the temperature boundary conditions. The precise location of IR measurements is provided in Figure 3.

Day	UTC	Tair (ºC)	T4 (ºC)	T5 (ºC)	T7 (ºC)	T2 (ºC)	T1 (ºC)	T9 (ºC)	Tstreet (ºC)
22/08/2017	12	26.0	29.3	28.4	28.4	27.4	26.8	28.6	40.2

Table 4 Temperature data used for setting the temperature boundary conditions in the five scenarios evaluated in this Deliverable.

The boundary and initial conditions set in the simulations derived from experimental data obtained during the intensive experimental field campaign carried out in Bologna in August 2017. The observations gathered during the experimental campaigns in Marconi St. were also used for the validation of the numerical results presented in this report. Below we report a brief synthesis of the data used in this report to set the boundary and initial conditions and validate the CFD simulations:

Wind and temperature meteorological observations were obtained from measurements by two ARPAE meteorological stations in two different locations of the city: the first one is a synoptic meteorological station located at the top of Asinelli's tower (96 m above ground and the highest building of the city), while the second one is an urban meteorological station placed on the roof of ARPAE's headquarter (27 m above the ground level: Silvani meteorological station).

At the inflow boundary, vertical profiles for mean velocity *U*, turbulence kinetic energy *k* and turbulence dissipation rate ε of the neutrally stratified atmospheric boundary layer have been imposed, according to Di Sabatino et al. (2007):

$$U(z) = \frac{u_*}{k} ln(\frac{z-d}{z_0}) \quad (12)$$

$$k(z) = \frac{{u_*}^2}{\sqrt{C_\mu}} ln(1-\frac{z}{\delta}) \quad (13)$$

$$\varepsilon(z) = \frac{{u_*}^3}{k(z+z_0)} ln(1-\frac{z}{\delta}) \quad (14)$$

with z the vertical position above the ground, z_0 the roughness length neighbourhood level representative for the terrain windward the computational domain, u_* the friction velocity, k=0.42 the van Karman constant, C_μ=0.09 and δ the height of the computational domain.

The inflow wind profile has been calculated solving a two equations system using data from the two meteorological stations (Asinelli and Silvani), in order to obtain the friction velocity u_* and the roughness length z_0 for every different wind condition. The displacement height d has been set to 11 m, equal to 1/3 of the street canyon medium height; this approach highlights the relationship between wind direction and urban geometry.

The street canyon façade temperatures were obtained from the measurements taken during two thermographic campaigns, thoroughly described in D5.2 (first version). In particular, the building façades temperature was measured on 6 buildings along Marconi street chosen for the characteristics of the wall emissivity, with 3 building for each side of the street canyons. The position of the buildings is shown in Figure 3. The buildings 1, 2 and 9 are on the East side and 4,5 and 7 are on the west side, while 3 and 8 are the positions where the street temperatures have been measured.

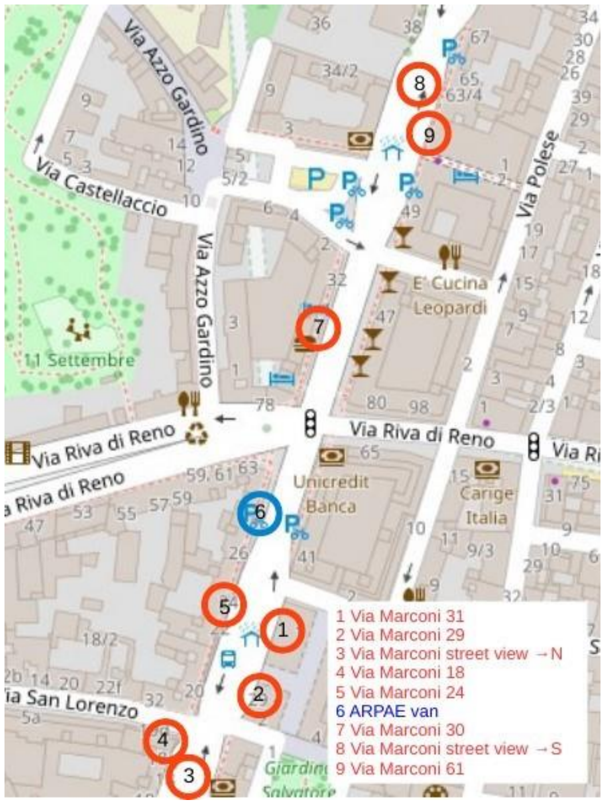


Figure 3 Positions of the building chosen for IR temperature measurements (source:OpenStreet map).

The measurements of temperature provided by the monitoring stations were analysed to create air temperature profiles. During the day, the temperatures do not present a significant variation with height, therefore constant vertical profiles have been set. Conversely, during the night of the summer case, thermal inversion occurred at a height of about 100 m; therefore, the temperature profiles present a constant increase (about 2 °C/100 m) until the temperature inversion height and then a constant decrease (0.7 °C/100 m).

Input traffic emissions data were derived from the traffic counts available from counting stations using inductive loops technology in the street canyon with a 5-min time resolution provided by ARPAE. In particular, emissions were derived converting traffic counts into traffic counts per vehicle type (fuel type, vehicle type, and EURO technology). First of all, the number of buses passing were derived from bus schedules in Bologna (available from the regional transport company on the web at www.tper.it/o). The local fleet composition was then extracted from the regional inventory of circulating vehicles (also available on the web as open data from the Italian Car Club (www.aci.it/laci/studi-e-ricerche/dati-e-statistiche/open-data.html) and was used to disaggregate the difference between the traffic counts and the number of buses into traffic counts per vehicle type using the extracted local fleet composition. Pollutant emission rates were then estimated using the European Monitoring and Evaluation Programme/European Environment Agency (EMEP/EEA) air pollutant emissions for each vehicle category (EEA, 2016). Pollutant concentrations measured by ARPAE's mobile stations located at ground level in the street canyon and meteorological and turbulence observations obtained at the middle level (about half of the canyon height) and top level (located on the rooftop of the highest building) stations were used to validate the numerical model.

Below we summarize the set of instrumentations deployed in Marconi St. as part of the intensive field experimental campaigns:

- Ground station:
  - Sonic anemometer (Windmaster, Gill)
  - Thermohygrometer (HC2S3-L, Campbell Scientific)
  - Nitrogen oxides (NO_x), ozone (O_3), carbon monoxide (CO), BTEX (Teledyne Instruments) and particulate matter in the form of PM_{10} and $PM_{2.5}$ (Fai Instruments) concentration sensors
- Balcony station at 8 m:
  - Sonic anemometer (Windmaster, Gill)
  - Thermohygrometer (HC2S3-L, Campbell Scientific)
- Rooftop station at 25 m:
  - Sonic anemometer (uSonic-3, Metek) coupled with LI-COR (LI-COR 7500 RS)
  - Net radiometer (CNR4, Kipp & Zonen)

As described in D5.2, this instrumentation setup provided air pollutant concentrations with 1-min time resolution (apart from BTEX and PM, measured with 1 hour and 1 day time resolution, respectively), and measurements of meteorological and turbulence parameters, namely air temperature, velocity components and turbulence, at 1 min and 50 ms and time resolution, respectively; 1-h averages of concentrations, meteorological and turbulence measurements were used for validating the CFD simulations results.

3.1.3 Model setup

The computational domain has a size of 1288 m x 920 m x 368 m (L x W x H). The dimensions of the domain are a multiple of the base size of the mesh equal to 11.5 m. Symmetry boundary condition has been assigned to the lateral sides and the domain top, a velocity inlet condition was set to the inlet boundary and a pressure outlet condition to the outflow boundary; a no-slip boundary condition was applied at the ground and at the building surfaces.

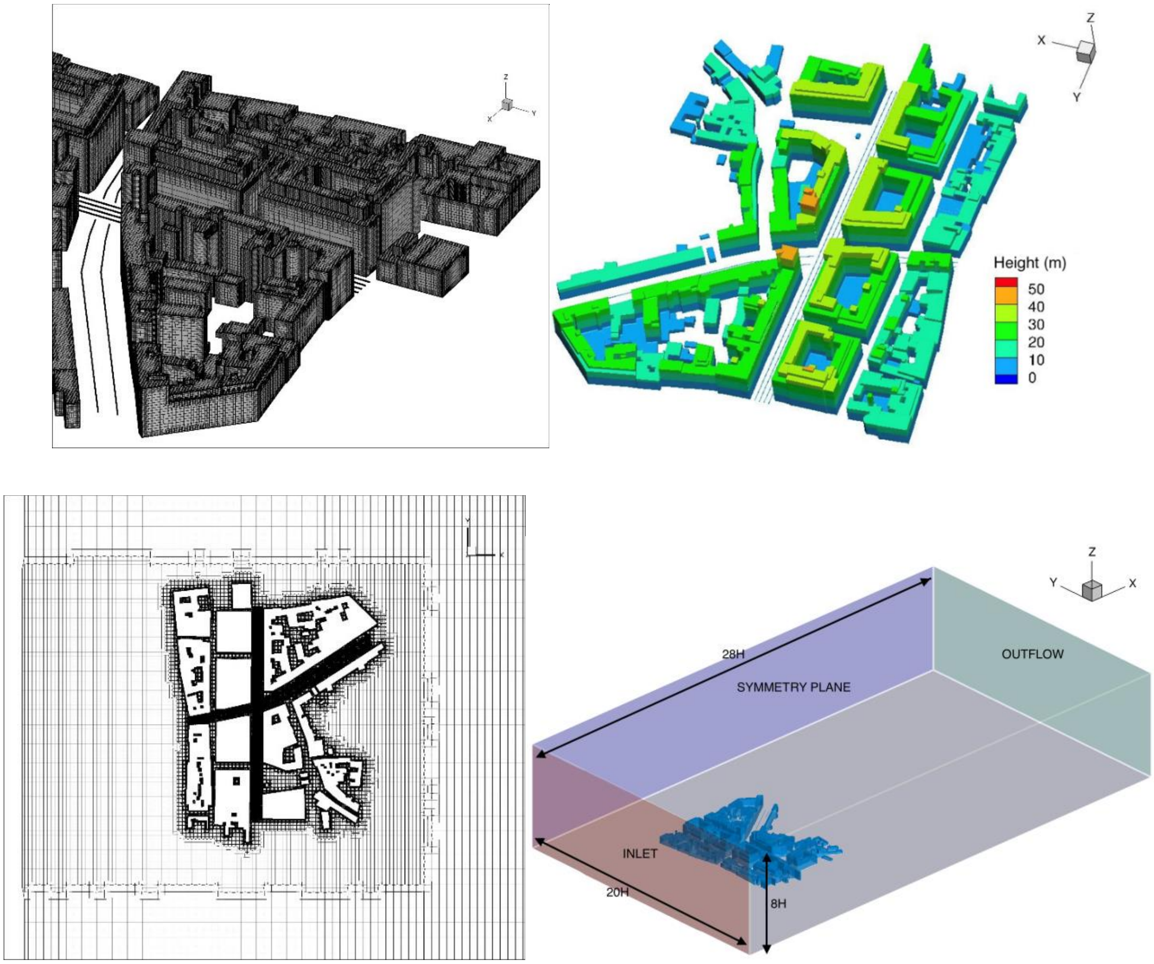


Figure 4 Marconi street. Mesh on the building surfaces (left top), the elevation of the buildings (right, top), top view of the mesh (left, bottom) and the computational domain (right, bottom).

Since the maximum reported height in the domain is a building height (H) of 46 m, the computational domain was built with its boundaries placed more than 15H away from the modelled area. The dimensions of the outer domain provide an appropriate mesh size for the required flow detail and run time, according to the literature (Di Sabatino et al., 2007). The computational domain has been built using unstructured elements with a finer resolution close to the ground and the walls within the neighbourhood scale. The smallest dimension of the elements, in the region near the heated walls, is 0.25 m in the direction normal to the wall and 0.5 m in the other directions. Figure 4 shows the computational domain (left) and some details of the mesh (right and down).

The maximum building height H was set to base size for the mesh. Two refinement boxes were created in the proximity of the geometry: the first one includes the upcoming wind area and the geometry and has a mesh dimension of H/2; the second box includes the street canyon and has a mesh dimension of H/8. The pollutant sources are modelled as linear volume on the ground of the street with the dimensions of the section of 0.5 m x 0.5 m, while the length coincides with the length of the street canyon. In Marconi street four linear sources have been created, two for car traffic and two for bus traffic; in Riva di Reno street two linear sources for car traffic have been created. For every source, the base grid dimension is equal to 0.1 m and the smaller cells have a dimension of 0.05 m. The final number of computational cells used for Marconi street is about 12 million cells.

Within the domain, two regions with different grid resolution were generated: one in the area surrounding the buildings and in the area approaching the city with a dimension of 5.75 m, and the other one comprehending Marconi street canyon and with a cell size of 1.4375 m. Several refinements have been done on the building surfaces in order to have a close representation of the real geometry, especially on the building edges.

3.1.3.1 Grid sensitivity tests

A set of preliminary sensitivity tests have been performed, to choose the dimensions of the boxes used for refinements and those of the elements near the building walls. As shown in Figure 4, the mesh is built by three zones, each of them characterized by structured elements with homogeneous dimensions. The first zone is the external domain, with the coarsest elements, containing a box with elements with a medium size and another box surrounding the area and the street canyons, containing the finest elements. An example of the three zones is provided in Figure 5.

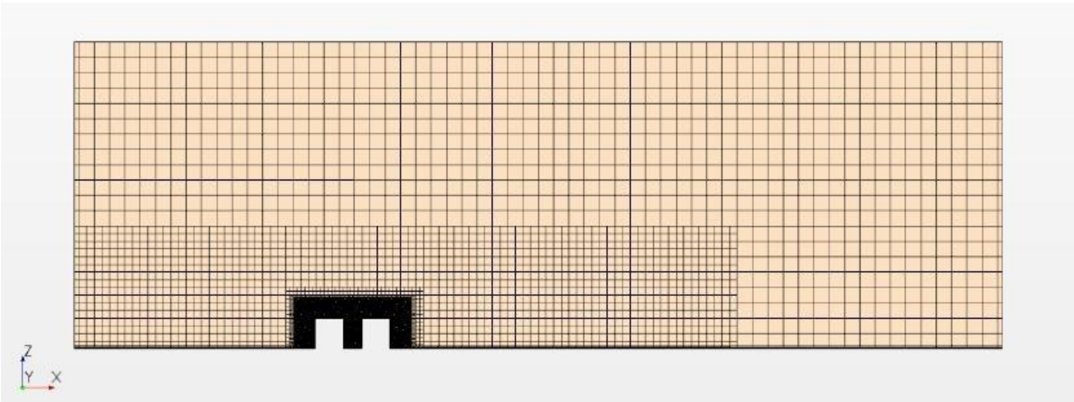


Figure 5 Example of mesh zones.

A geometry with a canyon with the same dimensions of Marconi street has been used as a base geometry for the first part of the sensitivity tests.

Table 5 shows the dimensions of the box containing the finest elements, the size of the elements and the total number of cells N_{cells} in the computational domain. Six refinements have been compared, in the range N_{cells} = [0.302 – 6.181] millions of elements.

Grid name and index	Box dim	s_{min}	Number of cells (millions)
Very coarse - 5	$2\sqrt{2}H$	2.917	0.302
Coarse - 4	$2H$	2.062	0.528
Medium - 3	$2H/\sqrt{2}$	1.458	1.083
Fine - 2	H	1.031	2.550
Very fine - 1	$H/\sqrt{2}$	0.729	6.181
Ultra-fine - G	$H/2\sqrt{2}$	0.516	15.904

Table 5 Some of the grids used for the sensitivity tests.

Figure 6 shows the normalized root mean square deviation obtained from a vertical line in the middle of the canyon, defined by

$$NRMSE_g = \sqrt{\frac{\sum_p (\frac{x_{g,p} - x_{G,p}}{\overline{x_G}})^2}{N_p}} \quad (15)$$

where x is the variable used for the comparison, g is the grid number, p is the point along a probe line where the comparison is made, N_p is the number of points in the probe line. Figure 6 shows that the convergence is achieved for velocity, CO concentration and temperature results.

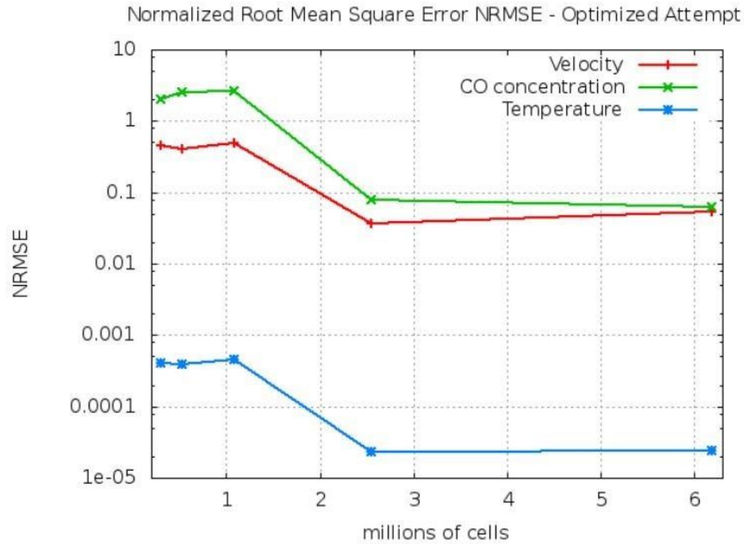


Figure 6 Convergence tests for velocity, CO concentration and temperature in the CFD simulations for Marconi street canyon.

3.1.4 Scenarios

In this work, we have evaluated the effect of different types of trees that could be placed in a street such as Marconi street. Literature values for these four tree species (average height, crown width, and LAD) were taken from Breuer et al. (2003) (Table 6). Figure 7 presents visually the characteristics of these tree species.

	Type of tree		
	Average height (m)	**Crown width (m)**	**LAD ($m^2\ m^{-3}$)**
Populus tremula	10.5	3.5	2.03
Fagus sylvatica	18	7	0.97
Liridendrum tulipifera	20	3	2.00
Alnus incana	15	6	1.47

Table 6 Characteristics of different types of trees chosen for the simulation scenarios evaluated for Marconi street.

Figure 7 Populus tremula (left, top) (source: www.naturephoto-cz.com/common-aspen-photo-24120.html), Fagus sylvatica (right, top) (source: www.vdberk.dk/traeer/fagus-sylvatica), Liridendrum tulipifera (left, bottom) (source: underthesunseeds.com/products/american-tulip-tree-seeds-liriodendron-tulipifera-20-seeds) and Alnus incana (right, bottom) (source:www.venditapianteonline.it/shop/alnus-incana-ontano-bianco-grigio).

As shown in Table 7, for this work we have selected five scenarios. For the first two scenarios we chose 'Populus tremula' since this tree is characterized by a LAD similar to that used in used in the simulation of the other street canyon where the intensive experimental field campaigns were carried out (Laura Bassi street) in D6.2, but with a smaller crown; on the other hand, for the other three scenarios 'Fagus sylvatica' was chosen because it presents the biggest foliage and a reduced LAD.

Number of scenarios			
	Tree type	**Crown width (m)**	**Distance between the crowns (m)**
1	Populus tremula	3.5	3.5
2	Populus tremula	3.5	1.75
3	Fagus sylvatica	7	7
4	Fagus sylvatica	7	3.5
5	Fagus sylvatica	7	1.75

Table 7 Characteristics of the trees inserted in the five scenarios chosen for Marconi street.

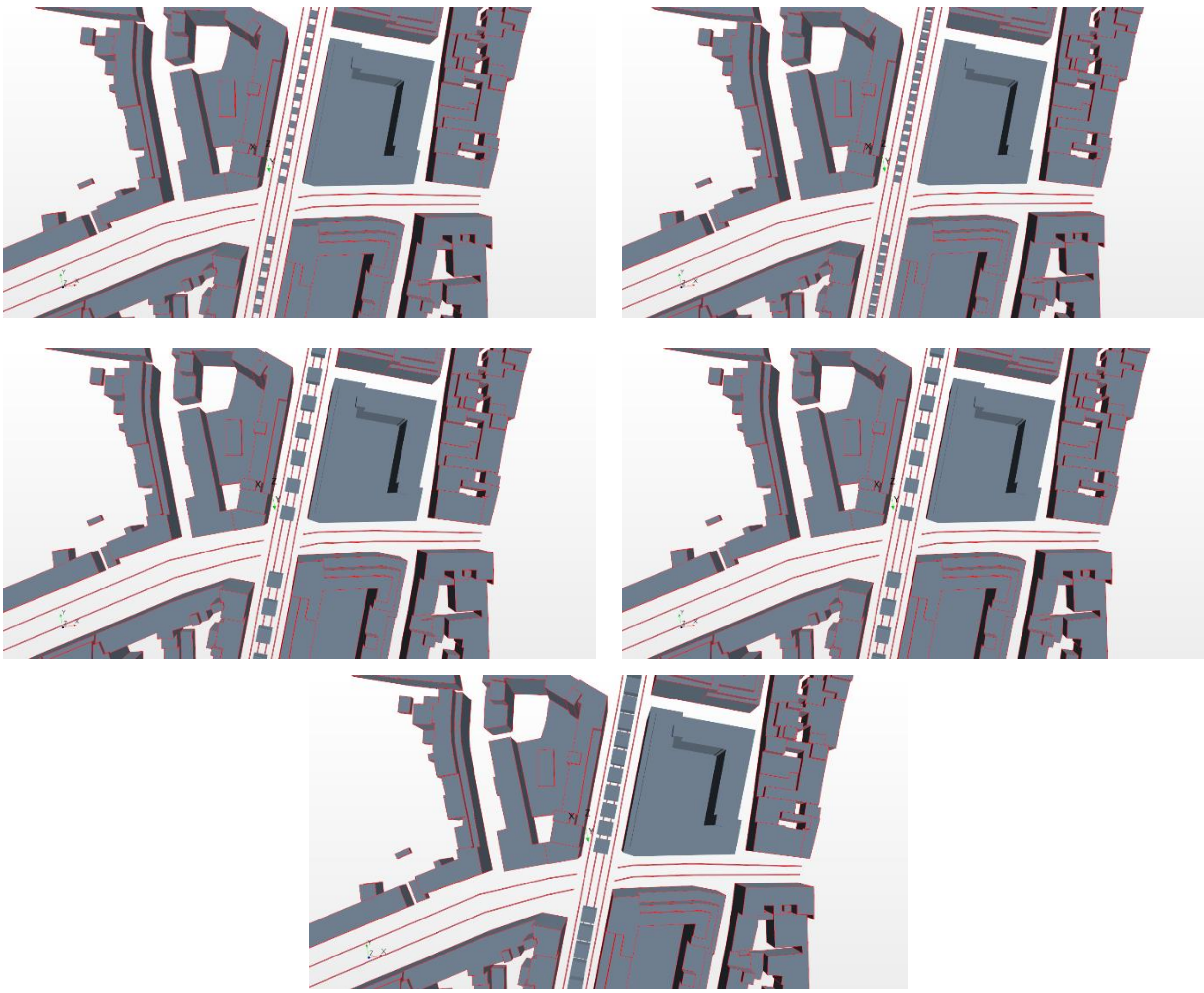


Figure 8 Representation of the five scenarios: 1 (left, top), 2 (right, top), 3 (left, middle), 4 (right, middle), 5 (bottom).

In all simulations, the crowns are represented as suspended cubes placed in the middle of Marconi street. The different distance between crowns and the different crown width of trees are important to evaluate how trees modify flow dispersion, impacting on air pollution and urban thermal comfort, in a real urban environment where vegetation is completely absent.

3.1.5 Model validation

As previously summarized, the setup of CFD simulations presented in this Deliverable has been validated by comparing the hourly values of meteorological, turbulence variables together with concentrations of CO gaseous pollutant obtained as outputs of the numerical simulations with the observations gathered during the summer experimental campaign whose setup was shortly presented in Section 2.1.2 and thoroughly described in D5.2 and D6.2.

3.1.6 Results for model validation

Figure 9 shows the comparison between the simulations and the observations in Marconi street canyon during the summer campaign. As described in D5.2, instrumentation for measuring CO concentrations was located on the top of the ARPAE van, while temperature, velocity and TKE (turbulent kinetic energy) were measured over a balcony 8 m high and 1 m distant from the building wall.

Figure 9 Marconi street, summer. Comparison between numerical results (red) and experimental results (blue). The uncertainty bars refer to the analytical uncertainty of meteorological and air quality observations.

For the purpose of the validation of the model setup, as previously described here we chose to focus only on one of the cases analysed with CFD simulations, and specifically on that of 22/08/2017 14:00 UTC. In particular, Figure 8 shows that in this case CO concentration (top line, first from left) obtained from numerical simulations overestimates the real observed value, as the numerical value (1.32 mg m^{-3}) is about five times larger than the measured one (0.24 mg m^{-3}). In order to achieve a better agreement between the simulations and the measured concentrations, the original emissions estimated with the methodology previously delineated have been reduced for this case. By setting the CO emissions equal to 2.51E-6 kg $m^{-3}s^{-1}$, the numerical simulation result in obtaining a concentration of 0.26 mg m^{-3}, in very good agreement with the hourly observed value.

The comparison between air temperatures obtained by numerical simulation and experiment (Figure 9, top line, middle) shows that the temperature is almost 3 degrees higher than the experimental value: this is caused by the fact that the temperature boundary conditions were obtained by averaging measurements conducted on highly non-uniform temperatures on the building façades, due to the sun shadows. Finally, Figure 8 shows that although the simulations tend to underestimate the TKE, numerical velocity components are in a good agreement with experimental values.

3.1.7 Results for scenarios

In this section, we report the description of the different scenarios compared to the baseline scenario, previously presented and discussed in D6.2. In particular, the effect of different types of trees on pollutant distribution in Marconi street has been investigated.

3.1.7.1 Baseline Scenario

Here, we report the results obtained from the simulations conducted in the real scenario (without trees in Marconi street) for the case 22/08/2018 at 14 UTC, when the wind direction was 93^{o} and the wind velocity was 4.4 m s^{-1}.

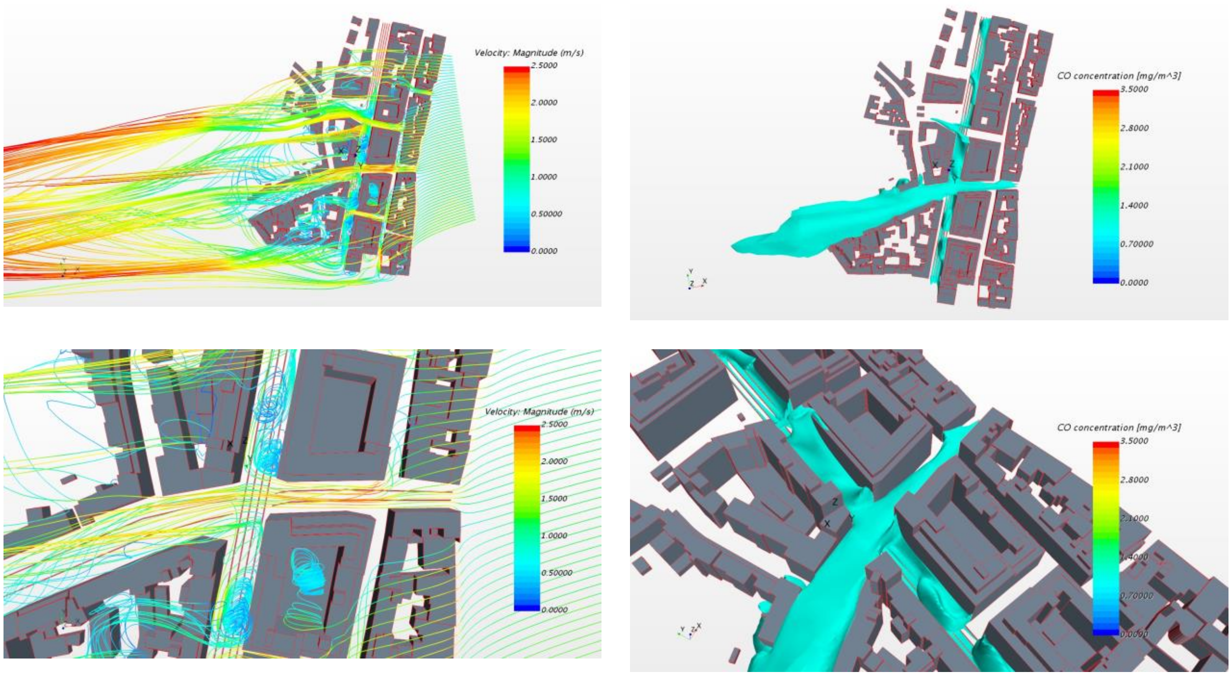


Figure 10 Marconi summer, afternoon. Real case 22/08/2017 UTC 14:00: Streamlines (top, left); intersection streamlines (bottom, left); CO concentrations (top, right); intersection CO concentrations (bottom, right).

Figure 10 shows the streamlines and CO concentrations obtained for this case. Here the flow is almost parallel to Riva Reno street and the streamlines show similar behaviour of the flow field: a channelling flow from East to West in via Riva Reno street, with two recirculation vortices at the entrance of the two sides of Marconi street. It is interesting to observe that the two recirculation vortices have the same length of one building block, i.e. the recirculation is broken by the air inlet from tributary side streets. The shape of recirculation vortices depends on the intersection geometry in combination with wind direction and wind velocity: when the wind direction is perpendicular to Riva Reno street, as in this case, only two vortices appear at the two sides of Marconi street. In particular, CO concentration peaks are observed in correspondence of these recirculation zones.

We can verify this concept in Figure 11 where the velocity vector magnitude and the CO concentration along the intersection at 1.5 m from the ground are reported to understand better the distribution of pollution at a pedestrian level near the intersection.

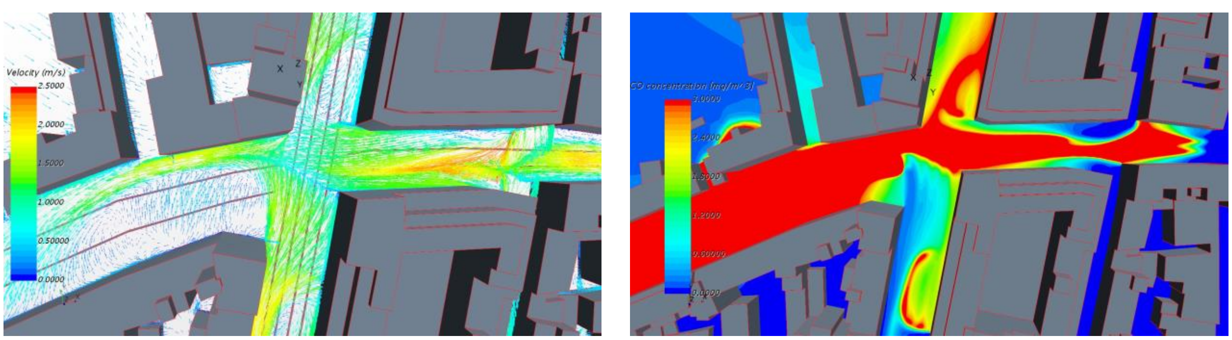


Figure 11 Marconi summer, afternoon. Real case 22/08/2017 UTC 14:00: Velocity vectors (left); CO concentrations (left).

The combination of a high velocity channelling along Riva Reno street, together with the presence of a curve in Riva Reno street after the intersection creates flow separation in the South side of Riva Reno street, after the intersection. The recirculation vortices at the two sides of the intersection correspond to CO concentration peaks. Near those peaks, high pollutant concentration gradients are observed.

In Figure 12, CO concentration is shown on the plane section where the ARPAE van was located, in order to compare observed and simulated values along Marconi street canyon. Figure 11 shows that:

1. The CO concentration in the Marconi street canyon (top, left) shows that most of the pollutant is concentrated on the bottom-right part of the canyon. This is caused by the counterclockwise vortex created on the top of the canyon acting as a cap (bottom, right), which also causes a higher temperature in proximity of the higher CO concentration (bottom, left).
2. The vortex created is not perfectly perpendicular to the canyon and this causes a CO removal in the upper part of the canyon and a strong velocity and concentration gradient at a height close to that of the ARPAE van (top, right). This result indicates that in this case the dimension of the vortex obtained in the simulation is underestimated with respect to the real one, which suggests that in the real case the CO gradient was below the ARPAE van station.

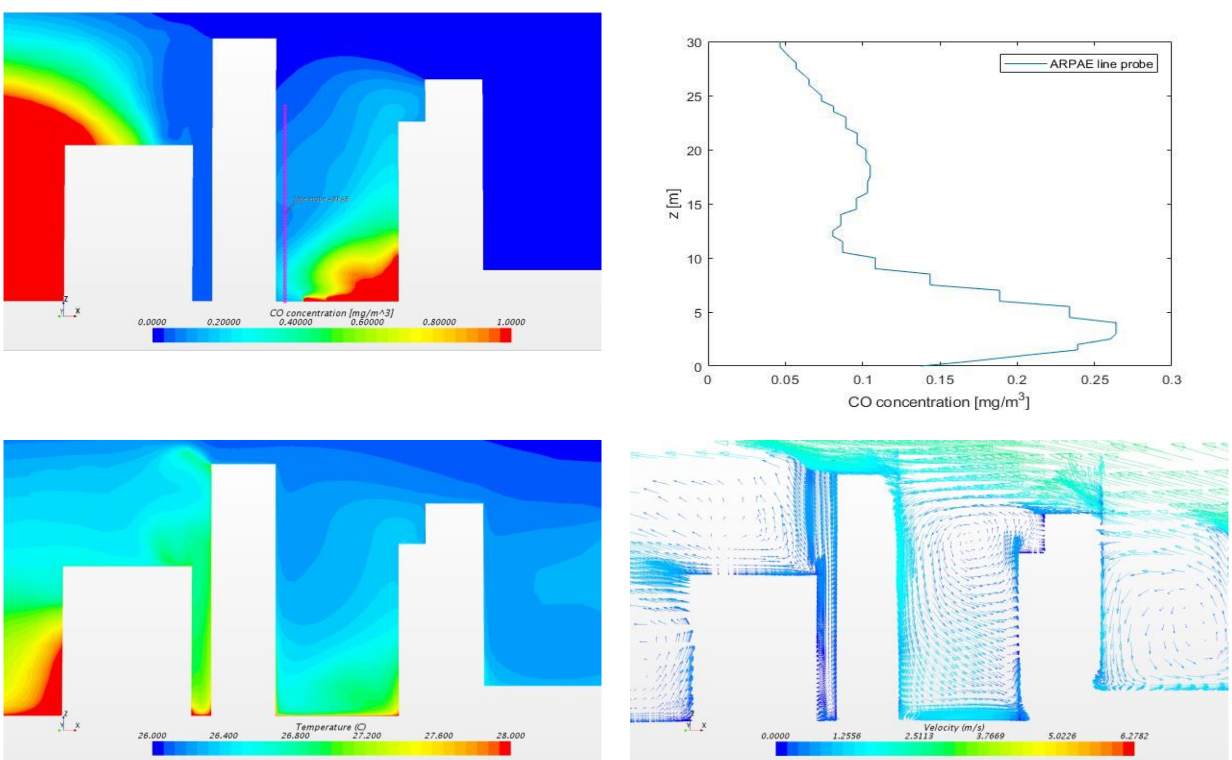


Figure 12 Marconi summer, afternoon. Real case 22/08/2017 UTC 14:00: CO concentration (top, left); plot line probe CO concentration (top, right); temperature (bottom, left); velocity vectors (top, right).

3.1.7.2 First Scenario

In this scenario, Populus tremula tree has been placed in the middle of Marconi street canyon at a regular distance of 3.5 m. The shape of the trees and LAD are provided in Table 8.

Scenario number	**Type of tree**	**Distance between crowns**
1	Populus tremula	3.5 m
Average height	**Crown width**	**LAD**
10.5 m	3.5 m	2.03 m^{2} m^{-3}

Table 8 Characteristics of the first scenario chosen for Marconi street.

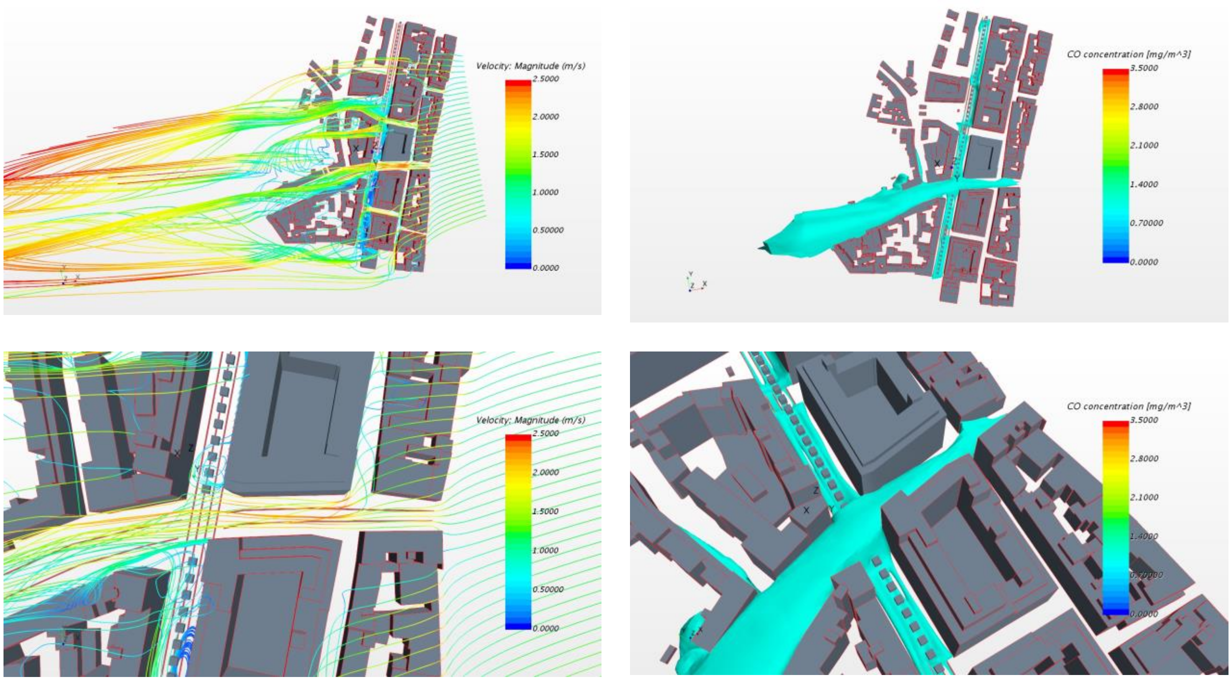


Figure 13 Marconi summer, afternoon. First case 22/08/2017 UTC 14:00: Streamlines (top, left); intersection streamlines (bottom, left); CO concentration (top, right); intersection CO concentration (bottom, right).

By comparing Figure 13 with Figure 10, it can be observed that the flow field obtained for this scenario is very different from that obtained for the real Marconi street simulation. The presence of trees inhibits the formation of recirculation vortices at the street intersection between Marconi street and Riva Reno street. As a consequence, the pollutant distribution obtained for the scenario with trees is very different, as CO concentration peaks are not visible on the lateral sides of the intersection.

We can verify this result in Figure 14 which shows the air velocity vectors on the left and the CO concentration on the right along the intersection at a height 1.5 m from the ground.

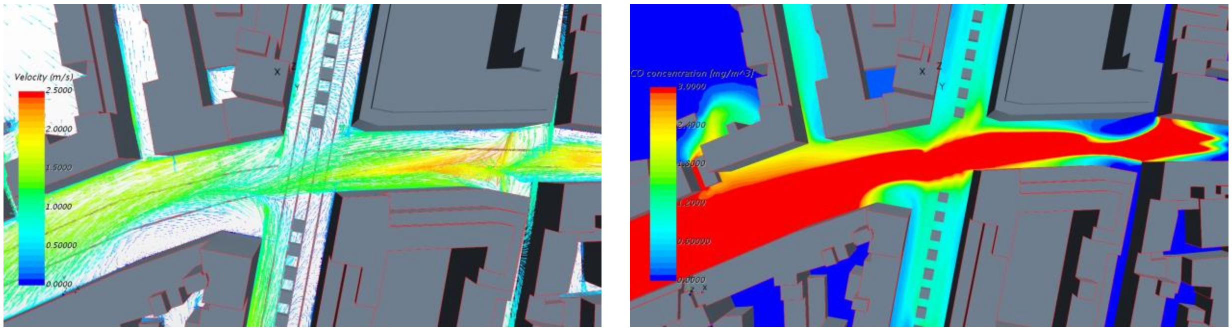


Figure 14 Marconi summer, afternoon. First case 22/08/2017 UTC 14:00: Velocity vectors (left); CO concentration (left).

The vector map obtained for this scenario shows main flow on Riva Reno street with secondary flows from the two sides of Marconi street, dragged by the main flow without the creation of vortices. The crowns positioned at the centre of Marconi street act as a cap for the pollution that cannot migrate upwards and for that it remains at ground level, distributing itself uniformly. As a result, the local pollutant concentration obtained in Marconi street is higher in the case of the presence of trees than the real case.

This result appears with more evidence visualising the plane section where the ARPAE van was set, to show a comparison between measured values. In particular, Figure 15 shows that most of the CO was concentrated on the bottom of the Marconi street canyon (top, left), in the proximity of which a higher temperature is obtained.

In addition, at the position of the ARPAE station, most of CO was found at the bottom of the canyon (Figure 15 right).

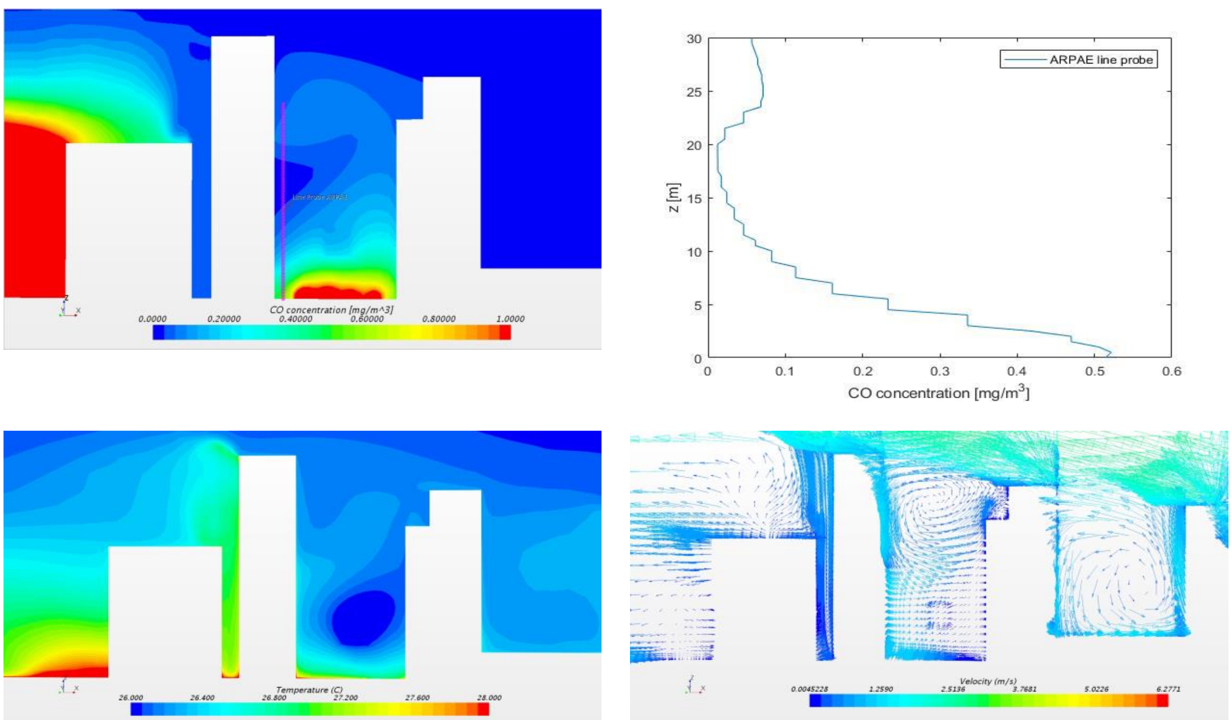


Figure 15 Marconi summer, afternoon. First case 22/08/2017 UTC 14:00: CO concentration (top, left); plot line probe CO concentration (top, right); temperature (bottom, left); velocity vectors (top, right).

3.1.7.3 Second Scenario

This scenario was created from the baseline case in which trees were added as suspended cubes positioned in the middle of Marconi street; the main characteristics of this scenario are reported in Table 9.

The only difference with the previous scenario (number 1) is in the distance between crowns, which was halved compared to the first one.

Scenario number	**Type of tree**	**Distance between crowns**
2	Populus tremula	1.75 m
Average height	**Crown width**	**LAD**
10.5 m	3.5 m	2.03 m^{2} m^{-3}

Table 9 Characteristics of the second scenario chosen for Marconi street.

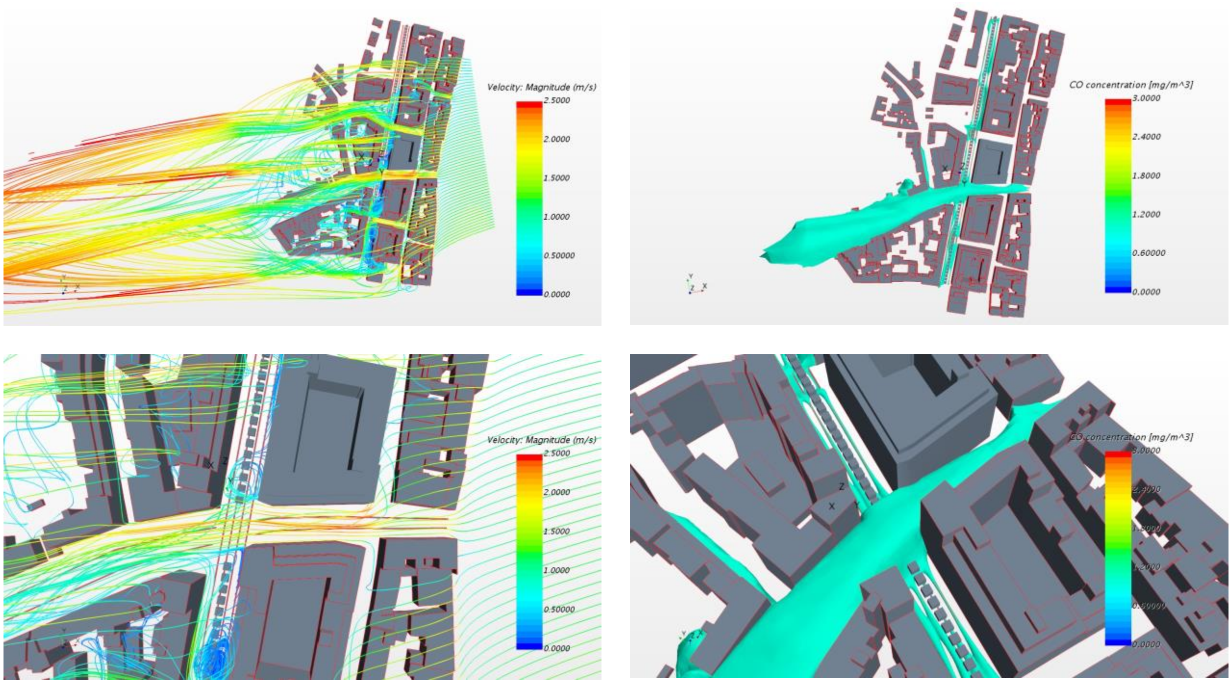


Figure 16 Marconi summer, afternoon. Second case 22/08/2017 UTC 14:00: Streamlines (top, left); intersection streamlines (bottom, left); CO concentration (top, right); intersection CO concentration (bottom, right).

By relating Figure 16 and Figure 10, it can be observed that the flow field achieved for this scenario is very different from that obtained for the real Marconi street simulation. The presence of trees limits the formation of recirculation vortices at the street intersection between Marconi street and Riva Reno street. Consequently, the CO concentration peaks are not so visible on the lateral sides of the traffic intersection and the crowns border almost the pollution flows directly in Riva Reno street.

Also for this scenario, we can validate this concept in Figure 17 which reports the velocity vector magnitude on the left and the CO concentration on the right along the intersection at 1.5 m from the ground.

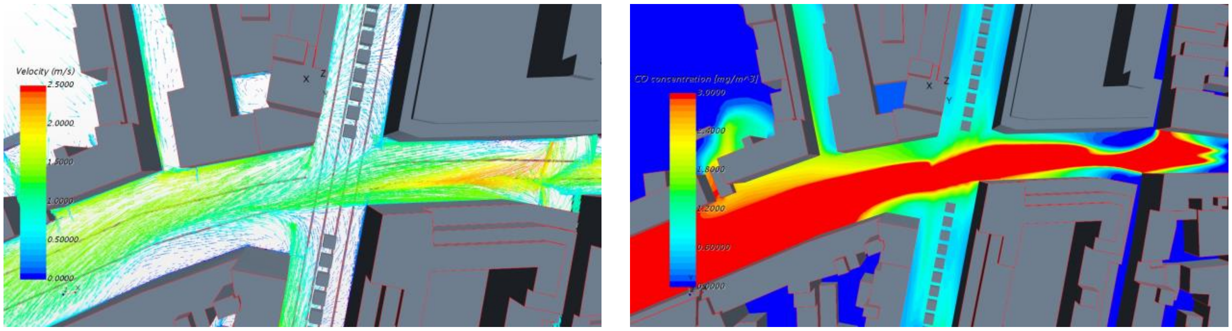


Figure 17 Marconi summer, afternoon. Second case 22/08/2017 UTC 14:00: Velocity vectors (left); CO concentration (left).

The vector and the pollution maps obtained for this case show the main flow on Riva Reno street with secondary flows from the two sides of Marconi street, dragged by the main flow without the creation of vortices (as seen in the first scenario).

A comparison between the first and the second scenario shows the impact of the crown distance on pollutant distribution. The two simulations presented a very similar situation:

- The highest pollutant level is concentrated on the bottom of the Marconi street canyon near the pollution source since the crowns act as caps for pollutants, worsening air quality;
- The peak of temperature is observed at the pedestrian level.

Comparing these two cases by visualising Figure 15 and Figure 18, we can see that by decreasing the distance between crowns the CO concentration tends to increase at a bottom level probably because of the larger effect caused by the tree crowns of nearer trees. As a result, in this scenario, we obtained a higher local pollutant concentration in Marconi street.

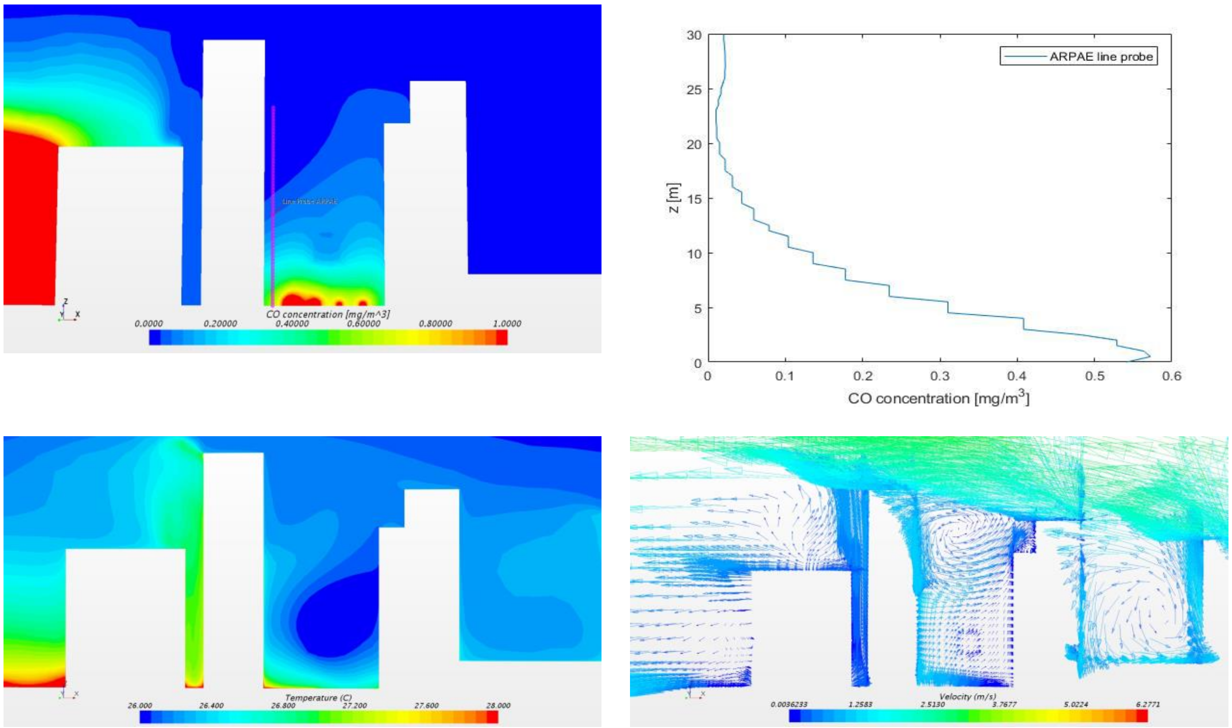


Figure 18 Marconi summer, afternoon. Second case 22/08/2017 UTC 14:00: CO concentration (top, left); plot line probe CO concentration (top, right); temperature (bottom, left); velocity vectors (top, right).

3.1.7.4 Third Scenario

In this scenario, the Fagus sylvatica tree has been placed in the middle of Marconi street canyon at a regular distance of 7 m. The shape of the trees and LAD are provided in Table 10.

Scenario number	**Type of tree**	**Distance between crowns**
3	Fagus sylvatica	7 m
Average height	**Crown width**	**LAD**
18 m	7 m	0.97 $m^2 m^{-3}$

Table 10 Characteristics of the third scenario chosen for Marconi street.

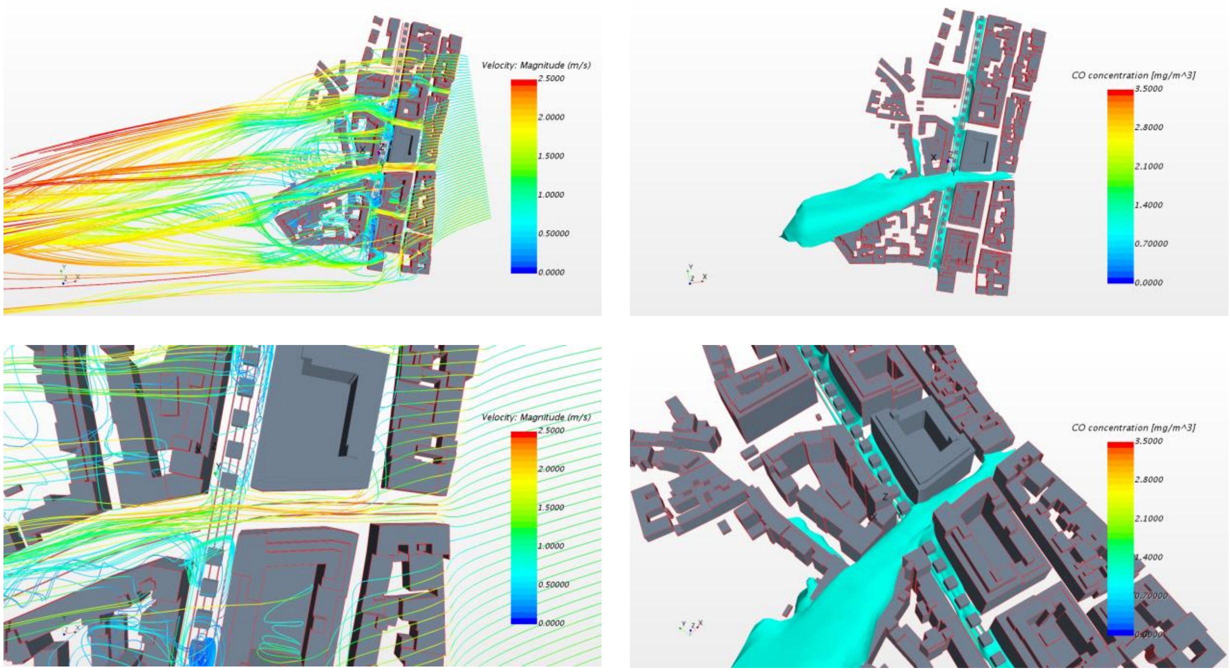


Figure 19 Marconi summer, afternoon. Third case 22/08/2017 UTC 14:00: Streamlines (top, left); intersection streamlines (bottom, left); CO concentration (top, right); intersection CO concentration (bottom, right).

By comparing Figure 19 with Figure 9, it can be observed that the flow field obtained for this scenario is very different to that obtained for the real Marconi street simulation: the presence of trees inhibits the formation of recirculation vortices at the street intersection between Marconi street and Riva Reno street. Therefore, the pollutant distribution obtained for the scenario with trees is altered, as CO concentration peaks are not so visible on the lateral sides of the intersection. This result has been already seen in the two previous scenarios, even if with a different type of tree.

We can verify this concept in Figure 20 which reports the air velocity vectors on the left and the CO concentration on the right along the intersection at 1.5 m from the ground to better understand the pollution distribution at the pedestrian level.

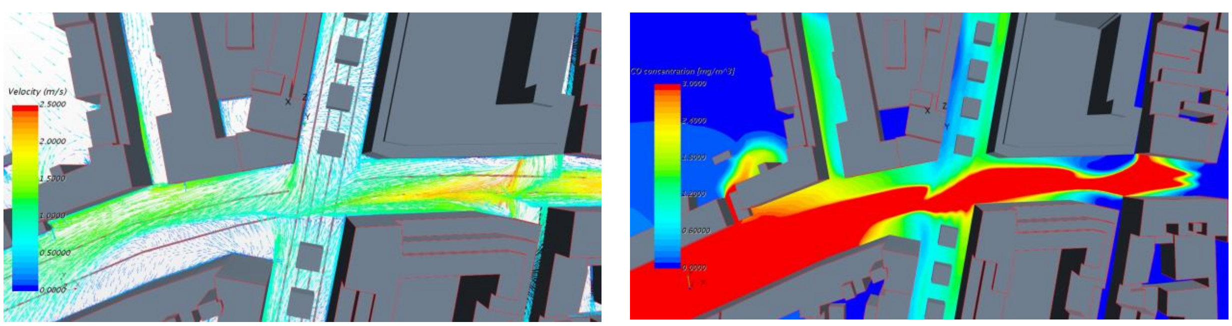


Figure 20 Marconi summer, afternoon. Third case 22/08/2017 UTC 14:00: Velocity vectors (left); CO concentration (left).

The vector map obtained for this scenario shows a main flow on Riva Reno street with secondary flows from the two sides of Marconi street, dragged by the main flow without the creation of vortices. Despite this observation, the crowns positioned at the centre of Marconi street act as a cap for the pollutant that cannot migrate upwards and for that it remains at ground level. As a result, the local CO concentration obtained in Marconi street appears higher in this scenario than in the real one.

This concept appears with more evidence visualising the plane section where the ARPAE van was placed; in particular, Figure 21 shows that:

- most of the CO pollutant is concentrated on the bottom of the canyon because of the tree cap crowns, which also cause higher temperatures in the proximity of the higher CO concentration (bottom, left);
- the probe line placed where the ARPAE station van was located (top, right) confirmed that the highest CO concentration was found at the bottom of the canyon; this can cause increasing pollution at pedestrian level;
- the only vortex created in Marconi street canyon is located above the crowns, at their centre (bottom, right).

As a result, we can notice that even if the geometry inside the canyon was changed using a different type of trees, all the three simulations analysed so far are very similar: the only difference is that in this scenario the CO concentration is located at the bottom of the street canyon, to the right side. This phenomenon was already observed in the baseline scenario because of the counterclockwise vortex created on the top of the canyon; in this case, considering larger tree crowns than in the first two cases, the counterclockwise vortex is not destroyed by the crowns.

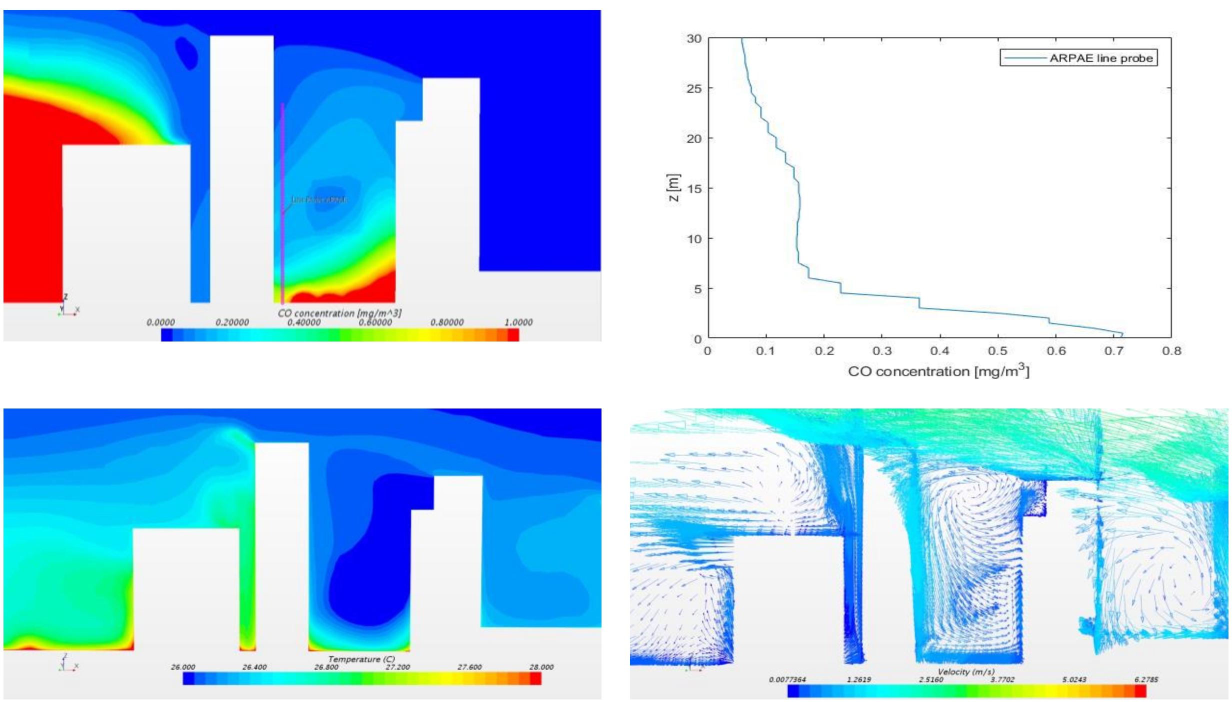


Figure 21 Marconi summer, afternoon. Third case 22/08/2017 UTC 14:00: CO concentration (top, left); plot line probe CO concentration (top, right); temperature (bottom, left); velocity vectors (top, right).

3.1.7.5 Fourth Scenario

This scenario was created from the baseline case in which trees were added as suspended cubes positioned in the middle of Marconi street; the main characteristics are reported in Table 11.

Here, the only difference with the previous scenario (number 3) is in the distance between crowns, which here was halved with respect to the third case.

Scenario number	**Type of tree**	**Distance between crowns**
4	Fagus sylvatica	3.5 m
Average height	**Crown width**	**LAD**
18 m	7 m	0.97 $m^{2}\ m^{-3}$

Table 11 Characteristics of the fourth scenario chosen for Marconi street

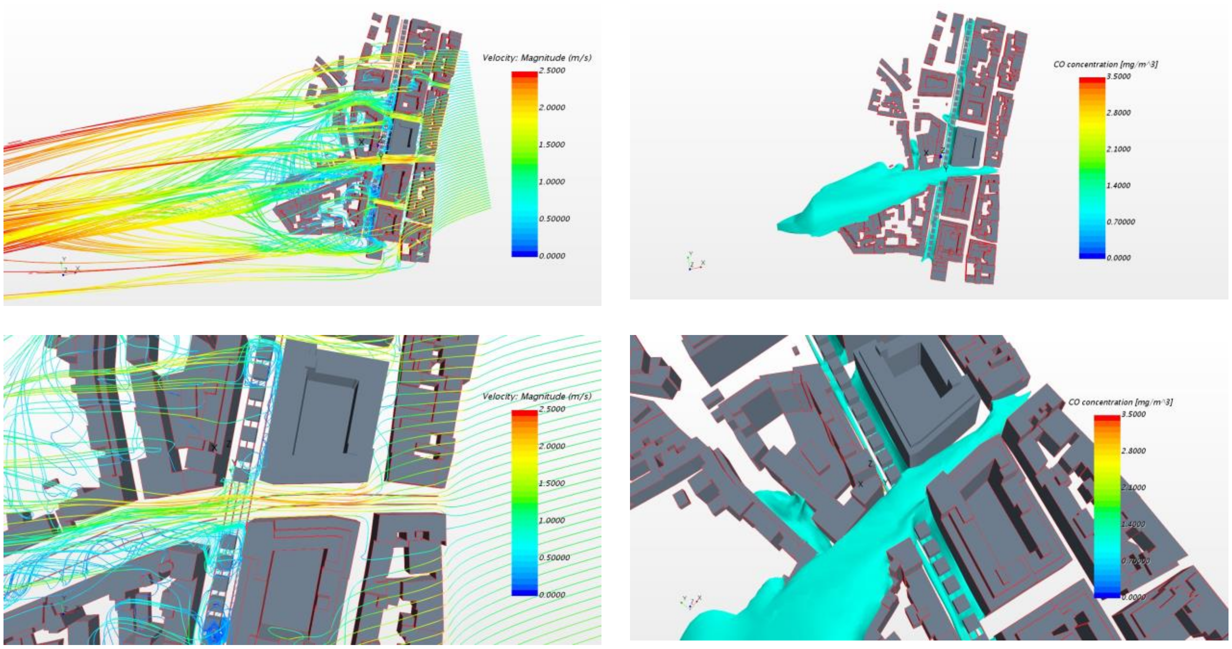


Figure 22 Marconi summer, afternoon. Fourth case 22/08/2017 UTC 14:00: Streamlines (top, left); intersection streamlines (bottom, left); CO concentration (top, right); intersection CO concentration (bottom, right).

Comparing Figure 22 with Figure 10, it can be observed that the flow field obtained in this scenario is very different to that obtained for the baseline simulation: the presence of trees prevents the formation of recirculation vortices at the street intersection between Marconi street and Riva Reno street. Similar to the results obtained in previous scenarios, the pollutant distribution obtained for the scenario with trees is very different, as CO concentration peaks are not so evident on the lateral sides of the intersection.

We can further verify this concept in Figure 24 which reports the velocity vector magnitude on the left and the CO concentration on the right along the intersection at 1.5 m from the ground.

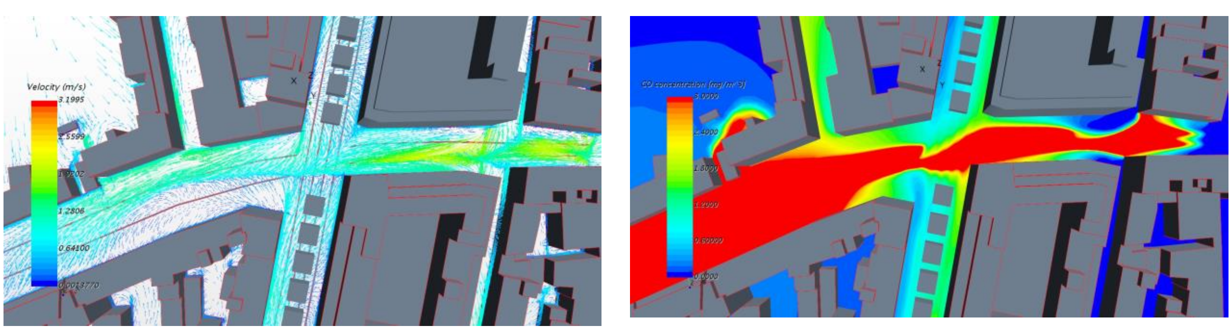


Figure 23 Marconi summer, afternoon. Fourth case 22/08/2017 UTC 14:00: Velocity vectors (left); CO concentration (left).

The vector and the pollution distribution found for this case show a main flow on Riva Reno street with secondary flows from the two sides of Marconi street, dragged by the main flow without the creation of vortices (as seen in the third scenario): this is because of the crowns put at the centre of Marconi street that seem to concentrate the pollution at ground level, acting as a cap. As a result, the local pollutant concentration obtained in Marconi street appears higher in this scenario than in the real one.

This concept appears stronger looking at the plane section where the ARPAE van was located; in particular, Figure 24 shows that all the considerations made for the previous scenarios, regarding, for example, the location of most of CO pollutant, are still valid. It is important in this case to make a comparison between the third and the fourth case, to better understand the influence of the crown distance on the pollutant distribution. Comparing these two scenarios by visualising Figure 21 and Figure 24 (top, left and right), we can see that by decreasing the distance between crowns the CO concentration tends to increase at the bottom level, probably because of the larger effect caused by the tree crowns of nearer trees. As a result, the local pollutant concentration obtained in Marconi street is a bit higher in this case.

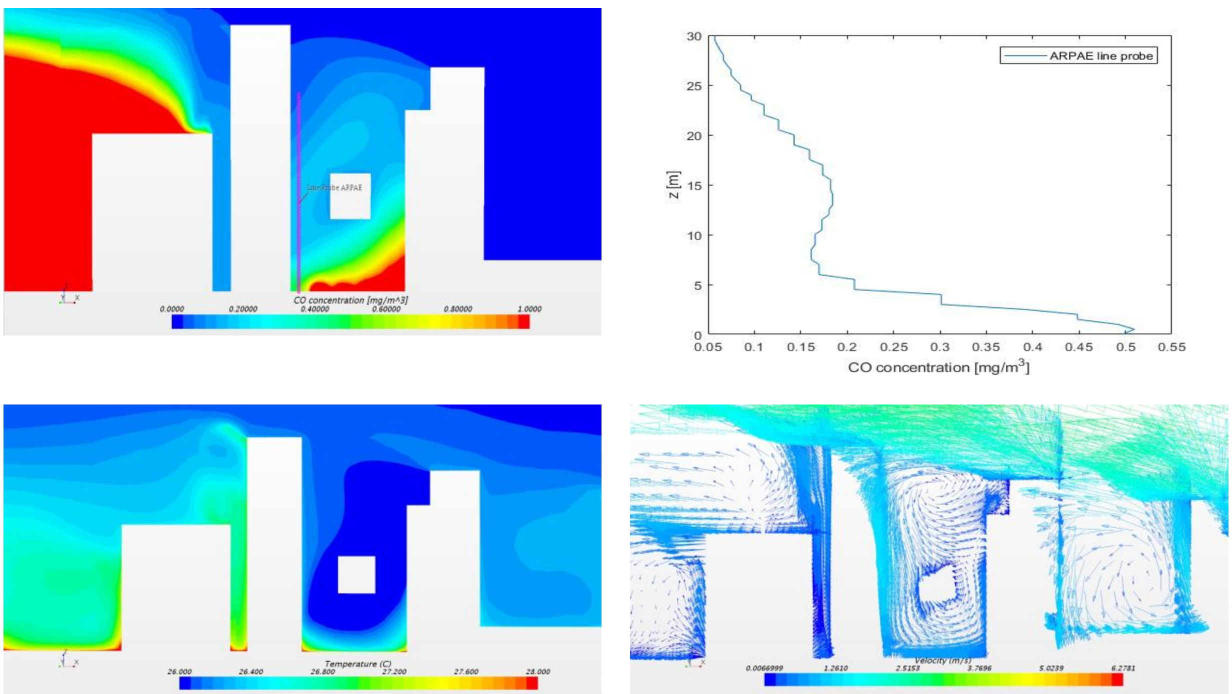


Figure 24 Marconi summer, afternoon. Fourth case 22/08/2017 UTC 14:00: CO concentration (top, left); plot line probe CO concentration (top, right); temperature (bottom, left); velocity vectors (top, right).

3.1.7.6 Fifth Scenario

This last scenario was created from the baseline case in which trees were added as suspended cubes positioned in the middle of Marconi street; the main characteristics are reported in Table 12.

Here, the only difference with the previous two scenarios (number 3 and 4) is in the distance between crowns that in this case was halved with respect to the fourth case.

Scenario number	Type of tree	Distance between crowns
5	Fagus sylvatica	1.75 m
Average height	**Crown width**	**LAD**
18 m	7 m	0.97 $m^2\ m^{-3}$

Table 12 Characteristics of the fifth scenario chosen for Marconi street.

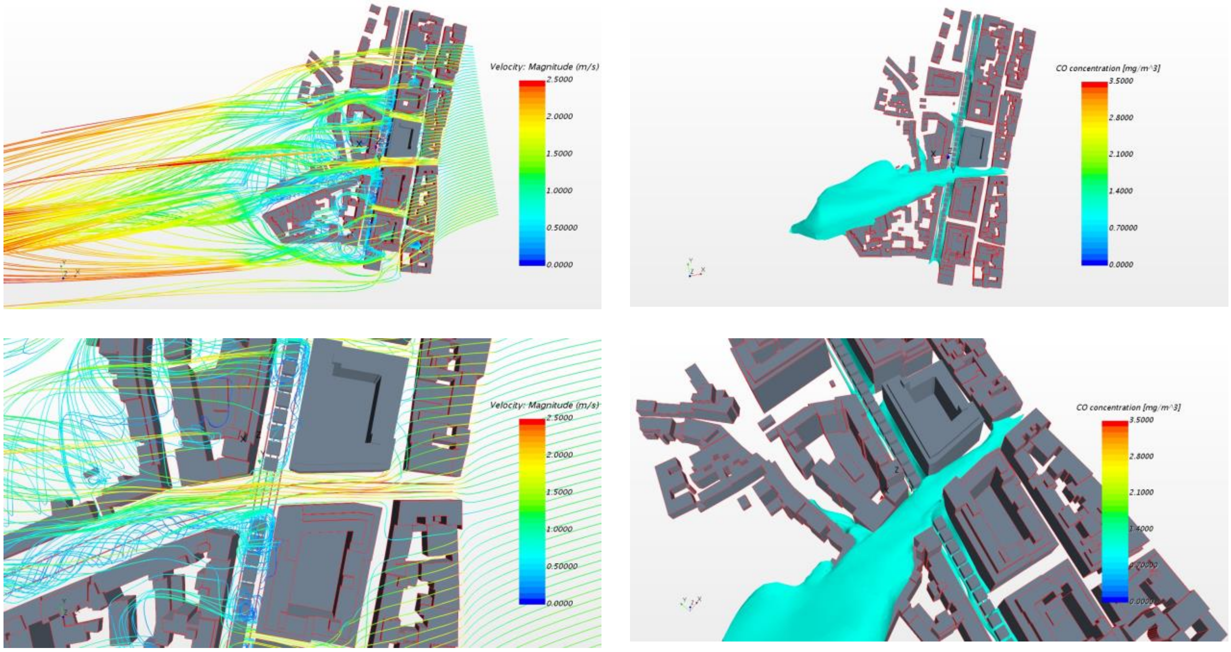


Figure 25 Marconi summer, afternoon. Fifth case 22/08/2017 UTC 14:00: Streamlines (top, left); intersection streamlines (bottom, left); CO concentration (top, right); intersection CO concentration (bottom, right).

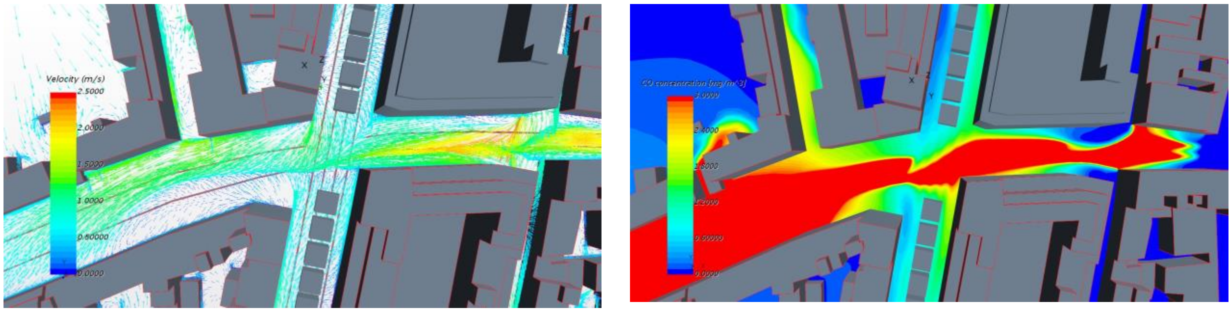


Figure 26 Marconi summer, afternoon. Fifth case 22/08/2017 UTC 14:00: Velocity vectors (left); CO concentration (left).

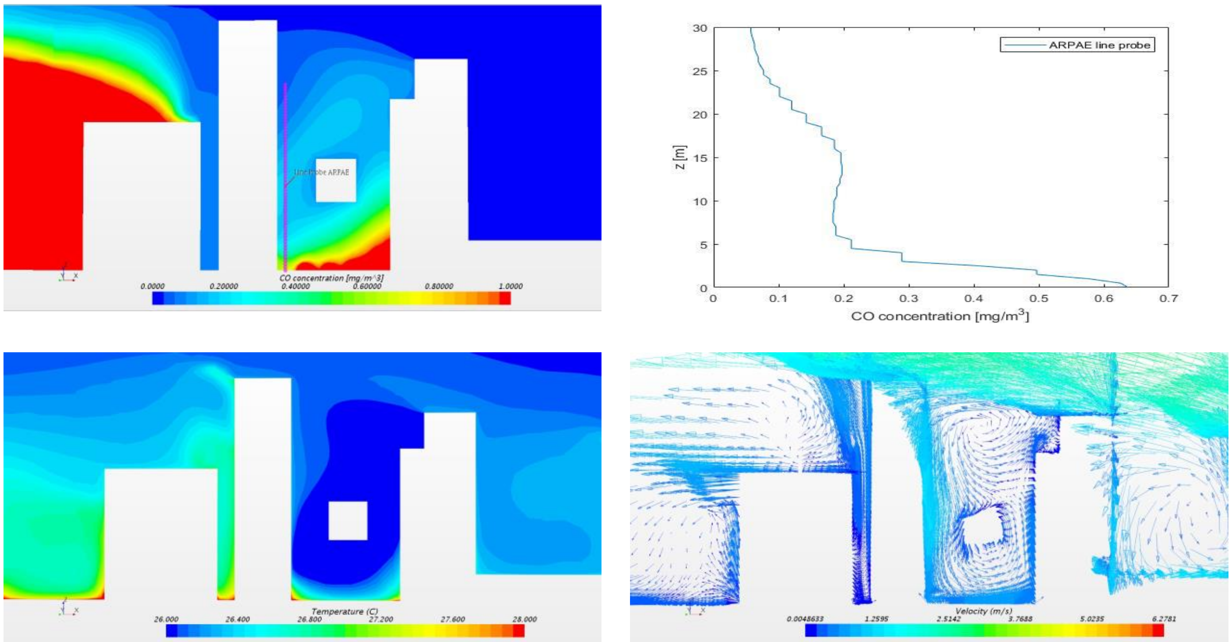


Figure 27 Marconi summer, afternoon. Fifth case 22/08/2017 UTC 14:00: CO concentration (top, left); plot line probe CO concentration (top, right); temperature (bottom, left); velocity vectors (top, right).

Investigating this scenario, as we can see from Figure 25, Figure 26 and Figure 28, we obtained the same conclusions obtained in the two previous cases in terms of CO concentration, maximum temperature etc.

In the following, we focus our analysis on the CO concentration obtained in all the simulations, reported in Table 13. The first column reports the CO concentration simulated in the point where the ARPAE instrumentation was located; the second column provides the mean CO concentration in the Marconi canyon area at 4 m height from ground level and the last column shows the mean value of CO concentration considering the entire volume of Marconi street canyon.

	Canyon ARPAE point CO concentration [mg m^{-3}]	**Canyon ARPAE section CO concentration [mg m^{-2}]**	**Canyon ARPAE volume CO concentration [mg m^{-3}]**
ARPAE: measured concentration	**0.24**	_	_
Baseline scenario: simulated concentration	**0.26**	**0.87**	**0.73**
First scenario: simulated concentration	**0.34**	**0.58**	**0.48**
Second scenario: simulated concentration	**0.41**	**0.52**	**0.41**
Third scenario: simulated concentration	**0.36**	**0.61**	**0.52**
Fourth scenario: simulated concentration	**0.29**	**0.64**	**0.57**
Fifth scenario: simulated concentration	**0.30**	**0.63**	**0.55**

Table 13 CO concentration for all scenarios.

From Table 13, we can observe that:

1. Observing the first column, we can see that the introduction of any type of trees inside Marconi street canyon causes an increase in CO concentration near ARPAE van station position. This very local results could lead to conclude that the effect of trees is to increase the pollutant concentration within the street canyon. In addition, considering the first and the second scenarios, i.e. the planting of the ‘Populus tremula’ tree, it seems that if the distances between crowns decrease, the foliage increases and the final local CO concentration will be higher because of larger effect caused by the tree crowns when trees are closer, described previously.

   This does not happen in the other three cases with ‘Fagus sylvatica’ trees; in these cases, in fact, we have a combination of the effect of nearer crowns with the hindering of the passage of the pollutant from the intersection between Riva Reno street and Marconi street caused by the trees (Figure 29, Figure 30). The CO concentration local value reported for the third scenario is lower because in this case the ARPAE van was located under a crown, while the value reported for the fifth scenario is higher because more foliage entails a lower amount of CO pollutant entering Marconi street from Riva Reno street (Figure 30). We can conclude finally that the CO concentration obtained in the last three cases is about the same.

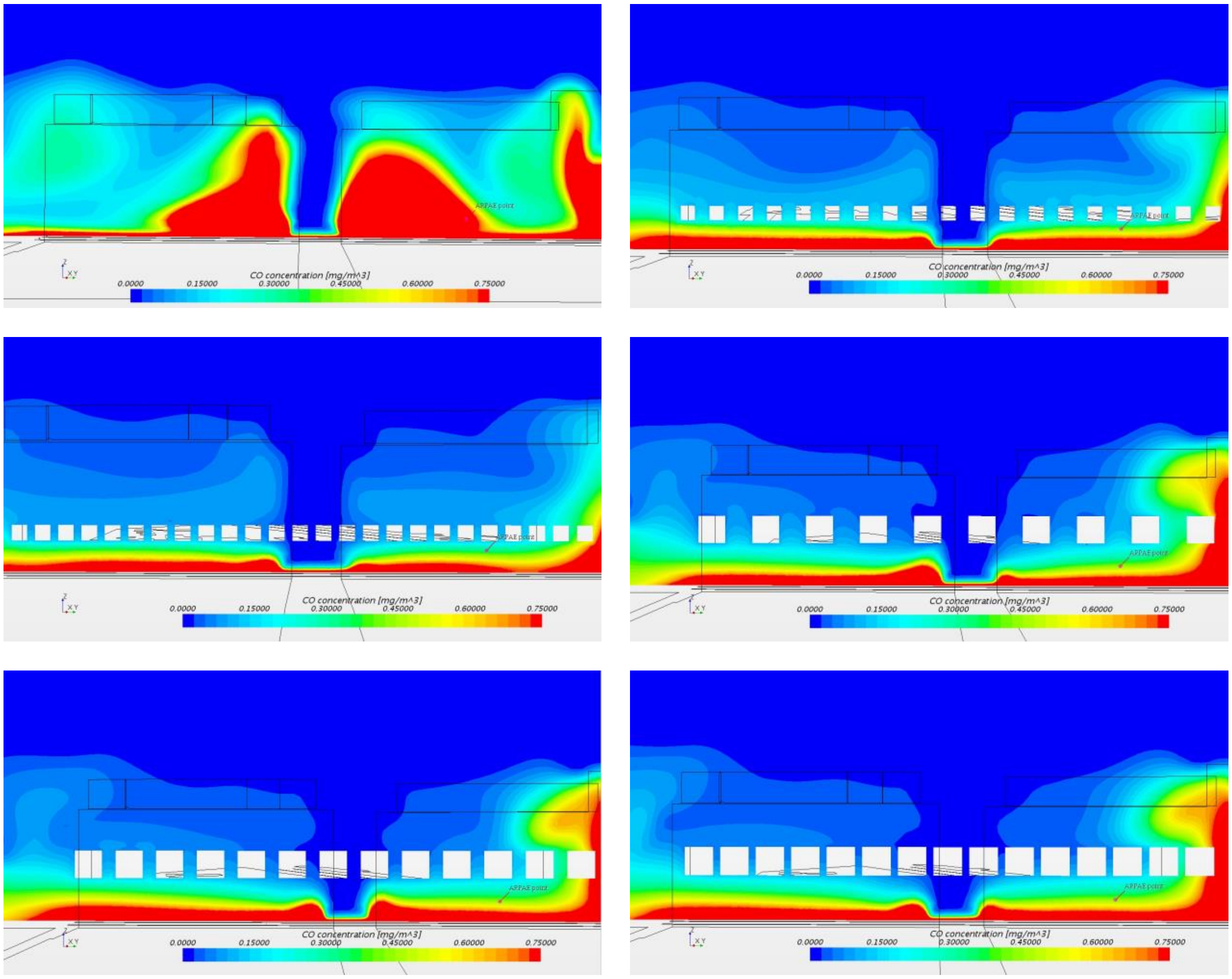


Figure 28 Marconi summer plane section before the intersection, 22/08/2017 UTC 14:00: CO concentration. Baseline case (top, left); First case (top, right); Second case (middle, left); Third case (middle, right); Fourth case (bottom, left); Fifth case (bottom, right).

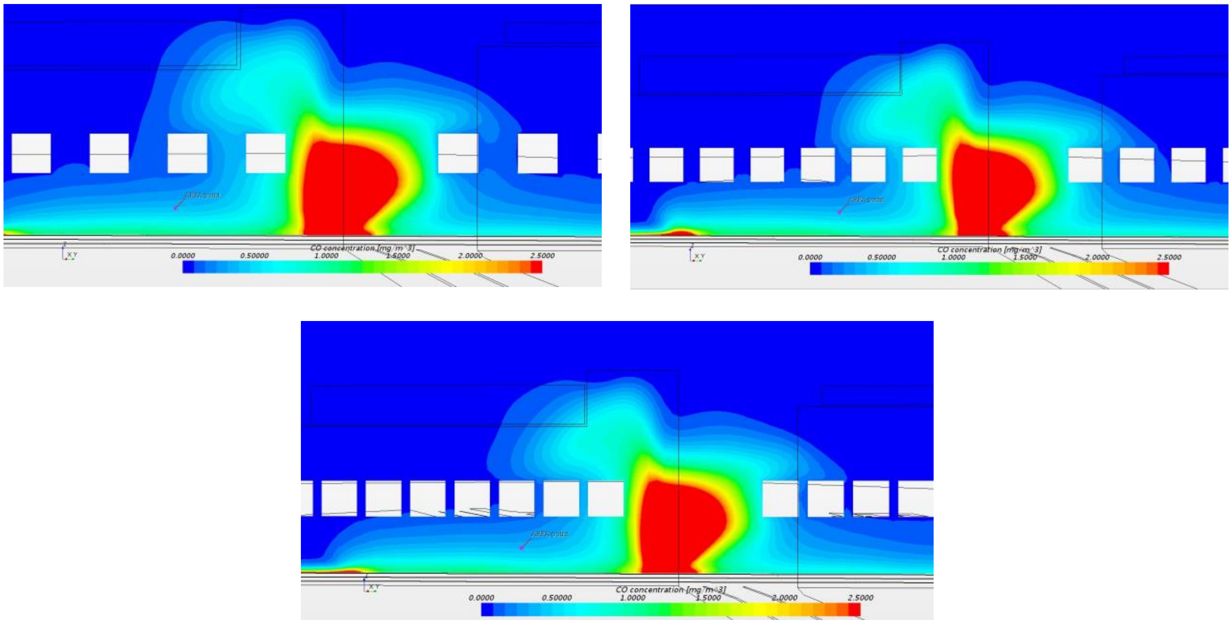


Figure 29 Marconi summer plane section near the intersection, 22/08/2017 UTC 14:00: CO concentration. Third case (top, left); Fourth case (top, right); Fifth case (bottom).

2. A local single point, generally, cannot provide results representative for a whole street canyon; the second column of Table 13 reports the average of CO concentrations over a horizontal plane at a height of 1.5 m, while the third column reports the CO concentration averaged over a volume that occupies completely the street canyon. From the second and third columns, we can observe a different trend from that observed for local CO concentration: the introduction of trees in the baseline scenario actually reduces pollutant concentrations. This probably means that having introduced the trees' absorption effect is synonymous of an overall improvement in terms of pollution within a street canyon as Marconi street. This observation can be explained with the fact that the absorbing effect of the crowns on the pollutant, connected with the LAD value, is not appreciable punctually. As such, for the first and the second scenarios, we observed that increasing the crowns' number, the CO concentration value decreased, while this did not occur in the other cases where instead we can observe an almost constant concentration. For these cases, the bigger crown of trees showed no effect for two main reasons, i.e. the halved LAD value and the greater distance of the crowns from the ground level.
3. The local CO concentration along three lines at a height of 1.5 m was obtained to better understand the influence of the local pollutant distribution on pedestrians. Two of the three lines, shown in Figure 31, are placed at a distance of 1.75 m from the right and left street canyon sides respectively (right and left are the sides of the street with reference to a pedestrian walking from South to North). The third one is placed in the middle of the street canyon.

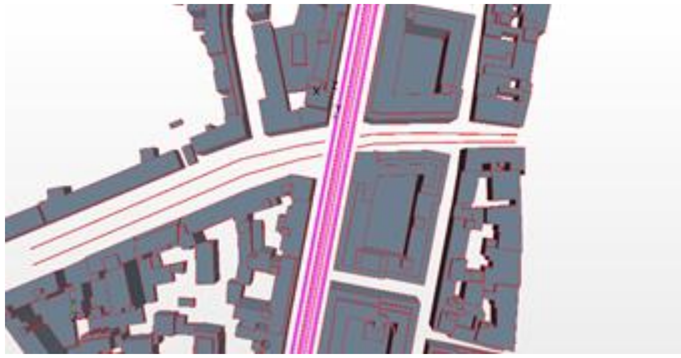


Figure 30 Position of probe lines in Marconi street canyon (left, middle and right).

Figure 31 shows the local CO concentration obtained along a line at the left side of Marconi street. All the plots in the figure present a peak near the intersection between Marconi street and Riva Reno street, *i.e*. at a distance of 60 m from the south entrance of Marconi street canyon. The local CO concentration obtained for the case without trees (baseline scenario) is about twice that obtained in the cases with trees, on the North side of Marconi street, after the intersections (between 60 m and 90 m from the beginning of the street). The ARPAE station was located on the south side of Marconi street, at a distance of about 20 m from the intersection. In that position, the local CO concentration obtained for the case without trees is lower than that obtained in the case with trees. The air flow is deviated toward the North side of Marconi street at the intersection (as shown in Figure 11) due to the non-symmetrical geometry of the buildings near the intersection. All the CO peaks obtained for the baseline scenario on the North side of Marconi street are higher than those obtained for the cases with trees. The effect of trees appears to lower the CO concentration on the peaks and to make the local CO distribution more uniform.

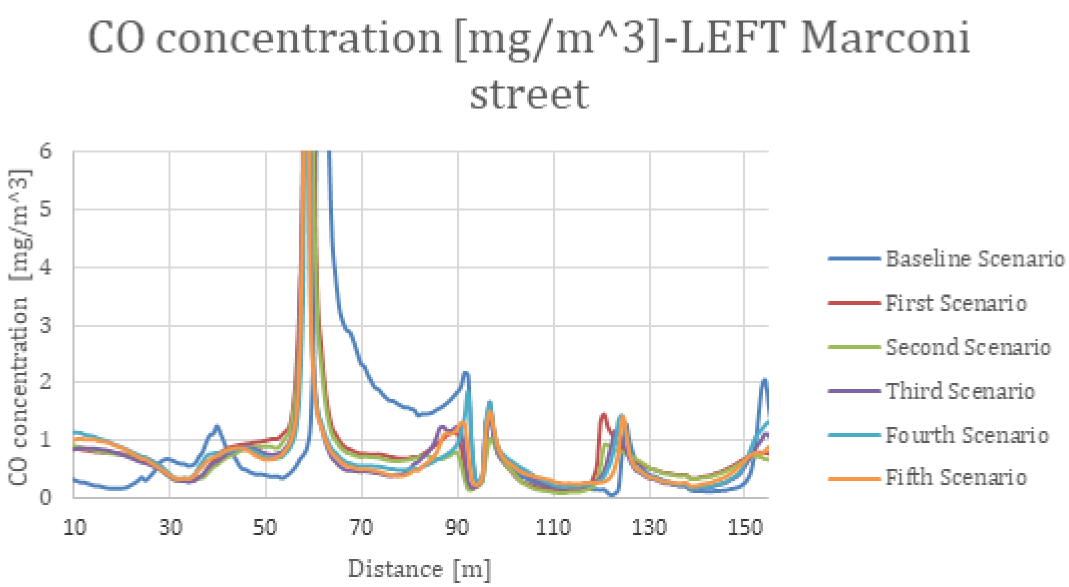


Figure 31 Left probe line along the Marconi street reporting the CO concentration at 1.5 m from the ground for all scenarios (without the main intersection peak).

Figure 32 shows the local CO concentration obtained along a line in the middle of Marconi street. All the plots on the figure show a peak near the intersection between Marconi street and Riva Reno street, *i.e*. at a distance of 60 m from the south entrance of Marconi street canyon. The local CO concentration obtained for the case without trees (baseline scenario) is about three times higher than that obtained for the cases with trees, on the North side of Marconi street, after the intersections (between 60 and 90 m from the beginning of the street). Extreme CO peaks are observed on the south side of Marconi street, where local CO concentration values are more than twice than those obtained for the cases with trees. All the CO peaks obtained for the baseline scenario on the North side of Marconi street are higher than those obtained for the cases with trees. These results confirm what is shown in Figure 31, i.e. that the trees tend to lower the value of CO concentration on the peaks and to make the local CO distribution more uniform.

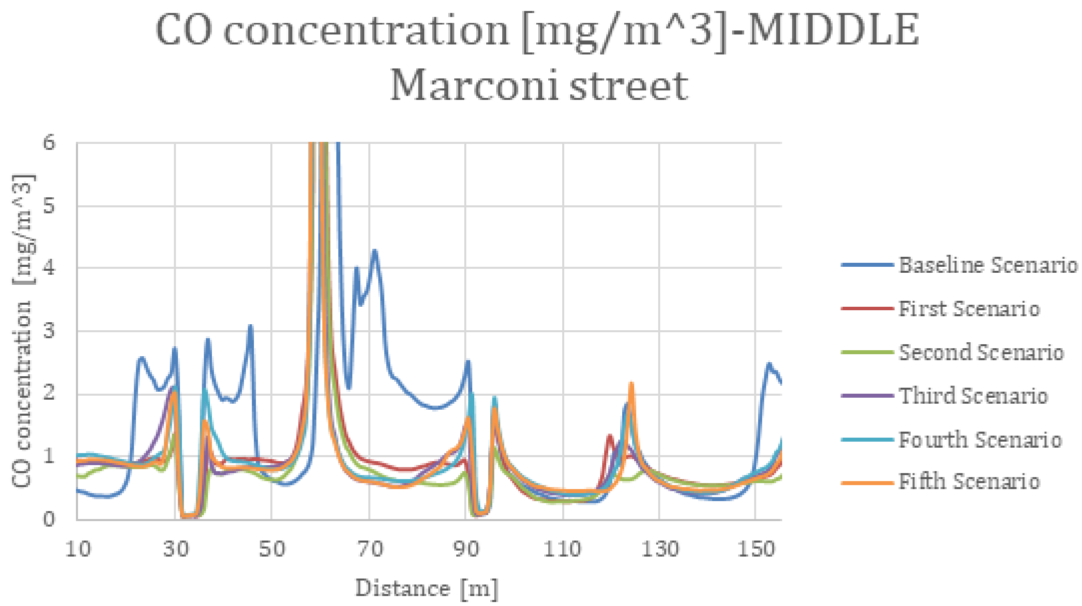


Figure 32 Middle probe line along the Marconi street reporting the CO concentration at 1.5 m from the ground for all scenarios (without the main intersection peak).

Figure 33 shows the local CO concentration obtained along a line near the right side of Marconi street. All the plots on the figure show a peak near the intersection between Marconi street and Riva Reno street, *i.e*. at a distance of 60 m from the south entrance of Marconi street canyon. The local CO concentration obtained for the case without trees (baseline scenario) is about three times that obtained in the cases with trees, on the North side of Marconi street, after the intersections (between 60 m and 90 m from the beginning of the street). Strong CO peaks are obtained on the south side of Marconi street, where local CO concentration values are more than twice those obtained for the cases with trees. All the CO peaks obtained for the baseline scenario on the North side of Marconi street are higher than those obtained for the cases with trees. These results confirm what previously shown in Figure 32, i.e. that the trees have the effect to lower the CO concentration on the peaks and to make the local CO distribution more uniform.

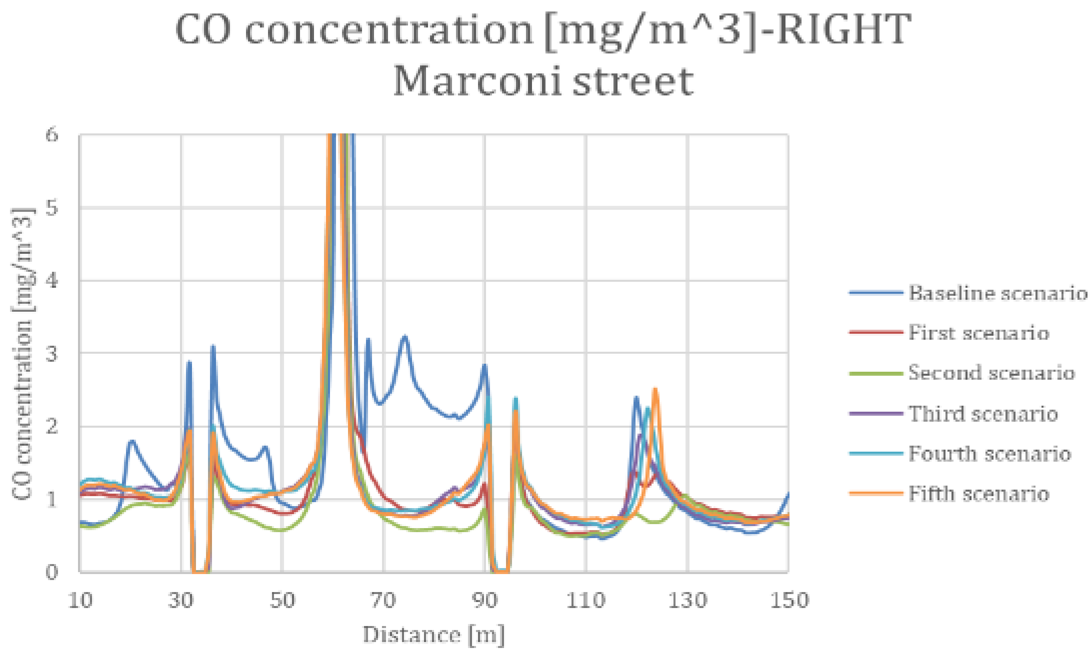


Figure 33 Right probe line along the Marconi street reporting the CO concentration at 1.5 m from the ground for all scenarios (without the main intersection peak).

From Figures 31+33, it is evident that the baseline scenario results in the highest peaks of the local CO concentration. In particular, the difference between the North and South side of Marconi street is due to the presence of airflow recirculation zones. All these peaks are damped for the scenarios with trees and this confirms the importance of considering also CO mean values and not only a single local concentration value.

3.1.8 Section conclusion

The introduction of trees in Marconi street canyon clearly shows a mitigation of air pollution since we can observe a strong decrease of CO levels in proximity of the peaks for all the scenarios compared to the baseline scenario, indicating an effective absorption of CO pollutant and in agreement with the findings obtained in D5.2 analysing the observations gathered within the two intensive experimental campaigns.

Table 15 shows the average CO concentration reduction obtained in the scenarios with the different tree species with respect to the baseline scenario without trees (first column) and the reduction of the CO peaks near the minor intersections between Marconi street and secondary streets, *i.e*. at a distance of 35 m from the south entrance of Marconi street and at a distance of 95 m from the south entrance of Marconi street, as shown previously in Figure 33.

The table shows that the local reduction obtained near the intersections is higher than the average reduction evaluated over the whole street canyon.

	An average reduction of CO concentration with respect to the baseline scenario	Reduction at the first intersection	Reduction at the second intersection
First scenario: simulated concentration	**34%**	**46%**	**61%**
Second scenario: simulated concentration	**44%**	**51%**	**73%**
Third scenario: simulated concentration	**29%**	**41%**	**40%**
Fourth scenario: simulated concentration	**22%**	**31%**	**39%**
Fifth scenario: simulated concentration	**25%**	**39%**	**36%**

Table 14 CO reduction for all scenarios.

As a consequence, even if an increase in CO concentration can be measured locally, especially in the case the measurements are carried out under a crown, the average CO concentration obtained over a volume that occupies completely the street canyon is lower in the presence of trees, i.e. an overall improvement in terms of pollution within a street canyon is obtained with the introduction of trees. The local concentration distributions obtained along the pedestrian pathways shows that the CO concentrations decrease near the intersections in all the scenarios considered. The second scenario, where Populus tremula trees distant 1.75m were placed in Marconi St., shows the best performances among the scenarios analysed, both near and between the intersections: this effect was attributed to the fact that smaller and more packed tree crowns with higher LAD values can reach higher CO reduction effects.

We can conclude that, even if the presence of trees gives always lower CO distribution, the better performances are obtained with smaller trees with higher LAD values and higher packing density within the street canyon. However, we must note that this result was obtained considering only one particular simulation case during the whole diurnal cycle analysed during the summer season, i.e. considering one particular wind direction and wind intensity.

3.2 Bottrop

Environmental assessments are an important part of environmental protection. By involving authorities and citizens as well as environmental reports, the possible consequences of a project or plan for the environment can be recognised at an early stage and taken into account in the decision on the project. There are various instruments for this, such as the environmental impact assessment (EIA) and the strategic environmental assessment (SEA) (Bundesministerium für Umvelt, Naturschutz und nukleare Sicherheit, 2019).

The most recently amended Environmental Impact Assessment (EIA) Directive (2014/52/EU) requires integration of the effects of climate change to a greater extent than in the past. This applies in particular to so-called “catastrophic risks” (see Art. 3 § 1) while climate protection aspects such as greenhouse gas emissions had already to be considered previously.

In urban planning, basic studies on climate and air pollution are of great importance for qualifying land use planning and development planning in particular in densely populated areas. Against the background of climate change, this importance continues to increase. Since the statements in question refer to a planning area, the use of maps as a result of spatial analyses and the basis for information is recommended. In this context, spatial analyses are an essential tool for planners, but also an important information carrier for decision-making and involvement of the public.

This investigation needs to be done e.g. by the use of micro- and urban- scale climate modelling (see D6.3 “Detailed report based on numerical simulations of the effect of PCSs at the urban level”). The models are to be regarded as an analysis tool within the framework of the EIA which is a legal obligation within the EU for each project or plan which may have significant effects on the environment. The more meaningful and convincing the climatic and air quality phenomena are investigated, the greater the chance of proper consideration in planning.

3.2.1Environmental assessment

On the one hand, environmental assessments aim to protect human health and the natural environment from foreseeable and significant adverse environmental effects of projects or plans. On the other hand, environmental assessments should contribute to the acceptance of the project through transparency and involvement of the public in the decision-making process. In this way, project promoters are given planning security for the respective project (Bundesministerium für Umvelt, Naturschutz und nukleare Sicherheit, 2019).

In accordance with the relevant EU directives, a distinction must be made between an environmental impact assessment (EIA) for public and private projects and a strategic environmental assessment (SEA) for programmes and plans. The scope of application of German municipal urban land-use planning comprises, on the one hand, a more strategic-conceptually oriented preparatory urban land-use planning, land-use planning (zoning plan) for which a SEA has to be carried out. On the other hand the legally binding urban land-use planning (development plans), for which a strategic, as well as the project-related assessment of the environmental impacts, is required. The choice of environmental assessment procedures depends on the respective national legislation. For the field of application of urban land-use planning in Germany, the requirements of the EU Directives in the Federal Building Code (Federal Building Code, 2017) were implemented (last updated November 2017). Because of this "dual function" of the testing instrument (strategic and project-related), the term "environmental assessment" (EA) was chosen in the BauGB. The term environmental assessment (EA) thus refers to the assessment of environmental effects of urban land-use plans.

The European Union Environmental Impact Assessment (EIA) Directive (2011/92/EU amended with the 2014/52/EU Directive) and Strategic Environmental Assessment (SEA) Directive (2001/42/EC) ask for the preparation of an environmental impact assessment report. This report requires,

- a modelled baseline scenario with the current state of the environment without the implementation of a project and,
- an assessment of the environmental effects of so-called “reasonable planning alternatives” (main alternatives are defined as “interventions” in the iSCAPE project). The results are then to be compared in terms of effectiveness in reducing heat stress (as a climatic effect) or improving the air quality as the two protection goods as laid down in Annex I f) of the SEA Directive, which is addressed by the iSCAPE project.

According to the German building code (§ 1 Abs. 6 Nr. 7 a) BauGB), impacts on the climate as an object of protection are described as relevant for consideration and include local impacts of climate change. According to Annex IV No. 5 lit. f) BauGB, the environmental report must contain a description of the effects of the project on the climate (e.g. type and extent of greenhouse gas emissions) and the vulnerability of the project to climate change. In addition, a description of the aspects of the current environmental status (the so-called baseline scenario) and an overview of its likely development if the plan is not implemented are required (Battis et al., 2015). The baseline scenario will change as a result of climate change. It is therefore possible that, under the signs of climate change, additional significant environmental effects, which may not be avoidable, mitigatable or compensable, are to be expected (e.g. due to the intensification of the heat island effect in cities), which ultimately raises the question of the legality of a project or plan for approval in the process of consideration.

As a result of the new environmental assessment regulations, a distinction must, therefore, be made between four areas of effects:

1. Effects of a projected climate change (changed baseline trend) on existing (and future) spatial structures and land uses, taking into account planned climate adaptation measures to avoid, mitigate or compensate for expected significant environmental impacts.
2. Effects of the climate (current climatic situation and projected climate change) on planned land use. Even the current climate may have significant effects on planning (see today's extreme events), while the projected climate change will most likely be related with an increase in extremes and consequently lead to more significant effects.
3. Effects of planning on the climate:
    a. Effects on the global climate,
    b. effects on today's local climate and climatic changes in the future.
4. The impact of planning on major accidents and catastrophic risks.

Principally speaking, new procedural steps in urban land-use planning are not required to take climate change into account. However, regardless of the existence of possible city-wide climate impact analyses and environmentally relevant studies on climate and air quality (or noise, soil conditions, etc.), small-scaled studies of the effects on the areas under investigation should be carried out.

In the context of the iScape project (see “Detailed report based on numerical simulations of the effect of PCSs at the urban level”, D6.3) micro-scaled climatic analyses were carried out for the City of Bottrop for various investigation areas by using the ENVI-met programme. The results of these analyses will be used by the City of Bottrop for future planning processes, in processes of consideration and decision-making, and in corresponding environmental assessments.

3.2.2 The contribution of climate models and climate simulations to environmental assessments

3.2.2.1 The ENVI-met software and simulation model

ENVI-met is a three-dimensional prognostic numerical flow-energy balance model. The physical basics are based on the laws of fluid mechanics, thermodynamics and atmospheric physics. The micro-scale model is used to simulate wind, temperature and humidity distribution in urban structures. It captures urban structures as an overall system and describes dynamic climatological processes. So ENVI-met enables the numerical consideration of urban structures as a holistic complex of effects with special consideration of small-scale environmental design such as street greening, building structures or various sealing materials. The calculation model provides a large number of different variables from the flow field over the temperature up to the turbulence distribution as simulation results and thus allows a consideration of the complex physical processes and their interaction in the form of the microclimate.

This microscale model simulates the interactions between surfaces, plants and the atmosphere in an urban environment. Parameters such as building surfaces, soil sealing, soil properties, vegetation and solar radiation are included. Due to the interaction of sun and shade as well as the different physical properties of the materials (specific heat, reflection properties, ...) different surface temperatures develop in the course of a simulated day, which in turn release their heat more or less strongly into the air depending on the wind field. In order to simulate interactions between vegetation and the atmosphere, the physiological behaviour of plants is simulated. This includes opening and closing the stomata to control the exchange of water vapour with the environment, the absorption of water via the roots or the change in leaf temperature during the day (Envi_Met GMBH, 2019).

ENVI-met exclusively calculates atmospheric flow processes on the basis of real climate data, whereby regional climatic processes can be reliably considered. The more detailed the resolution of the climate model is, the more complex is the calculation of atmospheric processes. However, climatological input values of global models are used for the simulations of regional models. Accordingly, these model results represent an important foundation for the representation of microclimatological processes in urban scenarios. The reproduction of real surfaces and atmospheric conditions in simulation models just approximates a given real environment. The missing representation of small-scale conditions by grid cells causes inaccuracies in the modelling of atmospheric processes. The resulting solution proposals regarding the development of a finer resolution remains a technical challenge. Despite these limitations, model simulations serve as a reliable projection of meteorological changes in the course of climate change on a global and regional level as well as its impacts on the urban fabric. In this context, it is particularly important to take into account changes to the land-use patterns. On this evidence basis of a parallel modelling of climatic and societal changes, objectives for climate protection and adaptation can be derived (Greiving et al., 2017). The associated increase of heat stress in the city is a crucial societal problem that needs to be tackled by politics and urban planning. Accordingly, the adaptation strategies, anticipated in terms of an ex-ante assessment of their effects by the model simulations, provide decisive solutions for the reduction of thermal health risks in urban areas.

A detailed explanation of the input data and the model set up for the models in Bottrop is given in D6.3 “Detailed report based on numerical simulations of the effect of PCSs at the urban level”, and therefore only a short description of the most important input parameters is provided here.

The methodology for the mapping of the model was carried out in three steps:

1. the mapping of the building structures (shape and height);
2. the mapping of the streets and footpaths (flooring);
3. and the mapping of the green areas - mainly trees (shape and height).

The mapping was carried out on the basis of existing maps, aerial photographs and on-site inspections. In the next step, the recorded data of the three mappings were transferred to the ENVI-met program where they were used for virtual modelling of the actual state of the study area and as a basis for two building structure measures (scenarios).

One summer radiation day over 24 hours was simulated to achieve maximum warming in the model area. In addition to the building, vegetation and surface structure of the model area, meteorological parameters were determined for a micro-scale modelling of the actual state as well as the variants. These values correspond to the typical initial conditions of a summer radiation weather situation with the heat load. The initial values of the meteorological parameters are chosen the same for all variants. All results determined with ENVI-met are representative for the daily situation with the values for 4 p.m. CET and a height of 1.5 meters.

Start and duration of the model run

- Start date of the model: 21/06/2018
- Start time: 20:00
- Total simulation time: 24 h
- Output interval for files: 60 min

Meteorology settings

- Wind speed at 10 m height: 2 m/s
- Wind direction: 60° (from NE, see Figure 34)
- Roughness length: 0.01
- Specific humidity at the model top (2500 m): 5 g/kg
- Simple Forcing of temperature and humidity is activated
  - MIN – Temperature: 14°C at 6:00
  - MAX – Temperature: 28°C at 16:00
  - MIN – Relative humidity: 50% at 16:00
  - MAX – Relative humidity: 70% at 6:00
- Solar radiation: No modification of calculated radiation
- Clouds: No clouds in the model run
- Turbulence model: Standard TKE Model (Mellor and Yamada, 1982).

Soil data conditions

- Initial conditions for soil – soil wetness (%) / initial temperature (ºK)
  - Upper layer (0-20 cm): 40% / 300 ºK
  - Middle layer (20-50 cm): 45% / 298 ºK
  - Deep layer (50-200 cm): 50% / 297 ºK

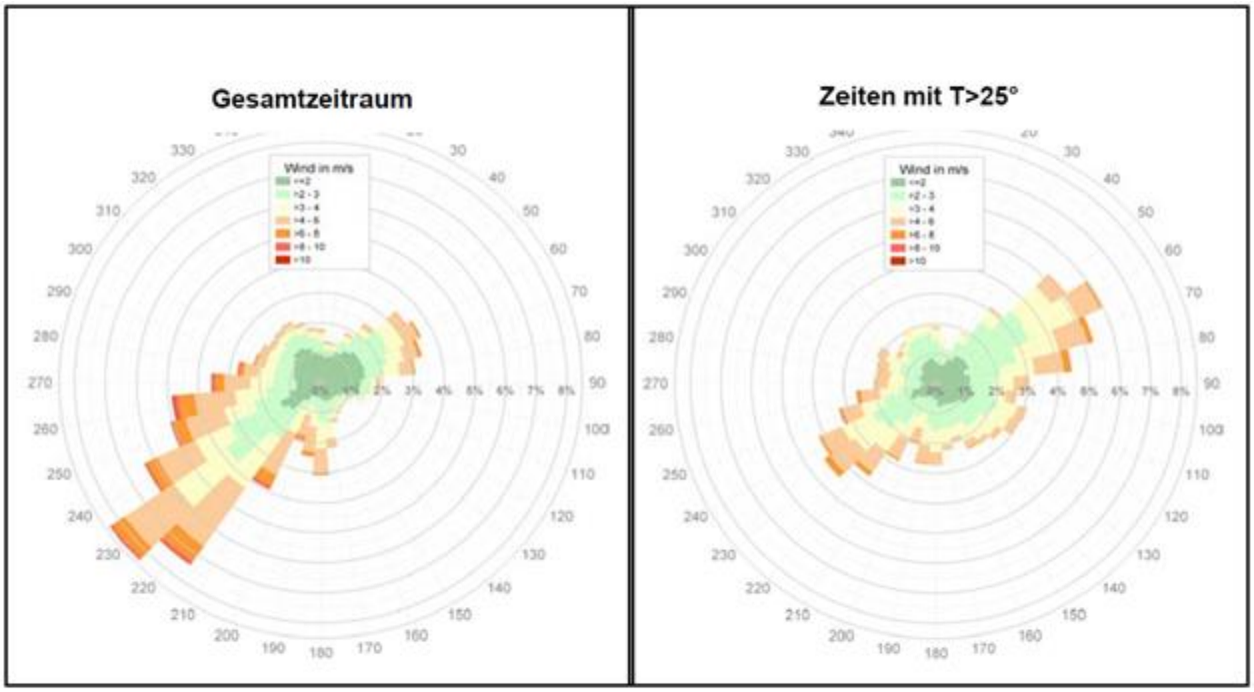


Figure 34 Wind direction distribution at the Bottrop-Welheim station from 1986 to 2005 (source: Stadt Bottrop (2014))

Figure 34 compares graphical analyses of the wind direction distribution for two scenarios. For the left wind rose, all data of the investigation period were evaluated, while the right wind rose only contains the cases where the air temperature is above 25°C.

3.2.2.2 Model validation and verification

The area of the model was selected in coordination with the Environmental Office of the City of Bottrop. The selection of the modeled scenarios and the methodological approach were also developed and coordinated in cooperation with the Environmental Office of the City of Bottrop. For input data, official data of the City of Bottrop were used; meteorological input data are based on local weather data. The selection of the area, the development of the scenarios and the methodological approach (e.g. the ENVI-met setup) were discussed and agreed with representatives of the City of Bottrop and other stakeholders at a stakeholder workshop in October 2018.

For model validation, the modelled results for heat stress were compared with the corresponding values of existing ENVI-met simulations within the framework of the Climate Adaptation Concept Bottrop and measured values of local weather stations (Stadt Bottrop, 2014).

3.2.2.3 Human health as an object of protection

Central climate signals with regard to human health are, in particular, the increase in heat days and tropical nights. High air temperatures have a high potential for damage to humans and the environment, especially in the summer months. Climate change can lead to an increase in extreme heat during the day and at night, which can increase the health risks for certain groups of people. Phases with extreme heat lasting several days are of particular importance for health. Such heat waves particularly affect vulnerable population groups such as children and senior citizens. Future changes in the age structure (due to demographic change) will increase the sensitivity of the population to thermal stress. Against this background, the requirements of vulnerable population groups must be taken into account in climate-friendly urban planning and in the design of climate-sensitive facilities (Bundesinstitut für Bau-, Stadt- und Raumforschung, 2016).

Heat waves have a particularly strong effect on sealed and dense settlement structures. Densely built-up areas, such as city and district centres, inner-city residential and mixed-use areas as well as commercial and industrial areas, represent heat islands and increase the heat load. Here the solar radiation is stored due to dark surfaces on buildings and streets and is only released slowly. This leads above all at night to a slower cooling compared to the ambient temperature (Bundesinstitut für Bau-, Stadt- und Raumforschung, 2016).

The human health as an object of protection is still frequently discussed in environmental assessments via rather trivial indicators such as the loss of space and impairment of space in the immediate living environment, impairments of recreation-relevant areas, or the compliance of limit values (e.g. noise or air pollutants). However, when considering the objectives of climate-friendly urban development, additional indicators that relate to people's health and well-being appear to be essential.

In the context of climate-friendly planning, the need for planning action is defined by the following central objectives (among others):

- Improving the quality of stay with regard to the thermal comfort / bioclimate
- Improvement of settlement ventilation
- Promotion of fresh air supply through local wind systems
- Reducing the release of air pollutants and greenhouse gases
- Determination and appropriate evaluation of existing or future expected loads / pollution
- Appropriate reaction to load situations through adaptation of utilisation concepts (Ministerium für Verkehr und Infrastruktur Baden-Württemberg, 2012: 192)

In the context of the urban microclimate, thermal comfort is an essential indicator to describe the subjective experiences of people with outdoor temperature. Thermal comfort summarises the influence of sun, wind, air temperature and humidity on the perception of heat. Assessing the microclimate conditions of urban space means finding out how pedestrians feel under certain climatic conditions - especially their thermal and wind comfort - and how this affects behaviour within the urban structure. In addition, appropriate thermal conditions can play a key role in the economic success of outdoor facilities such as cafes, shopping streets or recreation areas. Different thermodynamic models in ENVI-met allow a holistic evaluation of stationary and transient thermal comfort conditions (Envi_Met GMBH, 2019).

In order to characterise or determine the intensity of the urban climate and the urban heat island, climate elements such as air temperature, humidity or radiation properties of surfaces are usually used. However, it makes sense to limit the urban climate not only to atmospheric or surface properties but also to the resulting effects. Simple indices or combined variables that only take air temperature or humidity into account are rather unsuitable for this purpose. Methods that describe and quantify the effects of the human thermal environment in thermo-physiological terms are particularly suitable here. They are based on the energy balance of the human body and can be expressed using thermal indices (e.g. physiologically equivalent temperature, PET) (Matzarakis, 2013).

3.2.3 Key results for the city of Bottrop (focus on building structure)

For the City of Bottrop, ENVI-met was processed for four selected investigation areas to simulate the actual urban climate (baseline scenario) and various reasonable planning alternatives (vegetation structures/street trees, roof greening or building position/building variety). The following explanations refer to model 3, the residential area “Am Lamperfeld”, for which two planning variants have been investigated with regard to the building structure. All results can be found in the iScape project “Detailed report based on numerical simulations of the effect of PCSs at the urban level” (D6.3). The investigation area “Am Lamperfeld” is an existing mixed area close to the city centre (residential, commercial, sports). The modelled part is the area between the stadium and the street Am Lamperfeld, which is currently being redeveloped (residential use). The model area is currently still undeveloped and characterized by quite dense vegetation and the immediate proximity to the Jahnstadion (stadium), with sports grounds and northern and southern parking lots (see Figure 35).

Figure 35 Model Bottrop ‘Am Lamperfeld’ – Overview of modeled interventions (source: own account, data: City of Bottrop)

The baseline scenario shows the status quo. In scenario A, the implementation of a row development with a height of 12 m is modelled. In scenario B, loose buildings with 9 town houses are modelled with the building height remaining unchanged. The scenarios and planning alternatives for the investigation area are identical to those of the city of Bottrop. The model results should, in particular, provide information about the shading and ventilation situation as well as any local climatic changes caused by the planning. With the aim of improving the quality of stay for the residents and minimising changes to the local climate, recommendations for action can be derived for construction measures and measures to improve the microclimatic situation.

3.2.3.1 Air Temperature

The highest air temperatures in the baseline scenario with over 27.5°C (see Figure 36, red) occur over the open area of the Stadium and the unshaded street intersection Am Lamperfeld and Kirchhellener Straße in the north-east. In the areas with open residential buildings and green inner courtyards, the lowest air temperatures occur with values between less than 26.0°C.

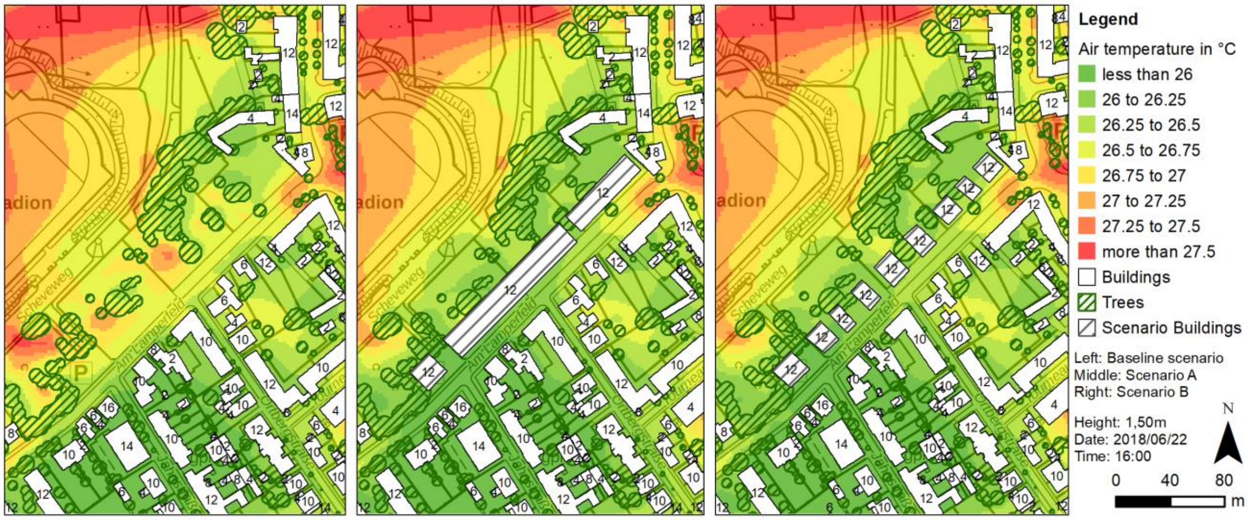


Figure 36 Model Bottrop 'Am Lamperfeld' – ENVI-met calculated air temperature (source: own account, data: City of Bottrop)

The changes in the air temperature in scenario A show very low cooling effects of up to 0.3°C (Figure 37, green). In the model, this circumstance is due to changes caused by shading and changes in the wind field as a result of the new row development. The shading reduces the heating of the soil surface. In addition, a street canyon is formed at the street Am Lamperfeld, which also increases shadowing and can influence the ventilation of the study area.

The changes in air temperature in scenario B show cooling effects of up to 0.3°C (Figure 37, green), as in scenario A. The changes in the building structure are too small to lead to significant changes in the microclimatic situation. As in scenario A, the improvement of the air temperature in the model is due to the new shading and changes in the wind field as a result of the new buildings. The shading reduces the warming of the soil surface. In addition, the wind speeds at the Am Lamperfeld road increase, which can have a positive effect on the ventilation of the investigation area.

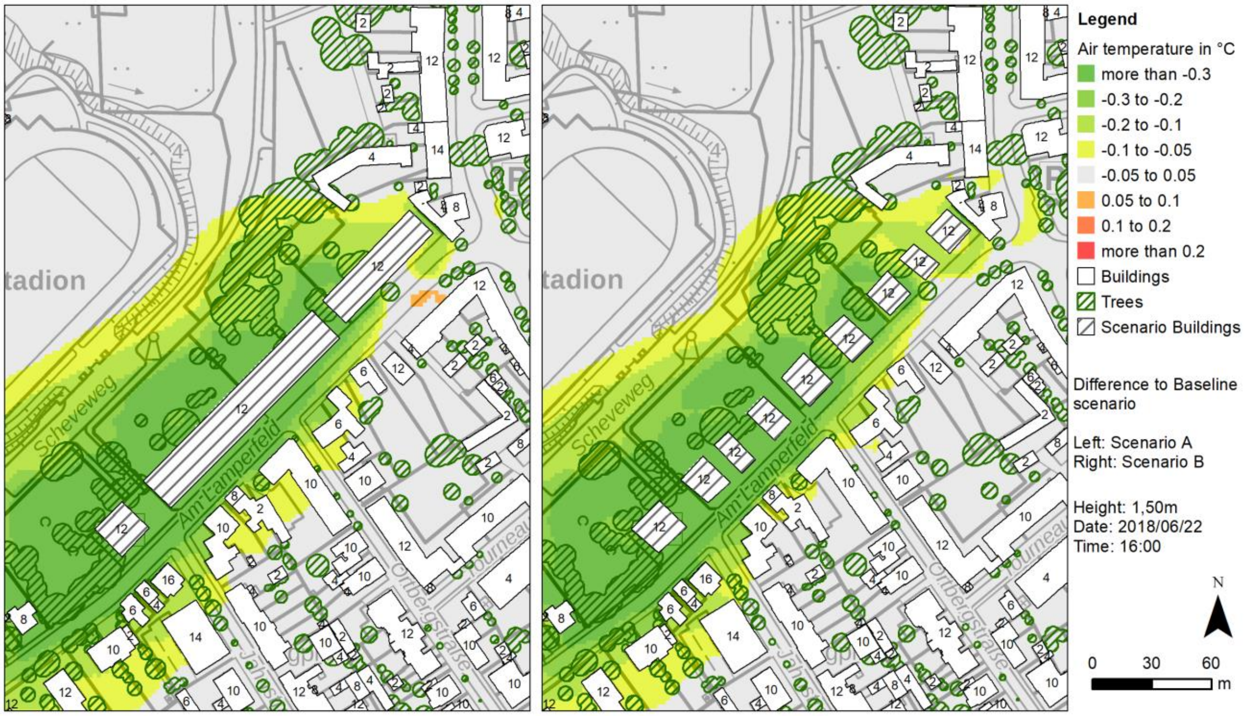


Figure 37 Model Bottrop 'Am Lamperfeld' – Difference of air temperature, scenario A/B minus baseline scenario (source: own account, data: City of Bottrop)

3.2.3.2 Physiologically Equivalent Temperature (PET)

The PET values for the actual situation in the investigation area are shown in Figure 38. The high proportion of open, sealed or unplanted areas and the dense development in the southeast lead to a high bioclimatic load on parts of these areas. This also applies to a large extent to areas of the inner courtyards where PET values of up to 48°C can be achieved despite greening (Figure 38, red). The moderate bioclimatic situation within the buildings is also due to the building density and thus moderate ventilation of the residential area. Areas of the shadow cast by buildings and greened inner courtyards of the buildings show slightly reduced PET values between 39 and 33°C in some parts. In areas where buildings cast shadows, the PET values are much lower than in unshaded areas. In these shaded areas, a somewhat lower thermal load is felt. PET values tend to be somewhat lower in street areas and partly also on the stadium surface, but remain at a very high load level. The bioclimatic situation is significantly lower in areas with vegetation than in areas without vegetation. The reduction of the PET values remains locally limited but can improve the quality of stay in areas without shading by buildings. The greened inner courtyards, as well as the already existing roadside greenery, thus represent an important contribution to the small-scale improvement of the microclimatic situation.

Figure 38 Model Bottrop 'Am Lamperfeld' – ENVI-met calculated PET (source: own account, data: City of Bottrop)

For the representation of the biometeorological situation, the differences with respect to the actual situation were calculated. The changes in PET values due to the new buildings are shown in Figure 39. The PET values are up to 12°C lower in the area of building shading than in the actual situation. These improvements are located at a maximum of 10 m directly at the new buildings. The red areas with a very slight increase in PET values of up to 3°C indicate a trend towards a reduction in the quality of stay. However, this is far too low to have a noticeable effect on humans. The visible changes are very locally limited to the immediate surroundings of the new buildings.

The changes in PET values due to the new buildings in scenario B are shown in Figure 39. The PET values in the area of building shading are up to 12°C lower than in the current situation. These improvements are located at a maximum height of 10 m directly at the new buildings. The red areas with a very small increase in PET values of up to 3°C indicate a trend towards a reduction in the quality of stay. However, this is far too low to have a noticeable effect on people. The visible changes are very locally limited to the immediate surroundings of the new buildings. Compared to scenario A, there are additional shaded areas between buildings where the quality of stay improves.

Figure 39 Model Bottrop 'Am Lamperfeld' – Difference of PET, scenario A/B minus baseline scenario (source: own account, data: City of Bottrop)

The overall microclimatic situation in the study area is characterised by dense development in the southeast and a high proportion of open, unvegetated space in the area of the stadium. In locations with a stronger greening, the shading and ventilation are somewhat better, which means that the heat stress is slightly less pronounced. Small-scale shading by buildings or large trees shows a very locally limited somewhat higher quality of stay. In the areas of the traffic areas exposed to radiation and the stadium, very strong heating of the sealed surfaces is sometimes achieved.

For both scenarios with different building types, the microclimatic changes remain locally limited. In both scenarios the shading and ventilation changes. From the climatic point of view, scenario B with open buildings is preferable to scenario A. For both scenarios, additional extended adaptation measures to improve the quality of stay should be considered. For this purpose, shading of the sealed areas by large trees and/or technical solutions can be used as design elements. When redesigning surfaces (including buildings), the lightest possible materials should be used, as these heat up much less. Depending on the building structure, an increase in the thermal level caused by the buildings remains locally limited. The overall effect of the changed climate function of the planned area can be classified as rather low.

3.2.4 Conclusion and outlook: Climate impacts and UHI in environmental assessment

The presented approach for the assessment of climate impacts in a municipality offers great potential to better classify the climatic impacts of urban planning in the environmental assessment and to prepare them for consideration. The ENVI-met results make it possible to evaluate reasonable planning alternatives in accordance with Art. 5 § No. 1 d) EIA Directive, especially with regard to heat resistance and thermal comfort. The decisive factor here is a clear separation of the current effects of today's building structures on the current climate from the expected effects of the selected planning alternatives on the future climate.

The examined reasonable planning alternatives in terms of urban design options have a partially clear effect on the bio-climate, but no general statements can be made here. Each building variant must be examined in detail. The simulated effects are mainly based on changed shading and wind conditions. For example, a block perimeter development can contribute to a channelling of the wind and to an increase in the wind speed, which may have a positive effect on the bio-climate. The model runs show that building shading in combination with relatively high wind speeds leads to a better bioclimatic situation.

To conclude, micro-scaled modelling enables the City of Bottrop to simulate and compare the potential effects of reasonable planning alternatives and identify tailor-made adaptation measures to climate change and mitigating heat stress and air pollution control. This requires an ex-ante assessment of significant environmental effects of the given planning alternatives on climatic and air-related conditions in accordance with Art. 5 § 1 of the EIA and SEA Directives. On this sound evidence basis, a land-use plan can be approved by the responsible city assembly. However, the selection of planning alternatives calls for an iterative process where modellers and representatives of a city planning department collaborate with each other - which is, by the way, the basic idea of the living lab approach.

3.3 Dublin

The test installation in Dublin is aimed to evaluate the effectiveness of low boundary walls (LBWs) as a passive control system in reducing the exposure of air pollution to the pedestrian preventing pollutants from flowing from the roadway to the footpath. Low-Boundary walls (LBWs) can provide a solution to enhance localized dispersion and improving air pollution inside distinct street canyons settings. Within iSCAPE, Dublin city in Ireland has been chosen as the location for examining LBWs in the built environment. LBWs are a type of physical PCSs and have been shown to effectively impact on airflow and pollutant dispersion in low-rise street canyons and more details are provided in the iSCAPE reports 1.2, 3.3 and 3.8. Dublin provides an experimental setup and location to examine the implications of the LBW on personal exposure to air pollution as a type of PCS. A measurement campaign was conducted in a street of the Dublin centre to estimate to what extent LBWs are able to reduce pollutant concentration on the footpath.

3.3.1 Modelling methodology

In Dublin case study a linear statistical modeling approach has been used. The statistical model has been driven by the experimental results from the two-phase experimental work that has been implemented as part of the iSCAPE activities in Dublin. The pollutants concentrations' reduction coefficients have been calculated and used for driving the scenarios and results presented in this report. This section provides a description of the setup, data and scenarios.

3.3.2 Model input

A comprehensive measuring system was implemented to describe the environment of the test. As pollutant concentration is the key parameter to assess the effectiveness of our passive control systems, three categories of pollutant were evaluated: NO_x, $PM_{2.5}$ and PM_{10}. NO_x was taken as reference pollutants in the first phase of experiments while PMs were taken as reference in a second phase. Several analysers were installed in the street following a placement which allowed to compare the concentrations in both sides of the walls. To complete the monitoring system wind speed and wind direction were sampled from a high position to avoid the disturbance of the wind in the street canyon and traffic count was sampled using a manual multiple click counter. LBW setup and sampling times were randomised to take account of the variations of wind speed, wind direction and traffic volume, which may affect the dispersion of the pollutant in the street canyon. The sampling was carried out for three random hours each day. The first was done in the morning, second in the afternoon and third and final in the evening. The logging interval was set at 5 minutes. Therefore, each hour of sampling provides 12 data point. Along with the random days of LBW setup, random sampling hours helps in covering different parameters which affect the dispersion of the pollutant in a street career such that wind speed, wind direction and traffic volume. All the mentioned experimental results of datasets were used as the input data for the linear data-driven statistical model to assess the impact of the LBW intervention.

3.3.3 Model setup

The first model of LBWs was set up based on the experimental work in Pearse Street in the centre of Dublin. The street profile is characterised by a large width, a high traffic volume with four lanes of circulation going in the same direction and the absence of any other elements that could alter the flow of pollutants from the road to the footpath like car parks or trees. Two sets of LBW were put in place on existing bollards separated by a small gap. LBWs were installed some days and removed the others to highlight their effect on the air pollution flow. The sensors were installed both behind and in front of the wall to measure pollutant concentration on both sides of the wall. These sensors provided the basics to evaluate to what extent LWBs reduce pollutant concentration on a local scale. Average concentrations are calculated from the measurement series in each framework (with or without LBWs). A more advanced work based on these data (Deliverable 3.8) has underlined the effect of LBWs on the particle concentrations on the footpath is quite uncertain, depending on the direction of the wind and the unpredictability of experiments. Thus, values are averaged to offer an overview of the impact of LBWs.

Figure 40 Low boundary walls set up

Average NO_x concentration with and without LBWs is simply calculated from the data from the analyser behind and in front of the wall. It is worth to mention that the overall amount of pollution is not changed, LBWs only move the pollution from the footpath to the roadway in some wind conditions. NO_x concentration in front of the wall may be assumed to be slightly higher than what it would be on the footpath without a wall. PM concentration measurements were conducted both with and without LBWs according to the day. Average concentrations are found for the “with” case from the data collected with a wall and for the “without” case from the data collected without. The percentage of decrease in the footpath concentration for the three categories of pollutant considered (NO_x, $PM_{2.5}$, PM_{10}). These coefficients are aimed to provide a good indication of the ability of LBWs to prevent pollutants from flowing through the footpath in every site similar to the experiment site.

3.3.4 Scenarios

To assess the possible socio-economic impact of LBWs, a wide deployment of them on the scale of Dublin is envisaged in several scenarios. Exposure reduction percentage which has been obtained previously on a local scale are generalised on the city scale envisaging a deployment of the LBWs in all Dublin's streets where there is not any other passive system susceptible to acting as an LBW like park cars. It is clear that the previous reduction coefficients are valid for one street profile, the one where the measuring campaign was done. Many other streets in the Dublin area have a different street profile where LBWs may not have the same effect on the pollutant dispersal because of a different road width for example. However, to simplify the process and because the measuring campaign has been only conducted with a single street profile, previous results are considered valid for the whole Dublin area whenever a LBW can be implemented in a suitable street canyon. With this reasoning, the coefficient of total emission reduction for the whole Dublin area is assimilated to the coefficient of local exposure reduction.

The different scenarios are built following a study of Diesel ban in the Dublin area (Dey et al., 2018). In this study, a 2030 Diesel ban scenario is drawn from a 2015 Baseline considering a progressive ban of the Diesel vehicles. This includes the evolution of the fleet of vehicles, the annual amount of pollution released and socio-economic consequences due to this pollution. Socio-economic consequences are assessed in terms of damage costs and health effects. Damage costs include the health effects but also the effects on crops, buildings and biodiversity. Health effects are calculated in terms of DALYs (Disability Adjusted Life Years) which is the sum of years of potential life lost due to premature mortality and the years of productive life lost due to disability. In our study, a wide deployment of LBWs is also considered alongside a ban on Diesel vehicles. These two evolution factors lead to two more scenarios in addition of the 2015 Baseline and the 2030 Diesel ban scenario: a 2015 alternative scenario to model what would have been the impact of the deployment of LBWs based on the 2015 levels of pollution and a 2030 Diesel ban scenario with LBWs to model the possible impact of LBWs on the frame of a ban of Diesel vehicles. Emission reductions on account of LBWs are added or not to the ones on account of the traffic regulation to assess socio-economic consequences in line with the scenario considered.

The relevance of those scenarios lies on the necessary plurality of the way to reduce air pollution exposure. As the LBWs are designed to reduce the flow of pollution the pollution is only moved from the footpath to the road in some favourable conditions, they are effective to reduce the exposure of air pollution to the pedestrians but they may not protect cyclists according to street configuration and even fewer automobilists in their car. A deployment of LBWs is indissociable from a policy of emission reductions through the ban of the most polluting vehicles. Our scenarios are designed to enhance the effectiveness of those two ways of improvement combined.

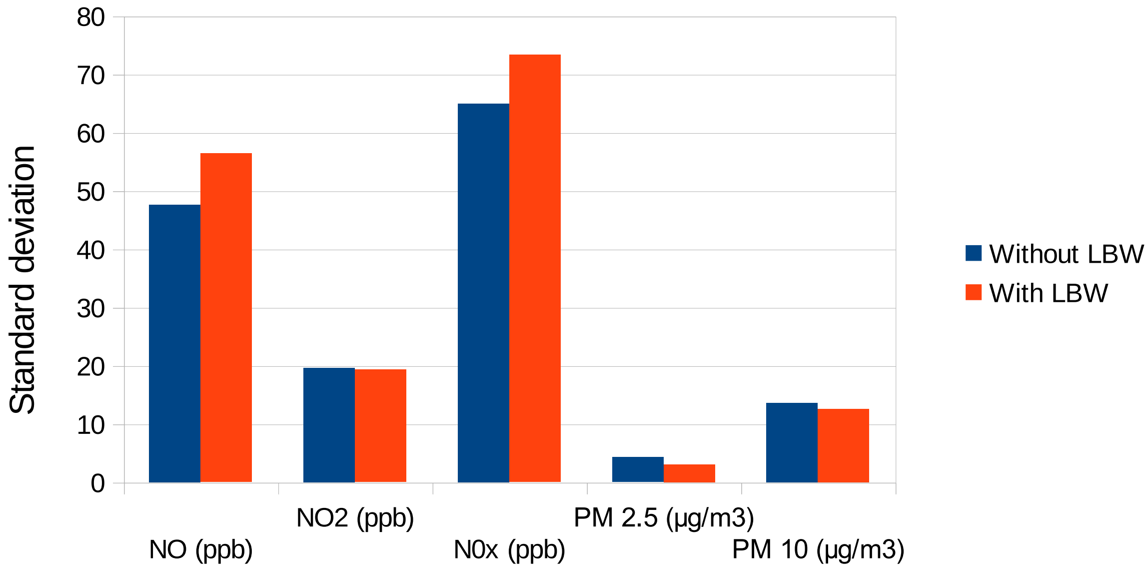
3.3.5 Results for scenarios

This section provides a description of the results of the different scenarios derived based on the description in the previous section.

The data analysis has highlighted the extent of the air pollution exposure reduction that can be credited to the LBWs in the street configuration of Pearse Street. Since LBW setup and sampling times were randomised and data were averaged, following results, see Figure 41 and Table 15, are only relevant on a large and extended framework.

Average concentration	Without LBW	With LBW	Reduction percentage (%)
NO (ppb)	19.69	11.17	43.27
NO2 (ppb)	6.66	9.87	-48.2
N0x (ppb)	26.35	21.04	20.15
PM 2.5 (µg/m3)	10.47	8.2	21.68
PM 10 (µg/m3)	38.92	34.64	11

Table 15 Pollutant concentrations and exposure reduction percentages.



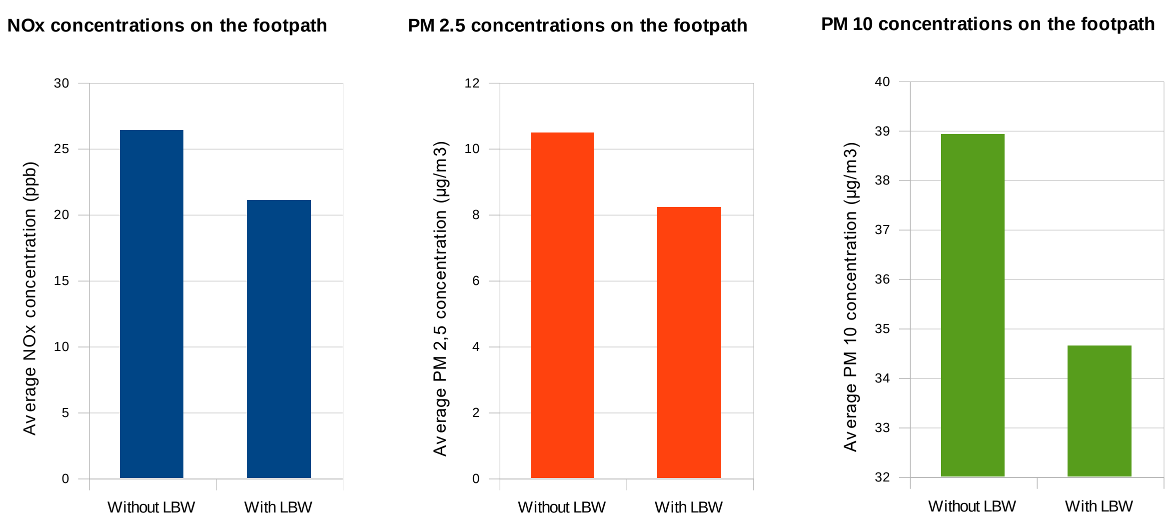


Figure 41 Pollutant concentration standard deviations (top), pollutant concentrations on the footpath with or without LBW (bottom).

LBWs can be credited of a reduction of air pollution exposure around 10% according to the pollutant categories. Surprisingly, the NO_2 concentration is higher in the presence of LBW by a factor of 1.5. As the NO concentration is decreased in a larger proportion, the NOx concentration is lower even so. Fine particle concentration is successfully diminished by a small factor.

2015 Baseline	**Pollutants**		
No Diesel ban - No LBWs	N0x	PM 2.5	PM 10
Car emissions (t)	2987,46	185,26	268,39
LCV emissions (t)	1332,69	61,67	81,44
Bus emissions (t)	571,84	10,14	12,23
Total emissions (t)	4891,99	257,07	362,06
Unit damage cost (€/t)	5861	200,24	19,143
Damage cost (x1000€)	28671,95	51,48	6,93
Unit health damage (DALYs/kt)	90	700	
Health damage (DALYs)	440	180	

Table 16 2015 Baseline - No Diesel ban - No LBW deployment

Table 16 shows the data used to model the different projected scenarios. This includes the total emissions based on the vehicle fleet at this time. Unit damage cost and unit health damage are the coefficients used to find the damage costs and the health damage associated with one pollution emission amount. Damage costs and health damage at this time are put here as a comparison for the other scenarios.

The following tables,*Table 17* and *Table 18*, show the projections of annual pollution reduction in the Dublin area with associated cost-saving and health damage saving that would be obtained thanks to the deployment of LBWs and/or the ban of the Diesel vehicles according to the scenario. Health damage saving related to PM 10 emissions has not been found because the unit health damage was not available.

2015 Alternative scenario	Pollutants		
With LBWs	NO_x	$PM_{2.5}$	PM_{10}
Reduction on account of LBWs (%)	20.15	21.68	11
Emission reduction (t)	985.74	55.73	39.83
Cost saving (x1000€)	5777.42	11.16	0.76
Health damage saving (DALYs)	89	39	

Table 17 2015 Alternative scenario – LBW deployment

2030 Diesel ban scenario	Pollutants		
Without LBWs	NO_x	$PM_{2.5}$	PM_{10}
Reduction on account of traffic regulation (%)	46.95	51.76	38.68
Emission reduction (t)	2296.79	133.06	140.04
Cost saving (x1000€)	13461.49	26.64	2.68
Health damage saving (DALYs)	207	93	

Table 18 2030 Diesel ban scenario – No LBW deployment

2030 Combined scenario	Pollutants		
Diesel ban and LBWs deployment	NO_x	$PM_{2.5}$	PM_{10}
Reduction on account of traffic regulation (%)	46.95	51.76	38.68
Reduction on account of LBWs (%)	20.15	21.68	11
Emission reduction (t)	2759.59	161.91	155.45
Cost saving (x1000€)	16173.96	32.42	2.98
Health damage saving (DALYs)	248	113	

Table 19 2030 Combined scenario – Diesel ban – LBW deployment

Cost saving and health damage saving on account of the deployment of LBWs are significant even compared to the restriction of Diesel vehicles. The deployment of LBWs alone could have lead to a cost saving of 5.79M€ and health damage saving of 128 DALYs in the 2015 environment. It could lead to a total cost saving of 2.72M€ and health damage saving of 61 DALYs in addition to Diesel restriction in the 2030 framework, assuming that the effect of LBWs remains the same in proportion in a less polluted air implied by a ban of Diesel vehicles. These savings are substantial but need to be moderated with respect to the financial and technical constraints of a wide deployment of LBWs in the Dublin area.

3.4 Guildford

Traffic emissions are a major source of air pollution in urban areas and the dominant source of air pollutants including PM_{10}, $PM_{2.5}$, and NO_x. For instance, vehicular emissions are responsible for up to 30% of PM in European cities; 32-85% of NO_X in Asian cities; and 55-97% of NO_X in Mexico City and São Paulo (United Nations Environment Programme and World Health Organization, 2009, World Health Organization, 2019). In order to comply with the current and future air quality standards, the UK government is undertaking several nationwide programs, which include fleet modernisation and promoting public transportation (Department for Transport, 2015a). Despite those efforts, it is estimated that many cities, of different population density, in the UK have challenges meeting current and future air quality limits (Department for Environment Food & Rural Affairs, 2017). For instance, 45 and 27 roads in Guildford will exceed the annual mean limit for NO_2 in 2020 and 2030, respectively.

GI (Green infrastructure) surfaces, such as leaves, stems, barks, fruits and heads, serve as effective deposition sites compared to grey infrastructure (buildings, roads or build-up area) for different air pollutants (Air Quality Expert Group, 2018) in different ways. For instance, for gaseous pollutants, GI generally biologically degrade gaseous air pollutants after taking them up through their leaf stomata; and deposited PM gets resuspended to the atmosphere, washed off by rain or dropped off the leaf to the ground depending on the environmental conditions and the GI characteristics (Gourdji, 2018, Rowe, 2011).

The importance of GI in reducing air pollution in urban areas has been studied since the mid-1990s (Nowak, 1994). Urban trees and shrubs can help to reduce up to CO by 0.009%, NO_2 by 2.7%, O3 by 4.4%, PM_{10} by 3.5%, and SO_2 by 4.3% in 11 different cities in year 1994 (Nowak et al., 2006); and $PM_{2.5}$ by 0.24% in 10 different US cities in year 2010 (Nowak et al., 2013). For the contiguous US, (Nowak et al., 2014) estimated that trees help to reduce NO_2 by 0.296%, O_3 by 0.514%, $PM_{2.5}$ by 0.199%, and SO_2 by 0.483%; thereby providing health benefits valued between $1.5–13.0 billion annually. A similar pollutant deposition modelling study was performed by Tallis et al. (2011) for assessing the effect of urban tree canopy on the removal of PM_{10} for the Greater London Authority (GLA). It was estimated that the current urban tree canopy (20% area of the domain) led to PM_{10} reduction by 1.4%, and an increase in the tree canopy (from 20% area to 30% area) would lead to a reduction of PM_{10} by 2.6 % in GLA. It was also suggested that tree plantation, with a large proportion of coniferous to broad-leaved, should be targeted in high pollution zones such as busy streets to maximise their PM10 reduction potential (Tallis et al., 2011). In contrast to above, some GI (especially trees in street canyons) may increase the air pollution concentration levels locally by reducing vertical mixing (Buccolieri et al., 2018, Tong et al., 2015). Increasing the level of urban green infrastructure has therefore been suggested as a means to reduce air pollution concentrations (McDonald et al., 2007, Tallis et al., 2011, Abhijith et al., 2017).

Therefore, through this investigation, we will evaluate the potential of GI planting in controlling the concentration of different traffic-related air pollutants (NO_x, PM_{10}, $PM_{2.5}$), beyond the regulatory limit for Guildford in 2039, and its health impacts in terms of change in mortality and morbidity rate under various scenarios (section 3.4.1.3), which can serve as a case study for future replication amongst other cities and boroughs across the UK and Europe. The year 2039 has been chosen since 2040 is the year when the strategic road network of UK aspires to have zero breaches of road-side air quality (Department for Transport, 2015a) and the UK government will end the sale of new conventional petrol and diesel cars and vans (Department for Environment Food & Rural Affairs, 2017). Guildford is a good case for this type of analysis since it is a city with large urban green spaces as well as strong traffic sources inside and in the vicinity of the city that is similar to most of the European cities.

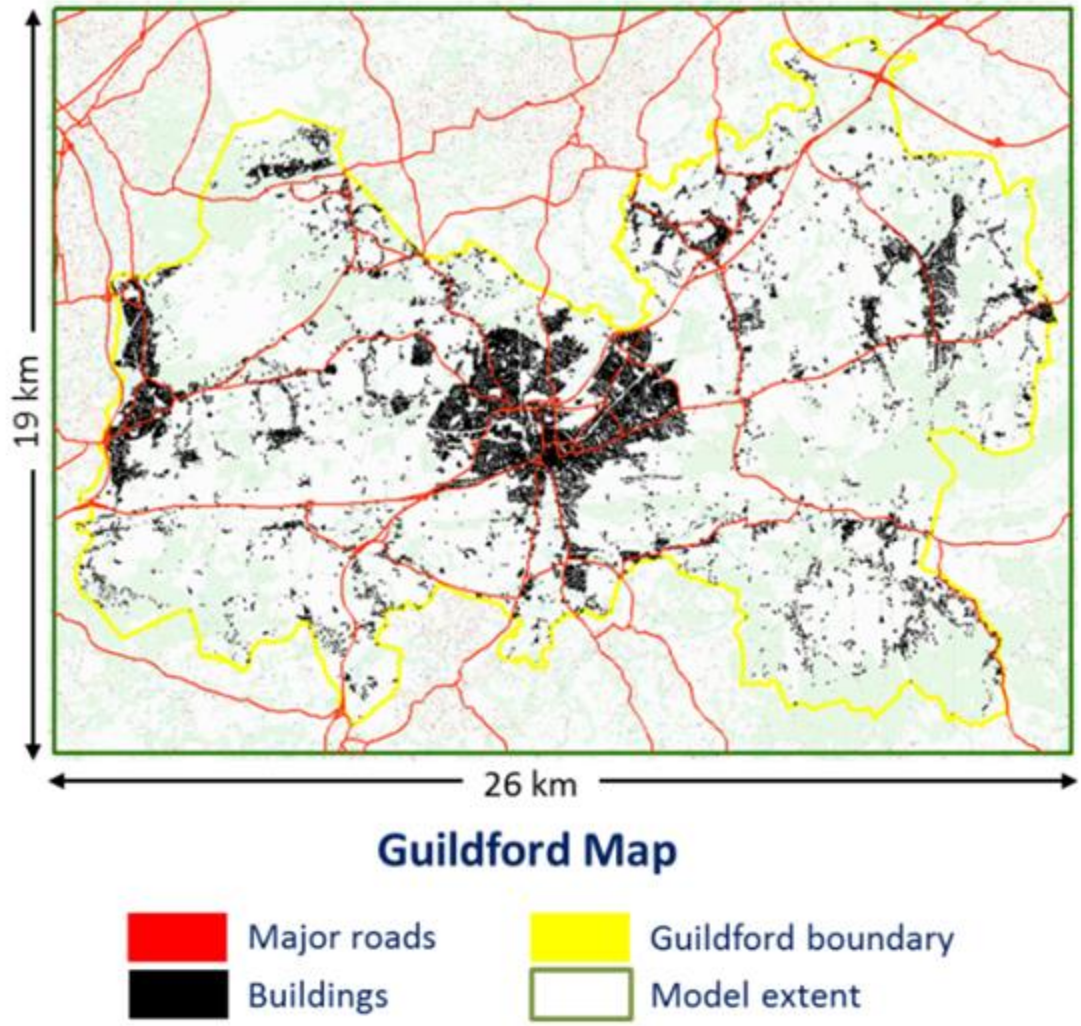


Figure 42 Modelled domain of Guildford borough along with the major roads and buildings (source: https://www.ordnancesurvey.co.uk/opendatadownload/products.html).

3.4.1 Modelling methodology

The area of interest in this study is the urban area of Guildford. Guildford is one of iSCAPE cities and town similar to other UK town with respect to land cover and meteorological condition. The integrated modelling approach described below will be used to study the urban air quality benefits of the existing vegetation cover for a 19 km × 26 km area that encompasses the complete Guildford borough in the UK (borough area = 270.9 km2) as shown in Figure 42. The land use in Guildford is predominantly residential, and about half of the city's population (population estimated at around 130,000) lives within the urban area of Guildford town, located in the centre of Guildford borough where building density is the highest (Guildford Borough Council, 2017). This modelling will help to understand the effect of existing GI in the reduction of air pollutant concentration levels. In this study, we will assess effect of increase in traffic emission on air quality and benefits of new vegetation planting on the city-scale model with the help of integrated modelling approach that combines (i) reduction of air pollutant concentration levels via enhanced atmospheric turbulence due to increased surface roughness in dispersion modelling by using Gaussian plume model (ADMS-Urban) and (ii) reduction of air pollutant concentration levels due to pollutant deposition over vegetation by using deposition modelling as shown in figure below.

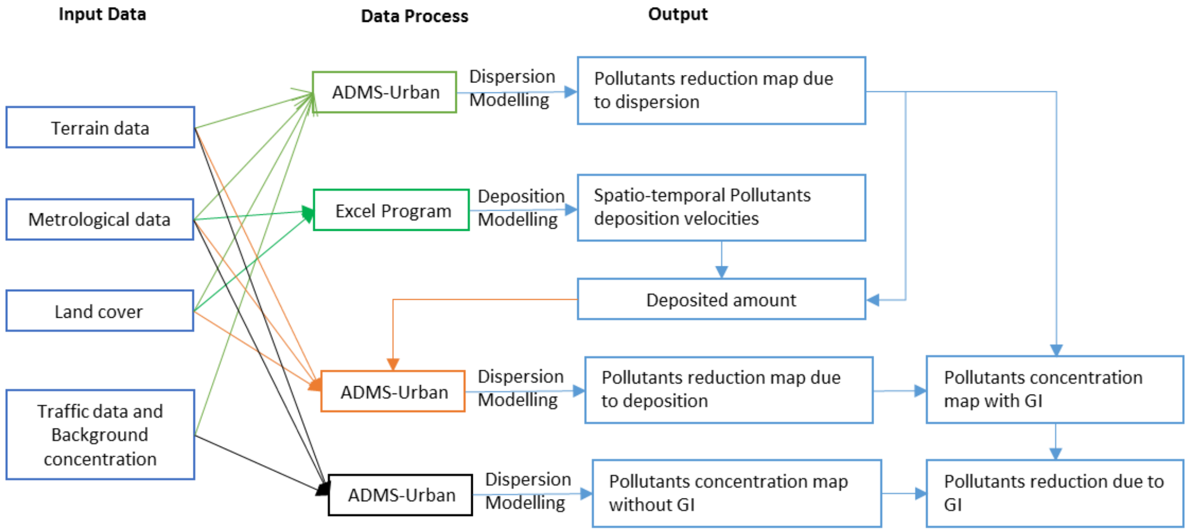


Figure 43 An integrated framework for evaluating air pollutants reduction through dispersion model

3.4.2 Model input

3.4.2.1 Traffic input

Road traffic is the major source of air pollution in Guildford (Guildford Borough Council, 2017), and the major roads (M roads, A roads, and B roads) in Guildford are shown in Figure 42. In the modelled domain, there are 16.6 km of M roads (motorways) and 232.9 km of A roads; henceforth referred to as “major roads”, 99.6 km of B roads and C roads (classified unnumbered); henceforth referred to as “minor roads”, and 1379.0 km of U roads (unclassified unnumbered); henceforth referred to as “Local roads”. The majority of the traffic volume passes through the major and minor roads; whereas local roads have relatively much lower traffic volumes (Department for Transport, 2014).

In order to estimate the pollutant emissions from the roads, the EFT v8.0.1 developed by Department for Environment Food & Rural Affairs (2019b) was used, which requires (i) vehicle counts, fleet composition, and traffic speed as inputs. We obtained the data for the average traffic counts, as AADF (Annual Average Daily Flow), without diurnal, weekly or annual variation, and fleet composition in Guildford for the year 2015 from the Department for Transport (DfT), UK which operates ~130 traffic counters for “major roads”, and ~30 traffic counters for “minor roads”. The traffic speed on the roads was assumed to be constant, and taken to be the average traffic speed in the UK as shown in Table 20 (https://www.gov.uk/government/collections/speeds-statistics). The road category is based on type on the road (A, B, C, U and M roads) and locality (U-urban and R-rural). The total emission rate, E, (g/km/sec) is calculated by using Eq. (16).

$$E = EF_i \times C_i \qquad (16)$$

Where i is vehicle type, EF_i is an emission factor (g/km/sec) and C_i is on-road AADF of i. In order to project to the year 2039 traffic pollutant emissions rate, the EFT v8.0.1 developed by (Department for Environment Food & Rural Affairs, 2019b) was used to project till the year 2030 and then extrapolate to the year 2039 by best fit polynomial regression (for R2 > 0.9) as shown in Figure 44. The traffic counts for the vehicle fleet are projected for the year 2039 based on the historic average (scenarios-1) for forecasts of road traffic in England (Department for Transport, 2015b) and fleet composition is estimated based on vehicle fleet composition projections by National Atmospheric Emissions Inventory (National Atmospheric Emissions Inventory, 2017), respectively. The traffic speed on the roads was assumed to be constant (the same as the year 2015, Table 20).

Apart from traffic sources, the other pollutant sources are considered in background pollutant concentration.

Speed (Km/hr)

Road Category	Vehicle Type				
	Car	Bus	Motorcycle	LGV	HGV
AU	48	41	48	48	41
AR	97	82	97	97	82
BR	24	21	24	24	21
BU	48	41	48	48	41
CR	24	21	24	24	21
CU	48	41	48	48	41
UR	32	27	32	32	27
UU	16	14	16	16	14
MM	97	82	97	97	82

Table 20 Speed of different vehicles based on road category

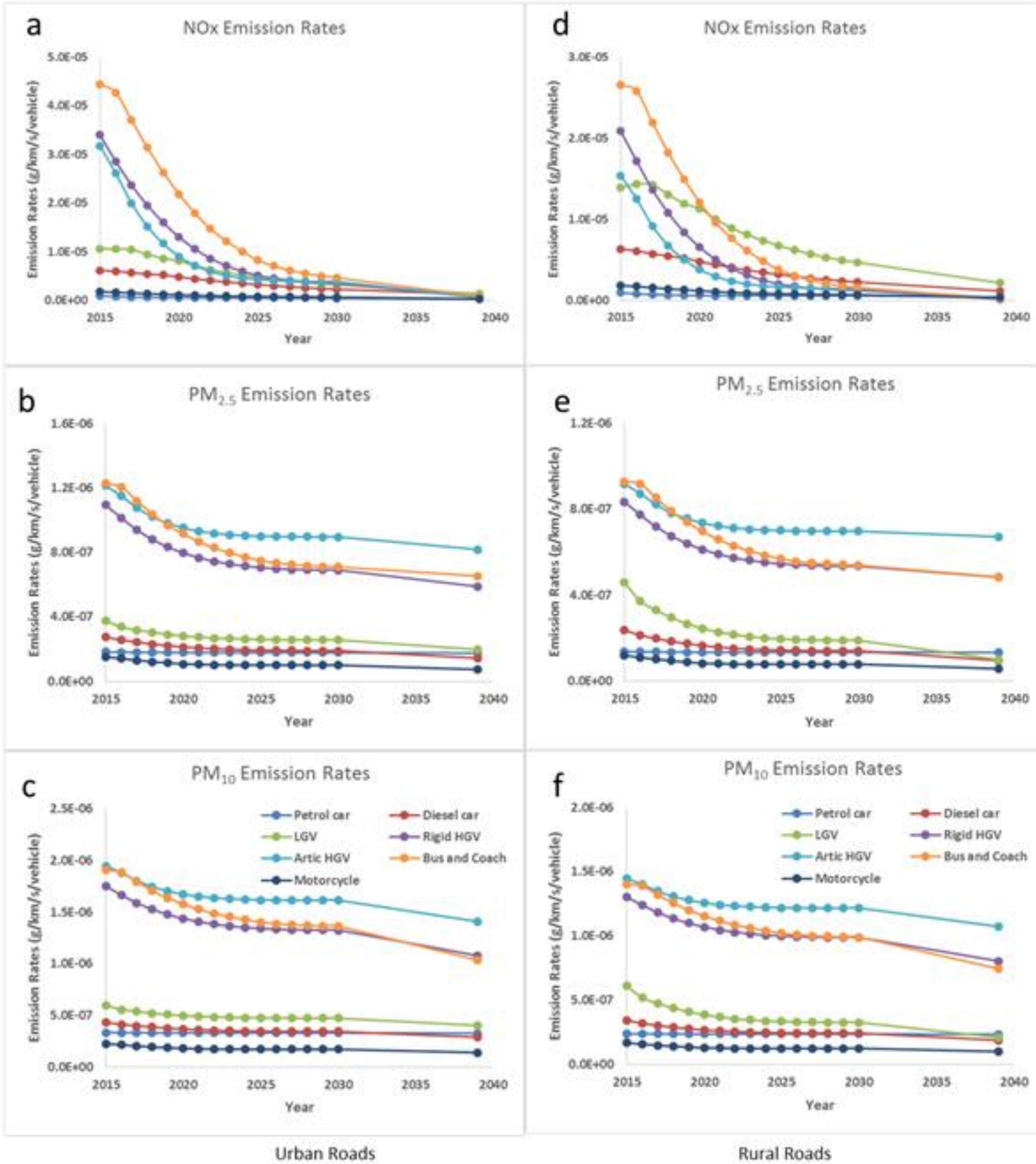


Figure 44 Projected air pollutant emission factors for different vehicles types depending on the road types - Urban roads (a) NOx (b) PM2.5 (c) PM10 and Rural roads (a) NOx (b) PM2.5 (c) PM10 based on national data.

Meteorology, land cover and topography: Meteorological variables such as wind velocity and direction, temperature, relative humidity, and cloud cover are required for dispersion calculations that are driven by hourly meteorological profiles and characterized through Monin-Obukhov similarity theory in the ADMS-Urban model. The hourly data for those variables were obtained for the year 2015 from a weather station located in South Farnborough (latitude = 51:28N longitude = 00:77W, and altitude = 65 metres above the mean sea level), which is at a distance of 14.5 km from the centre of the modelled domain. Guildford has a similar dominating wind direction from South-West, as other UK towns (Earl et al., 2013), as seen in the wind rose diagram in Figure 45.

The land-cover data for the modelled domain was obtained for the year 2015, at a spatial resolution of 25 m and with a minimum mapping unit of 0.5 ha (Centre for Ecology & Hydrology, 2017).To cover the whole area, the domain was divided into seven types of land cover. These are deciduous forest (Df), coniferous forest (Cf), grassland (Gl), soil surface (ss), water surface (wf), agriculture surface (Arf) and artificial surface (Af) as shown in Figure 46. The percent land cover for the year 2015 in Guildford borough is presented in Table 21. A constant surface roughness value was used based on the type of land cover.

The effect of variation in topography on dispersion was incorporated in the model by use of the OS terrain 50 terrain data for 2017, which has a spatial resolution of 50 m (https://www.ordnancesurvey.co.uk). It is assumed that the topography has negligible change over the year from 2015 to 2039. The geometry of roads was obtained as shapefiles from the Consumer Data Research Centre (Consumer Data Research Centre, 2015). The meteorology and topography data are likewise assumed constant for the year 2039.

Land Cover	Percentage area	Surface roughness (m)	Land Cover	Percentage area	Surface roughness (m)
Grassland	37.8	0.02	Coniferous forest	8.2	1
Rural Surface	21.4	1	Urban Surface	2.2	1.5
Deciduous forest	20.3	1	Water surface	0.8	0.0001
Agricultural Surface	9.2	0.25			

Table 21 Type of land cover and contribution in the total area in the Guildford borough council

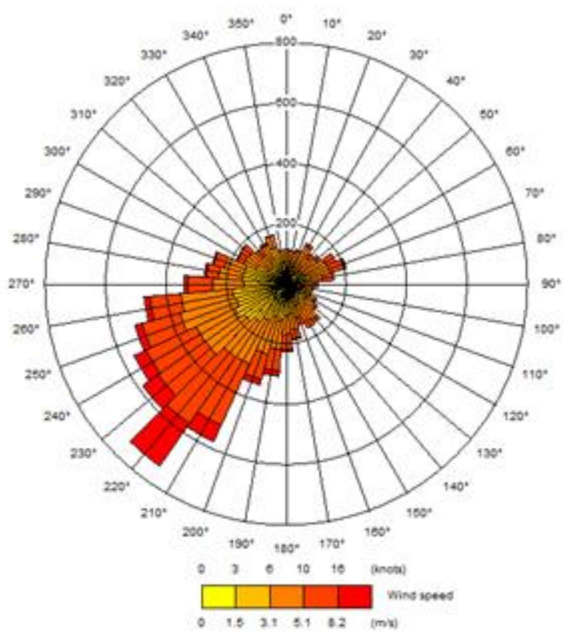


Figure 45 Windrose diagram at a 65m above mean sea level at South Farnborough meteorological station (source: Metrological department, UK).

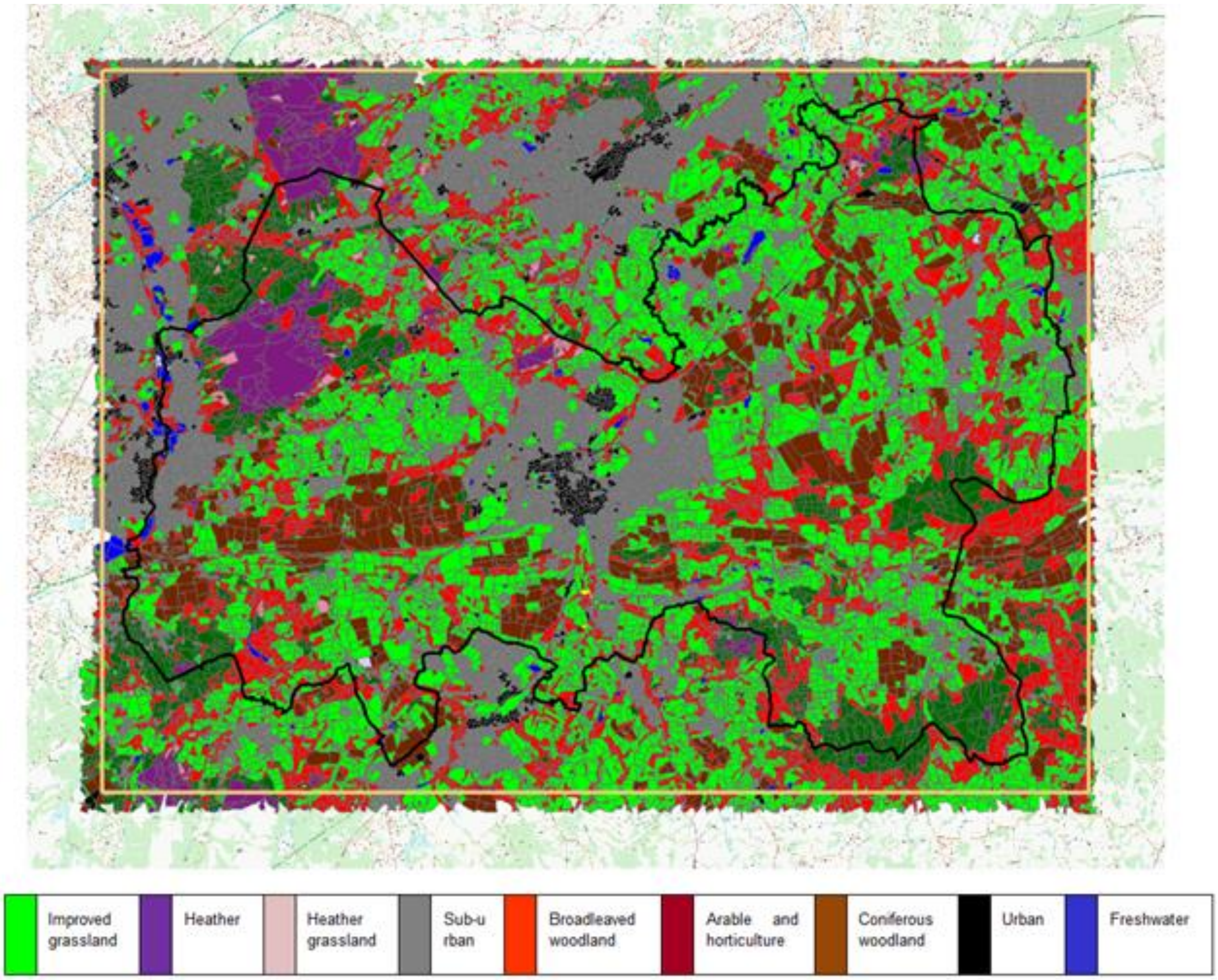


Figure 46 A map showing spatial distribution of different land covers at 25 m resolution in modelled domain over Guildford city (source: Centre for Ecology & Hydrology (2017)).

3.4.3 Model setup

The limited number of dispersion models are rarely developed to access the impact of GI on urban air quality. Tiwari et al. (2019) summarized a range of air quality models that have been used to simulate the air pollutant concentration at the city scale and highlighted that most of them are not designed specifically for considering the effect of GI on air pollutant concentration reduction. Tiwari et al. (2019) also reviewed the limitations of ADMS-urban in terms of evaluating GI impacts in air pollutant deposition modelling because it is not developed to estimate the deposition velocity over GI surface. For instance, ADMS-Urban estimates deposition velocity by assuming constant surface resistance throughout the modelling domain, which may lead to uncertain in air quality simulation. The present approach has been developed to overcome an above-mentioned limitation in which spatially distributed air pollutant deposited amount are estimated in two steps: firstly, the spatial distribution of air pollutant concentrations over GI surface have been simulated by pollutant dispersion modelling in ADMS-urban. Secondly, the spatial distribution of deposition velocities has been estimated based on GI characteristics and meteorological conditions (discussed below). The total deposition of air pollutant over GI and other surfaces have been estimated by a combination of pollutant concentration level estimated by dispersion modelling and vegetation characteristics (deposition velocity). The sources are defined as grid sources as land cover size, and emission rate depends on the deposition velocity over the surface.

Dispersion Modelling: The ADMS-Urban has been used to simulate the air pollutant dispersion in the modelled domain. The model inputs (discussed in Section 3.4.2) are used to define emission sources and atmospheric condition to set the air pollutant dispersion model in ADMS-urban for Guildford borough.

Deposition Modelling: The deposition flux (F; g m^{-2}) to GI is proportional to the deposition velocity (Vd; m s^{-1}), time of exposure (t; sec) and pollutant concentration (C; g m^{-3}) (Bottalico et al., 2016, Jeanjean et al., 2016, Tiwary et al., 2009).

$$F = V_d \cdot C \cdot t \tag{17}$$

The deposition velocity for different gases pollutant is calculated as the inverse sum of aerodynamic resistance (Ra; in sm^{-1}), quasi-laminar boundary layer resistance (Rb; in sm^{-1}) and surface resistance (Rs; in sm-1) (Janhäll, 2015, Jayasooriya et al., 2017, Tallis et al., 2011, Tiwary et al., 2009, Wesely, 1989) as Eq. 18. To calculate particle deposition velocity, virtual resistance (Ra.Rb.Vs; in sm^{-1}), aerodynamic resistance and quasi-laminar layer resistance should be considered in series and the whole term in inverse will be calculated in parallel to settling velocity (Vs) without surface resistance (Seinfeld and Pandis, 2006, Wesely and Hicks, 2000) shown Eq. 19.

$$V_d = \frac{1}{R_a + R_b + R_c} \quad \text{for gaseous pollutants} \tag{18}$$

$$V_d = V_s + \frac{1}{R_a + R_b + R_a R_b V_s} \quad \text{for particulate matter} \tag{19}$$

The hourly meteorological data were used to estimate for the spatial distribution of R_a and R_b (National Power and CERC, 2017) and R_c (for gases) was calculated depending upon the land cover and seasonal category as per Wesely (1989). V_d (only for particles) was evaluated within ADMS-Urban.

The deposition schemes, which are a part of air transport models, use mathematical equations to describe atmospheric turbulence, absorption (for gases) and gravitational settling (for particles) processes within the atmospheric mixing layer, that estimate the accumulated quantity of air pollutant removal over any solid surface area without involving water in the atmosphere. The deposition schemes for gaseous pollutants are shown in Figure 47.

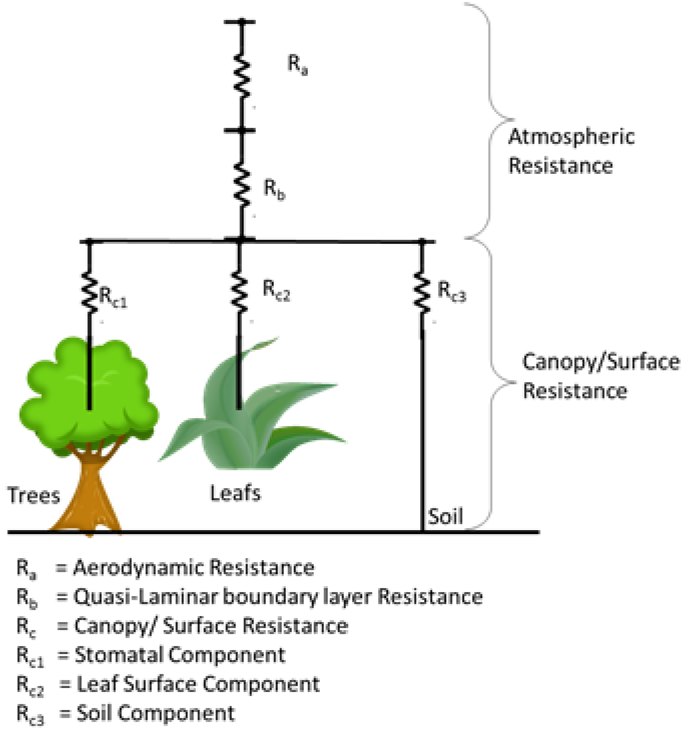


Figure 47 Schematic diagram showing the resistance relationship with Ohm's law in electrical circuits where Ra is aerodynamic Resistance; Rb is quasi-laminar boundary layer Resistance; Rc is canopy/surface resistance; Rc1 is atmospheric buoyancy, lower canopy and in-canopy resistance; Rc2 is stomatal, mesophyll and cuticular resistance; and Rc3 is canopy soil, ground, water, snow or any other surface resistance; adopted from Tiwari et al. (2019).

3.4.4 Scenarios

In order to evaluate the benefits of planting vegetation in Guildford vis-à-vis reducing the roadside NO_x concentration and complying with the relevant standards, as discussed in Section 3.4, we have investigated different scenarios with new GI developed for the years 2015 and 2039 as described below. The year 2015 has been chosen to represent the current situation in Guildford since data for the model inputs are freely available for this year. The strategic road network will be implemented in the year 2040 in the UK. This means that the end of the year 2039 would mark a radical shift towards zero-emission vehicles, and therefore year 2039 is an ideal year for studying the impact of planting new vegetation on avoiding the ongoing breaches in air quality standards. The simulation of air quality in the year 2039 will also provide sufficient time for planting the new GI. In the present study the following scenarios were used in the present study:

2015-BASE: This is the baseline case for the year 2015 with the current estimated vegetation cover in Guildford borough.

2039-BAU: This is the business as usual scenario for the year 2039, which assumes that the traffic and fleet composition have changed, while the green infrastructure remains at the same level as a 2015-BASE scenario. By subtracting this scenario with the 2015-BASE, we will be able to estimate the air quality benefits provided by the existing green infrastructure and the effect of new government policy intervention for continuous reductions in emission source to meet the national air quality target for the year 2039.

2039-Max-Con/2039-Max-Dec/2039-Max-Grassland: These are three alternative scenarios for the year 2039 with the maximum possible coniferous/deciduous tree or grassland cover on available GI areas which is a 66.3% in the year 2015. Comparison with 2039-BAU will give maximum potential air quality benefits achieved by planting coniferous/deciduous trees or grassland.

2039-NR_Con/2039-NR_Dec/2039-NR_Grassland: These are three alternative scenarios for the year 2039 with the maximum coniferous, deciduous trees and grassland cover around (250 m) all traffic lanes. Comparison with 2039-BAU will give maximum air quality benefits achieved by planting mix coniferous, deciduous trees and grassland near traffic lanes.

Thus, through studying the eight scenarios outlined above, we will estimate the air quality benefits of developing new GI land cover in Guildford and estimate the potential for reductions in the concentrations of different air pollutants (NO_x, PM_{10}, $PM_{2.5}$) in the year 2039.

3.4.5 Model validation

Model validation is performed (for 2015-BASE only) by comparing the model results for the annual mean NO_x concentration in Guildford in 2015 (2015-BASE scenario described) with the corresponding annual concentrations at 17 different sites in Guildford borough as shown in Figure 48.,The measurements used for validation was done by the Guildford borough council (Guildford Borough Council, 2017) and used diffusion tubes for measuring monthly average concentrations. Those measurements include roadside, urban background, and rural background concentrations of NO_2. Validation was as well performed against modelled annual mean background concentration for air pollutants NO_x, PM_{10} and $PM_{2.5}$ provided by Defra for the year 2015 (as discussed in D6.3). The coefficient of determination (R2) for modelled annual mean hourly concentration with Guildford Borough Council measured NO_x concentration was 0.74 and with Department of Food & Rural Affairs modelled annual mean hourly concentration for NO_x, PM_{10} and $PM_{2.5}$ were 0.82, 0.81, and 0.75 respectively. The statistical analysis between DEFRA annual mean hourly concentration and modelled annual mean hourly concentration have been conducted using openair package in R (Carslaw and Ropkins, 2012), shown in Table 22.

Statistical Parameters	NO_x	PM_{10}	$PM_{2.5}$
Fraction of predictions (FAC2)	0.67	0.29	0.51
Mean Bias (MB)	0.78	0.23	0.08
Mean Gross Error (MGE)	1.91	0.25	0.12
Normalised Mean Bias (NMB)	0.17	0.91	0.34
Normalised Mean Gross Error (NMGE)	0.41	1.01	0.53
Root Mean Squared Error (RMSE)	2.55	0.28	0.14
Pearson correlation coefficient (r)	0.91	0.87	0.90
Index of Agreement (IOA)	0.72	0.41	0.66

Table 22 Comparison of statistical parameters between DEFRA annual mean hourly concentration and ADMS-Urban modelled annual mean hourly concentration

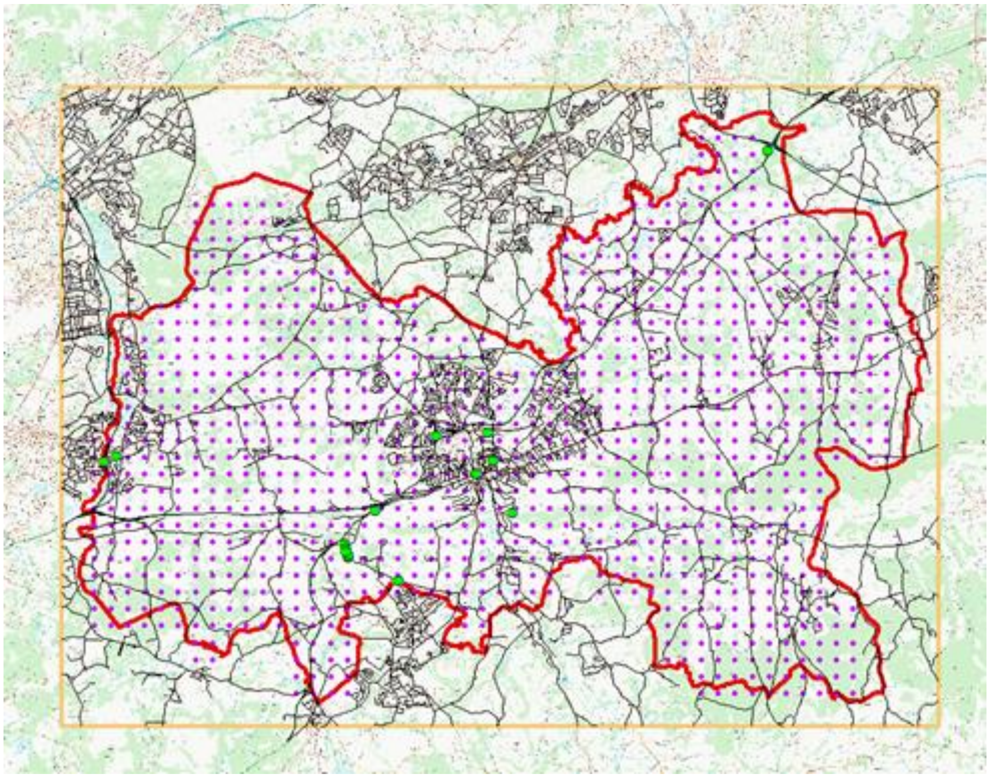


Figure 48 GBC monitored points (green) and output grid points (purple) along with road network (source: Original UoS elaboration).

3.4.6 Results for scenarios

The simulated results of the annual average air pollutant concentration level and spatial distribution are shown in Figure 49, Figure 50, Figure 51, and Figure 52. The annual average air pollutant concentrations for NO_x, PM_{10}, and $PM_{2.5}$ in year 2015-BASE are estimated as 11.04 µg. m^{-3}, 10.19 µg. m^{-3}, and 7.91 µg. m^{-3}, respectively, which are calculated to be 9.74 µg. m^{-3}, 10.04 µg. m^{-3}, and 7.98 µg. m^{-3} in the year 2039 under 2039-BAU scenario (Table 23). This concentration difference is due to projected increment in traffic numbers and decrement in vehicular air pollutant emission rates. The annual average NO_x and PM_{10} was decreased by 11.8% and 1.5%, respectively, due to the UK government policies for emission reduction from exhaust (Department for Environment Food & Rural Affairs, 2019a) but $PM_{2.5}$ levels were increased by 1.0% because non-exhaust contribute more $PM_{2.5}$ than exhaust (Panko et al., 2019). Under the scenario 2039-Max-Dec, annual NO_x, PM_{10} and $PM_{2.5}$ concentration increased by 0.9%, 3.5% and 1.6%, respectively with compare to 2039-BAU case. The main reason for these annual pollutant concentration increase was less deposition surface offered by deciduous trees during the autumn season. Reduced deposition rate offered by deciduous trees' leaves and calm wind condition could be a reason for an episode of high air pollutant concentration levels in the autumn season. For instance, Sun et al. (2014) observed that the air quality was worse in winter season due to lack of leaves on the trees compare to spring in Jiufeng National Forest Park (a coniferous forest) in Beijing, China during the year 2013.

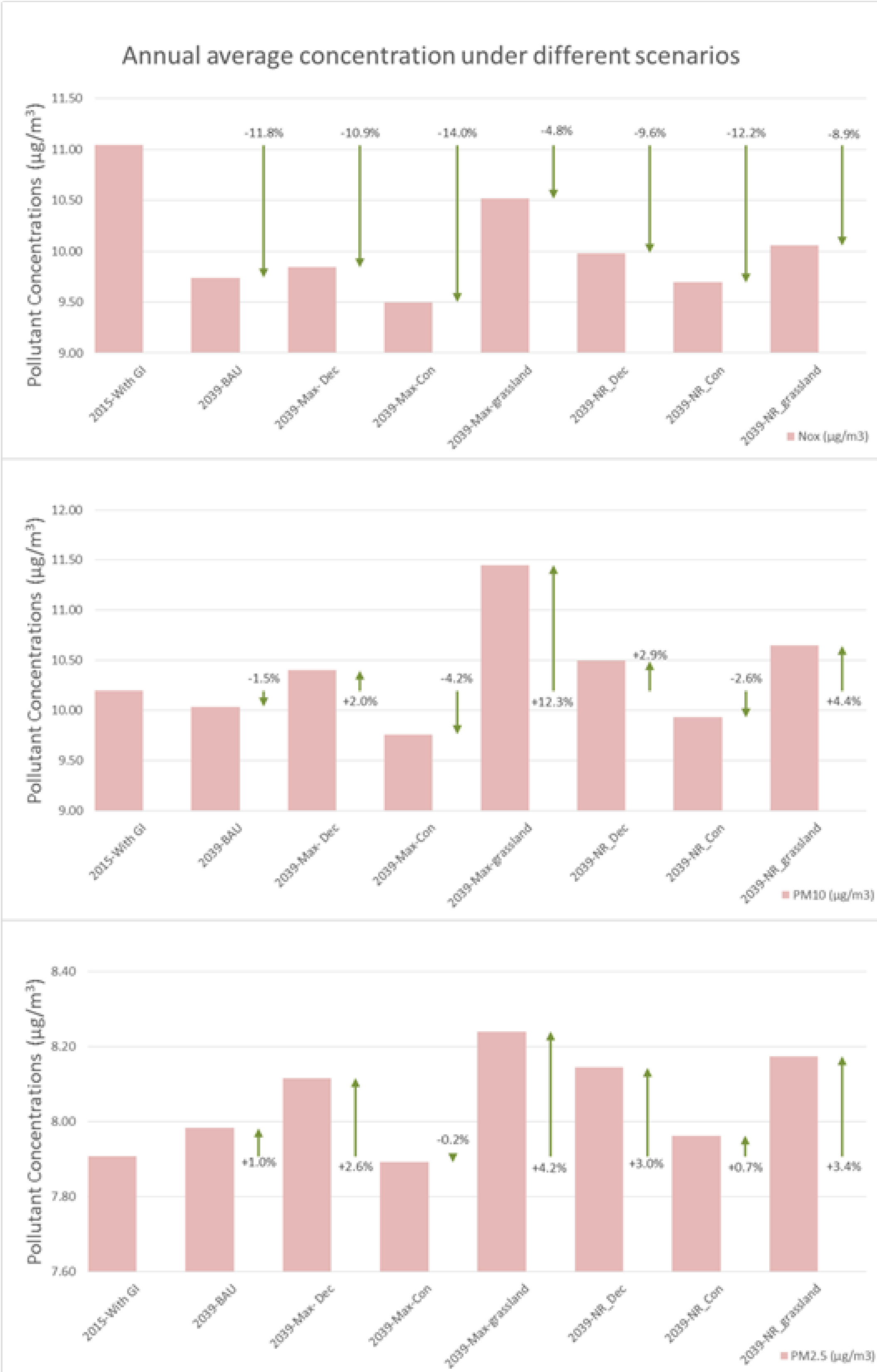


Figure 49 Potential pollutant concentration reduction to different scenarios of planting composition within the study domain of the Guildford borough

Furthermore, concentration levels of air pollutant NO_x, PM_{10} and $PM_{2.5}$,compare to 2039-BAU case, further reduced by 2.2%, 2.7% and 1.2% respectively (Figure 49) under the 2039-Max-con scenario when land covered by deciduous trees and grassland were anticipated as coniferous or evergreen trees in air pollutant dispersion modelling. These reductions are caused by two factors (i) pollutant deposition over leaves surface of coniferous trees throughout a year whereas in 2039-BAU deciduous trees were covering 20.3% land cover that offered no deposition in autumn season, and (ii) enhanced pollutant dilution due to increased surface roughness compare to 37.8% grassland cover with neglected surface roughness in scenario 2039-BAU. Therefore, the annual air pollutant NO_x, PM_{10} and $PM_{2.5}$ concentrations were decreased to 9.50 µg. m^{-3}, 9.76 µg. m^{-3}, and 7.89 µg. m^{-3} respectively under scenario 2039-BAU (Table 23). But in another scenario, 2039-Max-grassland (section-3.4.1.3), air pollutants NO_x, PM_{10} and $PM_{2.5}$ concentration increased by 7.0%, 13.8% and 3.2% respectively (Figure 49) balance with the 2039-BAU scenario. These pollutant concentration incensement is mainly due to reduced surface roughness that causes less atmospheric dilution and reduced deposition velocities. In general terms, air pollutant deposition velocities are a function of surface roughness and friction velocity (Gallagher et al., 2002). Similarly, Donateo and Contini (2014) have studied the correlation between $PM_{2.5}$ deposition velocity and friction velocity over the different surface and highlighted that $PM_{2.5}$ deposition velocity increases with friction velocity and surface roughness. As a result of low atmospheric turbulence and deposition velocity because of projected grassland as a majority of the cover over-estimated increase in annual pollutant concentration to 10.52 µg. m^{-3}, 11.45 µg. m^{-3}, and 8.24 µg. m^{-3} respectively in NO_x, PM_{10} and $PM_{2.5}$.

Scenarios	NO_x (µg/m^3)	PM_{10} (µg/m3)	$PM_{2.5}$ (µg/m3)
2015-With GI	11.04	10.19	7.91
2039-BAU	9.74	10.04	7.98
2039-Max- Dec	9.84	10.40	8.12
2039-Max-Con	9.50	9.76	7.89
2039-Max-grassland	10.52	11.45	8.24
2039-NR_Dec	9.98	10.49	8.14
2039-NR_Con	9.69	9.93	7.96
2039-NR_grassland	10.06	10.65	8.17

Table 23 Summary of annual concentration in various scenarios

We have also investigated three more realistic scenarios (Section 3.4.1.4) to simulate air quality by altering GI near traffic lanes, up to 125 m both sides of roads, which is around 137 Km^2 and shared as grassland~69 km^2; deciduous trees ~47 Km^2 ; coniferous trees ~21 km^2 under the 2039-BAU scenario. In the scenario 2039-NR_Dec, deciduous trees are proposed to plant around traffic lanes in order to assess their effect on air quality. It was observed that annual pollutant concentrations were increased by 2.2%, 4.4% and 2.0% respectively in NO_x, PM_{10} and $PM_{2.5}$. These observations indicate that planning deciduous trees near road may deteriorate further air quality by eliminating deposition near to source during the autumn season which could increase NO_x, PM_{10} and $PM_{2.5}$ concentration levels to 9.98 µg. m^{-3}, 10.49 µg. m^{-3}, and 8.14 µg. m^{-3} respectively.

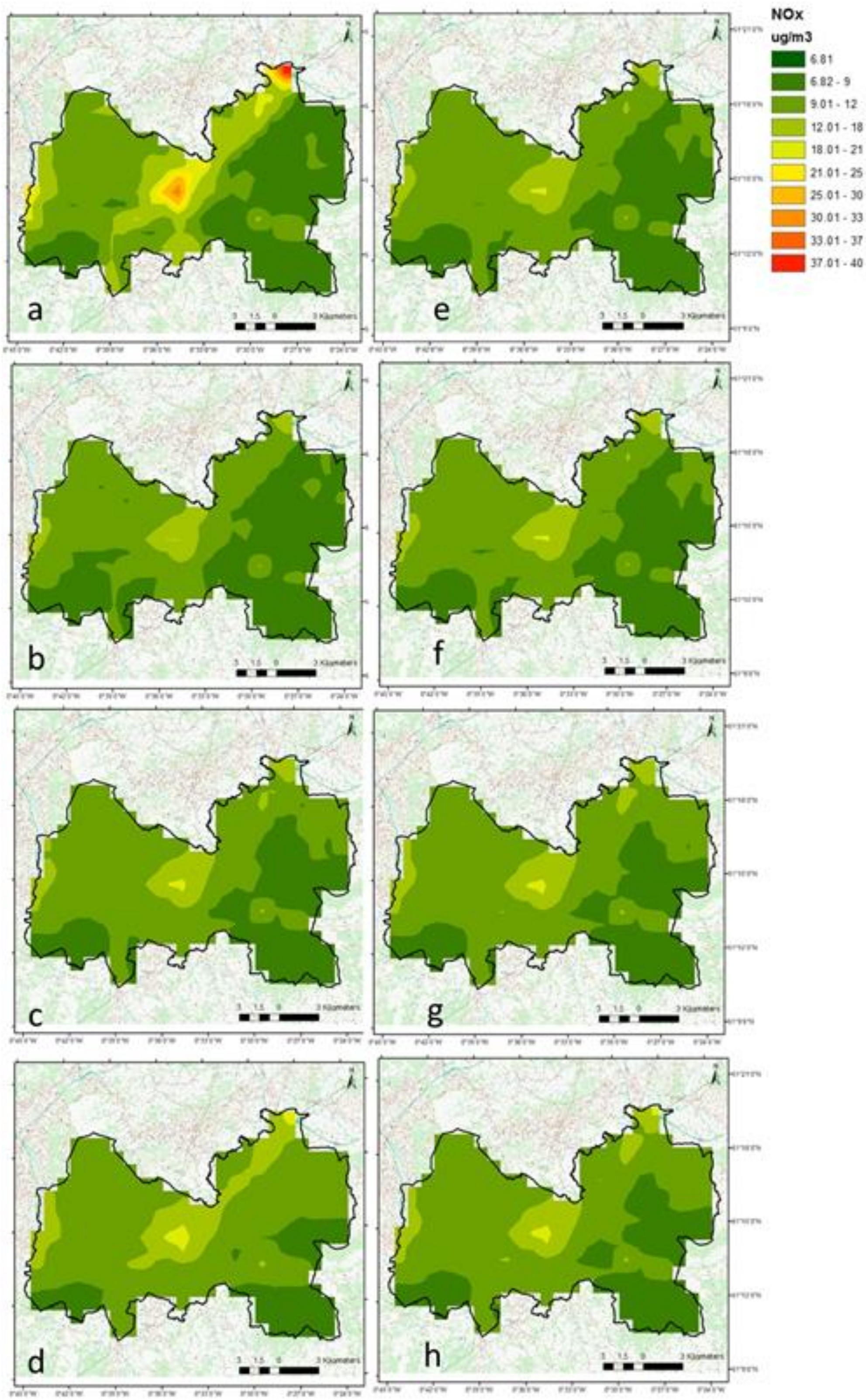


Figure 50 Hourly averaged modelled NOx concentration under different GI sceneries using bilinear interpolation (a) 2015-Base (b) 2039-Max-Con (c) 2039-MAX-Dec (d) 2039-MAX-Grassland (e) 2039-BAU (f) 2039-NR_Con (g) 2039-NR_Dec and (h) 2039-NR_Grassland

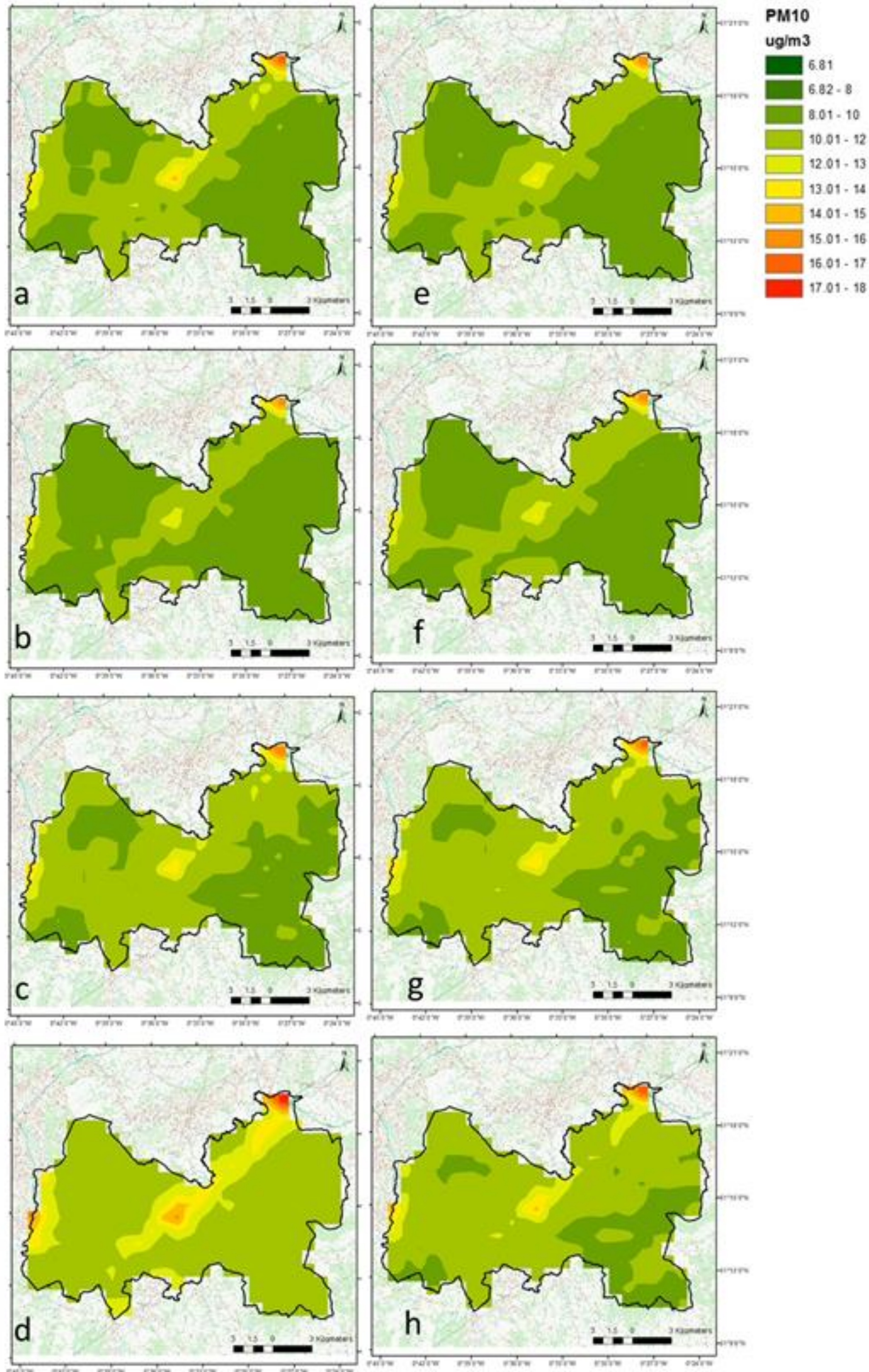


Figure 51 Hourly averaged modelled PM10 concentration under different GI sceneries using bilinear interpolation (a) 2015-Base (b) 2039-Max-Con (c) 2039-MAX-Dec (d) 2039-MAX-Grassland (e) 2039-BAU (f) 2039-NR_Con (g) 2039-NR_Dec and (h) 2039-NR_Grassland

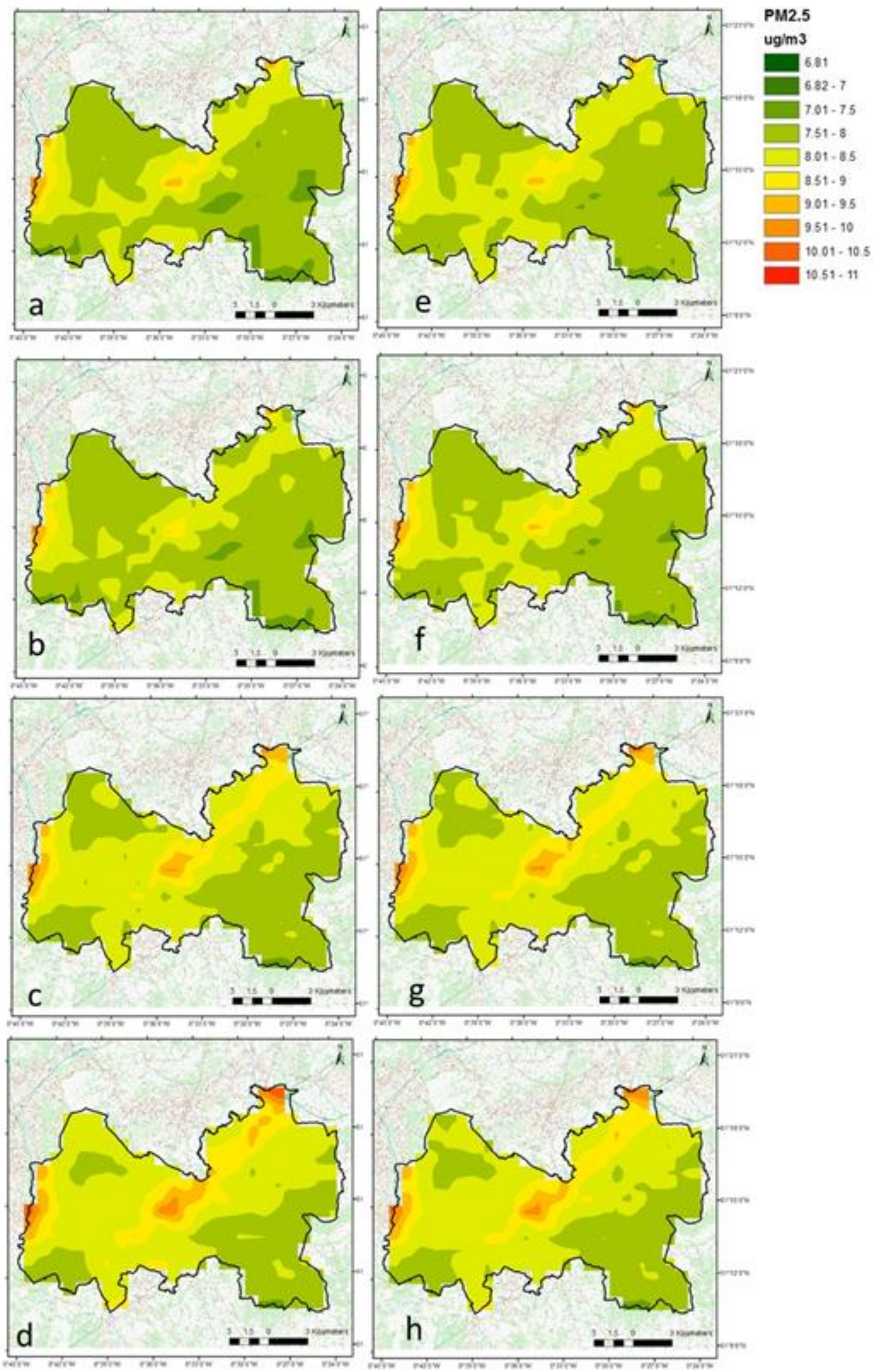


Figure 52 Hourly averaged modelled PM2.5 concentration under different GI sceneries using bilinear interpolation (a) 2015-Base (b) 2039-Max-Con (c) 2039-MAX-Dec (d) 2039-MAX-Grassland (e) 2039-BAU (f) 2039-NR_Con (g) 2039-NR_Dec and (h) 2039-NR_Grassland

As opposed deciduous trees, planning coniferous trees around traffic lanes showed a positive impact on air quality by decreasing NOx, PM10 and PM2.5 concentration by 0.4%, 1.1% and 0.3% respectively and reducing concentration levels to 9.69 µg. m-3, 9.93 µg. m-3, and 7.96 µg. m-3 respectively under the scenario 2039-NR_Con. It is expected that these reductions have occurred as a result of dilution and deposition near to source that could decline the downwind concentrations (Figure 50, Figure 51, and Figure 52). In contrast with planting trees, the scenario 2039-NR_Grassland has been investigated to study the impact of growing grassland near traffic lanes on annual air quality. Our results (Figures 50-52) show that enhanced dilution and large deposition amount cannot be achieved by growing grassland near traffic lanes. As a result of low atmospheric turbulence and high deposition velocities, grassland near traffic lanes could increase the annual air pollutants NO_x, PM_{10} and $PM_{2.5}$ concentration levels by 2.9%, 5.9% and 2.4%.

3.5 Vantaa

Vantaa is one of the cities in Finland's capital region. It is a relatively green city and it has vast agricultural and natural areas (Figure 53). It has also relatively good air quality. For instance, in 2018 the observed PM2.5 concentration in Vantaa Tikkurila Neilikkatie measurement station exceeded the WHO recommendation for daily levels (25 micrograms) during 3 days and PM10 (50 micrograms) during 10 days (FMI, 2019). Still, as the urban structure is expanding and possibly creating street canyons, the air quality and exposure simulations are an important source of information for the urban planners trying to mitigate air quality problems. Recent research from three Finnish cities, including Vantaa, shows that there has been a learning process among urban planners regarding how they approach green infrastructure (Lähde and Di Marino, 2019). There has been a shift from referring GI mainly as a spatial and functional classification to acknowledging the multifunctional aspects of GI.

In Vantaa, the aim of the exposure modelling exercise is to assess the impact of trees, green roofs and green infrastructure on citizen exposure. The impact of trees and green roofs on air quality is first modeled with ENVI-met software in building block scale, and the results are then upscaled to city level for informing the socio-economic impact assessment.

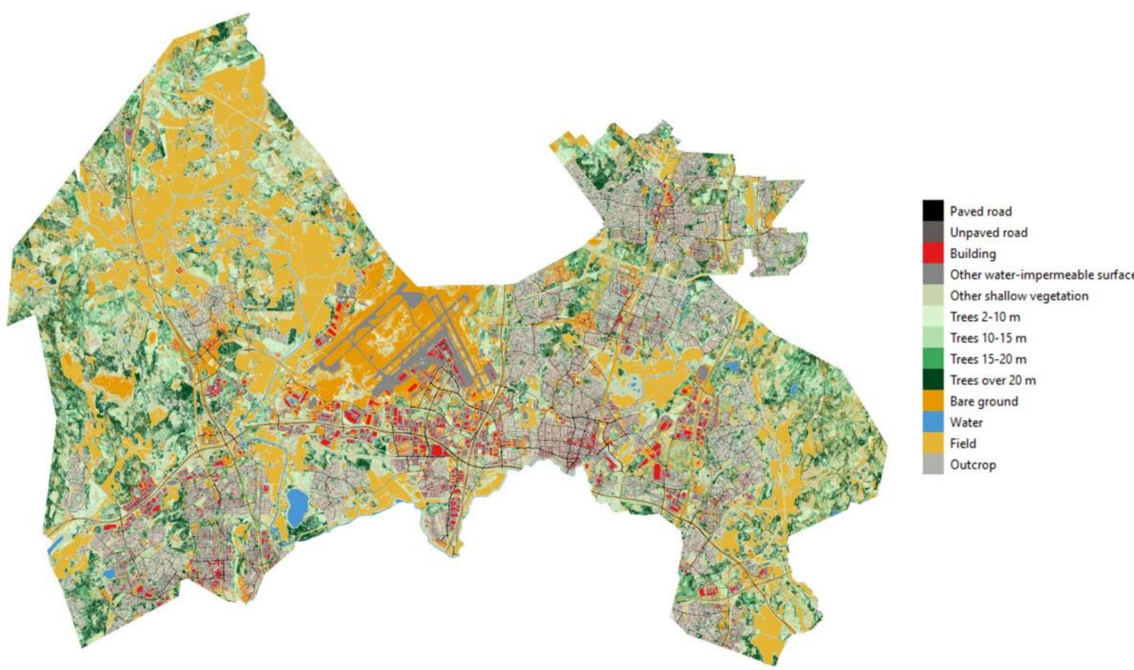


Figure 53 The land-use map for Vantaa (data source: Helsinki Region Environmental Services Authority (2019))

3.5.1 Modelling methodology

The area Myyrmäki Vaskivuorentie was chosen out of three areas suggested by the Vantaa city authorities. The reason why this area was chosen was that it lies in an area which achieved a mature stage of development. To increase the urban efficiency complementary building will also be introduced to the Myyrmäki area. The modelled area lies in the centre of housing development district of the earlier 1970s within the westerly part of Vantaa. The population density in the inner core area is about 5.800 people per km^2 (wikipedia.org, 2014).

Due to the northern geographically location the growing season only lasts about 180 days from the end of April to October. During the construction period, special attention was given to the local green infrastructure that nowadays the age of trees in the area is comparable to the age of trees in the neighbouring surroundings.

For the modelling and simulation the ENVI-met, V4.4.2, software were used.

Figure 54 Aerial picture of the larger Myyrmäki area, the red open rectangle shows the location of the northern part of the Vaskivuorentie residential area (https://asiointi.maanmittauslaitos.fi/karttapaikka/).

Figure 55 Detail aerial picture of Figure 54 of the Myyrmäki Vaskivuorentie area (60° 15' 51,005", 24° 50' 57,262", https://asiointi.maanmittauslaitos.fi/karttapaikka/).

The tree population mainly exist of birch (Betula pendula) and pine (Pinus sylvestris). Several other tree species were planted in small amounts after the construction period. In uncovered areas, the mostly loamy ground is covered with grass. Parking lots and pedestrian paths are covered with stone slabs and tarmac.

3.5.2 Model input

The meteorological background information (air temperature, relative humidity, wind speed) were calculated from a five-year hourly time series 2006 – 2010 from the Finnish Meteorological Institute synoptical weather station at the Helsinki-Vantaa airport, 9.2 kilometres north-east from Myyrmäki.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	units
Air temperature	-1.4	-7.3	-2.3	5.5	9.9	12.8	18.5	18.3	10.2	4.8	2.6	-4.6	°C
Humidity	91	82	83	66	64	75	74	75	80	84	92	88	%
Wind speed	4.7	4.2	3.1	3.5	4.3	5.3	4.6	3.9	3.8	4.3	4.9	4.0	m/s

Table 24 Helsinki-Vantaa, airport, monthly average meteorological data, 2006 - 2010

The averaged wind flow direction for every month is estimated to be wind from the south-west (225°, annual climatological average for Southern-Finland (Drebs et al., 2002)). The monthly averages refer to 15th day of the month, 12 months a modelled year.

Average cloudiness for different heights and soil temperature for different depths were estimated.

		Cloudiness unit: x/8				Soil-temperature, unit: °C		
	low	middle	high		0-20 cm	20-50 cm	50-200 cm	200 cm -
Jan	5	2	0		1	2	5	10
Feb	5	2	0		1	2	5	10
Mar	5	2	0		1	2	5	10
Apr	4	3	0		6	7	9	10
May	4	3	0		6	7	9	10
Jun	3	3	1		12	11	10	10
Jul	3	3	1		12	11	10	10
Aug	3	3	1		12	11	10	10
Sep	3	3	1		6	7	9	10
Oct	4	3	0		6	7	9	10
Nov	5	2	0		1	2	5	10
Dec	5	2	0		1	2	5	10

Table 25 Estimated cloudiness values and soil temperatures for Vantaa Myyrmäki Vaskivuorentie

The road Vaskivuorentie can be characterised as main collecting road, where traffic is lead to from the surrounding storey-house areas. Therefore the main traffic volume is observed in the morning and afternoon hours. There is no public transportation on Vaskivuorentie, but there is a shopping mall, schools, public buildings and small business on the eastern side of the research area. The traffic emissions were estimated by using data of traffic volumes counting dated from the year 2014. Detailed data about the distribution of several car types on Vaskivuorentie is based on traffic counting in 2008 (Finnish Meteorological Institute, 2018). The traffic emissions were calculated with the help of a distribution key based on the traffic counting in 2008 as follows:

Hour	**01:00**	**02:00**	**03:00**	**04:00**	**05:00**	**06:00**	**07:00**	**08:00**
M	0.152	0.152	0.152	0.152	0.152	0.193	1.034	1.865
Hour	**09:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**
M	1.976	1.338	1.338	1.338	1.338	1.338	1.743	1.743
Hour	**17:00**	**18:00**	**19:00**	**20:00**	**21:00**	**22:00**	**23:00**	**24:00**
M	1.855	1.662	1.348	1.044	0.851	0.669	0.416	0.152

Table 26 Hourly distribution multiplier (M) for traffic emissions at Vantaa Myyrmäki Vaskivuorentie

The average emission values were calculated for Vantaa Kielotie, a road section in western-Vantaa, similar to Vaskivuorentie. The basic values for nitrogen oxides is 172 microgram/m^3 and for carbon monoxide is 217 microgram/m^3.

The background traffic emissions and emissions from other sources are currently measured at 11 air quality station of Helsinki Region Environmental Services Authority (Helsinki Region Environmental Services Authority, 2019). The use of background concentration for the simulation runs are the long-term averages from two stations, Tikkurila, 10.9 km in the east and Leppävaara, 5.8 km in the south.

	Tikkurila		Leppävaara		
	Period	Value	Period	Value	Units
NO	1992-2016	24	1993-2016	20	µg/m³
NO_2	1992-2016	27	1993-2016	26	µg/m³
PM_{10}	1997-2016	18	1996-2016	20	µg/m³
$PM_{2.5}$	2009-2016	7	2009-2016	7	µg/m³
SO_2	1992-1998	4	1994-2003	3	µg/m³
CO	1997-2013	428	1994-2008	401	µg/m³
O_3	1990-2013	43			µg/m³

Table 27 Long-term air pollution concentration of two HSY stations Tikkurila (60° 17' 22,026", 25° 2' 19,278") and Leppävaara (60° 13' 4,749", 24° 49' 2,912")

3.5.3 Model setup

The Vaskivuorentie model area was set up based on the OpenStreetMap chart (https://www.openstreetmap.org/). The area was horizontally divided in a 5 x 5 m grid and vertically into a 2 m level to keep the calculation time reasonable. The investigation level was set to 1.4 m above ground, the level where most people were living.

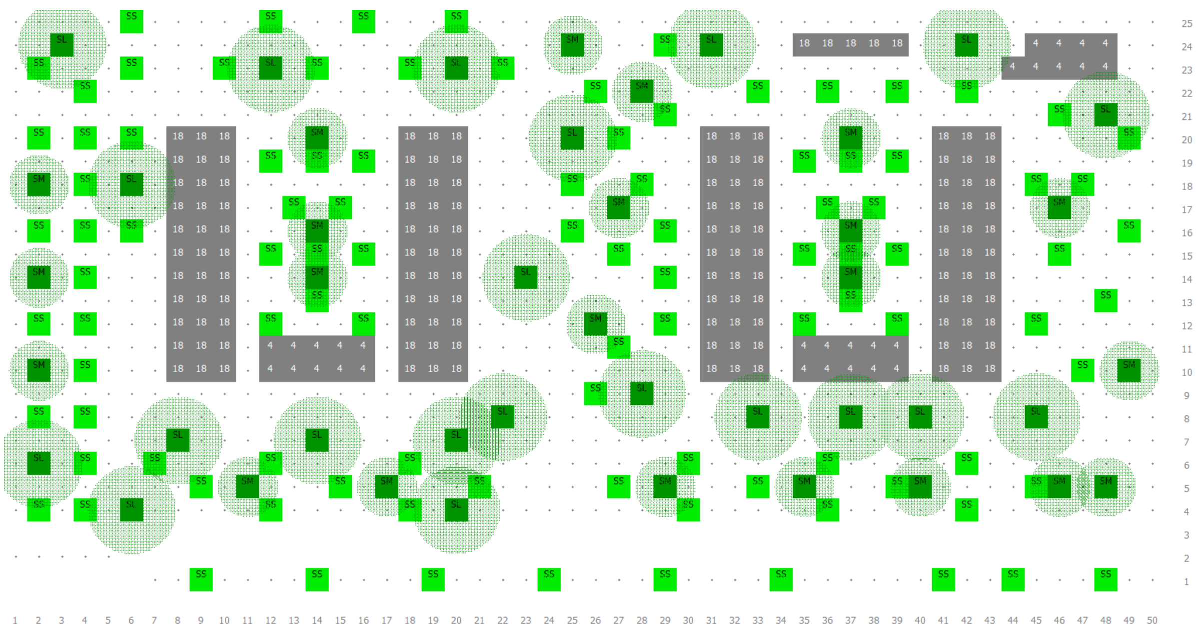


Figure 56 The vegetation and building scheme of the ENVI-met tool 'SPACE' of the Vantaa Myyrmäki Vaskivuorentie area; gray: building with height (m), light green: low trees up to 5 m height, small shading areas, dark green: trees with different heights up to 15 m and different shading areas.

Figure 57 A 3-dimensional picture from the ENVI-met tool 'SPACE' of the Myyrmäki Vaskivuorentie area; grey: buildings, light green: trees with different heights and shading areas, orange: unsealed loamy area, not vegetated; white: sealed areas, stone slabs, black: main sealed roads with tarmac.

3.5.4 Scenarios

There were several approaches to find the right twosome scenarios for conducting the research of socio-economic and urban heat island effects. Some of these approaches were discussed with the City of Vantaa authorities. Of course, the status quo situation was the first scenario. For that, there was sufficient information available about green infrastructure, traffic volumes and buildings properties. The discussion to find the second main scenario let into two directions, the first to remove all current green infrastructure and the second to add green infrastructure into the area in different amounts. There was one attempt to double the amount of trees and green-up all parts of the unsealed ground with grass. The second approach was to add a reasonable amount of trees to open areas. All these actions demanded to change the tree properties in height and treetops. It was decided not to do because it was known that an increase in the canopy layer will be followed a decrease in airflow and increase of air pollution concentration under the canopy layer. On the other hand, a rapid increase of green infrastructure is very unlikely in the harsh climatic condition in Finland. The outcome of the discussion with the city authorities was to use the status quo and the unvegetated scenarios for the comparisons. The unvegetated scenario is considered to be the baseline scenario, where the status quo scenario will refer to. For the socio-economic researches a test year with one simulation in the midst of every month was conducted, for the urban heat island comparison researches only from April to September were used.

3.5.5 Model validation

The executed simulations and analysis were based on averaged meteorological and traffic emissions background data transferred to an urban area of interest where no meteorological nor air quality data through measurements was available. The estimation of the used data based on the evaluation, that the meteorological data is valid for a larger area and that the traffic volumes at Tikkurila and Leppävaara are comparable with Vaskivuorentie. Therefore, model validation was not executed (see Section 3.6.1.4). Otherwise, the ENVI-met simulation software is validated and evaluated extensively and there are an adequate amount of publications about this available on the internet.

3.5.6 Results for scenarios

The comparison of two different scenarios will describe in detail with one example from the simulation and analysis results. The number of examples is limited to one due to the fact, that the meteorological and traffic volume input data is averaged, therefore changes in the month to month results follow more or less the changes in the averaged input data. The two presented results are an air pollutant scenario and urban heat island scenario.

3.5.6.1 Air pollution scenario, observation level 1.4 meter above ground

The example presented here shows a September afternoon situation at 16 o'clock when normal workday return traffic (about 400 vehicles/hour) flows through the Vaskivuorentie. Wind from the south-west and with speed about 2 - 3 m/s in unvegetated traffic areas drives about 8% more of car emissions into the lower vegetated area between the housing blocks.

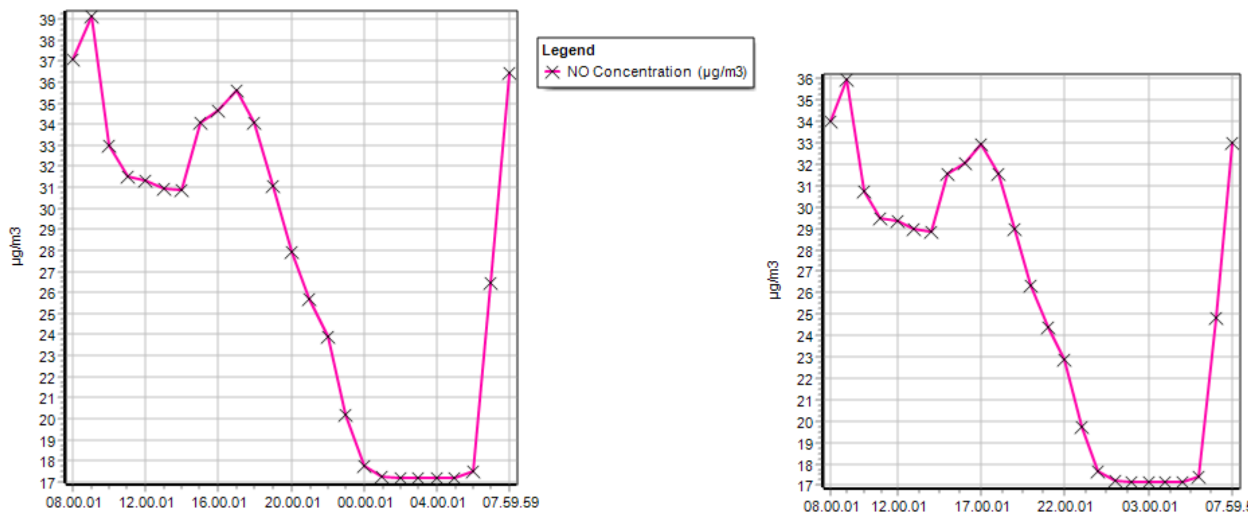


Figure 58 NO - concentration at gridpoint 25,8,3 (south, between the housing blocks), left: unvegetated area; right: status quo, 15.9. 2018.

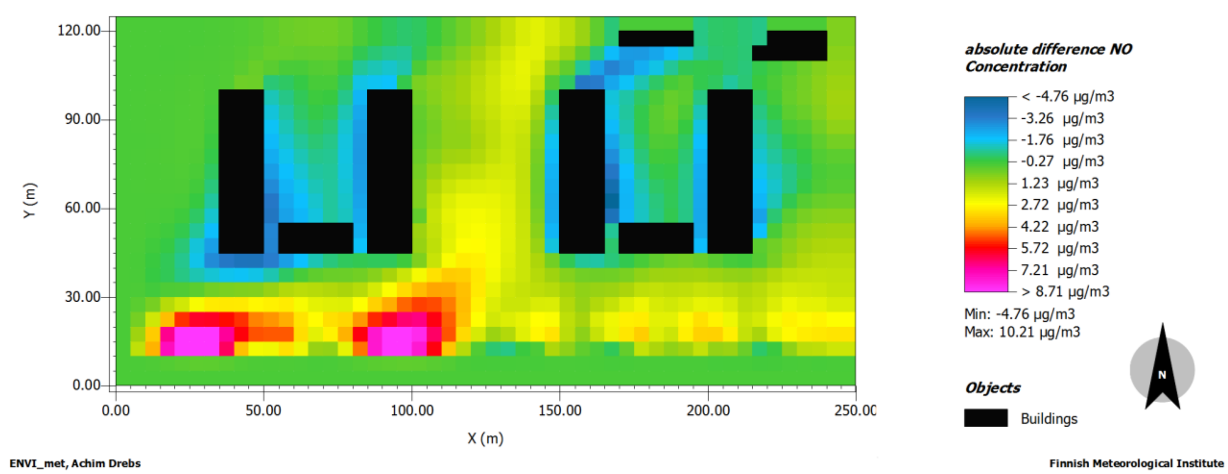


Figure 59 Comparison of traffic emissions, NO, unvegetated vs. status quo (vegetated area), Vantaa Myyrmäki Vaskivuorentie, time: 16.00, date: 15.9.2018, x/y cut at k = 3 (z=1.4000m).

The NO concentration changes during the month of September are presented in Figure 59. The comparison between and vegetated area and a fully unvegetated area shows a reduction of NO concentration of about 8% during the active traffic time between 6.00 and 20.00 o'clock. The largest differences of NO concentrations can be observed nearby the sources on the main route of Vaskivuorentie. Positive NO concentration is transported by the constant air flow through lower green infrastructure into the area between the housing area. During the night hours from 21.00 to 05.00h (local time), the differences were smaller due to the inactive role of the green infrastructure.

3.5.6.2 Urban heat island scenario, observation level 1.4 meter above ground

The PET (Physiologically equivalent temperature) is one of the most often used indices to characterize environmental human thermal conditions. PET takes into account the surrounding air temperature, air humidity, air velocity and the mean radiant temperature (Höppe, 1999). In our approach, we were focused on a single point analysis inside the Vaskivuorentie area to show the possible differences between vegetated and unvegetated area. The analyses of PET were influenced by assumption of an averaged cloudiness. Therefore the results showed not the results expected under clear sky thermal conditions. The differences of PET and mean radiant temperature in our comparison were far more moderate. We adapted the thermal perception and physiological stress definition from Matzarakis and Mayer (1997). The values (PET ranges, Thermal perception, Grade of physiological stress) presented in Table 28 Helsinki-Vantaa, airport, meteorological data, 2006-2010, based on hourly observation aimed at the thermal condition in southern Europe.

	Apr	May	Jun	Jul	Aug	Sep	units
Temperatur	5.5	9.9	12.8	18.5	18.3	10.2	°C
Humidity	66	64	75	74	75	81	%
Wind speed	3.5	4.3	5.3	4.6	3.9	3.8	m/s

Table 28 Helsinki-Vantaa, airport, meteorological data, 2006-2010, based on hourly observation.

PET (°C)	Thermal perception	Grade of physiological stress
<4	very cold	extreme cold stress
4 - 8	cold	strong cold stress
8 - 13	cold	moderate cold stress
13 - 18	slightly cold	slight cold stress
18 - 23	comfortable	no thermal stress
23 - 29	slightly warm	slight heat stress
29 - 35	warm	moderate heat stress
35 - 41	hot	strong heat stress
>41	very hot	extreme heat stress

Table 29 Ranges of physiological equivalent temperature PET for different grades of thermal perception and physiological stress; internal heat production: 80 W, heat transfer resistance of the clothing: 0.9 clo (according to Matzarakis and Mayer (1997)).

There still not enough researches about thermal perception in northern Europe to modify the values for the thermal condition in northern Europe. In our research, the averaged PET values for the months from October to March lied with between 4.7°C in October and -4.4 °C considerable under the threshold for strong and extreme old stress.

	mean PET	mean MRT	units
April	9.81	23.65	°C
May	13.18	30.91	°C
June	16.69	36.91	°C
July	22.56	40.16	°C
August	21.53	36.13	°C
September	11.17	21.94	°C

Table 30 Mean PET and mean MRT temperatures at grid point 25,15,3 (black cross at aerial picture Vaskivuorentie, Figure 55)based on 5-year hourly observation from Helsinki-Vantaa airport calculate by ENVI-met software.

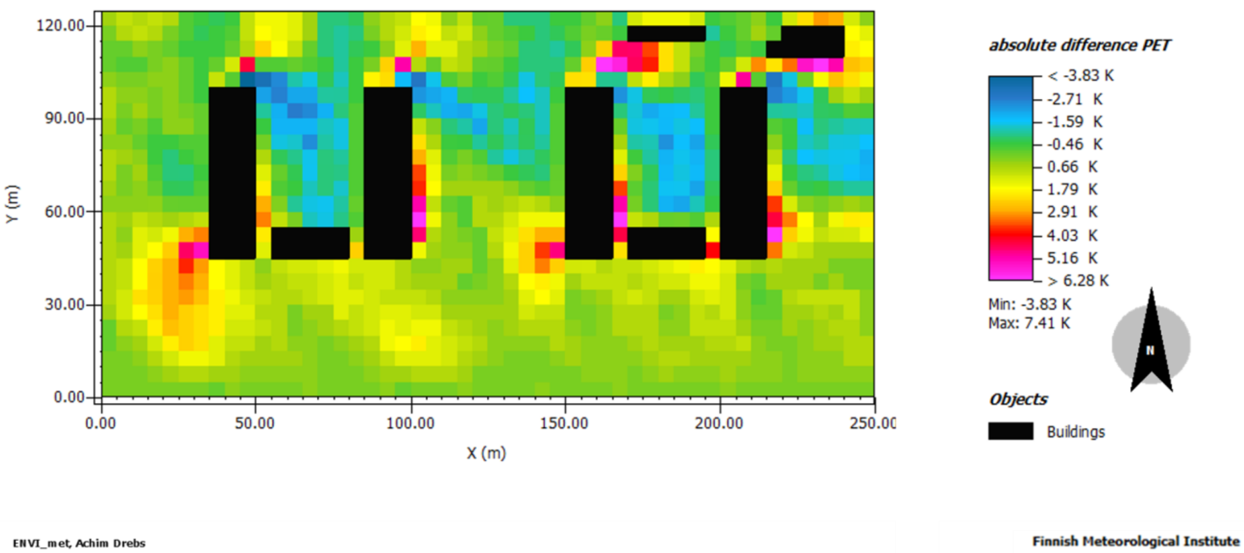


Figure 60 Comparison of PET temperature unvegetated vs. status quo (vegetated area), Vantaa Myyrmäki Vaskivuorentie, time: 12.00, date: 15.7.2018, x/y cut at k = 3 (z=1.4000m).

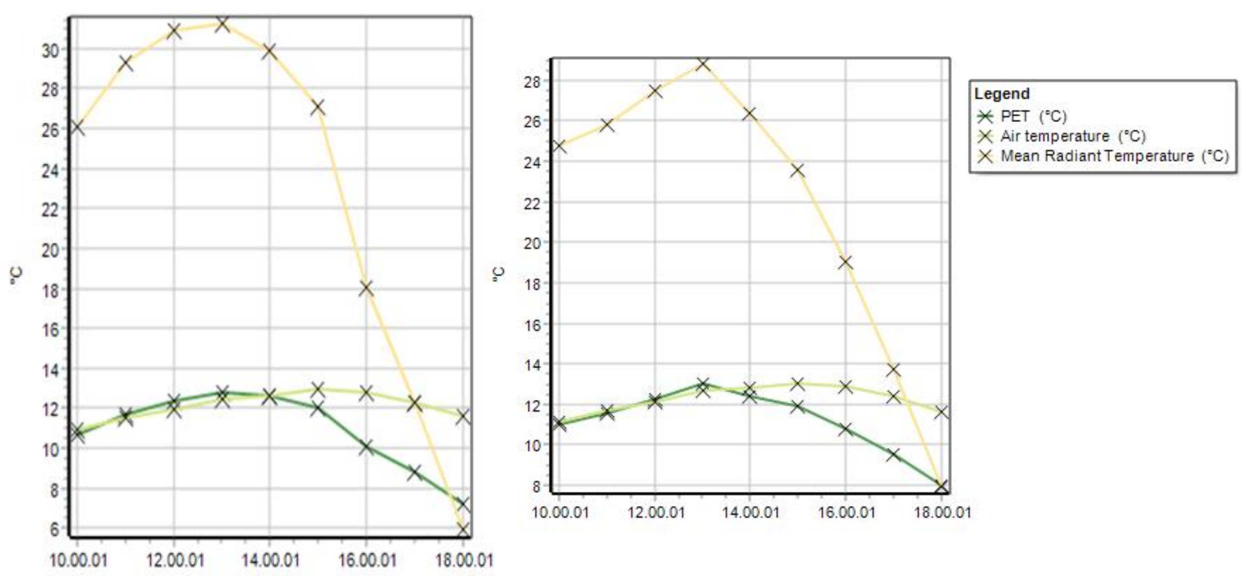


Figure 61 PET, air temperature and mean radiant temperature at gridpoint 25,15,3 (black cross at aerial picture Vaskivuorentie, Figure 55), left: unvegetated area; right: status quo, 15.9. 2018.

Figure 61 indicates the small differences for physiologically equivalent temperatures and Mean radiant temperatures under averaged meteorological condition. The use of averaged meteorological conditions as part of the description of the living environment is justified to characterize different human surroundings.

4 Socio-economic impact assessment

Socio-economic impact assessment activities aim to assess the impact of iSCAPE research project on society and economy. The framing of the socio-economic impact assessment into the iSCAPE project starts with the identification of the project outputs under assessment. Accordingly, the iSCAPE project has 2 main outputs:

- Modification in the concentration and distribution of a set of defined air pollutants achieved by mean of different instruments/processes (passive control systems, behavioural change interventions and policy interventions).
- Engagement of citizens and local stakeholders in pilot actions following a LL approach.

The scientific production of the iSCAPE consortium represents the third relevant output of the project. However, the analysis of the scientific production is outside the scope of this report which focuses on the project interventions and LLs activities and therefore is not presented here. In order to map and describe the impacts of the above-mentioned different outputs, an ad hoc impact assessment methodology has been developed and is reported in detail in D5.6. This methodology builds on the experience of the SEQUOIA project and similar projects (Passani et al., 2014), based on the combined use of diverse impact assessment techniques to calculate monetary (quantifiable) and non-monetary (not quantifiable) impacts. By combining different impact assessment techniques, the methodology overcomes the limitation of each single and isolated method (i.e. the collection of statistics, case studies, cost-benefit analysis, multi-criteria analysis, input-output models, etc.) and contributes to integrated and aggregated quantitative and qualitative data within the same analytical framework. However, it must be disclaimed that the methodology, while still valid from a conceptual point of view, has been just partially applied due to two main challenges. On the one side, the citizen engagement activities have been transformed along with the iSCAPE project, making some impact areas (e.g., the Behavioural one) more relevant than others. On the other side, on some occasions motivating participants to fill the questionnaire has been challenging. In this way, at its current stage, the database does not allow to reveal definitive conclusions on some of the identified impact areas. The following analysis, therefore, will mainly have a descriptive goal, although it can represent a relevant step for providing a general description of impacts by iSCAPE along these years.

4.1 Impact assessment and the quality of life

The social impact assessment framework is based on the Quality of Life approach (Costanza et al., 2007), that allowed developing and selecting a set of dimensions and indicators that are assessed against data provided by different actors involved in iSCAPE interventions and LLs' activities. Interventions and activities are highly different across iSCAPE LLs and produce different impacts. In this way, the assessment exercise was designed to have a modular and flexible way to capture non-monetary impacts. In recent years, indicators able to describe the everyday life of people beyond the GDP have been employed to have a more "on the ground" representation of wealth that does not include just income but also key concepts such as wellbeing and quality of life. These indicators describe those values that indicate a part of the wealth of a country or community but cannot be explicitly expressed in monetary terms. Natural environment and phenomena such as climate change are fully part of the debate on the quality of life.

In this respect, the indexes developed by Eurostat(European Statistical System, 2011) ISTAT (the Italian statistical office) and OECD (Organisation for Economic Co-operation and Development,

2019) represented the baseline of the iSCAPE social impact assessment framework. Based on a review of the aforementioned indexes and the consultation with the partners (see D5.6), a range of dimensions and sub-dimensions were identified as suitable to capture impacts of all the iSCAPE interventions and activities and to complement the economic impact assessment. Below, Table 29 summarizes the main quality of life areas to be investigated according to Eurostat, ISTAT and the OECD.

EUROSTAT	ISTAT	OECD
Productive or other main activity	Health	Housing
Material living conditions	Education and training	Income
Health	Employment and Work-Life balance	Jobs
Education	Economic wellbeing	Community
Leisure and social interaction	Social relations	Education
Economic and physical safety	Political life and institutions	Environment
Governance and basic rights	Safety	Civic engagement
Natural and living environment	Subjective wellbeing	Health
Overall experience of life	Landscape and cultural heritage	Life satisfaction
	Environment	Safety
	Research and innovation	Work-Life balance
	Quality of Services	

Table 31 Dimensions of quality of life: a comparison between Istat, Eurostat and OECD approaches.

Notwithstanding some similarities across these three approaches, the Eurostat approach was selected as the baseline for the iSCAPE social impact assessment framework. Indeed, the Eurostat approach represents the European standard for quality of life research and therefore ensures data consistency across European countries. It is worthwhile mentioning that the quality of life dimensions are populated with national statistical data coming from diverse official sources and surveys conducted by the national statistic offices of European countries on statistically representative samples. In this way, data represented in these frameworks are mainly at the national (macro) level. Conversely, iSCAPE interventions and activities have been deployed at a very local level and engaged citizens statistically not representative of the population. In addition, iSCAPE interventions and activities engaged a restricted number of citizens and stakeholders, therefore the interventions did not have a direct impact on the entire urban population. For this reason, to perform the assessment it was necessary to: a) adapt the Eurostat indicators and variables to the micro level and b) gather data directly from the engaged citizens.

4.2 The social impact assessment framework

The social impact assessment framework consists of 9 impact areas, each one articulated in sub-dimensions tailored to the Living Lab pilots and their expected outcomes. The dimensions that could be impacted by the project interventions considering the iSCAPE activities were selected. Three out of all the selected dimensions (Economic and physical safety, Governance and basic rights, and Overall experience of life) were however excluded as iSCAPE did not significantly affect upon them. The Health dimension was also excluded because it was already covered by the economic impact assessment approach (see Section 4.12.1).

In the second step, the sub-dimensions and the related variables of each of the above-listed macro dimensions were analysed. Each macro dimension is composed of several sub-dimensions and related variables, not all relevant to the social impact assessment. Eventually, the final list of impact areas and sub-dimensions deriving from the Eurostat approach to quality of life was the one presented in Table 32 below.

Productive or main activity	Quantity of employment
	Quality of employment: Work-life balance
Material living conditions	Income
Education	Competenies and skills
	Opportunities for education
Leisure and social interaction	Quantity of leisure
	Quality of leisure
	Social interaction
	Social cohesion
	Social capital
	Community empowerment
Natural and living environment	Pollution
	Access to green and recreational spaces
	Landscape and built environment

Table 32 iSCAPE areas of impact deriving from Eurostat quality of life approach.

Further areas were added to these impact areas. By considering that social innovation interventions should be both more efficient and effective than the previous ones and more equal and fairer, the **Inclusiveness and equal opportunities** category was added to explore the capacity by iSCAPE interventions to engage different social groups and to be sensible to topics such as social exclusion and discrimination. Then, driven by some iSCAPE pilot actions (see D2.2), the **Behaviours** impact area was also added to map the capability of iSCAPE to positively influence pro-environmental behaviours. Afterwards, we also added the **Policy** impact area to assess the capability by iSCAPE interventions to impact on local policies. Finally, being iSCAPE a Horizon research project, the **Scientific Impact** area was added to assess the scientific value generated by the project but, as mentioned earlier, this area is not represented in this report as not related to the interventions and LLs activities. The variables selected for social impact assessment are sometimes slightly different from the official ones used by Eurostat. This adaptation allowed, however, capturing the project activities with a more tailored analysis and identifying the micro-level changes occurred thanks to iSCAPE.

4.3 Social impact sub-dimensions, indicators and variables

Below, Figure 62 visualises the selected impact areas and their sub-dimensions.

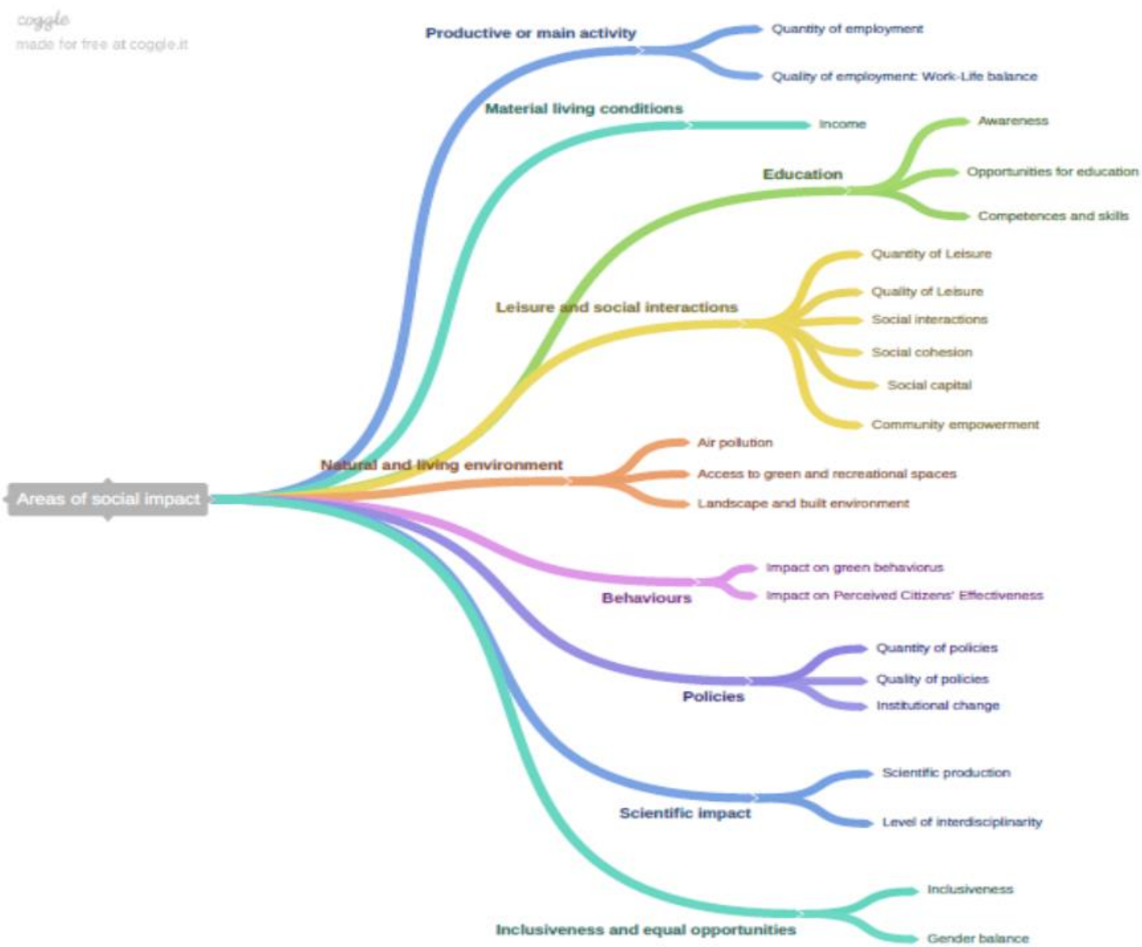


Figure 62 Impact areas and related sub-dimensions selected for iSCAPE social impact assessment.

As aforementioned, not all the impact areas are considered for, or are relevant for, all the iSCAPE pilots. In this way, we mapped the relevance of each impact area for each of the iSCAPE pilots. Maps were then validated by pilots' partners during a consultation process. Such consultation has been crucial for the impact assessment as it allows each pilot ensuring coverage for all the impact areas that partners considered as the most relevant for each pilot. The relevance level rates in Table 33 are the following ones: low (✓), medium (✓✓), high (✓✓✓).

Table 33 below presents the 9 impact areas and the related relevance for each of the iSCAPE pilot actions.

LLs	Productive or main activity	Material and living conditions	Educa-tion	Leisure and social interactions	Natural and living environment	Behaviors	Policies	Scientific Impact	Equality
Dublin	-	-	✓ ✓ ✓	✓ ✓ ✓	-	✓✓	✓ ✓	✓ ✓ ✓	✓ ✓
Guildford	✓	✓	✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓✓	✓ ✓	✓ ✓ ✓	✓ ✓
Vantaa	-	-	✓ ✓ ✓	-	-	-	✓ ✓	✓ ✓ ✓	✓ ✓
Bottrop	✓	✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✓	✓✓✓	✓ ✓	✓ ✓ ✓	✓ ✓
Hasselt	✓	✓	✓ ✓ ✓	-	-	✓ ✓ ✓	✓ ✓	✓ ✓ ✓	✓ ✓
Lazaretto	✓	✓	✓ ✓	✓	✓ ✓ ✓	-	✓ ✓	✓ ✓ ✓	✓ ✓
Bologna	✓	✓	✓ ✓		✓ ✓ ✓	✓✓	✓ ✓	✓ ✓ ✓	✓ ✓

Table 33 "Social" impact areas and their relevance for each iSCAPE pilot.

The full list of variables associated with the above-mentioned impact areas can be consulted in the D5.6.

4.3.1Data gathering and data analysis

The aforementioned methodology has been used to assess the socio-economic impacts of the pilots and of the iSCAPE project overall. Data were gathered from each city involved in the project. The social assessment gathered most of the data through paper-based or online questionnaires and surveys. The data were gathered from all the participants involved in the Living Labs activities and in the deployment of the interventions: iSCAPE partners, LL responsible, citizens and other institutional stakeholders. In the questionnaires and surveys, all participants have provided information related to:

- Demographic variables (e.g., age, gender, income, education, employment status)
- Psychographic variables: soft variables investigating participants' attitudes, values, interests and behaviours about the environment. This section of the survey has been developed in collaboration with the University of Hasselt (see D4.1), and will deal with participants' opinion about environmental issues and their pro-environmental behaviours, and their values according to a materialist/post-materialist approach.

Questionnaires and surveys have been administered by following the LL activities timeline, ranging from June 2017 until June 2019. Across the project, all Living Labs activities have been under development and their schedule and timeline have been constantly updated when new activities have been organized. In this way, we have constantly monitored the development and implementation of the activities through dedicated calls with Living Labs partners to be updated about progress, new events, and next steps.

4.3.2Aggregated demographic data

284 participants in the iSCAPE LLs' activities answered the questionnaires and surveys that were submitted by the T6 research team and LLs' teams. To these participants, we need to add

participants to the behaviour intervention study in Bologna, Dublin, Guildford, and Hasselt, that will be analysed later in this deliverable (see Section 4.9).

26 out of 284 participants are secondary school students that participated in an activity conducted by Dublin LL. Results from this activity can be found later in this deliverable (see Section 4.6.2). In this way, 258 participants (>18) years old responded to questionnaires and surveys. However, it must be mentioned that for some of the assessed activities the administered questionnaire/survey did not ask for demographic data due to specific characteristics of the activity or time constraints related to the length of the activity. The activities for which we do not have demographic data are the following:

- meeting with local stakeholders in Bottrop (3 participants)
- meeting with policy-makers in Bottrop, Guildford, Hasselt, Vantaa and Dublin (7 participants)
- Workshop by Vantaa LL with City of Vantaa representatives (3 participants)
- school activity by Vanta LL with Turku high school students (2 participants)

Therefore, we do not have demographic data for 15 participants. This means that the description of the aggregated demographic data will be based on 243 participants, that we consider as useful to provide a reliable portrait of participants' demographic details.

As Table 34 demonstrates, the largest age class represented participants between 13 and 35 years old (113, 47%), followed by the class 36-50 (53, 22%) and by the class 51-65 (32, 13%) with a large gap. 34 were the participants over 65 years old (14%), with 23 people in the class 66-75 (9%) and 11 in the over 75 class (5%).

	18-35	36-50	51-65	66-75	over 75	NA	Total
Number	113	53	32	23	11	11	243
% on total	47%	22%	13%	9%	5%	5%	100%

Table 34 Aggregated data of iSCAPE LL activities participants by age.

Sex differences show slightly larger participation of men (136, 56%) in comparison with women (100, 41%).

	Male	Female	NA	Total
Number	136	100	7	243
% on total	56%	41%	3%	100%

Table 35 Aggregated data of iSCAPE LL activities participants by sex.

In terms of citizenship, it is interesting to find that most of the participants came from the country of the LL (Italy, UK, Ireland, Germany, Finland, Belgium). Indeed, just 5% of the participants (11) came from other countries within the European Union different from the country of the LL (EU), while other 24 (10%) came from countries outside the European Union (OT, Others).

	Italy	UK	Ireland	Germany	Finland	Belgium	EU	OT	NA	Total
Number	44	40	10	37	22	28	11	24	27	243
% on total	18%	16%	4%	15%	9%	12%	5%	10%	11%	100%

Table 36 Aggregated data of iSCAPE LL activities participants by citizenship.

In terms of employment, the most represented categories are "Employed for wage" (81, 33%) and Student (68,28%), followed with a large gap by Retired (42,17%).

	Employed for wage	Self-employed	Homemaker	Student	Retired	Unable to work	NA	Total
Number	81	25	8	68	42	3	16	243
% on total	33%	10%	3%	28%	17%	1%	7%	100%

Table 37 Aggregated data of iSCAPE LL activities participants by employment.

In terms of education, the most represented category is the Bachelor one with 87 participants (36%), followed by Master (66, 27%). All other categories are however below 10%. It is, therefore, possible to say that participants' education is in line with the EU average[1].

	Less than high school	High school graduate	Trade/tech/vocation. Train	Ass. degree	Bachelor	Master	Professional degree	Doctorate	NA	Total
Number	8	14	9	15	87	66	21	11	12	243
% on total	3%	6%	4%	6%	36%	27%	9%	5%	5%	100%

Table 38 Aggregated data of iSCAPE LL activities participants by education.

Finally, in terms of income, the most represented category is the class 25000-49999 €, with 45 participants (19%), followed by the class <10000 € (34, 15%). However, it must be considered that 93 participants (38%, the highest percentage) did not provide a response or stated that they preferred not to respond.

	<10000	10k-24999	25k-49999	50k-74999	75k-99999	>100k	NA	Total
Number	34	33	45	23	6	9	93	243
% on total	14%	14%	19%	9%	2%	4%	38%	100%

Table 39 Aggregated data of iSCAPE LL activities participants by income.

4.4 Bologna

4.4.1 Description of the pilots

Bologna has developed two pilots. The first one dealt with the role of trees as a Passive Control System to improve the air quality inside the urban environment, relying on two fields in situ measuring campaign during winter and summer. With this pilot, the iSCAPE project monitored the impact of restricted traffic zones in different climatic conditions in support of the analysis of behavioural change. Effect of urban vegetation has to be assessed in terms of proof of concept by monitoring target neighbourhoods with and without trees and by studying the relationship between pollution dispersion, change in albedo and temperature.

[1] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Tertiary_education_statistics

The second pilot (Lazzaretto) dealt with photocatalytic coatings that have been deployed on building facades to test their performance in terms of air quality against different meteorological conditions (see D3.6). The iSCAPE project assessed the effectiveness of photocatalytic coatings both on buildings and road surfaces for a wide range of weather conditions.

For the first pilot, however, the analysis of the intervention cannot be conducted by following the methodology as described in D5.6 as the design of interventions by the Bologna LL did not include citizens' engagement or co-creation activities with citizens. However, by taking into account the environmental impacts described in the previous section, it can be said that the implementation of green infrastructure in Bologna can lead to both non-market benefits related to an improved air quality with health benefits, and market benefits related to residential real estate as described later into this deliverable about health impacts of iSCAPE activities.

For the Lazzaretto LL, the activities during the project did not include engagement activities with citizens, therefore social impact assessment has not been performed .

4.4.2 Other activities

The relevant activity for this assessment as conducted by Bologna LL was the event "Let's Plan The Green Together!", held in Bologna on 12 December 2018. In this event, students and local communities were invited to share their thoughts and ideas on how trees could improve wellbeing in Bologna. The activity focused on exploring with citizens how to make a plan for tree-planting in Bologna in four areas of the city: via Marconi, via Laura Bassi, via Zamboni and via del Lazzaretto. Each of these areas presented diversity in terms of air quality, tree availability, as well as car traffic flows. Based on the existing scientific knowledge about the role of trees in improving urban air quality, the participants were divided into four groups to develop and discuss a tree planting plan for different areas in Bologna. Then, each group was invited to present the plan and to discuss challenges and opportunities about the decision-making of the plan and its implementation.

4.4.3LLs activities socio-economic impacts: methodology and data sources

A questionnaire was submitted to participants of the event "Let's Plan The Green Together!" to explore socio-demographic dimensions of the participants, as well as their psychographic variables concerning environmental issues, human values, and ecological behaviours. The collected questionnaires were then analysed, and the main findings are presented below.

4.4.4LLs activities socio-economic impacts: participants description

41 people filled the questionnaire for assessing socioeconomic impacts of the activity. All 41 participants were all young or young adults with an age between 18 and 35 years old. Indeed, 95% of participants were students (39) of the local university. In terms of sex differences, 51% of participants were women (21) and 46% were men (19) (Figure 63).

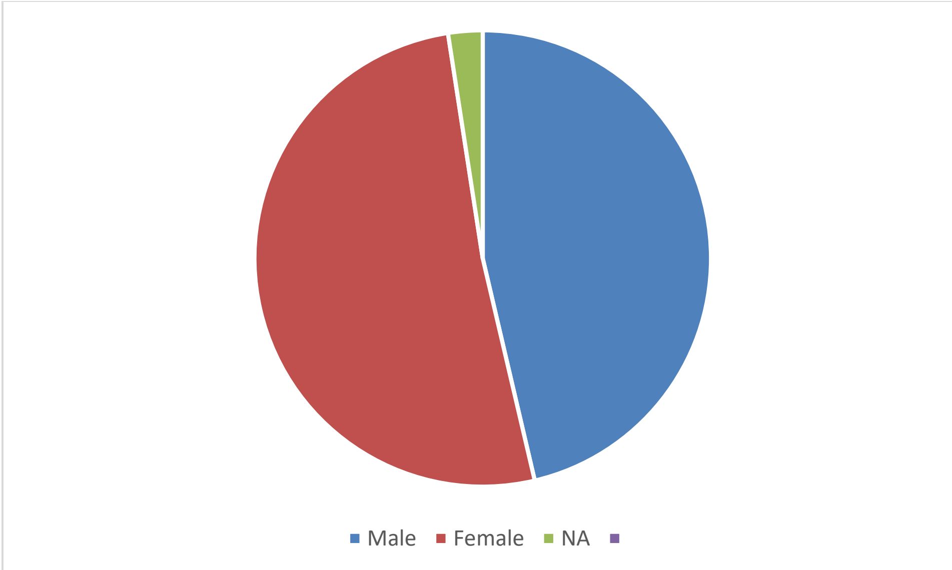


Figure 63 Participants of Bologna LL activity by sex.

Their nationality was quite variegated. Indeed, 19 participants were Italian (46%), while 7 (17%) came from other EU countries. A good number of participants (12, equal to 29%) came from non-EU countries, with preference to the Middle East and South America.

	Italy	EU	OT	NA	Total
Number	19	7	12	3	41
% on total	46%	17%	29%	7%	100%

Table 40 Participants of Bologna LL activity by citizenship.

Among participants, most of them had a bachelor degree (29, 71%), 10 had a master degree (24%), while 2 participants held a high school degree and a doctorate, respectively.

	Less than high school	High school graduate	Trade/tech/vocation. Train	Ass. degree	Bachelor	Master	Professional degree	Doctorate	Total
Number	0	1	0	0	29	10	0	1	41
% on total	0%	2%	0%	0%	71%	24%	0%	2%	100%

Table 41 Participants of Bologna LL activity by education.

Out of the 41 participants, 22 of them (52%) provided information to their income. Accordingly, 17 participants (41%) declared an income less than 10.000 €, while 4 of them (10%), reported an income between 10.001 and 24.999 €: only one declared an income between 25.001 and 49.999 €.

	<10000 E.	10k-24999	25k-49999	50k-74999	75k-99999	>100k	NA	Total
Number	17	4	1	0	0	0	19	41
% on total	41%	10%	0%	0%	0%	0%	46%	100%

Table 42 Participants of Bologna LL activity by income.

4.4.5 LLs activities socio-economic impacts: impact areas

In terms of environmental concerns, 33 out of 41 participants (80%) fall into the class "Postmaterialist" of 16-30, and 6 (15%) of them within the class "Very postmaterialist". This means that almost all the participants are concerned about environmental issues worldwide.

	Very materialist	Materialist	Postmaterialist	Very postmaterialist	Tot
Number	0	2	33	6	41
% on total	0%	5%	80%	15%	100%

Table 43 Participants of Bologna LL activity by a class of environmental concerns.

In terms of human values, participants also fall into average-high classes, with 19 participants (46%) in the class "Postmaterialist" and 21 (51%) in the class "Materialist".

	Very materialist	Materialist	Postmaterialist	NA	Total
Number	0	21	19	1	41
% on total	0%	51%	46%	2%	100%

Table 44 Participants of Bologna LL activity by a class of human values.

Responses in terms of ecological behaviour do not fully mirror the responses about from environmental concerns and human values. Indeed, 16 participants (39%) fall into the lowest class Very materialist from 2 to 10, while 22 (54%) in the class Materialist.

	Very materialist	Materialist	Postmaterialist	Very postmaterialist	Total
Number	16	22	2	1	41
% on total	39%	54%	5%	2%	100%

Table 45 Participants of Bologna LL activity by a class of ecological behaviours.

Participants were also asked to identify and rank from 1 (more important) to 6 (less important) the main changes they would like to prioritize into their city (see Table 46). The priority with the lowest average (and therefore the most important) is "Improving security" (2.6) followed by "Improving green areas" (2.7) and "Improve public transport" (3.1). The second and the third are strongly related to air quality and pollution and to the topics considered into the iSCAPE project. Less attention has been instead devoted to priorities such as "Increase the number of available parking areas" and "Increase the number of shops and commercial areas".

Improve security	2.6
Improve local green areas (park where to go with kids, friends, dogs...)	2.7
Improve public transport	3.1
Improve streets' cleanness	3.3
Increase the number of trees and green spaces in the streets	3.4
Increase the offer of leisure services (cinema; theatre, exhibitions)	3.7
Increase the number of shops and commercial areas (supermarkets, malls)	4.0
Increase street maintenance	4.7
Increase the number of available parking areas	5

Table 46 Average rank of main priorities as identified by participants of Bologna LL activity.

Overall, the feedback by the participants on the performed activity is positive. In order to better understand what participant brought home from the activity, we asked to agree or disagree with a set of items, using a 5 point Likert scale. In the questionnaire, the Likert scale code was described as it follows: 1=Strongly disagree; 2=Disagree; 3=Neutral; 4=Agree; 5=Strongly agree. In this assessment exercise, we limited the number of items in order to support participation, considering that respondents were passing by citizens not previously engaged in iSCAPE activities. Out of the 9 items considered, 8 had a score, on average, higher than 3 (which stands for "neutral" while 4 was for "I agree"). However, considering the mode, the values are much more positive. The graph below summarizes the results for the 39 participants who filled this part of the questionnaire using the mode value: Indeed the average resulted negatively influenced by few respondents that did not value positively the experience.

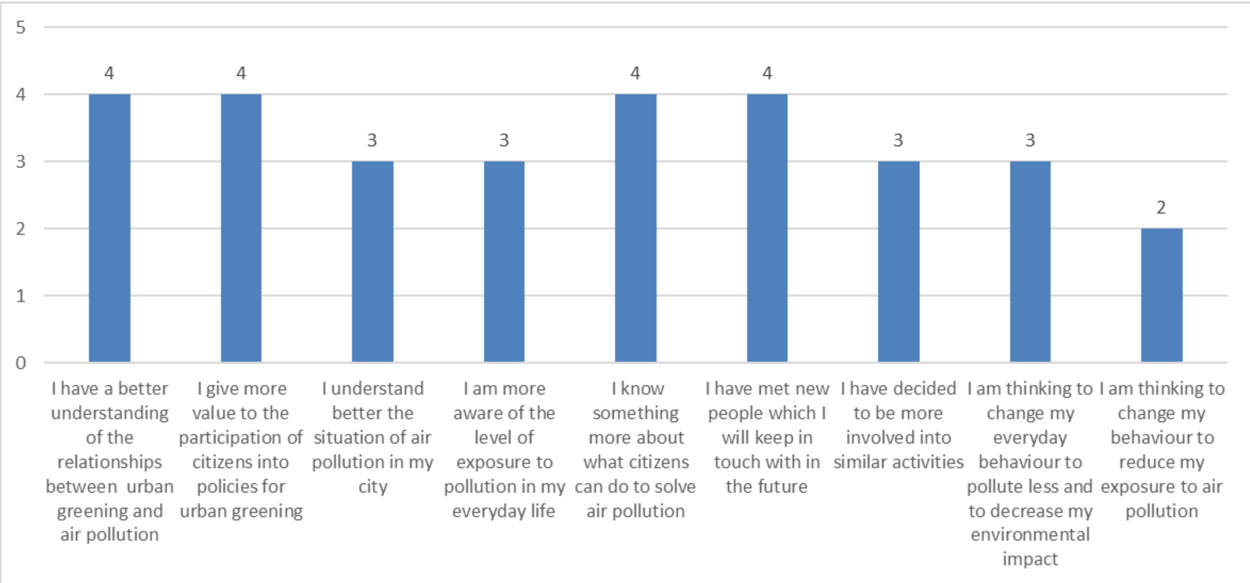


Figure 64 Feedback by participants on the performed activity by mode value.

The activity achieved the result of improving participants' understanding of the relationship between urban greening and air pollution. 25 out of 39 respondents declared to have learned also something else and mentioned:

"I better understood what green infrastructure is in practice"

"I learned how to make a plan for greening place between cities"

"The difficulties of finding ways for financing environmental projects and try to find ways to speak with the authorities"

"That projecting green spaces in historical areas of the city is difficult because it requires to use narrower spaces and to respect the appearance of the streets"

"The difference between a street with trees and without"

"I learned about the cost of activities aimed at improving green areas"

"To share ideas to solve problems"

"How we can work together to create a more green city"

"Importance of protecting the environment and how to protect it"

Other items with high score are the ones related to citizens' engagement in environmental issues (e.g., "*I give more value to the participation of citizens into policies for urban greening*"; "*I know something more about what citizens can do to solve air pollution*"; "*I have decided to continue to be involved in similar activities*"). This shows how LLs activities, besides the main aim of raising awareness about a specific topic, in this case of air quality could lead to positive civic impact in terms of higher participation in community life. Positive feedbacks were gathered also in terms of the capability by the activity to touch upon the impact area *Social Capital* by creating new socialization opportunities and potentially increasing participants' social capital (e.g. "*Thanks to this activity, I have met new people which I will keep in touch with in the future*").

The only item on which participant disagree is the one related to the impact area Behavioral Change (e.g., "*Thanks to this activity, I am thinking to change my behavior to reduce my exposure to air pollution*"). This is however not surprising since the LL activity under consideration was not meant to provide practical support for behavioral change. As we will see in Section 4.9, this was one of the aims of the behavioral interventions that have shown some positive results in this sense. However, 20 participants agreed on the capability of the activity to inspire behavioral changes and listed some possible actions to be undertaken, such as the following:

"I want to change my consideration to production in supermarket to environment-friendly goods"

"Participating more to this kind of workshop event; try to be more involved with my city"

"Using more the public transport; participate in voluntary activities regolating this; spread the idea"

"I will try to be more precise by choosing food and will pay attention on the packages and don't use the car"

"Planting trees in urban areas where I live and try to reduce the air pollution".

Participants were then asked if the activity could have an impact at a city level and the main results are that participants see in different ways their role in influencing positive changes at the local level, are willing to spread what learned and see potential in terms of policy innovation.

4.4.6 Contribution of Bologna LL's simulation to policy change

Policy-makers considered very positive the potential contribution by simulations in impacting on the impact area *Policy change* around air quality in Bologna. Accordingly, simulations can be used in policy-making around air quality for evaluating in advance the precise impact of potential policies. For example, iSCAPE simulations were able to compare the impact on air quality of two policies: the first one proposing to close the city centre to non-electric vehicle and the second one proposing to close the city centre to the non-electric vehicle but increasing the frequency of electric busses. The simulation showed that increasing the frequency of electric buses in the city centre would produce limited benefits to Bologna in terms of air. Therefore, iSCAPE simulations were useful for providing a better understanding of strategies to mitigate air pollution at the urban level and the attention of local stakeholder on this topic is high so that further interactions will probably happen in the upcoming months. For more details about this can be found in D4.6.

4.5 Bottrop

4.5.1Description of the pilot

Bottrop is a city of the InnovationCity Ruhr pilot project. In this project, Bottrop has been planned to become a model of energy efficiency. iSCAPE supported Bottrop in achieving its ambitious goals of reducing CO2 emissions by 50% by 2020 using innovative technologies and proven methods in mobility and climate-proof urban renewal. We have assessed socioeconomic impacts of the Bottrop LL based on a series of questionnaires submitted into four activities between January 2018 and April 2019. The Wandering Tree Parade was a series of events and workshops organized to show the importance of green areas to improve air quality and citizens' wellbeing by moving around the city of Bottrop some trees (Wandering Trees). The first activity was conducted in January 2018, where participants from civil society were explained the main features of the Wandering Tree Parade for the year 2018. Across these events, the Bottrop LL discussed with local residents the locations of the wandering trees and the beginning of the parade route. In addition, citizens were also engaged in deciding together opportunities for the involvement of relevant actors and participation in a planned street festival. The citizens also temporarily adopted a tree for the parade. The Parade is being repeated in 2019 with a large involvement of school pupils. The second assessed activity was conducted on 2nd October 2018. In this occasion, participants were asked to assess and provide feedback for the Wandering Tree Parade. The other two assessed activities are described in the next section.

4.5.2 Other LLs activities

The third assessed activity was conducted on 27th September 2018. Participants to this activity were local stakeholders and policy-makers from different organizations (e.g., local economic activities, City of Bottrop) gathered to discuss air quality and air pollution issues in Bottrop, and how to work together to improve existing conditions in the near future. The fourth assessed activity was conducted on 4th April 2019, under the form of a meeting between the Bottrop LL and the City of Bottrop partner within the iSCAPE project. The activity had the goal to discuss impacts by the iSCAPE project on local policies.

4.5.3 Social impact assessment of the intervention: methodology and data sources

To assess social impacts of Bottrop LL's intervention, we have administered a questionnaire to all participants across the assessed activities. Each questionnaire slightly differed from each other as they were based on specific characteristics of each activity, the focus of the activity, the kind of participants, and the participants' skills background (e.g., citizens and policy-makers). The questionnaire included questions related to demographic information, environmental issues, and feedback from the activity. For the Wandering Trees Parade, the methodology was initially based on an ex-ante and ex-post assessment. This meant that we would have administered a questionnaire to participants before and after the whole series of Wandering Tree appointments in order to track changes occurred across participants in terms of knowledge, attitudes and behaviours around air quality thanks to the performed activity. However, as we will see later, this has not been possible, and therefore we have described the assessment as we have done for the other pilots and LL activities.

4.5.4 LLs activities socio-economic impacts: results

Results related to socioeconomic impact assessment of Bottrop LL activities will be presented in detail for each conducted activity. Initially, the section presents results about the ex-ante and ex-post assessment of the Wandering Tree parade. Then, it presents results about the activity conducted with local stakeholders. The section will conclude with results from the meeting with local policy-makers.

4.5.4.1 Ex-ante Wandering Tree parade: participants

The ex-ante social impact assessment has been based on the activity conducted on 18th January 2018 to organize the Wandering Tree Parade. An ex-ante questionnaire was administered to participants, and 18 questionnaires were returned. Main results of the ex-ante assessment are presented below.

Participants were mainly from the class 36-50 years old (8, 44%) followed by the class 51-65 (5, 8%) and 18-35 (2, 11%). There were more women (10, 56%) than men (6, 33%), and they were all from Germany, with just one participant from a non-European country.

	18-35	36-50	51-65	66-75	over 75	NA	Total
Number	2	8	5	1	1	1	18
% on total	11%	44%	28%	6%	6%	6%	100%

Table 47 Number and percentage of participants to the ex ante assessment by age.

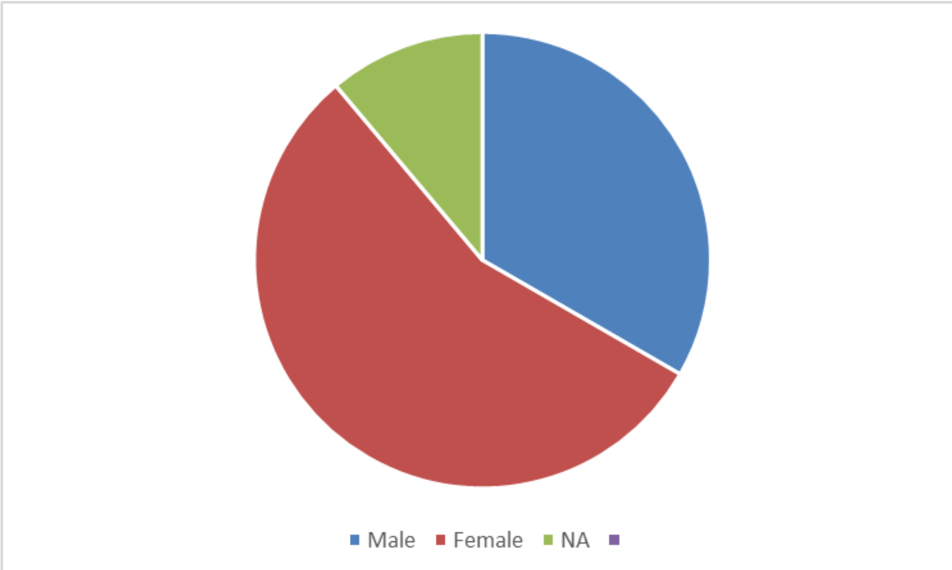


Figure 65 Participants to the ex ante assessment by sex.

In terms of employment, most of the participants were employed for a wage (13, 72%).

	Employed for wage	Self-employed	Homemaker	Retired	Unable to work	NA	Total
Number	13	1	2	1	0	1	18
% on total	72%	6%	11%	6%	0%	6%	100 %

Table 48 Number and percentage of participants to the ex-ante assessment by employment.

In terms of education, most of the participants held a bachelor (10, 56%), followed by master students (4, 22%)

	Bachelor	Master	Professional degree	Doctorate	NA	Total
Number	10	4	2	1	1	18
% on total	56%	22%	11%	6%	6%	100 %

Table 49 Number and percentage of participants to the ex-ante assessment by education.

In terms of income, respondents range mainly in the 25000-49999 € (4, 22%) and 50000-99999 € (3, 17%) classes. However, it must be mentioned that 10 people (56%) did not provide any detail on income.

	25k-49999	50k-74999	75k-99999	NA	Total
Number	4	3	1	10	18
% on total	22%	17%	6%	56%	100%

Table 50 Number and percentage of participants to the ex ante assessment by income.

4.5.4.2 Ex-ante Wandering Tree parade: impact areas

The environmental concern of participants looks quite high. Indeed, 11 respondents (61%) fall into the Postmaterialist class and other 6 (33%) in the very postmaterialist class. Similarly, response to human values seems to be relatively high, as almost all the respondents fall into the Postmaterialist class (17, 89%).

	Materialist	Postmaterialist	Very postmaterialist	Total
Number	1	11	6	18
% on total	6%	61%	33%	100%

Table 51 Number and percentage of participants to the ex ante assessment by environmental concerns.

	Materialist	Postmaterialist	Very postmaterialist	NA	Total
Number	1	16	0	1	18
% on total	6%	89%	0%	6%	100%

Table 52 Number and percentage of participants to the ex ante assessment by human values.

The table on ecological behaviour mirror the positive scores in the previous two tables. Indeed, 11 participants (61%) fall into the Postmaterialist, while there are 6 people (33%) that fall into the Very postmaterialist class.

	Very materialist	Materialist	Postmaterialist	Very postmaterialist	Total
Number	0	1	11	6	18
% on total	0%	6%	61%	33%	100%

Table 53 Number and percentage of participants to the ex ante assessment by ecological behaviours.

4.5.4.3 Wandering Tree parade: ex-ante impact areas

In terms of the impact area *Natural and Living conditions*, participants mainly responded they were satisfied with it their residential area. Indeed, 15 participants (83%) responded they were "satisfied".

	Partially satisfied	Satisfied	Fully satisfied	Total
Number	3	15	0	18
% on total	17%	83%	0%	100%

Table 54 Number and percentage of participants to the ex ante assessment by impact area Natural and Living conditions.

Similarly, in terms of the impact area *Leisure and social interaction*, participants were satisfied of leisure spaces and social interactions existing into their neighbourhood. For example, 14 participants (78%) reported that they have people to call in the neighbourhood when they need help (Table 56), as well as that they have someone to talk with (16, 89%) (Table 56).

	Y	N	NA	Total
Number	14	2	2	18
% on total	78%	11%	11%	100%

Table 55 Number and percentage of participants to the ex ante assessment by impact area Leisure and social interaction.

	Y	N	NA	Total
Number	14	2	2	18
% on total	78%	11%	11%	100%

Table 56 Number and percentage of participants to the ex-ante assessment by the presence of someone to call in the neighbourhood

	Yes	No	NA	Total
Number	16	0	2	18
% on total	89%	0%	11%	100%

Table 57 Number and percentage of participants to the ex-ante assessment by the presence of someone to talk within the neighbourhood.

Notwithstanding this, participants provided relatively low values on the impact area *Social cohesion* valued. Indeed, when participants were asked to assess trust across people, 11 of them (61%) fall into the Low trust range, while 6 (33%) fall into the Average trust. There is no one into the category High trust.

	Low trust	Average trust	High trust	NA	Total
Number	11	6	0	1	18
% on total	61%	33%	0%	6%	100%

Table 58 Number and percentage of participants to the ex ante assessment by impact area Social conhesion.

In addition to this, participants were also asked to rank the priorities of the changes they would like to see in their city. Participants were indeed asked to rank from 1 to 6 (from the most important to the less one) the aspects they would like to change in their area, that we then measured by calculating the average (Table 59).

Accordingly, the aspect with the lowest average value (and therefore the highest significance) is related to “Improve the trees and the green in the streets” (with an average value of 2.8), followed by “Improve security” (3), and “Increase the offer of leisure service” and “Improve the public transport” (both with an average value of 3.2).

Increase the number of trees and green spaces in the streets	2.8
Improve security	3.0
Increase the offer of leisure services (cinema; theatre, exhibitions)	3.2
Improve public transport	3.2
Improve local green areas (park where to go with kids, friends, dogs...)	3.3
Increase street maintenance	3.5
Increase the number of available parking areas	4.5
Increase the number of shops and commercial areas (supermarkets, malls)	4.6
Improve streets' cleanness	4.8

Table 59 Average score of changes to be prioritized in Bottrop.

Finally, we also asked to participants what they did expect from the Wandering Tree Parade. Accordingly, two participants responded that they expected to see "*more green elements*" in the city of Bottrop, and "*an improved neighbourhood through joint activities and traffic-calming through green spaces on the street ("tree-islands")*". Meanwhile, another participant expected "*more cooperation/interaction within the neighbourhood, get to know the neighbours, and civic participation leading to an improved ability to act/that people act more responsible*".

4.5.4.4 Wandering Tree parade: a summary of ex-post participants and impact areas

The ex-post social impact assessment has been based on the final event of the Wandering Tree Parade conducted in October 2018. After the activity, an ex-post questionnaire was administered to participants, and 9 questionnaires were returned; therefore the assessment will be based on a number of participants that is half in comparison with the ex-ante assessment. In this way, an ex-ante ex-post assessment cannot be conducted. However, the main findings from this assessment will be summarized below.

Similar to the ex-ante activity, participants in the parade were generally equally distributed across the various age classes, with more women (6, 67%) than men (3, 33%). Also for this case, participants were almost all from Germany (8), with the category "Employed for wage" as the most represented in terms of employment status. In terms of education status, participants mainly held a bachelor degree (5, 56%),

As also in the ex-ante assessment, it is difficult to understand the income range of participants. In this case, just one out of 9 participants declared his/her income (that falls into the 50000-99999 class), while other participants preferred not to respond.

Similarly to the ex-ante assessment, the environmental concern by participants looks high, with 5 participants (56%) falling into the class "Postmaterialist". The same occurs in terms of human values, where 7 participants (78%) fall into the class "Postmaterialist". On the same vein, ecological behaviour mirrors the positive scores in the previous two tables. Indeed, 4 participants (44%) fall into the class "Postmaterialist", while 4 other people (33%) are in the score "Very postmaterialist".

Participants in the activity were also quite satisfied with the *Natural and Living conditions*. Similar to the ex-ante assessment, 6 participants (67%) range in the class "Satisfied", with two people in the class "Very satisfied".

As in the ex-ante assessment, participants seemed to be satisfied with the impact area *Leisure and social interaction*. Indeed, 6 participants (67%) reported that they have someone to call in the neighbourhood when they need help, as well as that they have someone to talk with (7, 78%).

Differently from the ex-ante assessment, however, participants responded they were quite satisfied with the impact area of *Social cohesion*. Accordingly, there were some improvements in the level of trust in the city as perceived by the participants. Indeed, 6 participants (67%) fall in the medium score class "Satisfied", while 2 (22%) fall into the class "Very satisfied".

When participants were asked which changes they would like to see in the neighbourhood, they responded that the main important were the "Increase the trees and the green in the streets" (with an average value of 1.5), followed by "Increase the offer of leisure services" (with the value of 2.3) and "Increase the number of shops and commercial areas (with a value of 3). Interestingly, also in the ex-ante assessment, the first and third changes aspects were in the same position in the list. However, in this ex post assessment the change "Improve the trees and the green in the streets" has a much lower value (1.5) in comparison with the ex-ante assessment (2.8) and a large distance from the average value of the second aspect (0.8), that was 0.2 in the ex-ante assessment. In this way, it seems that the activity was successful in putting trees and urban greening at the centre of the agenda of participants to the Wandering Tree Parade.

We also asked what they learned from the activity and which impacts they expected from the activity in the city of Bottrop. In the first case, participants responded they learned to have "more awareness of our environment" and realized the "importance of green for the air, health and the city". Participants appreciated "the daily care of the trees", and the fact that "there was more green in the street" and that they had the opportunity to take responsibility of the trees by "watering the trees together with the family".

In the second case, participants also expected some impacts on Bottrop. Accordingly, one participant responded that can lead to the *"unsealing of surfaces"*, while others perceived an increase in sensitiveness *"to air pollution, healthy cities and reconsideration of their own behaviour"*. Another one saw more *"acceptance of trees in the inner city"* while another one realized that it fostered *"opportunities to help shape the city and neighbourhood"*.

4.5.4.5 Meeting with local stakeholders

On 2nd September 2018, the Bottrop LL met local stakeholders to explain what the Bottrop LL was doing within the iSCAPE project and which the opportunity for future partnerships and collaboration were. We conducted a social impact assessment by administering a short version of the questionnaire and received responses from three participants. Two participants represented a local authority, while one was from the City of Bottrop. All three participants declared that the stakeholder meeting contributed to generally increase participants' awareness about air quality issues. Accordingly, the activity made the participants more aware of the topic of air quality and pollution and supported participants in posing their own research questions and to evaluate and assess the data. All three participants also agree on the added value of the stakeholder meeting in providing new skills and competencies to participants. Accordingly, the meeting fostered a discussion on air pollution and the necessity for increasing greening into streets. Meanwhile, it was also helpful to gather together different actors to reach consensus about problems and solutions. In addition, the meeting supported stakeholders in interpreting local data on air quality and pollution.

All three participants also agreed on the fact that the meeting led them to have more pro-environmental behaviours. A participant argued that the activity increased his/her *"acceptance of street greenery and trees"*, even if these greening initiatives could *"potentially take away parking space"*. The same participant also argued that he/she understood better the necessity for regular maintenance of public green areas, for example also through care-takers who can "adopt" and take care of a tree for a given amount of time.

Two out of three participants also agreed on the contribution of the meeting to increase social cohesion among citizens. A participant argued that activities like this or the Wandering Tree Parade can improve the relationships among people and among stakeholders in the neighbourhood. Two out of three participants also claimed that local market activity perceived positively the Wandering Tree Parade. For example, the fact that they had to adopt 3 Wandering Trees across the year surely contributed to increase their awareness about air quality issues and greening requirements in the city.

Conversely, all three participants agreed that the activity did not touch upon yet on the development of new air quality policies by the City of Bottrop. On this regard, one participant claimed that there are similar projects focusing on air quality issues, as for example the InnovationCity Ruhr, Model City Bottrop[2] that aims to realise a sustainable urban redevelopment in Bottrop to cut CO_2 emissions by half and to increase the quality of life. Similarly, two out of three participants argued that the activity did have just very local impacts on vegetation management. All the participants, however, stated that the City of Bottrop can repeat this kind of activity in the near future. Indeed, the City of Bottrop and the Bottrop LL are working together to organize a new Wandering Tree Parade that is taking place in summer 2019.

The participants were eventually asked to describe what did they like most and find less interesting or difficult to understand during the activities with the Bottrop LL. All of them provided positive feedback on the Wandering Tree Parade and on the activities conducted with citizens. In particular, these activities were useful or participants to understand better the importance of trees and greening for the city of Bottrop. These activities also supported the development of common interests between scientists, citizens and policymakers. For sure, the continuation of the activities in 2019 (and beyond) represents positive news for reaching further people and undertaking common actions around air quality issues in Bottrop.

4.5.4.6 Meeting with policy makers in Bottrop

On 4th April 2019, the Bottrop LL met policy-makers in a meeting dedicated to discussing the contribution of Bottrop LL and of iSCAPE project on the impact area P*olicy change*. In this occasion, social impact assessment has been conducted based on three questionnaires focusing on policy change in the City of Bottrop thanks to iSCAPE activities. From the responses to the questionnaires, slight disagreement existed across participants about the potential for iSCAPE activities to foster a focus on urban planning into the local policy agenda. Indeed, each participant responded differently and assigned a different score (2, 3, and 4 on a 5 Likert scale, respectively) on this question. A little bit more consistent was the response about the contribution by Bottrop LL activities in improving or creating new policies related to urban planning, land use, built environment, and health. In this case, all participants assigned a score between 3 and 4, therefore making the result slightly more homogeneous and generally positive. In particular, a participant argued that the Bottrop LL activities were able to bring a "combination and aggregation of new innovative ideas and approaches", that can be integrated into existing policy framework, or supporting the creation of new policies.

Finally, policy-makers acknowledged and appreciated the contribution by the Bottrop LL in supporting policy-making and policy-change in the City of Bottrop not just around air quality but also associated issues such as urban planning or built environment.

[2] http://www.icruhr.de/index.php?id=3&L=1

4.6 Dublin

4.6.1 The pilot

The pilot of the Dublin LL aimed at assessing the effectiveness by LBW in reducing air pollution exposure for pedestrians by engineering flow patterns and ventilation conditions in a high-trafficked street canyon in Dublin. To do this, two separate field campaigns were conducted in Dublin, one in July 2018 and one in December 2018. During these campaigns, LBW structures were set up along central streets of Dublin where people use to everyday walk and shop. Measurements were undertaken on the concentrations of the pollutants nitrogen oxides (NO_X) and particulate matter at inhalation level in front of and behind the walls and lasted from two weeks to one month depending on the stage.

4.6.2 Other LLs activities

In addition to LBW field campaign, the Dublin LL has also been engaged with primary school pupils. Several activities were conducted to explore with the air pollution issues in Dublin, and to find with them solutions to be applied to reduce air pollution and their exposure to it. For example, in April 2018 the Dublin LL conducted an activity with pupils called Play and Learn workshop, that however has not been part of this assessment. On 17th January 2019, the Dublin LL organized a co-creation workshop at St. Catherine's National School as follow up activity of the first workshop. This workshop aimed at co-creating new multifunctional solutions that reduce pedestrian exposure to air pollution. Through a highly interactive and hands-on session, children were engaged in a process of design thinking to generate new ideas, develop concepts and build prototypes.

4.6.3 Social impact assessment of the intervention: methodology and data sources

While taking measurements in the LBW field campaigns, the research team asked people walking on the street to spend few minutes with the Dublin LL team to give a look at the experiments and receive a quick explanation about the LBW. After this, the research team submitted to them a very short questionnaire about what they did learn from the activity. The assessment is based on 8 questionnaires. In addition, for the co-creation workshop at St. Catherine's National School, we have performed a socioeconomic impact assessment by submitting a short questionnaire to the participating pupils, with 26 returned questionnaires[3]. The questionnaire included questions related to demographic information, environmental issues, and feedback from the activity.

4.6.4LLs activities socio-economic impacts: results

4.6.4.1 LBW fieldwork campaigns

The participants reached during the LBW fieldwork campaigns in Dublin were mostly people in the age class 18-35 (7, 88%). 5 of them (63%) were women. Just four participants disclosed their citizenship. Of these four, just one came from Ireland, while one participant was from another European country and other two from outside Europe. Out of 8 participants, 3 of them held a high school degree while 4 had a bachelor. Most of the participants were concerned about environmental issues. Indeed, 6 of them (75%) fall into the Postmaterialist class 3 in the Very postmaterialist class (16-25). From this information, it can be said that the range of participants was made by international people <35 years old with postmaterialist or very postmaterialist attitude in terms of environmental concerns.

In order to describe the value of the engagement activity as perceived by the participants, we asked to agree or disagree with a set of items using a 5 points Likert scale. The Likert scale code was described as follows in the questionnaire: 1=Strongly disagree; 2=Disagree; 3=Neutral; 4=Agree; 5=Strongly agree. In this assessment exercise, we limited the number of items in order to support participation, considering that respondents were passing by citizens not previously engaged in iSCAPE activities[4]. The graph below shows the mode values for the considered items.

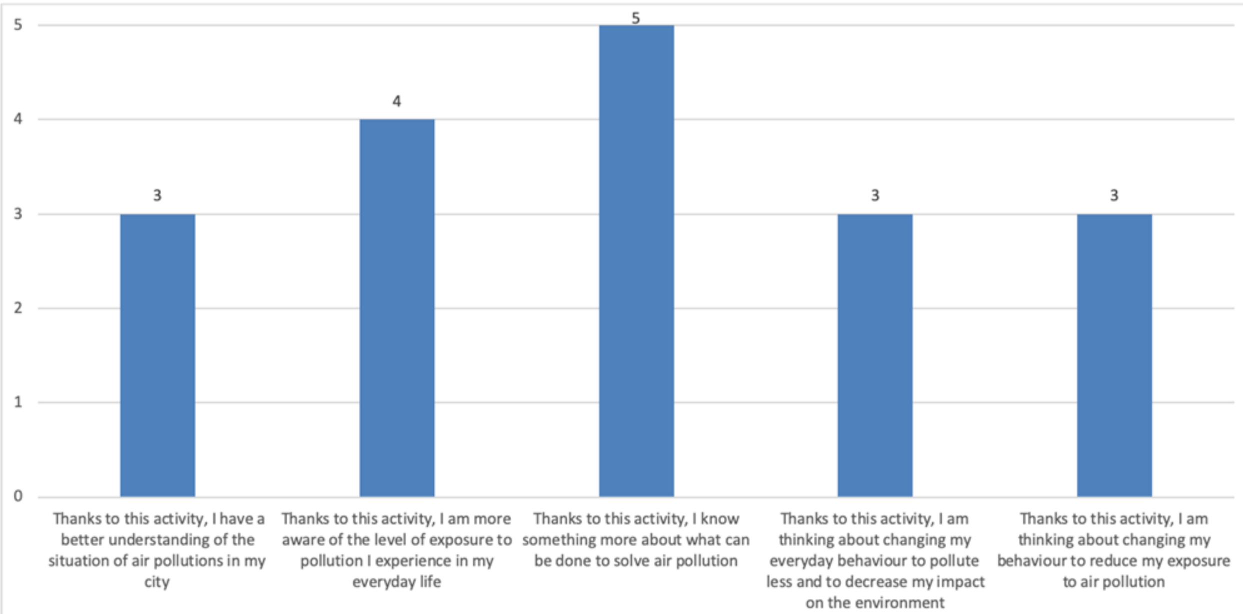


Figure 66 Feedback by participants on the performed activity by mode value.

The item on which most of the participants strongly agreed is the one related to the capability of the activity to provide new information on how to fight air pollution. Most of the participants also agree that the activity was able to increase their awareness about their level of exposure to air pollution. Considering the very short interaction between respondents and the LL team, these results can be considered very positive. By looking more in details to the results on the last item, related to the willingness by participants to change their behaviors, most of them are neutral or positive about this and mentioned possible changes such as: "*Avoid driving when it is possible to use more green modes*"; "*Use less petrolchimical products. Reduce plastic products. Carpool/Take public transit*".

4.6.4.2 Co-creation workshop with pupils at St. Catherine's National School in Dublin

26 pupils took part on the co-creation workshop organized by the Dublin LL. All pupils were 11-13 years old. The most frequent age is 12 (18 participants, 69%), followed by 7 pupils 11 years old (7%).

[4]The questionnaire was approved by the UCD Human Ethics Research Committee.

	11	12	13	Total
Number	7	18	1	26
% on total	27%	69%	4%	100%

Table 60 Number and percentage of pupils participating in the co-creation workshop by age.

In terms of gender, half of the participants were male (13), and 12 female (46%), with one agender pupil. 24 out 26 are British, while the remaining have other cultural backgrounds.

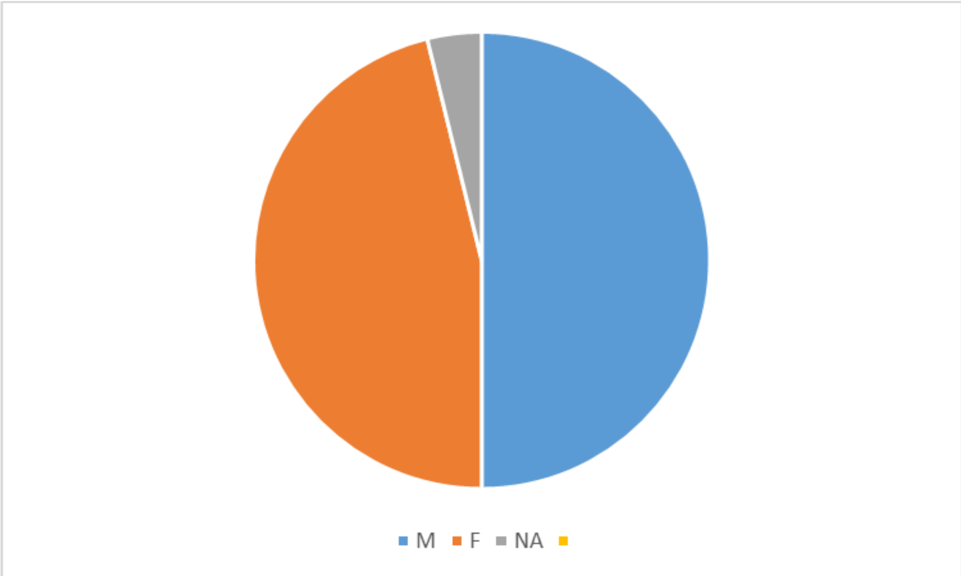


Figure 67 Number and percentage of pupils participating in the co-creation workshop by gender.

When we asked pupils if they learned something from the activity, 10 of them (38%) answered Yes, while other 14 (54%) responded No.

	Yes	No	NA	Total
Number	10	14	2	26
% on total	38%	54%	8%	100%

Table 61 Number and percentage of pupils participating in the co-creation workshop by learning from the activity.

Few of those pupils who responded Yes also provided details about what they did learn. While a pupil responded "*I learned about ways to reduce air pollution*", the other ones stressed the novelty of ideas for reducing air pollution. Indeed, a pupil wrote that "*I learned what an innovator is*"; meanwhile, the others added that "*they are using our idea to possibly build what we came up with*", "*learning genious ideas from the citizens*", and "*new ways to help the environment*".

While Yes response to the previous question was relatively low, however when asked pupils if they can do something to reduce air pollution all of them stated that they can do.

	Yes	No	Total
Number	26	0	26
% on total	100%	0%	100%

Table 62 Number and percentage of pupils participating in the co-creation workshop by engagement in reducing air pollution.

For example, a pupil responded that "*I could convince people to cycle and use the bus more, to reduce the number of people using cars*". Similarly, most of the pupils mentioned bikes, public transport, and electric cars as an alternative to cars, or using the car less as a way to mitigate air pollution. For example, pupils specified "*Using bus*", "*Use car less*", "*Tell people to use electric car*", and "*Cycle and walk instead of driving*". Other pupils focused on the needs for greening their areas and for equipping emission sources with air filters, and sometimes mentioned together the different solutions. For example, some pupils added "*Plant more plants*", "*Plant more trees, filters on the road and cigarette bins*", as well as "*Put air filters on things like chimyneys and exhaust pipes*" and "*Ride more bike. Put filter on things. Travel on the bus*".

The last question was related to how much pupils did like the activity from 1 to 5. 13 of them (50%) scored 4, while other 12 scored 3 and 5 (6 each). In this way, it can be said that pupils enjoyed the activity.

	I did not like it!	**It was not so good!**	**I like it!**	**I really like it!**	**I liked it very much!**	**NA**	**Total**
Number	0	0	6	13	6	1	26
% on total	0%	0%	23%	50%	23%	4%	100%

Table 63 Number and percentage of pupils participating in the co-creation workshop by satisfaction with the workshop.

4.6.4.3 Meeting with policy-makers in Dublin

On 27th May, the Dublin LL met one policy-maker to discuss the role of iSCAPE simulations in fostering policy change for the impact area *Policy change*. We have administered a questionnaire to the participant, who returned it to us with very insightful responses. According to the participant, simulations will provide "*evidences on the performance on the wall*", and in this way can foster a focus on LBW into the local policy agenda (score 3 on a 1-5 Likert scale of agreement). The participant was also convinced that simulations activities will contribute to both improve existing urban planning, land use, built environment, and health policies and create new policies on this regard. For both cases, the participant assigned score 5. According to the participant, in the first case, thanks to simulations, it would be possible to explore the existing interlinks between air quality and climate change. In the second case, the simulation will contribute to creating new policies "*by pre-empting the interlinked impacts on air quality and climatic variables*". In addition, the participant is also convinced that simulations activities will contribute to both improve existing air quality policies and create new ones. In both cases, the participant assigned score 4. In the first case, simulations will contribute to "*providing evidence on the impacts of the proposed interventions*", while in the second case they will contribute to "*studying the multiple effects in terms of climate change*". Having discussed policy change by simulation with just one questionnaire, final observations cannot be made yet. However, in line with other findings for both Dublin LL and other iSCAPE LLs, it can be said that simulations have the potential for promoting policy change into local policy agenda of Dublin, to be further explored in the future.

4.7 Guildford

4.7.1Description of the pilot

Guildford LL aimed to assess the influence of a roadside vegetation barrier on air pollutants concentration and associated exposure under different vegetation and meteorological conditions.

This test site presented typical roadside conditions along the busy roads in the UK and elsewhere, where vegetation barriers such as trees and hedges have been used to restrict air pollution from reaching sidewalks.

4.7.2Other LLs activities

The Guildford LL took part in public meetings and organized a series of workshops with local associations to explain to the people what GI is and which their benefits are. On June 2018, the Guilford LL took part in the Waterloo Festival (June 2018), where through a series of activities the Guildford LL did show potential and benefits of green infrastructure to festival participants. On December 2018, the Guildford LL organised an air pollution workshop in collaboration with Burpham Community Association. Within the activity, participants split into smaller groups to discuss, and develop suitable Green Infrastructure solutions for Burpham, that is a part of Guildford characterised by large heavily trafficked roads. Once each group identified the most suitable solution for each area, each group presented their conclusions to the others. A general discussion about air pollution in Burpham followed. The activity employed dissemination and co-creation approaches in order to make participants able to take part in meaningful discussions about locations and types of GI as well as idea generation for air pollution mitigation in Burpham. Other three similar workshops were organized with Guildford Vision Group (January 2019, the Guildford Labour Party (January 2019), and the Merrow Residents' Association (June 2019). During these three workshops, the benefits of GI infrastructure and their potential for the city of Guildford were explained.

4.7.3LLs activities socio-economic impacts: results

4.7.3.1 LLs activities' participants

In the five activities conducted by the Guildford LL between June 2018 and June 2019, we have collected questionnaires from 39 participants. Differently, from several activities by other iSCAPE LLs, participants from these activities tend to be in the middle-old age classes. Indeed, 10 participants were from the class 51-65 years old and 10 from the class 66-75, with other 4 from the over 75 class. This means that 62% of respondents were over 50, while just 4 of them (15%) were from the class 18-35 (see Table 64). In terms of sex, 21 respondents were male (54%), and 17 female (44%). Participants were mostly all UK citizens (27, 69%); there were no participants from other EU countries while there were and 4 participants from countries outside the European Union. It must be also added that 8 participants did not provide information.

	18-35	36-50	51-65	66-75	over 75	NA	Total
Number	4	6	10	10	4	5	39
% on total	10%	15%	26%	26%	10%	13%	100%

Table 64 Participants to Guildford LL activities by age.

The employment status (see Table 65) partially overlaps within the analysis of participants' age. Indeed, about half of the participants (20, 51%) were retired. Other 8 (21%) were employed for wage and other 6 (15%) were self-employed. Just two of them were students (8%).

	Employed for wage	Self-employed	Homemaker	Student	Retired	NA	Total
Number	8	6	2	2	20	1	39
% on total	21%	15%	5%	5%	51%	3%	100%

Table 65 Participants to Guildford LL activities by employment.

In terms of education, participants had mainly bachelor (8, 21%), master (11, 28%), and a professional degree (7, 18%).

	Less than high school	High school graduate	Trade/tech/vocation. Train	Ass. degree	Bachelor	Master	Professional degree	Doctorate	NA	Total
Number	2	2	3	2	8	11	7	1	3	39
% on total	5%	5%	8%	5%	21%	28%	18%	3%	8%	100%

Table 66 Participants by Guildford LL activities by education.

Finally, in terms of income, the most common classes were 10000-24999 € (11, 28%) and 24000-49999 € (9, 23%), however, there are also 5 respondents with an income between 50000 € and 79999 €. It must be also added that 12 participants did not provide data (31%).

4.7.3.2 LLs activities impact areas

In terms of environmental concerns, most of the respondent position themselves in the Postmaterialist class (15, 38%) and Very postmaterialist classes (19, 49%). Interestingly, there are also 2 people in an Extremely postmaterialist class (5%).

	Very materialist	Materialist	Postmaterialist	Very postmaterialist	Extremely postmaterialist	NA	Total
Number	1	1	15	19	2	1	39
% on total	3%	3%	38%	49%	5%	3%	100%

Table 67 Participants by Guildford LL activities by environmental concerns.

Human values mirror the attention to environmental issues, with 17 (44%) respondents situated in the Postmaterialist class and 5 respondents (19%) in the Very postmaterialist class. It must be also noted that there are 12 participants (31%) in the Materialist class.

	Very materialist	Materialist	Postmaterialist	Very postmaterialist	NA	Total
Number	2	12	17	5	3	39
% on total	5%	31%	44%	13%	8%	100%

Table 68 Participants by Guildford LL activities by human values.

Conversely, the Table on ecological behaviours reveals values that are slightly different from the previous two tables. In this case, indeed, the lowest class Very materialist includes 13 respondents (59%), and the Materialist class 11-20 includes 8 people (21%). Just 5 people are in the Postmaterialist class (13%). This implies that even though most of the participants are aware of environmental issues and have high human values to solve environmental problems, their ecological behaviour does not always correspond to these statements.

	Very materialist	Materialist	Postmaterialist	NA	Total
Number	23	8	5	3	39
% on total	59%	21%	13%	8%	100%

Table 69 Participants by Guildford LL activities by ecological behaviours.

When asked to identify and rank the main priorities into their local areas, participants ranked "Improving public transport" as the first priority (with an average of 2.2), followed by "Increase the number of trees and green spaces in the streets" (2.5) and "Improving local green areas" (3). As we have seen also for Bologna, these are urgent issues that are very related to air quality and pollution and have been considered into the iSCAPE project activities in these years.

Improve public transport	2.2
Increase the number of trees and green spaces in the streets	2.5
Improve local green areas (park where to go with kids, friends, dogs...)	3.0
Increase the number of shops and commercial areas (supermarkets, malls)	3.5
Improve security	3.8
Increase street maintenance	3.9
Improve streets' cleanness	4.0
Increase the offer of leisure services (cinema; theater, exhibitions)	4.4
Increase the number of available parking areas	4.7

Table 70 Priorities of changes required for the city of Guildford.

Similar to Bologna and Dublin, also in this case, the feedback by the participants on the performed activity can be considered as positive. To have a better understanding of what participants took home from the several activities performed by the Guildford LL in 2018 and 2019, we asked to agree to a set of items, using a 5 points Likert scale[5]. Out of the 7 items considered, all of them had an average higher than 3 (which means "neutral") and 2 of them had an average higher than 4 (which means "I agree"). By considering the mode value, positive impacts are also clearer. In the graph below we have reported the mode value for each question across the 33 participants

[5] The Likert scale code was described as follows in the questionnaire: 1=Strongly disagree 2=Disagree 3=Neutral 4=Agree 5=Strongly agree

who filled the questionnaire in relation to the LL activities. From this, it seems that participants brought at home a better understanding of air quality and air pollution and about the necessity for acting as citizens or communities to fight air pollution.

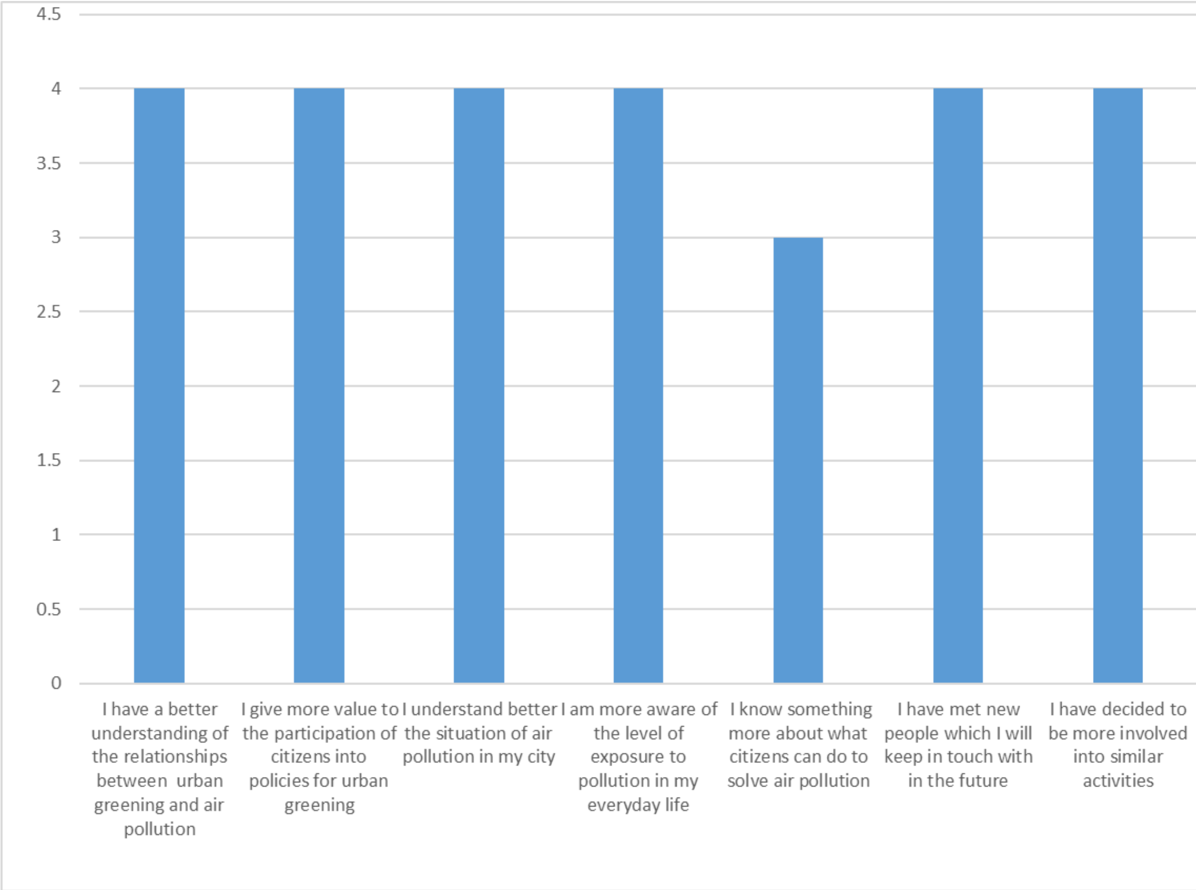


Figure 68 Feedback by participants into Guildford LL activities by mode value.

In terms of what citizens can do about air pollution, participants responded:

"Possibily get rid of my old car which I hardly use; walk away from the main road, main side walk use"

"*Consider getting rid of my car*"

"*Walking streets with fewer cars*"

"*Being more aware of route I do on a normal day*"

In terms of how being involved and take action into similar activities, participants responded:

"*Think about organising more event to raise awareness, and educate people about how to act for cleaner air*"

"*Involvement with the local association in monitoring and later action*"

"*I will prioritize these issues in my work with local politics*"

Furthermore, out of 33 participants, 17 of them (44%) reported they have learned something from the activity, including:

"*I learnt a lot about polluting and also a little bit more about types of pollution. It has made me more passionate about communicating about it*"

"*Understanding more detail about hedges and what things can help and how*"

"*Which hedges to plant to best help with traffic pollution near my home*"

"*Increasing public awareness means more people can make improvements to the environment*"

"*The benefit that suitable foliage can have on pollution from vehicles*"

Participants also expected some changes thanks to the activity, including:

"*We need more pedestrian way in the town center. We need to prepare for electric autonomous cars*"

"*I would have that we see more green infrastructure and informed citizens*"

4.7.4 Guildford LL's impacts as perceived by policy-makers

In April 2019, the Guildford LL performed an activity with local policy-makers to assess impacts by simulation activities for the impact area *Policy change*. During this activity, a questionnaire was administered to participants to ask them the impact by simulation on green infrastructure policies in Guildford. Just one out of three policy-makers participating in the study returned the questionnaire. The participant who declared that simulations will foster a focus on green infrastructure into policy-agenda as they *"help to show opportunities"* for using green infrastructure. Simulations also help to improve existing policies and create new policies as they *"help to formulate and influence new policies"*.

In terms of policies, however, it is also worthwhile mentioning the substantial contribution the Global Centre for Clean Air Research (GCARE) by the University of Surrey gave to policy change at the regional and national level in the UK. Indeed, on 4th April 2019, the City Hall Mayor's Office in London released the guide "Using Green Infrastructure to Protect People from Air Pollution" that summarises the current best practice for how green infrastructure can reduce public exposure to air pollution in the urban environment. The GCARE's iSCAPE team was involved in providing inputs to the draft of this document, using their experience on the topic and their work is done within the iSCAPE project. This is a milestone policy document for London and the whole UK as it is a first guidance document on the use of green infrastructure for air pollution mitigation published in the UK. Its relevance is also recognized by the fact that with this document all London councils will be committed to spending Mayor's £1 million in implementing green infrastructure in their areas[6].

4.8 Vantaa

4.8.1Description of the pilot

The Vantaa LL aimed at assessing different green passive cooling systems and find out different options; the physical properties of these systems will be studied and the cost-benefit structure of different options will be analysed in the current climate.

4.8.2 Other activities

Two other activities were conducted by the Vantaa LL in November and December 2018. The first activity was conducted on 9th November 2018 in Vantaa. The Vantaa LL met representatives from

[6] https://www.london.gov.uk/press-releases/mayoral/mayor-offers-1-million-green-grants

the City of Vantaa to discuss potential interactions between the iSCAPE project and planning activities by the City of Vantaa.

The second activity was conducted by the Vantaa LL with high school students from the City of Turku. During this activity, students reproduced at small scale the map of the city by using Legos, with the goal of providing a better understanding about the main urban features in relation to differences in temperature around the city.

4.8.3Social impact assessment of the intervention: methodology and data sources

We did not assess the social impacts of the Vantaa pilot as it did not include citizens' engagement. In this way, just economic assessment has been performed for the Vantaa pilot in terms of non-market benefits related to health and market benefits related to residential real estate that stems from improving air quality. Results from this will be found in the dedicated section of this deliverable, as well as a synthesis will be provided in D5.4.

However, the assessment has been conducted for the two other activities. For the first activity, data were gathered through participant observation of the meeting and a dedicated interview with the Vantaa LL team. For the second activity, data were gathered through a questionnaire administered to the teachers of the high school students, dedicated to exploring what did students experience and learn.

4.8.4LLs activities socio-economic impacts: results

4.8.4.1 Workshop with the City of Vantaa

The workshop organized by the Vantaa LL with City of Vantaa representatives on 9th November 2018 produced several impacts, in particular in relation to the impact area *Policy Change*. The three participants in the workshop were all from the planning department by the City of Vantaa. The participants were aware of climate change and air quality issues as occurring both globally and in Vantaa, however during the workshop the participants were able to gain a better understanding of the potential role by climate simulation and modelling software (e.g., ENVIMET) into urban planning. In this way, the workshop was considered as being very useful because the City of Vantaa did not have too much expertise around air quality and climate change, and therefore climate simulation and modelling as provided by the LL Vantaa can be useful to better integrate climate and climate change into urban planning. As the City of Vantaa did not consider yet the use of climate simulation and models, the workshop represented an important point to promote a short- and long-term collaboration with FMI (that is the iSCAPE partner organization running the Vantaa LL) and other climate change expert organizations. In this way, the activity has key impacts on policy change.

For example, one option to make relevant the information retrieved from the workshop with FMI could be the release of the new Masterplan by City of Vantaa in 2020. While there is a draft of the Masterplan, in 2019 its socio-economic impact assessment is taking place. In this way, this can represent an occasion to include air quality and climate change into the assessment by using climate simulation and modelling as discussed during the workshop. In the future, this can also bring to the development and availability of more accurate climate data for the City of Vantaa, to be integrated into planning and to provide cleaner air in some areas.

In particular, a better understanding of air quality and climate change impacts into new built-up areas that are planned into the Masterplan is necessary. Cost-benefit analysis methods can be useful to explore the social and economic impacts of some densification projects scheduled into the Masterplan to transform some green areas into built-up areas. Climate modelling and simulation can support cost-benefit analysis and demonstrate that this transformation might bring increasing costs in terms of worsened air quality conditions or climate change impacts. In this way, some green areas can be preserved from densification projects occurring in Vantaa.

A further opportunity for climate modelling and simulation as produced by Vantaa LL is related to the possibility for improving neighbourhoods that are less attractive in comparison with the central areas of Vantaa, and where house prices are lower. Accordingly, climate simulation and modelling can provide the necessary knowledge to make these areas more attractive and liveable, e.g. by increasing the number of green areas or improving accessibility with pedestrian and cycling paths and public transportation. By increasing the attractiveness of these areas, there could be a higher possibility to avoid the creation of segregated communities into Vantaa and to increase the house price level at the same level as the city.

4.8.4.2 Meeting Turku high school students at Eureka

Impacts emerged for the impact area Education from the activity with students organized on 12th December 2018 with high school students of Turku at Eureka. On this regard, the teachers argued that using Lego to represent the main urban features was a new and stimulating way for pupils to learn about the spatial representation of urban temperature. Indeed, nothing similar has previously been done in the school. The teachers stated that students had to think about the spatial representation of the city and to use mathematical skills to do it. In addition, students had to practice city planning and to think about how to locate different areas (for example parks, green elements, and built-up areas), according to temperature and the potential influence of climate. According to the teachers, students enjoyed the activity. On this regard, a teacher stated

"I liked (and students, too) this Lego activity because it was so different compared with other types of exercises."

Given that students liked the activity, when more results from this workshop will be available, it could be replicated in the future in the same school or in cooperation with other schools, also by employing 3D model pictures. On this regard, a teacher stated:

"Our students enjoyed the building and the Lego things very much. They are looking forward to hear more about the 3D model and results".

4.8.4.3 Meeting with policy-makers

On 31st May, the Vantaa LL conducted a meeting with two policy-makers to further explore the contribution by simulations in Vantaa to the impact area *Policy change*. We were able to collect one questionnaire from the participants. While this questionnaire cannot provide a final response to the linkage between the LL and policy-making improvements in Vantaa, however, it can provide an indication on current and future strategic direction. The questionnaire included questions to be assigned a score on a Likert scale 1-5. According to the participant, simulations will foster a focus on air quality into local policy agenda with a score 4, as now *"there are more detailed and reliable simulations"* that will hopefully contribute to having better information on air quality. For the same reasons, the simulation will also contribute to improving existing urban planning, land use, built environment, and public health policies with a score 4. Further to this, the availability of simulation will probably contribute to created new urban planning, land use, built environment, and public health policies with a score 3. In addition, simulations can contribute to promoting new air quality policies in the future, and therefore the participant assigned score 4 to this.

4.9 Behavioural interventions: assessment of socio-economic impacts

4.9.1 Behavioural interventions: a description

The analysis of the determinants of individual behavioural action is key to reveal the most important factors that guide a particular action by an individual. In the field of air pollution, understanding behavioural action in transportation is key to understand the exposure of individuals to most polluted areas and times and the ways individuals can decrease their exposure and mitigation their contribution to air pollution. To explore behavioural action with iSCAPE, Global Positioning System (GPS) technology has been used as that allows detecting the position of an individual with respect to time and space. The Transportation Research Institute (IMOB) at UHASSELT has developed a GPS based smartphone application, called SPARROWS, to be installed in smartphones with Android mobile operating system 3 or later. With SPARROWS, the GPS records personal traces under the form of mixed sequences of walking, cycling, public transport and car movements. A web-based application was then designed to collect information from the participants, as an individual can see his stops and trips on a map with the timestamps by logging into his/her account, and can annotate data regarding activity purposes, travel mode, and flexibility of activities. Adjustments were then done to translate the GPS traces into an activity-travel diary data, to be then presented in dedicated workshops to the users for annotating/labeling them with appropriate travel and activity characteristics (see D4.1 for details on the background and methodology for behaviour intervention study).

4.9.2 Behavioural interventions: methodology and data sources

Socioeconomic impact assessment for behavioural intervention is based on information regarding socioeconomic attributes and various personal traits such as attitude/values, perception and environmental awareness associated with travel behaviours. This information has been retrieved through a web-based questionnaire that was administered to the study participants. The questionnaire consisted of four major sections. In the first section respondents, socio-economic, personal and transport related information is gathered. Questions related to environmental awareness, perceived behaviour control, subjective. norms and transport facilities were asked in the second section. In the third section, questions were designed based on human values and attitudes. In the fourth section, changes in pro-environmental behaviour by participants was recorded.

4.9.3 Behavioral studies interventions: demographic characteristics of participants and results at an aggregated level

This section presents the demographic characteristics of responding to participants in the behaviour intervention study for the cities of Guildford, Dublin, Bologna, and Hasselt. Responding participants in the behaviour intervention study were 105, but this number does not include participants in the Hasselt school study, that will be presented separately at the end of these sections. Out of these 105 participants, the most represented age classes are the 18-35 (37, 35%) and 36-50 (36, 34%), while in terms of gender there is a slight predominance of women (57,54%) in comparison with men (48, 46%).

	18-35	36-50	51-65	66-75	over 75	Total
Number	37	36	29	3	0	105
% on total	35%	34%	28%	3%	0%	100%

Table 71 Aggregated number and percentage of participants into behaviour intervention study by a class of age.

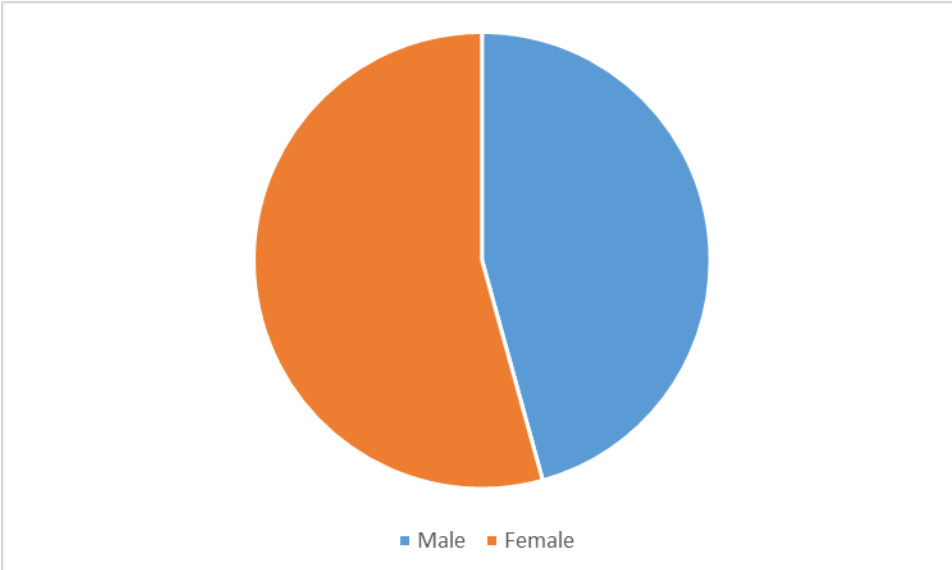


Figure 69 Aggregated number and percentage of participants into a behaviour intervention study by sex.

In terms of participants' citizenship, 101 of them (96%) are citizens of the hosting countries of the selected cities (Bologna, Italy; Dublin, Ireland; Guildford, UK; and Hasselt, Belgium) while just 4 participants (4%) are from another European country or from outside Europe.

	Italy	UK	Ireland	Belgium	EU	OT	Total
Number	44	16	4	37	2	2	105
% on total	42%	15%	4%	35%	2%	2%	100%

Table 72 Aggregated number and percentage of participants into a behaviour intervention study by citizenship.

The employment status of the participants is mainly the "Employed for wage" one (71 participants, 68%) followed with the large gap by Student (15, 14%) and Retired (8, 8%).

	Employed for wage	Self-employed	Out of work and looking for	Homemaker	Student	Retired	Unable to work	Total
Number	71	6	3	1	15	8	1	105
% on total	68%	6%	3%	1%	14%	8%	1%	100%

Table 73 Aggregated number and percentage of participants into behaviour intervention study by employment status.

In terms of education, participants mostly have a master degree (43, 41%), followed by High school (20, 19%) and Associate degree (18, 17%).

	High school graduate	Trade/tech/vocation. Train	Ass. Degree	Bachelor	Master	Professional degree	Doctorate	NA	Total
Number	20	1	18	5	43	8	1	9	105
% on total	19%	1%	17%	5%	41%	8%	1%	9%	100%

Table 74 Aggregated number and percentage of participants into behaviour intervention study by education.

Participants' income is quite heterogeneous. The most common income class is the 25000-49999 € (26, 25%) followed by upper-income classes over 50000 € (19, 18%), including 15 participants (14%) with an income over 100000 €.

	<10000 E.	10k-24999	25k-49999	50k-74999	75k-99999	>100k	NA	Total
Number	2	6	26	19	17	15	20	105
% on total	2%	6%	25%	18%	16%	14%	19%	100%

Table 75 Aggregated number and percentage of participants into behaviour intervention study by income.

Almost all the participants have a car (101, 96%), and over half of them has 2 cars (54, 51%). Meanwhile, 35 participants (33%) responded they hold just one car. Most of the participants use Diesel (39, 37%) and Petroleum (45, 43%) as car fuel type.

	0	1	2	3	Total
Number	9	35	54	7	105
% on total	9%	33%	51%	7%	100%

Table 76 Aggregated number and percentage of participants into behaviour intervention study by a number of hold cars.

	DIE	CNG	PET	EV	LPG	PPH	NA	Total
Number	39	7	45	2	3	4	5	105
% on total	37%	7%	43%	2%	3%	4%	5%	100%

Table 77 Aggregated number and percentage of participants into behaviour intervention study by car fuel type.

The majority of the participants also hold a bike (72, 69%), indicating that participants possibly already had some forms of environmental concerns and awareness.

In terms of satisfaction impact area *Leisure and social interaction*, most of the participants fall in the average class Satisfied (41, 39%), while a good number (49, 47%) fall into the class Very satisfied.

	Low satisfied	Satisfied	Very satisfied	NA	Total
Number	12	41	49	3	105
% on total	11%	39%	47%	3%	100%

Table 78 Aggregated number and percentage of participants into behaviour intervention study by satisfaction around community.

In terms of environmental concerns, most of the participants resulted having a Postmaterialist (67, 64%). and Very postmaterialist (17, 16%) attitude towards environmental concerns. This implies that participants in the behaviour intervention study are very aware of current environmental issues and are concerned about them..

	Very materialist	Partially materialist	Materialist	Postmaterialist	Very postmaterialist	NA	Total
Number	1	2	16	67	17	2	105
% on total	1%	2%	15%	64%	16%	2%	100%

Table 79 Aggregated number and percentage of participants into behaviour intervention study by score of environmental concerns.

Similarly, the participants resulted to generally have postmaterialist human values. Indeed, most of the participants (69, 66%), fall into the Postmaterialist class, while other 26 participants (26, 25%) fall in the Very postmaterialist class.

	Very materialist	Materialist	Postmaterialist	Very postmaterialist	NA	Total
Number	0	7	69	26	3	105
% on total	0%	7%	66%	25%	3%	100%

Table 80 Aggregated number and percentage of participants into behaviour intervention study by score of human values.

However, as also occurred for several of the LL's pilots and activities presented in previous chapters, values are different when we asked participants about their environmental behaviour. In this case, almost half of the participants (54, 51%) fall in the Materialist class, while a good number of them (34, 32%) falls in the lowest class, the Very materialist one.

	Very materialist	Materialist	Postmaterialist	Very postmaterialist	NA	Total
Number	34	54	11	1	5	105
% on total	32%	51%	10%	1%	5%	100%

Table 81 Aggregated number and percentage of participants into behaviour intervention study by score of ecological behaviours.

On the same vein, we asked the participants to select across a range of transport-related goods/services the one they would have invested for with a 1000 € award. The range of options was related to car services (e.g. car maintenance and gasoline), active transportation (buying an ebike or a bycle), and public transportation (public transportation tickets and passes). Accordingly, the good/service participants would have invested for with the highest average price was the Car maintenance and gasoline (304 €), followed by Buying an ebikes (approximately 250 €) and Buying a bicycle. This indicates that while participants still seem to have a materialist attitude in using transport related good and services, however, there is also a consideration of environmental issues in everyday transportation.

Car maintenance and gasoline	304
Buying an ebike	250.375
Buying a bicycle	208.125
Public Transport Tickets/passes	203.75
Other	41.5

Table 82 Aggregated number and percentage of participants into behaviour intervention study by average price assigned to transport-related issues.

Once explained the main results of behaviour intervention study at the aggregated level, specific findings for each participating cities are reported below.

4.9.4Consideration of city-specific results

4.9.4.1 Bologna behaviour intervention study: data analysis

44 participants in the behaviour intervention study answered to the questionnaire. The most represented age class is the youngest one (18-35), with 19 participants (43%), followed by the class 36-50 (13, 30%) and the class 51-65 (12, 27%).

	18-35	36-50	51-65	66-75	over 75	Total
Number	19	13	12	0	0	44
% on total	43%	30%	27%	0%	0%	100%

Table 83 Participants in the Bologna behaviour intervention study by age.

In terms of sex, participants are more women (27, 61%) than men (17, 39%), while in terms of citizenships participants were all Italian.

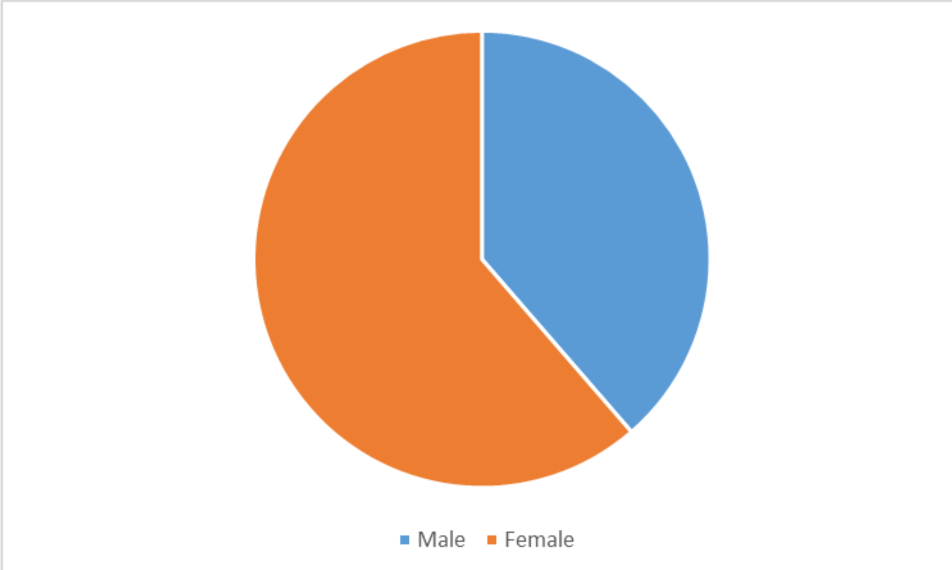


Figure 70 Participants in the Bologna behaviour intervention study by sex.

In terms of employment, the category Employed for a wage is the most represented with 26 participants (59%), followed by the category Student, with 13 participants (30%).

	Employed for wage	Self-employed	Out of work and looking for	Student	Retired	Total
Number	26	2	2	13	1	44
% on total	59%	5%	5%	30%	2%	100%

Table 84 Participants in the Bologna behaviour intervention study by employment.

The education status of the participants seems to be quite variegated. The most represented category is the Master one (12, 27%), followed by High school graduate (11, 25%), and Doctorate and Associated degree, with 9 participants each (20%).

	High school graduate	Ass. degree	Master	Professional degree	Doctorate	Total
Number	11	9	12	3	9	44
% on total	25%	20%	27%	7%	20%	100%

Table 85 Participants in the Bologna behaviour intervention study by education.

Similarly, the income status looks heterogeneous with five categories represented. The most common category is the 25000-49999 € (12, 27%), followed by the category 50000-749999 € (10, 23%). However, it must be also pointed out that we do not have information for 9 participants (20%).

	<10000 E.	10k-24999	25k-49999	50k-74999	75k-99999	>100k	NA	Total
Number	0	4	12	10	5	4	9	44
% on total	0%	9%	27%	23%	11%	9%	20%	100%

Table 86 Participants in the Bologna behaviour intervention study by income.

95% of participants (42) hold a driver licence. In terms of held cars, 29 participants (66%) have 2 cars, while 10 (23%) have 1 car. In addition, 4 participants (9%) revealed to have 3 cars.

	0	1	2	3	Total
Number	1	10	29	4	44
% on total	2%	23%	66%	9%	100%

Table 87 Participants in the Bologna behaviour intervention study by a number of held cars.

Participants also responded that fuel type of their cars is mainly Petrol (PET20, 45%), followed by 10 participants reporting the Diesel (DIE) fuel type (23%). 7 participants also have Compressed Natural Gas (CNG), and 3 participants also have both Liquid Petroleum Gas (LPG) and Petrol plugin Hybrid (PPH) (7%). 26 participants (59%) revealed they have a bike.

	DIE	CNG	PET	LPG	PPH	NA	Total
Number	10	7	20	3	3	1	44
% on total	23%	16%	45%	7%	7%	2%	100%

Table 88 Participants in the Bologna behaviour intervention study by car fuel type.

26 participants (59%) revealed they have a bike.

In terms of the impact area Leisure and social interaction, participants look generally quite satisfied with their community. 22 participants (50%) fall into the Satisfied class, and other 15 (34%) fall into the High satisfied class, with just 4 participants (13%) scored a low level. Those who scored low satisfaction reported that there is too much traffic and high commuting time to the workplace, as well as too much noise and air pollution.

	Low satisfied	Satisfied	High satisfied	NA	Total
Number	4	22	15	3	44
% on total	9%	50%	34%	7%	100%

Table 89 Participants in the Bologna behaviour intervention study by impact area Leisure and social interaction.

Participants look also postmaterialist in terms of environmental concerns. Indeed, 26 participants (59%) fall in the Postmaterialist class, 7 people (16%) in the Very postmaterialist class. There are also 9 people (20%) in the Materialist class, while there are no people in the Vert materialist class..

	Very materialist	Materialist	Postmateri alist	Very postmateri alist	NA	Tot
Number	0	9	26	7	2	44
% on total	0%	20%	59%	16%	5%	100%

Table 90 Participants in the Bologna behaviour intervention study by scored environmental concerns.

Similarly, 21 participants (48%) falling in the Postmaterialist class in terms of human values, followed by 16 (36%) in the Very postmaterialist class, and just 4 people (9%) in the Materialist class.

	Very materialist	Materialist	Postmaterialist	Very postmaterialist	NA	Total
Number	0	4	21	16	3	44
% on total	0%	9%	48%	36%	7%	100%

Table 91 Participants in the Bologna behaviour intervention study by scored human values.

The ecological behaviour table, conversely, reports lower scores. 55% of the participants (24) fall in the Materialist class, while 9 participants (20%) are included in the Very materialist class. Differently, from the previous two tables, there are no participants in the Very postmaterialist class.

	Very materialist	Materialist	Postmaterialist	Very postmaterialist	NA	Total
Number	9	24	8	0	3	44
% on total	20%	55%	18%	0%	7%	100%

Table 92 Participants in the Bologna behaviour intervention study by scored ecological behaviours.

When asked participants how they would have spent a 1000 € award in transport-related goods/services, differently from the aggregated results the highest average was for the category Buying an ebike (321 €), followed by the Car maintenance and gasoline (298 €) and Buying a bicycle (163 €).

Buying an ebike	321
Car maintenance and gasoline	292
Public transport Tickets/passes	181
Buying a bicycle	163
Other	56

Table 93 Participants in the Bologna behaviour intervention study by average expenses for transport-related goods/services.

Out of 42 participants in the behaviour intervention study for Bologna, 18 provided feedback on the study. 6 out of 18 (33%) claimed that they changed their transport routine upon participating in the study.

	Yes	No	Total
Number	6	12	18
% on total	33%	67%	100%

Table 94 Participants' feedback on changing the transport routine upon participating in the Bologna behaviour intervention study.

Participants reported that they tried to combine their travels with travels of other people (therefore sharing the use of the car on similar roads) or their car travel with other activities to do along the day on the same road (therefore reducing the frequency in using the car). On this regard, a participant reported that: “*I tried as much as possible to combine my travels by car with those of other people who needed to go in the same direction, with a focus on pollution and economic convenience*". Another participant argued that “*I made sure to combine my travels with more things to do along the same road*". In addition, other participants reported that they increased the use of public transport.

About the lessons learned by participants from the study, some participants reported that they learned the necessity to change the transport means. Some participants, for example, realized the dependence of their life on the car. A participant argued on this regard: “*I depend too much on the use of the car*". Similarly, other participants added that “*I have to try to change my habits by using the car less*", and that the study “*made me more aware of the movements I make and the alternatives available*".

Participants also learned the benefits of walking or cycling for commuting on health and air. For example, a participant declared that “*if it is compatible with my needs, it is preferable to go walking or cycling*". Another participant added he/she learned about: “*How much physical activity should be done in a week and how much we are exposed to air pollution*".

Conversely, participants also realized that walking or using the bike is also a way to be exposed to air pollution, therefore, it is better to avoid congested roads. On this regard, a participant reported that: “*It was…useful to know that even if you're not in the car, I'm subject to pollution, even more than the average*".

4.9.4.2 Dublin behaviour intervention study: data analysis

5 participants in the behaviour intervention study filled the questionnaire. 3 participants (60%) fall into the class of age 36-50, while other 2 falls into the 18-35 and 51-65 classes. Sex composition sees 3 men (60%) and 2 women (40%) participating in the study.

0	18-35	36-50	51-65	66-75	over 75	Total
Number	1	3	1	0	0	5
% on total	20%	60%	20%	0%	0%	100%

Table 95 Participants in the Dublin behaviour intervention study by age.

Most of the participants have Irish citizenship (4, 80%), while 1 participant come from another EU country (outside Italy, Germany, Belgium, Finland and UK that are other countries of iSCAPE LL partners).

	Ireland	EU	Total
Number	4	1	5
% on total	80%	20%	100%

Table 96 Participants in the Dublin behaviour intervention study by citizenship.

In terms of employment status, 3 participants are employed for a wage (60%), while the other two participants are self-employed and a student, respectively.

	Employed for wage	Self-employed	Student	Total
Number	3	1	1	5
% on total	60%	20%	20%	100%

Table 97 Participants in the Dublin behaviour intervention study by employment.

In terms of education, the situation is quite homogeneous. While there are two participants graduated with the master (40%), the other three participants hold a high school diploma, a bachelor, and a doctorate.

	High school graduate	Bachelor	Master	Doctorate	Total
Number	1	1	2	1	5
% on total	20%	20%	40%	20%	

Table 98 Participants in the Dublin behaviour intervention study by education.

Income from Dublin participants looks quite high. 3 participants (6%) reported an income higher than 100000 €, while another one declared an income in the class 50000-99999 €.

	<10000 E.	10k-24999	25k-49999	50k-74999	75k-99999	>100k	NA	Total
Number	0	0	0	1	0	3	1	5
% on total	0%	0%	0%	20%	0%	60%	20%	100%

Table 99 Participants in the Dublin behaviour intervention study by income.

All participants reported to have a driver licence, and 3 of them responded to have 2 cars (60%). Further to cars, 3 out of 5 participants (60%) also hold a bike.

Participants also responded that fuel type of their cars is Diesel for three of them (60%) and Petrol for 2 of them (40%)

	DIE	PET	Total
Number	3	2	5
% on total	60%	40%	100%

Table 100 Participants in the Dublin behaviour intervention study by car fuel type.

In terms of impact area *Leisure and social interaction*, participants were quite satisfied with life within their community. Indeed, 4 participants (80%) fall in the Satisfied class, while the participant who is into the Low satisfied class added that he/she put a low score due to too long and unpredictable commuting time.

	Low satisfied	Satisfied	Very satisfied	Total
Number	1	4	0	5
% on total	20%	80%	0%	100%

Table 101 Participants in the Dublin behaviour intervention study by impact area Leisure and social interaction.

In terms of environmental concerns by participants, the situation is quite homogeneous. While there are two participants (40%) in the Materialist class with a score between 36 and 50, all the other classes have one participant each.

	Very materialist	Materialist	Postmaterialist	Very postmaterialist	Tot
Number	1	1	2	1	5
% on total	0%	20%	40%	20%	80%

Table 102 Participants in the Dublin behaviour intervention study by scored environmental concerns.

In terms of human values, 4 out of 5 participants (80%) the Postmaterialist class.

	Very materialist	Materialist	Postmater ialist	Very postmater ialist	Extreme materialist	Total
Number	0	0	4	1	0	5
% on total	0%	0%	80%	0%	0%	100%

Table 103 Participants in the Dublin behaviour intervention study by scored human values.

However, scores about ecological behaviours seem to be lower in comparison with previous scores. Accordingly, all participants result as being materialist, with two participants (40%) being in the Very materialist class.

	Very materialist	Materialist	Postmaterialist	Very postmaterialist	Total
Number	2	3	0	0	5
% on total	40%	60%	0%	0%	100%

Table 104 Participants in the Dublin behaviour intervention study by scored ecological behaviours.

Finally, the questionnaire asked participants how they would have spent awarded 1000 € in transport-related goods/services; and calculated the average of the reported values. The highest average value is for Buying a bicycle (420 €), followed by Car maintenance and gasoline (320 €). The lowest average is for Buying an ebike (40 €).

Buying a bicycle	420
Car maintenance and gasoline	320
Public transport Tickets/passes	220
Buying an ebike	40
Other	0

Table 105 Participants in the Dublin behaviour intervention study by average expenses for transport-related goods/services.

4.9.4.3 Dublin behaviour intervention study: feedback

Out of 5 participants in the behaviour intervention study in Dublin, two of them provided feedback about it. One participant reported that he/she changed the transport routine upon participating in the study but did not provide any explanation about why. However, the participant declared that he/she has "*learned that my travel and activity levels depends greatly on my daily plans. On the days I am working from home, I need to make more conscious efforts to move and go out for walks*". The same participant added that he/she appreciated the feedback document that was provided by the research team, as "*it was really interesting to see activity levels and air pollution levels and to be provided tips to improve both of these*".

Another participant reported issues in using the app. Accordingly, "*the app did not accurately capture my activities. It struggled in areas like Clontarf (Dublin) and showed my walking as driving*".

4.9.4.4 Guildford behaviour intervention study: data analysis

16 participants in the behaviour intervention study answered to the questionnaire. The most represented age class is the class 36-50, with 9 participants (56%), followed by the class 18-35 (4, 25%) and then the class 51-75 (3, 19%).

0	18-35	36-50	51-65	66-75	over 75	Total
Number	4	9	3	0	0	16
% on total	25%	56%	19%	0%	0%	100%

Table 106 Participants in the Guildford behaviour intervention study by age.

In terms of sex, there are more women participants (10, 63%) than men (6, 38%). All the participants have UK citizenship.

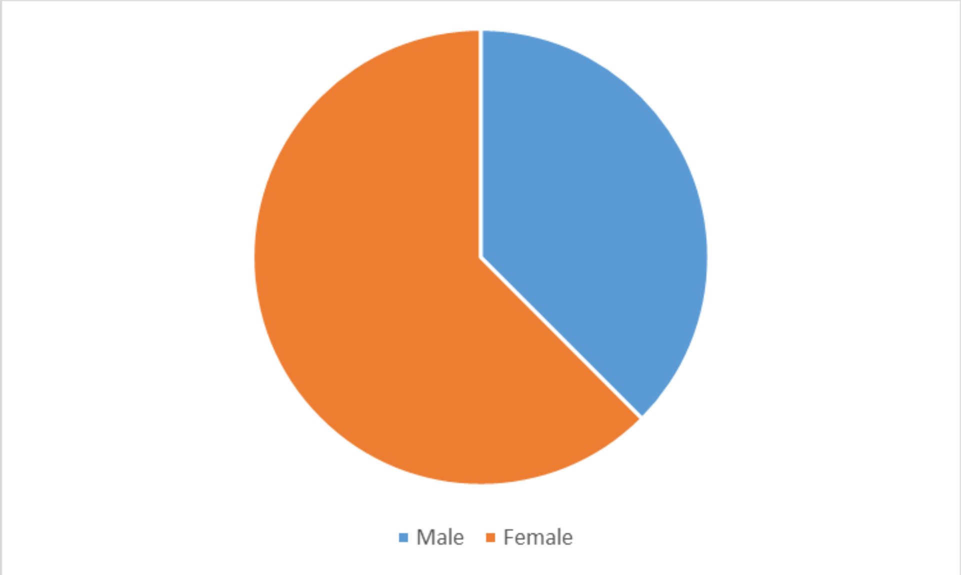


Figure 71 Participants in the Guildford behaviour intervention study by sex.

In terms of employment status, the most represented category is the "Employed for wage" one, with 13 participants (81%). Other categories (Self-employed, Homemaker, and Retired) are represented with one participant for each of them.

	Employed for wage	Self-employed	Homemaker	Retired	Total
Number	13	1	1	1	16
% on total	81%	6%	6%	6%	100%

Table 107 Participants in the Guildford behaviour intervention study by employment.

In terms of education, the most represented category is the Master one, with 8 participants (50%), followed by Professional degree with 4 participants (25%), and Bachelor (2, 13%). High school graduate and Trade training have one participant each.

	High school graduate	Trade/tech/vocation. Train	Bachelor	Master	Professional degree	Total
Number	1	1	2	8	4	16
% on total	6%	6%	13%	50%	25%	

Table 108 Participants in the Guildford behaviour intervention study by education.

The income condition is quite heterogeneous with four categories represented of middle and high income. Indeed, the categories 25000-49999 €, 75000-99999 € and over 100000 € have 4 participants each (25%), while the class 50000-74999 € has 2 participants.

	<10000 E.	10k-24999	25k-49999	50k-74999	75k-99999	>100k	NA	Total
Number	0	0	4	2	4	4	2	16
% on total	0%	0%	25%	13%	25%	25%	13%	100%

Table 109 Participants in the Guildford behaviour intervention study by income.

All 16 participants have a driver licence. In terms of holding cars, 8 participants (50%) revealed to have 1 car. 6 participants (38%) have 2 cars, while 2 of them (13%) have 3 cars.

	1	2	3	more	Total
Number	8	6	2	0	16
% on total	50%	38%	13%	0%	100%

Table 110 Participants in the Guildford behaviour intervention study by a number of held cars.

Participants also responded that fuel type of their cars is mainly Petrol (9, 56%), followed by 4 participants reporting the Diesel fuel type (25%). 2 participants also have Electric Vehicle (13%). In addition, 10 participants (63%) revealed they do not hold a bike

	DIE	PET	EV	PPH	Total
Number	4	9	2	1	16
% on total	25%	56%	13%	6%	100%

Table 111 Participants in the Guildford behaviour intervention study by car fuel type.

In terms of impact area *Leisure and social interaction*, participants look very satisfied with their community. 7 participants (44%) fall in the High satisfied class and other 7 falls in the Satisfied class. Just 2 participants (13%) fall in the Low satisfied class. Those who reported low satisfaction added that this is due to the high traffic level and commuting time in Guildford, that also makes people stressed.

	Low satisfied	Satisfied	High satisfied	Total
Number	2	7	7	16
% on total	13%	44%	44%	100%

Table 112 Participants in the Guildford behaviour intervention study by level of satisfaction within the community.

Participants in Guildford seem concerned about environmental conditions. Indeed, 10 participants (63%) the Very postmaterialist class, with 5 (31%) in the Extreme postmaterialist class.

	Very materialist	Materialist	Postmateri alist	Very postmateri alist	Extreme postmateri alist	Tot
Number	0	1	0	10	5	16
% on total	0%	6%	0%	63%	31%	100%

Table 113 Participants in the Guildford behaviour intervention study by scored environmental concerns.

The situation is similar also on the regard of human values. Indeed. 11 participants (69%) fall into the Postmaterialist class, while other 4 (25%) are in the Very postmaterialist class.

	Very materialist	Materialist	Postmateri alist	Very postmateri alist	Extreme postmateri alist	Total
Number	0	1	11	4	0	16
% on total	0%	6%	69%	25%	0%	100%

Table 114 Participants in the Guildford behaviour intervention study by scored human values.

Conversely, the situation about ecological behaviours looks very different low. Indeed, there are 6 participants (38%) in the Very materialist and 9 participants (56%) in the Materialist one. Just one participant (6%) Very postmaterialist class.

	Very materialist	Materialist	Postmaterialist	Very postmaterialist	Total
Number	6	9	0	1	16
% on total	38%	56%	0%	6%	100%

Table 115 Participants in the Guildford behaviour intervention study by scored ecological behaviours.

When asked participants how they would have spent 1000 € award in transport-related goods/services, the highest average was related to the good/service Car maintenance and gasoline (328 €), followed by the category Buying an ebike (250 €). The lowest average is for the option Other (41 €), that some participants described as “bike accessories” or “bike shade”.

Car maintenance and gasoline	328
Buying an ebike	250
Public transport Tickets/passes	216
Buying a bicycle	166
Other	41

Table 116 Participants in the Guildford behaviour intervention study by average expenses for transport-related goods/services.

4.9.4.5 Guildford behaviour intervention study: feedback

Out of 16 participants in the behaviour intervention study in Guildford, 9 of them provided feedback on the study. Two of them (22%) reported they changed their transport routine after completion of the study.

	Yes	No	Tot
Number	2	7	9
% on total	22%	78%	100%

Table 117 Participants' feedback on changing the transport routine upon participating in the Guildford behaviour intervention study.

One participant argued that he/she shifted towards active mobility such as bike or foot, as "*the apps illustrated clearly I was not walking as much as I'd like to, so I've tried to increase activity*". The other participant argued that he/she tried to "*taking public transport where possible (mostly when I was travelling alone, rather than with my toddler)*".

Some participants highlighted that it is possible to replace car trips with the bike, also to have a better level of physical activity. For example, a participant argued that: "*I've learnt that I do very few car journeys that could be replaced by walking. I've also learned that I don't do enough exercise*". Another participant added that the study provided him/her with a "*better appreciation of the number of short journeys I undertake by car. Would like to reduce these but there do not appear to be cost effective alternatives*". This also led to a better appreciation of the benefits to air quality by using public transport or active mobility, as a participant argued that the study "*reinforced things I was already aware of, such as the benefits to air quality of using public transport over driving, and for using your own power (e.g. walking or cycling) for shorter journeys*".

When participants were asked to describe what they liked most during the study and what they found less interesting or difficult to understand, participants generally reported that the study was not so difficult to participate in and was easy to understand. Among the others, participants reported that "*participation in the study was not difficult*", "*all easy to understand*", and "*nothing I didn't understand*".

Furthermore, for some participants, using the apps also was easy. On this regard, a participant claimed "*once open, the apps are easy to use and interesting*". Another one added that it was "*useful to be able to track the journeys I do, easy to understand*", while another argued that "*it was useful to see my trips*". Another interesting feedback is from a participant that summarized both the easiness and the benefits of the apps: "*I enjoyed using the app to annotate my journeys. I enjoyed thinking more about how I was going to travel, rather than just jumping in the car (although it is much easier to drive when travelling with our toddler)*". However, other participants expressed difficulties in using the app. For example, a participant argued that the app "*did not correctly track my movements. Most days there were spurious journeys or missing journeys*", and "*I don't think the app recording the amount of walking I do accurately*".

4.9.4.6 Hasselt behaviour intervention study: data analysis

40 participants in the behaviour intervention study responded to the questionnaire. Among these, the composition is quite heterogeneous. The classes 18-35 and 51-65 include 13 participants each (33%), while the class 36-50 includes 11 participants (28%).

	18-35	**36-50**	**51-65**	**66-75**	**Total**
Number	13	11	13	3	40
% on total	33%	28%	33%	8%	100%

Table 118 Participants in the Hasselt behaviour intervention study by age.

In terms of sex, the study sees the participation of 22 men (55%) and 18 women (45%).

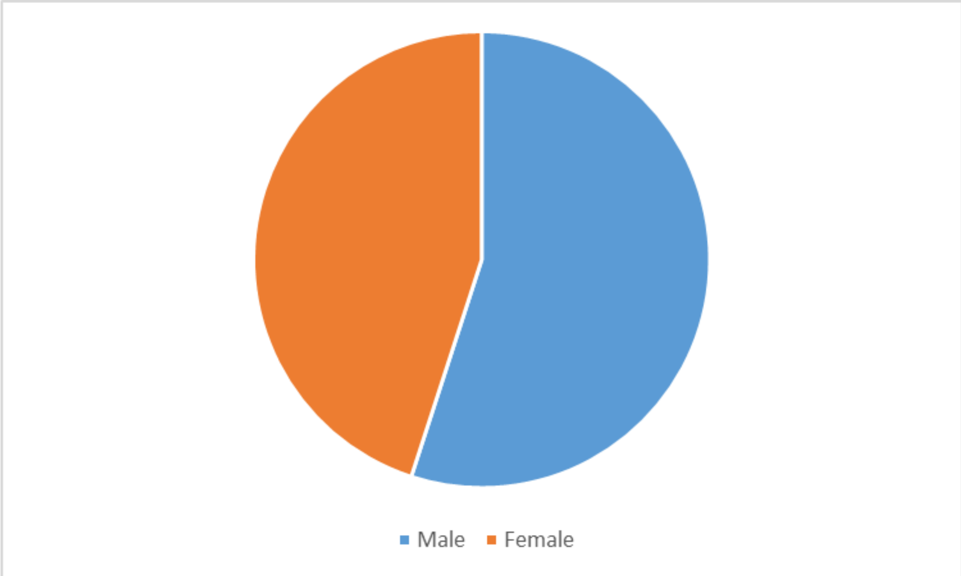


Figure 72 Participants in the Hasselt behaviour intervention study by sex.

In terms of citizenship, 37 participants were from Belgium (93%). Two participants were from non-European countries, while one participant was from a European country excluded Belgium, Italy, the UK, Germany, Ireland and Finland.

	Belgium	**EU**	**OT**	**Total**
Number	37	1	2	40
% on total	93%	2%	5%	100%

Table 119 Participants in the Hasselt behaviour intervention study by citizenship.

In terms of employment, most of the participants were employed for a wage (29, 73%), followed by retired participants (6, 15%), and other categories between 1 and 2 participants.

	Employed for wage	Self-employed	Out of work and looking for	Student	Retired	Unable to work	Total
Number	29	2	1	1	6	1	40
% on total	73%	5%	3%	3%	15%	3%	100%

Table 120 Participants in the Hasselt behaviour intervention study by employment.

In terms of education status, the most represented category is the Master one (21, 53%), followed by Associate degree (9, 23%), and High school graduate (7, 18%).

	High school graduate	Ass. degree	Bachelor	Master	Professional degree	Total
Number	7	9	2	21	1	40
% on total	18%	23%	5%	53%	3%	100%

Table 121 Participants in the Hasselt behaviour intervention study by education.

Meanwhile, regarding the income status, the situation looks very heterogeneous. The most common category is the 25000-49999 € (10, 25%), followed by the category 75000-99999 € (8, 20%) and 50000-74999 € (6, 15%). It must be also highlighted that 8 participants did not provide information (20%).

	<10000 E.	10k-24999	25k-49999	50k-74999	75k-99999	>100k	NA	Total
Number	2	2	10	6	8	4	8	40
% on total	5%	5%	25%	15%	20%	10%	20%	100%

Table 122 Participants in the Hasselt behaviour intervention study by income.

In terms of driver licence, 95% of participants (38) hold a driver licence. Meanwhile, In terms of held cars, 16 participants (40%) reported to have 2 cars, while 15 (30%) have 1 car. 8 participants (20%) answered that they do not have any car. In addition, almost the totality of participants (37, 93%) reported they hold a bike.

	Yes	No	Total
Number	38	2	40
% on total	95%	5%	100%

Table 123 Participants in the Hasselt behaviour intervention study by a number of driver licence.

	0	1	2	3	Total
Number	8	15	16	1	40
% on total	20%	38%	40%	3%	100%

Table 124 Participants in the Hasselt behaviour intervention study by a number of held cars.

Regarding the fuel type of the car, Diesel is the most common category (19 participants, 48%), followed by Petrol (12, 30%). We do not have a response about this question from 8 participants (20%).

	DIE	CNG	PET	EV	LPG	DPH	PPH	NA	Total
Number	19	0	12	0	0	0	1	8	40
% on total	48%	0%	30%	0%	0%	0%	3%	20%	100%

Table 125 Participants in the Hasselt behaviour intervention study by car fuel type.

In terms of impact area Leisure and social interaction, participants look satisfied about their community. 27 participants (68%) fall into the High satisfied class, while 8 (20%) fall in the Satisfied class. 5 participants (13%) fall into the Low satisfied class. Those who scored low satisfaction reported that this is caused by the fact that they have to drive every day to reach the workplace and this is a very time-consuming activity.

	Low satisfied	Satisfied	High satisfied	Total
Number	5	8	27	40
% on total	13%	20%	68%	100%

Table 126 Participants in the Hasselt behaviour intervention study by level of satisfaction within the community.

Participants are very concerned about the environment. Most of the participants (30, 75%) fall in the Very postmaterialist class, followed by 5 people (13%) into each Postmaterialist and Extreme postmaterialist.

	Very materialist	Materialist	Postmateri alist	Very postmaterialist	Extreme postmaterialist	Tot
Number	0	0	5	30	5	40
% on total	0%	0%	13%	75%	13%	100%

Table 127 Participants in the Hasselt behaviour intervention study by scored environmental concerns.

Human values also mirror score the previous table, with the largest part of participants (33, 83%) falling in the Postmaterialist class and 5 (13%) in the Very postmaterialist class.

	Very materialist	Materialist	Postmaterialist	Very postmaterialist	Total
Number	0	2	33	5	40
% on total	0%	5%	83%	13%	100%

Table 128 Participants in the Hasselt behaviour intervention study by scored human values.

Conversely, as occurred for the other cities participating in the behaviour intervention study, the ecological behaviour table reports low scores. 43% of the participants (17) fall in the Very materialist class (2-10), while 18 participants (45%) are included in the Materialist class (11-20). Just 3 participants can be classified as Postmaterialist, and there are no people in the Very postmaterialist class.

	Very materialist	Materialist	Postmaterialist	Very postmaterialist	NA	Total
Number	17	18	3	0	2	40
% on total	43%	45%	8%	0%	5%	100%

Table 129 Participants in the Hasselt behaviour intervention study by scored ecological behaviours.

Finally, participants reported that they would spend a 1000 € award in transport-related goods/services mainly to buy a bike or an ebike. Indeed, the average value for Buying an ebike is

392 €, followed by 252 € to buy a bicycle. Hasselt also represents the only participating city (including the aggregated data) where Car maintenance and gasoline is out of the first two positions.

Buying an ebike	392
Buying a bicycle	252
Car maintenance and gasoline	180
Public transport Tickets/passes	149
Other	29

Table 130 Participants in the Hasselt behaviour intervention study by average expenses for transport-related goods/services.

4.9.4.7 Hasselt behaviour intervention study: feedback

Out of 40 participants in the behaviour intervention study, 25 of them provided feedback about the study. 10 participants declared that upon participatingin the project pilot they changed their transport routine, while 14 participants responded they did not do so (see Table 131).

	Yes	No	NA	Total
Number	10	14	1	25
% on tot.	40%	56%	4%	100%

Table 131 Participants' feedback on changing the transport routine upon participating in the Hasselt behaviour intervention study.

One of the participants who changed the transport routine confirmed that he/she "*was not aware that outdoor activities could also be harmful to health*", but thanks to the knowledge gained into this activity, the participant argued that he/she will "*take more cycling trails through the green (by detour) than cycling paths along concrete roads*". Other participants claimed that the activity led them to reflect on the bad effect of their travel on the environment, and therefore to undertake appropriate measures to reduce it. Among these measures, replacing the car with bike or foot, or taking longer trips with the bike have been mentioned.

Participants were then asked what they did learn about the study. Generally, participants claimed they learned something more about air pollution and the damage it provokes on health. For example, a participant claimed that he/she learned "*which roads are to be avoided if one delivers physical effort (by bike or foot). If I go to work bike... there are some pieces where air pollution is high. On these pieces, I also suffer from an irritated throat*". Another participant argued that he/she learned "*about the daily carbon emissions related to my travel*".

In this way, participants learned that there is a transportation alternative to the car, and that car can be easily replaced in particular for small trips. For example, a participant argued that he/she "*usually use(s) the car, even if it is not necessary. By bike, you can also easily go to the bakery or take away*". Similarly, another participant argued that "*a car is not needed and it's quite good to do anything by bike*". Other participants, for example, also stressed that using a bike or walking is good as physical activity. On this regard, a participant added that "*though I have a lot of cycling and walking, I realized I do not yet have enough physical activity in a week*". Another participant added that a daily effort of 30 minutes by bike contributed to achieving a better air quality.

However, when using a bike, attention is required on the choice of the road to be used. For example, busy roads into peak time or roads with a high number of cars should be avoided due to air pollution that has effects on health. For example, a participant claimed that "*the choice of bike or steps in some concentrations of fine dust is not always the best*". A participant also added that on this regard we "*have too little attention for alternatives*". In addition, it is worthwhile mentioning that using a car for work commuting on medium distances is a necessity due to poor public transport. Similarly, other participants added that using the car is a necessity due to time restriction, other commitment during the day (for example, doing shopping or picking up children at school after work), and sometimes also due to weather circumstances.

In conclusion, it is clear that participants understood the necessity for adjusting their daily practice to be less exposed to air pollution and to contribute less to pollute the air. A participant claimed, therefore:

"*Small changes in my daily pattern can have a big impact on the battle against the warming of the beautiful blue planet!...Every little effort counts*."

4.9.4.8 Hasselt Route2school simulation study: feedback

Route2school project[7] was organized by the University of Hasselt to help schools and municipalities in analysing the traffic safety of school routes and the travel behaviour of pupils. Towards this goal, data have been collected about the travel behaviour of pupils and the mobility bottlenecks in Hasselt. Once these data were collected, they were transformed into a digital school route map, which can be consulted on the website as well as on the smartphone app. The school route map is therefore made by and for pupils. Among the participants in this study in Hasselt,15 participants provided feedback for the study. 80% of the participants (12) claimed that they did learn something new by participating in the study.

	Y	**N**	**Tot**
Number	12	3	15
% on total	80 %	20 %	100 %

Table 132 Number and percentage of participants in the Hasselt school route simulation activity that learned something from the activity.

When asked details about what participants learned, their response is very variegated and can be categorized into four main lessons. The first lesson is about the importance of hedges and trees as a green barrier "*between car and pedestrian*" that helps to "*reduce the exposure to air pollution*". The second lesson is that it is always "*better to take the greener route*" in order to be protected from air pollution by a green barrier. The third one is that it is better to "*keep a distance of 10 m when waiting to cross*" the road or waiting at a traffic light. The fourth lesson is that it is better "*walking in the direction of oncoming traffic*, "*on the side where the traffic meets you*".

While simulations have provided useful information to participants about exposure to air pollution, 10 participants (67%) have responded that they will not change the way they escort their kids to school. Some of the participants told they will not change route due to safety reasons. Indeed, a participant added that "*the alternative route is even more dangerous than the current one*", and therefore "*safety first, then air pollution*". A participant expressed similar views. Accordingly, "*the alternative route is perhaps greener but certainly not safer for young cyclists due to lack of cycle*

[7] https://www.route2school.be/?lang=en

path and footpath". Other participants argued they will not change route because they "*already go by bike or on foot every day*". However, five participants (33%) responded they would like to change or adjust their routes. Two of them added they would like to do so by using a bike or foot.

	Y	N	Tot
Number	5	10	15
% on total	33%	67%	100%

Table 133 Number and percentage of participants in the Hasselt school route simulation activity that would change the route to escort kids at school.

Participants were then asked if they think there is something that they can do to reduce air pollution in the city. 8 people (53%) responded that they can do something, for example by quitting or reducing the use of car to commute "*as much as possible by bike or on foot*", or to "*encourage the municipality to improve the safety around the school*".

	Y	N	Tot
Number	8	7	15
% on total	53%	47%	100%

Table 134 Number and percentage of participants in the Hasselt school route simulation activity doing something to reduce air pollution.

Finally, participants were asked if they liked the activity on a scale 1 to 5. The results look very promising. Indeed, there are no low scores (e.g. 1 and 2), while there are 5 people (33%) who scored 4 and 6 people (40%) who scored 5.

	1	2	3	4	5	Tot
Number	0	0	4	5	6	15
% on total	0%	0%	27%	33%	40%	100%

Table 135 Number and percentage of participants in the Hasselt school route simulation activity per score on the activity.

4.9.4.9 Meeting with policy makers in Hasselt

On 15th May, iSCAPE partners from the University of Hasselt met policy-makers in Hasselt to discuss impacts simulations had on the impact area *Policy change*. One participant answered the questionnaire, and in general terms, they ranked the contribution by simulations on local policies as high. On a Likert scale 1-5, the policy-maker assigned 4 to the first four statements: "Simulations activities will foster a focus on green infrastructure into the local policy agenda", "Simulations activities will contribute to improving existing urban planning/land use/built environment/health policies", "Simulations activities will contribute to creating new urban planning/land use/built environment/health policies", and "Simulations activities will contribute to improving existing air quality policies". Meanwhile, he/she assigned a score 3 to "Simulations activities will contribute to creating new air quality policies". In this way, the policy-maker highlighted the benefits of simulations provided by iSCAPE in improving different kinds of policies and in integrating air quality and pollution into the local policy agenda.

4.10 Social impact assessment of Citizen Science workshops

4.10.1 Citizen Science workshops: a description

Each iSCAPE Living Lab set up and conducted, two Citizen Science workshops to engage citizens in collecting air quality data through the iSCAPE Citizen Kit and use this to inform actions and change. The Citizen Science workshops have been undertaken within an approximately 3-week period between November 2018 and February 2019. The first workshop introduced participants to Citizen Science and the air quality sensors kit (Citizen Kit). Following the first workshop, participants have used Citizen Kits to collect data. As data can be much more powerful and easy to digest when visualised, during the second workshop participants did learn about the value and potential of the data they collected in order to inform opportunities for change.

As for previous LL activities, two questionnaires were administered to the workshops' participants by asking them questions about their demographic details, their concerns, values and behaviours toward the environment, and feedback about the use of the sensor and related air quality information.

4.10.2 First Citizen Science workshop

A total of 69 participants responded to the questionnaire administered into each. The first Citizen Science workshops half of the respondents (51%) fall in the 18-35 age class, followed by the class 36-50 (28%) (see Table 136).

	18-35	36-50	51-65	66-75	over 75	Total
Number	35	19	8	5	2	69
% on total	51%	28%	12%	7%	3%	100%

Table 136 Number and percentage of participants in the first Citizen Science workshop by age.

In terms of sex, 47 participants were men (68%), while 22 were women (32%).

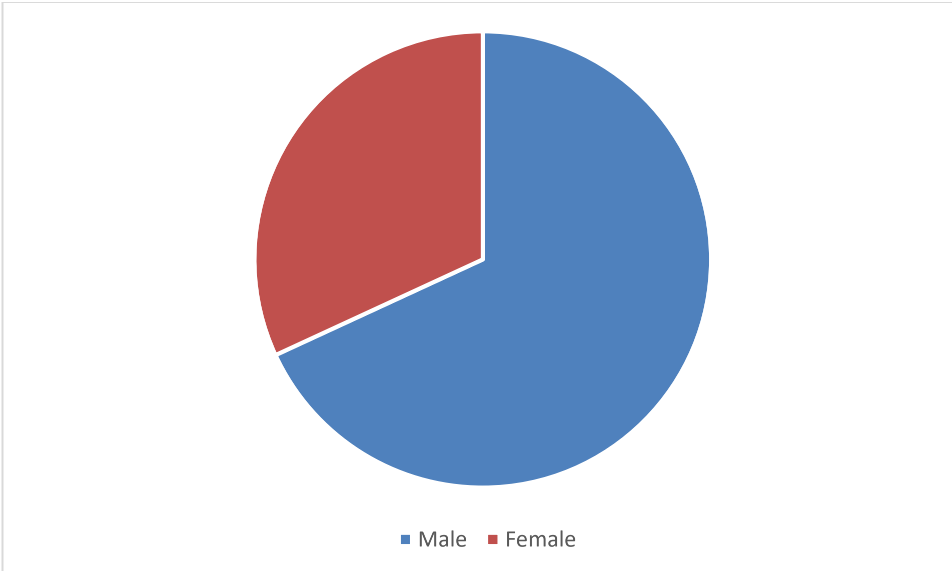


Figure 73 Participants in the first Citizen Science workshop by sex.

As we have previously mentioned for each workshop into each LL, almost all the participants of the workshop were from the country hosting each LL. Indeed, just 2 out of 69 participants came from European Countries diverse than the one of the LL, and just other 4 came from countries outside the European Union.

In terms of employment, the majority of participants (42%) were employed for a wage, followed by students (25%) and self-employed (14%), with also 9 retired (9%) (see Table 137).

	Employed for wage	**Self-employed**	**Homemaker**	**Student**	**Retired**	**Unable to work**	**NA**	**Tot**
Number	29	10	2	17	9	1	1	69
% on total	42%	14%	3%	25%	13%	1%	1%	100%

Table 137 Number and percentage of participants in the first Citizen Science workshop by employment.

In terms of education, 76% of the participants had a degree, with the majority of them holding a bachelor (25%) or a master (30%). Few of them had a high school degree (7%).

Differently from employment and education, class of income were more equally distributed, with 20% of participants included in the class 25000-49999 €, followed by those having an income less than 10000 € (17%), the class 10000-24999 € (14%), and the class 50000-79999 € (13%). However, it is worthwhile pointing out that 25% of respondents did not provide an answer to this question.

	<10000 E.	**10000 - 24999**	**25000-49999**	**50000-74999**	**75000-99999**	**>100000**	**NA**	**Tot**
Number	12	10	14	9	3	4	17	69
% on total	17%	14%	20%	13%	4%	6%	25%	100 %

Table 138 Number and percentage of participants in the first Citizen Science workshop by income.

In terms of environmental concerns, 33 participants (48%) fall into the Materialist class, and other 33 fall into the Postmaterialist class. In this way, there is a balance between two different worldviews about the environment.

	Very materialist	Materialist	Postmat erialist	Very postmat erialist	NA	Tot
Number	1	33	33	1	1	69
% on total	1%	48%	48%	1%	1%	100%

Table 139 Number and percentage of participants in the first Citizen Science workshop by environmental concerns.

Meanwhile, participants showed they were Materialist in terms of human values. Indeed, 54 participants (78%) fall into the Materialist class, with just 9 in the Postmaterialist class and no one into the Very postmaterialist.

	Very materialist	Materialist	Postmaterialist	Very postmaterialist	Tot
Number	6	54	9	0	69
% on total	9%	78%	13%	0%	100%

Table 140 Number and percentage of participants in the first Citizen Science workshop by human values.

On a similar trend, in terms of environmental behaviour see 21 participants falling into the Very materialist class (30%), with other 37 participants in the Materialist class (54%). Just 10 participants (14%) fall into the Postmaterialist class. At a general level, this means that part of the participants can be considered as being aware of environmental issues and also holding a certain degree of human values to be used for tackling environmental concerns including air pollution. However, the way they put in practice this awareness and these values is different and still materialist.

	Very materialist	Materialist	Postmaterialist	Very postmaterialist	Tot
Number	21	37	10	1	69
% on total	30%	54%	14%	1%	100%

Table 141 Number and percentage of participants in the first Citizen Science workshop by ecological behaviours.

When talking about specific questions on the sensor kit, 46 participants (67%) did show some interest in air quality information and declared they looked at information about air quality in the last calendar year. Notwithstanding this, 29 (42%) participants declared that this information were useful between 3 and 4 on a 5-score Likert scale, but it must be noted that 23 participants did not respond to this question. Meanwhile, the same number of participants showing interest in air quality information (46) declared that they received a warning of poor good air quality. This might imply that receiving warning information contributed to raising awareness of participants that looked by themselves at relevant information. When participants were asked about their beliefs on air quality impact on their life, 32 participants stated that it can impact with some health effects e.g. related to lung or heart symptoms, while 15 responded that it can have an elevate risk of lung and heart disease symptoms with slightly elevate the risk of acute disease and death. 14 participants reported that impacts on some everyday activities including commuting and hobbies. Just for 4 people air pollution does not have an impact on them. In this way, it is clear that participants recognized the impacts of air pollution on the occurrence of short and long term health symptoms.

Warning about air quality seems to have an effect on participants' behaviour. Indeed, 65 participants (94%) declared that after the air quality warning, they would like to change their daily behaviour (Table 189). In particular, the most common behaviours participants would like to change were "Using air cleaning equipment at home" (38 times), "Shutting down windows" (28), and "Changing the transport mode" (27 times).

	Shutting down windows	Using air cleaning equipment in home	Use of protective masks when outdoors	Staying indoors	Changing clothes after exposure	Having a shower after coming home	Changing the schedule of planned activities (e.g. having a run at night time)	Changing the transport mode (e.g. from walking to the car)	Some other? Please specify
Number	28	38	13	21	12	9	10	27	26

Table 142 Number of responses from the first Citizen Science workshop about changes in participants' everyday behaviour after air quality warning.

Participants were then asked to select from the previous table the two most relevant behaviours of their everyday life they would like to change and to indicate how much time and money they would have spent to change that behaviour. Several participants did not provide any response, however, those who responded reported a necessary time ranging from few minutes (e.g. 1, 10, 30 minutes) to few hours (e.g., 8 and 10 hours) to change the behaviours they have selected options. In terms of money, most of the participants reported that to change the selected behaviours they would need a few € (e.g., 5, 30, 250 €). However, in a couple of cases participants responded tht some thousands of Euros were necessary. From this, it can be stated that changing the main behaviours of their everyday life to improve air quality is generally a feasible operation for participants with relatively few money and time necessary.

We then asked the main reason why participants participated in the first Citizen Science workshop. The most common answer was related to "Raise my own awareness of air quality information" (47 times), followed by "To help researchers to gather data about air quality" (46), and with some distance by "More spatially accurate air quality information".

	More spatially accurate air quality information	Easier access to air quality information whenever needed	To plan my activities better with the help of spatially more accurate air quality information	To help researchers to gather data about air quality	Raise my own awareness of air quality information	Interest in research or environmental topics	As a statement to bring up environmental values and health concerns	Mostly for other information that can be collected with the kit, such as temperature	Out of interest for the technical specification of the Citizen Kit	Other
Number	28	15	6	46	47	18	5	7	7	3

Table 143 Main reasons for participants to participate in the first Citizen Science workshop.

The last question was related to the willingness of participants to pay to rent the sensor kit for one year. 17 participants (25%) responded that they were willing to pay between 0 and 10 €, while 17 (25%) responded from 10 to 20 € and 12 (17%) responded from 20 to 30%.

	0 E	**0-10**	**10 to 20**	**20 to 30**	**30 to 40**	**40 to 50**	**more than 50**	**NA**	**Tot**
Number	5	19	17	12	1	8	2	5	69
% on total	7%	28%	25%	17%	1%	12%	7%	3%	100%

Table 144 Number and percentage of participants per willingness to pay for an annual rent of the sensor.

4.10.3 Second Citizen Science workshop

59 participants in the second Citizen Science workshops conducted by each LL responded to the administered questionnaire. It is worthwhile noting that this workshop has been attended in some case also by people who did not participate in the first workshop but that had a curiosity for the activity and the sensor kit. In comparison with the first workshops, the percentage of participants in the class 18-35 decreases at 36% (21 people), followed by the class 36-50 (18 people, 31%) (see Table 145). Almost similar is the percentage for the older classes.

	18-35	**36-50**	**51-65**	**66-75**	**over 75**	**NA**	**Total**
Number	21	18	9	7	2	2	59
% on total	36%	31%	15%	12%	3%	3%	100%

Table 145 Number and percentage of participants in the second Citizen Science workshop by age.

Sex differences are similar to the first workshops. Male participants were 38 (64%), with 19 women (32%).

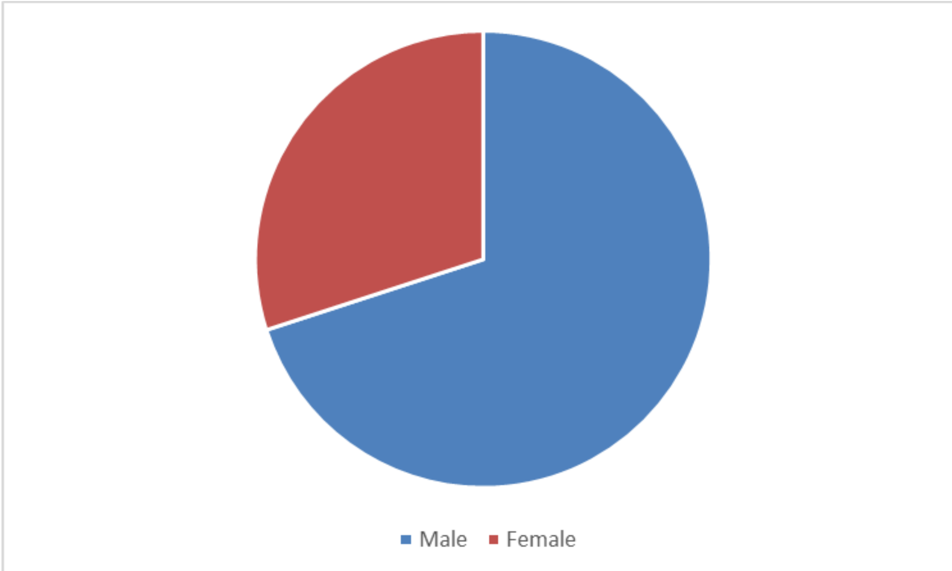


Figure 74 Number and percentage of participants in the second Citizen Science workshop by sex.

Similarly to the first workshop, in almost all cases participants' citizenship was from the hosting country, and there was just a participant from one European country and two from countries outside Europe.

	Italy	UK	Ireland	Germany	Finland	Belgium	EU	OT	NA	Total
Number	10	7	4	5	10	16	1	2	4	59
% on total	17%	12%	7%	8%	17%	27%	2%	3%	7%	100%

Table 146 Number and percentage of participants in the second Citizen Science workshop by citizenship.

Also in terms of employment status by participants, values are similar to the first workshop. Also, in this case, the most represented category is the "Employed for wage" one, with 25 participants (42%), followed by "Student" and "Retired", both with 10 participants each (17%) and then by the "Self-employed" (8, 14%).

	Employed for wage	Self-employed	Out of work and looking for	Out of work and not looking for	Homemaker	Student	Retired	Unable to work	NA	Tot
Number	25	8	0	0	1	10	10	2	3	59
% on total	42%	14%	0%	0%	2%	17%	17%	3%	5%	100%

Table 147 Number and percentage of participants in the second Citizen Science workshop by employment.

In terms of education, trends were quite heterogeneous and similar to the first citizen science. Also in this case the most represented categories were Bachelor (14, 24%) and Master (20,24%), followed by the other categories all between 5% and 7%.

	Less than high school	High school graduate	Trade/tech/vocation. Train	Ass. degree	Bachelor	Master	Professional degree	Doctorate	NA	Tot
Number	3	3	4	4	14	20	4	4	3	59
% on total	5%	5%	7%	7%	24%	34%	7%	7%	5%	100 %

Table 148 Number and percentage of participants in the second Citizen Science workshop by education.

In terms of income, differences from the first workshop are related to a lower number of participants with the lowest income (5, 8%) and a higher number of people with income falling into the class 25000-49999 (17, 29%)

	<10000	10k-24999	25k-49999	50k-74999	75k-99999	>100k	NA	Tot
Number	5	8	17	5	1	4	19	59
% on total	8%	14%	29%	8%	2%	7%	32%	100%

Table 149 Number and percentage of participants in the second Citizen Science workshop by income.

Similar to the first workshop, in terms of environmental issues, participants fall with a relative balance in the Materialist (26, 44%) and Postmaterialist classes (32, 54%). This indicates that as in the first workshop the participants have two main and quite different worldviews on environmental concerns.

	Very materialist	Materialist	Postmaterialist	Very postmaterialist	NA	Total
Number	0	26	32	0	1	59
% on total	0%	44%	54%	0%	2%	100%

Table 150 Number and percentage of participants in the second Citizen Science workshop per environmental concern score classes.

The same path of the first workshop also occurs in the case of the human values questions. Alo in this case, participants were mainly materialist (45, 76%) followed with a large gap by the Postmaterialist class (8,14%).

	Very materialist	Materialist	Postmaterialist	Very postmaterialist	Tot
Number	6	45	8	0	59
% on total	10%	76%	14%	0%	100%

Table 151 Number and percentage of participants in the second Citizen Science workshop per human values score classes.

As also occurred in the first workshop, a dichotomy exists between participants' responses to questions related to environmental concerns and human values and those related to ecological behaviour. Indeed, as in the first workshop, also, in this case, a number of participants fall into the

Very materialist (21, 36%) and Materialist classes (29, 49%). This generally means that even though part of the participants are concerned about the environment and have human values to potentially support ecological behaviour, their actual ecological behaviour is low.

	Very materialist	Materialist	Postmaterialist	Very postmaterialist	NA	Tot
Number	21	29	5	0	4	59
% on total	36%	49%	8%	0%	7%	100%

Table 152 Number and percentage of participants in the second Citizen Science workshop per ecological behaviour score classes.

In terms of air quality information, 41% of the participants (24) stated they used the air quality sensor provided by the iSCAPE project every day, while 16 (27%) used the sensor weekly. However, 9 participants (15%) did not use at all.

	Daily	Weekly	Monthly	Not at all	NA	Tot
Number	24	16	2	9	8	59
% on total	41%	27%	3%	15%	14%	100%

Table 153 Number and percentage of participants in the second Citizen Science workshop per sensor usage frequency.

46% of participants to the second workshop also found information related to air poor quality not just from the sensor, but also from other sources.

	Y	N	NA	Tot
Number	27	28	4	59
% on total	46%	47%	7%	100%

Table 154 Number and percentage of participants in the second Citizen Science workshop per air quality information retrieved from other sources.

We also asked participants whether, by using the sensor, they did receive a warning or collected information with the sensor that showed poor air quality during the test period (see Table 155). However, more than half of the participants (30, 51%) reported they did not receive information. Among those who responded Yes (26, 44%), 21 of them (81%) reported that they received the warning from the sensor, that observed poor air quality, while just 2 of them retrieved poor air quality information from an external source (see Table 154). This means that the sensor was useful to report on time air quality information for those who used it.

	Y	N	NA	Tot
Number	26	30	3	59
% on total	44%	51%	5%	100%

Table 155 Number and percentage of participants in the second Citizen Science workshop that received poor air quality information from the sensor in the test period.

	Mobile-sensor observed poor air quality	I received a poor air quality warning from an external source	NA	Tot
Number	21	2	3	26
% on total	81%	8%	12%	100%

Table 156 Number and percentage of participants in the second Citizen Science workshop per source of poor air quality information.

The participants' perceptions about the impacts of poor air quality warning on their life were similar to the first workshop. Also, in this case, the first response (23 participants) was that air quality can have some health effects in relation to e.g. lung or heart symptoms. 14 participants claimed that air quality can have effects on everyday activities such as communing and hobbies, while 8 people mentioned that it can cause elevated risk of lung and heart disease symptoms. Just 3 people stated air quality has no impacts.

We also asked whether information retrieved from the daily use of the sensor affected the daily routine of participants (e.g., it lead to change some behaviour or to be more aware of air quality). 18 participants (31%) responded that this information had effects, while 37 of them (63%) did not feel affected. This means that once received air quality information from the sensor, 31% of the participants took some strategies to reduce their exposure to polluted air in their daily routine. We asked them which these strategies were, and according to Table 207, the most common were "Shutting down windows" (5 participants), followed by "Avoiding exercise outdoor" and by "Changing the transport mode". 8 people also responded "Other".

	Y	N	NA	Total
Number	18	37	4	59
% on total	31%	63%	7%	100%

Table 157 Number and percentage of participants in the second Citizen Science workshop that perceive impacts by poor air quality.

	Avoiding exercise outdoor	Shutting down windows	Using air cleaning equipment in home	Use of protective masks outdoor	Staying indoor	Changing clothes after exposure	Having a shower after coming home	Changing the schedule of planned activities	Changing the transport mode	Other
Number	4	5	2	2	1	1	3	3	4	8

Table 158 Number of responses about participants' strategies to cope with poor air quality warned by the sensor.

We also asked whether air quality information from sources other than the sensor (e.g., tv, radio, apps) affected the daily routine of participants. Accordingly, just 11 participants (19%) perceived that the information on air quality as provided by sources other than the sensor affected their daily routine. It affected routine life as it led participants to e.g. "Avoiding exercise outdoor" (3 participants), "Shutting down windows" or "Changing clothes after exposure".

	Y	N	NA	Tot
Number	11	32	16	59
% on total	19%	54%	27%	100%

Table 159 Number and percentage of participants in the second Citizen Science workshop that perceived impacts by poor air quality warned from other source.

	Avoiding exercise outdoor	Shutting down windows	Using air cleaning equipment in home	Use of protective masks outdoor	Staying indoor	Changing clothes after exposure	Having a shower after coming home	Changing the schedule of planned activities	Changing the transport mode	Other
Number	3	3	1	2	1	3	2	3	3	1

Table 160 Number of responses about participants' strategies to cope with poor air quality warned by other sources.

As for the first workshop, participants were asked to select from the previous table the two most relevant behaviours of their everyday life they would like to change, and to indicate how much time and money they would have spent to change that behaviour. Several participants did not provide any response, however, those who responded reported that in most cases the necessary time ranged from a few minutes to 1 hour for both the options. Meanwhile. in terms of money, most of them reported 0 €. Generally speaking, also in the case of the first workshop participants consider changing their behaviours as something cheap that does not take so much time.

We asked the satisfaction of participants in the use of the sensor. On a scale 1-5 (1 worst, 5 best), the mobile-sensor fulfil the expectations/reasons of the participants mostly at level 3 (18, 31%), followed by the level 2 (9, 15%) and 4 (10, 17%).

	1	2	3	4	5	NA	Tot
Number	7	9	18	10	8	7	59
% on total	12%	15%	31%	17%	14%	12%	100%

Table 161 Number and percentage of participants per score of satisfaction about the sensor.

Participants were then asked to report and describe the benefits received from the use of the mobile-sensor during the test period. Generally, the benefits were related to three main topics, that are interrelated to each other and have overlapped. The first one was related to the gained knowledge about air pollution. For example, participants stated that:

"It was helpful to set an idea of the level of pollution on my street"

"I know how much I am exposed to pollutants on a busy intersecting road in my street"

The second topic was related to the interest in the activity that was conducted and on the use of the sensor. For example, some participants argued that a benefit was the

"Interest in future more user-friendly sensor and interface"

and that

"Looking at the data, I was able to match the transport type (waking, tram, cycle, etc.) with exposure to air pollution. I could also watch location to exposure. This insight can empower citizens by letting them choose to avoid certain hotspots".

The third topic was related to the use of the sensor in different indoor and outdoor environments, such as homes and offices or during commuting time. Here below we have reported verbatim some of the most significant description of these benefits:

"More knowledge about air quality generally. Scientific knowledge about the level of air pollution in the neighbourhood"

"I have learnt that on intersection and especially in a condition of congestion, there is mad air quality in that area"

"I got to see data from my area that was very interesting. Now I can search for the cause of weird things appearing in data"

Participants were then asked about their willingness to pay for an annual rent of the mobile sensor. In comparison with the first workshop, values have generally changed. The value 0-10 € and 10 to 20 € decreased by 19%, while higher values slightly increased, in particular, the value 40 to 50 €. This means that across the two workshops participants dramatically increased their trust in the use of the sensor and showed more willingness to rent the sensor.

	0 E	**0-10**	**10 to 20**	**20 to 30**	**30 to 40**	**40 to 50**	**more than 50**	**NA**	**Tot**
Number	5	11	11	11	2	10	3	6	59
% on total	8%	19%	19%	19%	3%	17%	5%	10%	100%

Table 162 Number and percentage of participants' per classes of willingness to pay for an annual rent of the sensor.

The last question was related to how much time the participants were willing to rent the sensor for. Almost half of the participants (28, 47%) stated they would rent the sensor for one year, followed by 9 participants with a willingness to rent for 3 years (9, 15%).

	a. 1-year	**b. 2-year**	**c. 3-year**	**d. 4 -6 year**	**e. 6 -10 year**	**f. more than 10 years**	**NA**	**Total**
Number	28	2	9	2	5	1	12	59
% on total	47%	3%	15%	3%	8%	2%	20%	100%

Table 163 Number and percentage of participants per classes of time for the rent of the sensor

4.11 Social impacts as perceived by LL partners

4.11.1 Impacts perceived by the Bologna LL

We have submitted to Bologna LL's members some questions to gather their impressions about the impacts of the LL activities on participants, citizens and local stakeholders. Accordingly, the LL member claimed that participants' feedback on the LL activities was very positive. Indeed, participants argued that they gained new knowledge, particularly in relation to the necessity for green areas into urban areas. In addition, participants also stated they have gained a better understanding of what green infrastructure mean in practice into urban areas, and a more comprehensive perspective of the challenges and benefits of planning and projecting green spaces into urban areas (e.g., budget issues, how to speak with local authorities, and so on).

The LL members reported that the engaged citizens were generally aware of environmental and climate issues, therefore reaching out an impact has been relatively easier also by considering that all the activities had a clear take-home message. Particularly, it was observed that participants in Bologna were keen to modify their behaviour, e.g. in terms of travel mode, to reduce their contribution to air pollution. Participants to the Citizen Science workshops were also generally aware of air pollution issues, therefore they took part in the workshops bringing their ideas about measuring air pollution with low-cost sensors.

In the case of the Citizen Science workshops, impacts were related to a correct low-cost sensors data treatment and analysis, and to a more in-depth knowledge of the limitations of the sensors. Finally, in the co-creation workshop focusing on vegetation, prior to the workshop most of the participants thought that planting trees was a good solution for air quality and urban thermal comfort. However, they did not realize the possible disadvantages deriving from planting trees, especially if not correctly planned. Therefore, the impact of this workshop helped the participants to gain a more solid and comprehensive overview of planting trees in an urban environment, including the limitations of such an intervention. The activities carried out by the Bologna LL can represent a paradigm to organize other similar initiatives in the future. After participating, most of the citizens involved in the initiatives will probably be more careful about environmental issues, and therefore will probably maintain interest in participating in citizens' science activities.

Further to impacts on citizens, the Bologna LL activities had also impact on local stakeholders and other local associations carrying out similar initiatives. Indeed, some of these stakeholders and associations participated in the LL activities. Some local associations were interested in the citizen science workshops with low-cost sensors, while stakeholders were interested in the potential of interventions at the local level to support citizens in changing their behaviours. Initially, the LL was a little bit slow in starting, but after the informative workshop organized the day after the mid-term event in Bologna it took a good pace. During the final year of the iSCAPE project, a number of initiatives including co-creation activities (low-cost sensors and vegetation) and Citizen Science workshops were organized. Perhaps, the most important moment among these activities was the co-creation workshop on urban vegetation, as it represented an opportunity for a real exchange of ideas between scientists and citizens. During this activity, it was realized that the participation of citizens into LLs can bring fresh ideas capable to foster the LL itself. After suggestions from some of the participants to plant trees along the Marconi St., for example, the Bologna LL decided to conduct simulations to analyse the effect of planting different types of trees along the Marconi St. in terms of urban thermal comfort and air pollution.

Several lessons were learned during the Bologna LL experience. Citizens caring for environmental and climate issues have already plenty of ideas or suggestions on how tackling these issues, although they are not always totally correct. The main challenge, however, is that often they do not trust too many local stakeholders and policymakers. Finally, stakeholders often want to know the impact of intervention not only in terms of air pollution reduction but also in terms of attractiveness for the citizens. Due to these reasons, the participative processes to the LLs initiatives with scientists is key to allow any kind of policy changes, in particular for a hot topic such as air quality.

- Mainly young participants (18-35 years old) took part into LL activities, mainly women from Italy with bachelor or more.
- Participants had postmaterialist and high postmaterialist environmental concerns and human values, however the associated environmental behaviour did not correspond to these high values and was mainly low materialist or materialist.
- However, participants realized the need to change their everyday behaviour towards reducing air pollution
- Participants prioritized changes in security, green areas availability and public transport as main changes required in the city
- Participants were mainly satisfied and high satisfied about the LL activities. The LL activities were useful to understand environmental issues in urban areas and to specifically understand how to plan and finance green infrastructure into urban areas to reduce pollution.
- Participants in the citizen science workshops shared their ideas about measuring air pollution with low-cost sensors and had more understanding of the sensors.
- Interest by local stakeholders (e.g., policy makers and local associations) in the sensors and in the potential of these initiatives in fostering better behaviours by citizens
- Impacts in terms of opportunities for promoting an exchange of fresh ideas between scientists and citizens.

4.11.2 Impacts perceived by the Bottrop LL

We have submitted to Bottrop LL's members a short questionnaire based on open-ended questions with the aim to gather the impressions about impacts of the LL activities on participants, citizens and local stakeholders. Along with the iSCAPE project, the Bottrop LL represented an arena for testing new ways and formats to raise citizens' awareness for urban green and have a positive impact on urban climate. The Bottrop pilot and LL activities (Citizen Science WS, Wandering Tree Parade) have always been characterised by active participation and co-creation with citizens of all ages, that gained more knowledge about these topics. The activities have been conducted with the aim (partially met) of changing behaviour or mindset. The Wandering Tree Parade 2018 strengthened the commitment by citizens in taking part in discussions of green issues, also on the media. These discussions contributed to raise awareness on the benefits of trees and to increase the acceptance of trees into the street design. The Wandering Tree parade also gave citizens the possibility to actively contribute to shaping the city they want to live in and reminded them that such a possibility exists. Within Citizen Science activities, the citizens measured the concentration of pollutants with low-cost citizen sensor kits and were then able to draw their own conclusions and consequently change their behaviour if desired.

Therefore, the Bottrop LL activities represented an attempt to bring science and society closer together, and to create an active community around the topics of urban green, climate and air quality. Hopefully, these and additional activities will be able to further sensitise on the topic and encourage behavioural changes. For example, the upcoming Wandering Tree Parade in 2019 ongoing these months is focusing on elementary schools and kindergartens. Pupils can be tree caretakers, with the potential to further contribute towards a pro-environmental education of pupils. Up to now, interactive lessons at elementary schools focussing on the functions of trees and their importance are held, as well as there is a discussion about the idea of a “project-week” around the topic. With its implementation, the education policy at elementary schools around the environment can be influenced and extended.

Furthermore, there is still interest around the Citizen Science activities. For example, some of the sensors are still in use and participants are still collecting additional data and testing the sensors. Such interest could increase in future if some more activities would be conducted.

The Wandering Tree Parade did not just have impacts on citizens but was also able to bring together a variety of different stakeholders (i.e. citizens of all ages, various departments of the city administration, economic actors, researchers). This provided an inside into a transdisciplinary perspective on air quality management and green issues and promoted the creation of a network of local stakeholders that can be expanded in the future.

The first Citizen Science workshop was successfully attended, and participants showed an interest in air quality and curiosity about the sensors. Participants came up with enthusiasm and excitement about how to use the citizen kits and what to measure. It was shown to them how to install the sensors, and then citizens did the setup together. After testing the sensors, participants provided feedback concerning the usability in order to improve the devices. They found out that most of their ideas in the first workshop were too complex to be measured, and because of these high expectations, the data analysis within the second workshop turned out to be more difficult.

The Bottrop LL learned several lessons from LL activities. First, setting up new co-creation formats for active participation (such as the Wandering Tree Parade and the Citizen Science workshops) requires a lot of resources and especially manpower to initiate interventions as a lot of educational work and sensitisation needs to be done. In addition, an “expert” from the civil society, that is already closely involved with air quality issues, would be very helpful especially in case of supporting the community by operating as mediator. By repeating the format, the resource input can be reduced since necessary steps are known and the framework is set. Initially, some of the citizens were sceptical about the innovation of the initiative, but when curiosity was stimulated, they were more willing to participate. Nevertheless, it was difficult to maintain motivation and commitment by participants over a long time especially when some difficulties might occur. To run a LL, face-to-face contact is necessary since there is considerable scope for dialogue and discussions. In this way, a local person is needed as a contact point. Notwithstanding some difficulties, the LL activities have been generally successful because they brought together many different actors and contributed to improving the relationship between the municipality and the citizens.

The City of Bottrop, therefore, had positive feedback about the LL activities. While a direct impact on Bottrop's air quality policy cannot be clearly determined at this stage, as it has been said the Wandering Tree parade is undergoing for the second edition in summer 2019 after the success of 2018 experience. This indicates therefore that a high degree of public recognition exists for this activity. Finally, referring back to Bottrop LL and especially the participative processes, sensitisation around air quality and UHI topics is a fundamental step that can definitely be assumed and might engage the stakeholders to introduce/weigh in the topic into several policy areas. Indeed, the topic of UHI and air pollution must be comprehensively anchored in municipal structures, political decisions or convictions/commitments and urban policies.

- Participants in the Wandering Trees Parade were mainly local residents between 36 and 55 years old, female, with bachelor or more in terms of education status
- Participants in the Wandering Trees Parade had average concerns about the environments and were sustained by post-materialist human values. Meanwhile, they also had postmaterialist ecological behaviours.
- Participants were satisfied about the impact areas Leisure and social interaction.
- Participants prioritized changes in the number of trees, improved security, and the offer of leisure services (cinema; theatre, exhibitions)
- Participants expected changes into green areas availability, improved security and public transport as main ones required for the city of Bottrop
- Participants were mainly satisfied and high satisfied about the Wandering Trees Parade. The parade was useful to understand the importance of trees and environmental quality into urban areas. Accordingly, the parade can have an impact on the city as it can lead to more attention about greening and environmental issues. After the parade, it seems that the participants were slightly more satisfied about trust into their neighbourhood.
- Thanks to LL activities, local stakeholders were more aware of the topic of air quality and pollution, and were provided with providing new skills and competences for a better acceptance of greening into Bottrop.
- Local stakeholders claimed that the Wandering Tree Parade can be repeated in the future, as it is currently ongoing in these months.
- Policy-makers also reported that the activities by the Bottrop LL can contribute to improve the policy agenda around air quality, also including urban planning, environmental issues, and human health
- Input for improving formats for citizens' engagement activities.
- Input for stimulating curiosity of citizens about greening into urban areas

4.11.3 Impacts perceived by the Guildford LL

We have submitted to Guildford LL's members few questions to gather their impressions about the impacts of the LL activities on participants, citizens and local stakeholders. In Guildford, activities like Citizen Science workshops and other engagement activities have contributed to raising awareness among citizens around air quality and pollution. LL activities have helped in making people understanding how they could reduce their personal exposure by changing some of their daily routines. Across these years, the Guildford LL has established strong relationships with both citizens and policy-makers. Feedback has always been positive, and therefore it can be said that opportunities exist for consolidating partnerships with citizens and communities by working together to raise awareness about air pollution and find strategies to tackle the problem by using passive solutions. For example, since the LL started disseminating information about how green infrastructure can help reduce personal exposure, citizens have become more aware of what kind of hedges they should have, what kind of species they should use etc. Further to citizens, LL activities also impacted policy-making by raising awareness among the citizens. Indeed, more aware local residents will encourage local stakeholders such as associations, policy-makers, civil servants, other research organisations, etc. to consider such passive solutions in their future plans.

In this way, the experience with LL activities has been positive and encouraging. Citizens were informed about the air pollution problem. During the citizen science workshops, participants were not just passive actors but they were also willing to debate, put forward their points and share potential solutions. In addition, results from LL activities have been regularly disseminated and shared not just with the citizens but also with the local council members. The council members gave value to LL's work and were willing to be more involved in LL activities targeted towards reducing pollution exposure. All these activities and interactions can be considered as small steps which can potentially lead to a policy change.

- Participants in the Guildford LL activities were mainly over 51 years old, with a balanced representation of male-female gender. Over half of them were retired, mainly with bachelor or higher education levels
- Participants had usually a postmaterialist and very postmaterialist approach to environmental concerns and human values. However, in terms of environmental behaviours they were mainly materialist, marking a relatively large difference between what they think about environment and what they put actually in practice.
- Guildford LL activities were useful to let participants understand the important of green infrastructure
- Guilford LL activities also represented an input to change behaviours towards reducing air pollution and to work as communities towards this within local associations.
- Policy makers stated that simulation in Guildford were helpful to show opportunities for using green infrastructure in Guildford
- Thanks to the Guildford activities, it was possible to have a key rfole in the development of the guideline "Using Green Infrastructure to Protect People from Air Pollution", summarising the best practice on the use of green infrastructure to reduce public exposure to urban air pollution.

4.11.4 Summary of impacts for Dublin LL

We do not have a response to our dedicated questionnaire by the Dublin ll. However, the contents below represent a summary of the main impacts as retrieved from the aforementioned activities.

- Participants in the LBW field campaign were international people between 18- and 35 years old with high status education.
- Participants in the LBW field campaign had postmaterialist and very postmaterialist approach to environmental concerns and were generally satisfied about the performed activity
- Pupils participating in the co-creation workshop at St. Catherine's National School in Dublin were mainly 12 years old with an equal male-female gender representation, mainly speaking English at home.
- Pupils claimed that they have enjoyed the co-creation workshop and that they have learned the problems of air quality in Dublin and the necessity for changing lifestyle in terms of everyday transportation, food, and behaviour.
- During a meeting with Dublin LL, policy-makers stated that iSCAPE simulations have been useful to provide evidences and background for improving the local policy agenda around air quality. In addition, the information provided with the simulation can also contribute to create new air quality policy by providing an understanding of the linkages between air quality and environmental variables.

4.11.5 Impacts perceived by the Hasselt LL

We have submitted to University of Hasselt iSCAPE partners some questions to gather their impressions about the impacts of their activities on participants, citizens and local stakeholders. Citizen engagement activities in Hasselt aimed at encouraging pro-environmental and healthy travel behaviour using information based behavioural intervention. One of the studies aimed at promoting environmental friendly activity travel choices among citizens in Hasselt and was based on strategies such as education and encouragement. Its findings revealed both individual and societal benefits by the study, that recorded a significant increase in active mobility which helps to achieve daily physical activity targets recommended by WHO. Meanwhile, the study also recorded a significant reduction in car use that leads to a decrease in CO_2 emissions and helps to lower the pollutant concentration created due to vehicular emissions. Another study was conducted to promote active school travel by adopting a less-polluted routes, by providing information about pollutant exposure and physical activity involved in current and suggested school routes are provided. Based on the feedback provided by the participants, again individual and societal benefits were found. Feedback from participants revealed that 46% of the participants showed the intention to adopt suggested routes with less exposure to pollutants. Meanwhile, 40% of the participants gave the impression that they can take steps to reduce air pollution in their surroundings, including less use of cars and more use of active modes, growing more vegetation, and spread the word. The activities can have impacts on citizens also in the future. Indeed, the main conducted activities are based on information-based strategies/interventions which can influence change in behaviour relatively easy with high benefits and affect/influence the behaviour for long periods as they have pull type of effects.

Further to impacts on citizens, the activities in Hasselt also have impacts on other local stakeholders, in particular, policy-makers. In Hasselt, the municipality supported the activities at every stage such as participant recruitment campaigns, dissemination event etc. In addition, city officials greatly appreciated strategy adopted to address air pollution and city mobility together.

The response of the city officials showed that pilot studies have influenced them as well and they want to create a sustainable policy based on the findings. The Stad Hasselt also appreciated the contribution by simulation study on policies. The city is indeed thinking of making inner ring car-free as well as of putting restrictions on car access to the inner ring. So, they took great interest and there was a healthy discussion on the implementation plans of this policy.

Therefore, activities by the University of Hasselt represented a moment of high engagement with citizens and local stakeholders. For example, after the end of the pilot study, the LL conducted a dissemination event that went very well and was very much appreciated by the City Officials. In addition, at the end of the active school travel study, participants provided nice feedback where they scored 4 out of 5 on average in terms of their satisfaction in the study. The reason behind this high score was the easiness and user-friendliness of the adopted approach. Notwithstanding this, there were also moments when doubts arose from citizens about the usefulness of the activities. For example, in the second Citizen Science workshop, few participants highlighted the issue that the temperature sensor of the citizen kit was significantly not accurate. One participant, for example, said that air pollutant sensors cannot be trusted if the temperature sensor was not working properly. Similarly, participants in the citizen science workshops responded that they were expecting the citizen kit more user-friendly and had many concerns about its hardware such as exposed components. The prime objective of the engagement activities is to educate citizens to adopt eco-friendly activity travel choices by providing consequences of their activity-travel behaviour. One step in the process of policy implementation is to take public consent. As individuals are already aware of the possible impacts of air quality so it will not take long for public consensus and proceed toward the policy implementation. This is the way to foster the participation of citizens in the Hasselt LL activities to lead to policy changes related to air pollution.

- Behavioural intervention studies in Hasselt represented citizens' engagement activities that supported a shits by some of the participants towards active mobility.
- These studies also provided individual and societal benefits by promoting a reduction into car use with a decrease in CO_2 emissions and pollutant concentration
- The Route2school activity made participants aware of the individual and societal benefits for adopting less pollutant routes to go to school.
- Citizen science workshops allowed to educate people around the use of sensors
- The City of Hasselt found useful the information provided with the simulations and the behavioural studies
- The City of Hasselt found useful the linkage provided between air pollution and city mobility. In this way, there is willingness by the City to create a sustainable policy using iSCAPEdata as a background

4.11.6 Impacts perceived by the Vantaa LL

We have submitted to Vantaa LL's members few questions to gather their impressions about the impacts of the LL activities on participants, citizens and local stakeholders. The observed impacts and benefits of the Vantaa LL are the following. Citizens have clearly learned how to observe the environment in a new way. For example, they can now realise that they can change the walking route to have less exposure to air pollution. In addition, citizens have better understood that environmental monitoring is today relatively easier and cheaper. Citizens have also been informed better about the kind of research conducted within the Vantaa LL and the available expertise. The Vantaa LL activities have received an only positive response, therefore there is space to produce future impacts on citizens. Further to citizens, also local stakeholders, especially the city workers, seem to have a better understanding of the capabilities for high-detail simulations, modelling, measurements etc. This is also due that there was a big knowledge gap on these issues before Vantaa LL openly talked about them. Vantaa LL activities demonstrated that children are really and surprisingly active and motivated to participate in science. In addition, the activities also demonstrated that local stakeholders often struggle with limited resources and time to improve the quality of life into cities. In this way, participatory activities like the ones promoted by iSCAPE can provide beneficial support for them. Participative processes into Vantaa LLs have also been able to lead to practical change. A small practical example is related to the use of sensor citizen kits for measuring air pollution levels (of smoking) in a residential building terrace that led to forbidding the smoking based on the measurements. Generally, air quality issues in Vantaa are limited in comparison with other iSCAPE cities, so at a larger scale, there are no big political changes observed. However, the Vantaa LL has impacted into city planning in relation or urban heat island.

- The Vantaa LL conducted a workshop with the City of Vantaa to discuss the potential integration of iSCAPE activities' results into local planning. The City of Vantaa declared that the data produced by the project can be integrated into the future Masterplan to detect the most vulnerable areas to climate change and to promote a better planning of the city in terms of building efficiency and green areas availability.
- On the same vein, in a meeting with the Vantaa LL, a policy-makers highlighted that simulations conducted in Vantaa will foster a focus on air quality into local policy agenda, as they will provide more detailed and reliable information on air quality. In this way, simulation will also contribute to improve existing urban planning, land use, built environment, and public health policies.
- Teachers participating into the activity organized by the Vantaa LL with Turku high school students in Eureka reported impacts around the Education impact area. Indeed, during this activity the students used their mathematical skills to think about the spatial representation of the city, and to practice city planning and to think about how to locate different areas (for example parks, green elements, and built-up areas).
- The Vantaa activities also stimulated curiosity and motivation round pupils and students to understand climate change and air quality

4.11.7 Summary of social impacts of the Living Labs

These sections have assessed impacts each activity of all LL participating within iSCAPE project had on participants. These activities were LLs' (where available), engagement and co-creation activities, behaviour intervention studies, Citizen Science workshops, and meeting and workshops with policymakers and local stakeholders. To do this, we have administered a series of ad hoc questionnaires to participants in all the activities, where we asked questions related to demographic details, to concerns, values and behaviour around environmental issues, and to a feedback of the performed activities. In terms of demographic characteristics (age, sex, income, education status) the engaged population is quite variegated. However, most of the activities have seen the engagement mainly of citizens from the country of the LL. In this way, there has been limited variation in terms of citizenships.

In terms of concerns, values and behaviours around the environment, we can say that in general terms participants were mainly people already concerned about the environment with a postmaterialist approach towards the environment. Similarly, in terms of human values, participants highlighted a postmaterialist trend, with people mainly interested in community and inclusive values instead of exclusive or individualistic ones. However, when we look at the findings on the ecological behaviours of these participants, we find that these behaviours just partially mirror environmental concerns and human values. Indeed, for several of the assessed activities, we have found that the responses around ecological behaviours questions provided mainly a materialist or very materialist portrait of the participants. In this way, although people were aware of environmental issues, and had such human values to sustain individual action towards improving air quality and reducing air pollution, their behaviours "on the ground" do not aliged yet with this awareness and values.

Notwithstanding this, it must be noted that all the activities led participants to reflect on the urban environment and the neighbourhood they live in. For example, participants have understood the necessity to have more green areas and infrastructure in urban areas, and to support policies for greening, as with the fruitful activities by Guildford LL with local associations, the Wandering Tree Parade in Bottrop or the co-creation activities in Bologna. Participants also understood the necessity to ask for a more efficient public transportation and to create areas at the local level where people can improve their social interaction and strengthen social cohesion and social capital.

However, participants were also stimulated to reflect on their own individual everyday practices. In this way, it was interesting to see that participants in all the LL activities expressed willingness to take action towards making their behaviours more relevant to contribute to air quality and to reduce their exposure to air pollution. On this regard, the behaviour intervention studies in Hasselt, Bologna, Dublin and Guildford represented an input for participant reflect about an individual shift from private car towards active mobility by walking or cycling, to increase interest in buying a bike or an e-bike, or to avoid polluted routes for their everyday commuting in order to reduce the individual exposure to air pollution. All LLs' activities also stimulated curiosity about specific and general impacts of air quality. This did not occur just among the adults participating in the LL activities, but also among pupils and students participating in activities of Dublin and Vantaa.

Other important impacts were found during the two Citizen Science workshops organized by each LL to explore the use of sensors in measuring air quality at the local level. Accordingly, these workshops were useful to stimulate the interests of citizens in using and testing low-cost sensors for air measurements. Indeed, at the end of the second workshops, citizens declared they would like to rent a sensor for a long time and sometime also to pay high price (e.g., 50 € per year) to rent and use this sensor. This also implied that citizens had the opportunity to develop their scientific capacities in collecting, communicating and analysing air quality data. Meanwhile, citizens had also the opportunity to share and gain scientific knowledge by working closely with experts and scientists around air quality.

Further to these impacts, it must be highlighted that LL's activities led and have the potential for leading to a policy change. In all the participating cities, during a dedicated meeting with policy-makers, these latter revealed that simulation and data collected into LL activities represented a useful background for improving policy agenda not just on air quality, but also on urban planning, environmental sustainability, and public health. This can also represent an input stimulus for the creation of new and updated policies and guidelines, as it occurred for example with the collaboration of the Guildford LL with the City of London around the development of air quality regulation guidelines, or with the ongoing dialogue between the Vantaa LL and the City of Vantaa for the development of the new Masterplan.

In this way, the iSCAPE project, thanks to its close involvement with citizens along three years, has undoubtedly contributed to touch upon several areas of impact as identified within the socioeconomic impact assessment framework. These impacts occurred at different levels for each LL, and next steps for further development are surely required.

Suggestions for future application of LLs into air quality issues can also be made. On the one side, strategies are required to find effective strategies to engage people that are not aware yet of environmental issues (that we can define "very materialist") or that is not fully part yet of the cultural background of the country hosting the participating cities (e.g., people with different citizenship or with an other-than-English language as language spoken at home). On the other side, while all LLs have been happy about the conducted activities, it is also true that innovative and creative strategies are required to stimulate local people in participating in LLs' activities. In terms of impacts, this would imply coverage of more impacts areas.

4.12 Economic impact assessment of intervention: methodology and results

The economic analysis estimates (a) the non-market benefits related to health and (b) the market benefits related to residential real estate that stems from improving air quality. The air quality improvements come from green infrastructure, which provides a broader bundle of ecosystem goods and services (see e.g. Bateman et al. (2011), Davies et al. (2011) for urban ecosystems specifically); we, therefore, estimate, as an indication, the market benefits of green infrastructure as well. It should be noted that all these benefits are estimated as partial equilibria and there also exist cross-sectoral and indirect effects that cannot be accounted for in this project; we do provide, however, a synthesis in this deliverable and portfolio analysis in D5.4 that attempt a comprehensive stance. The market benefits utilize the hedonic pricing method and are calculated using residential real estate values as the indicator of the benefits that air quality and green infrastructure improvements bring to the urban economy (see D5.6 for the methodological details). The non-market benefits are calculated using the impact pathway approach (Figure 75).

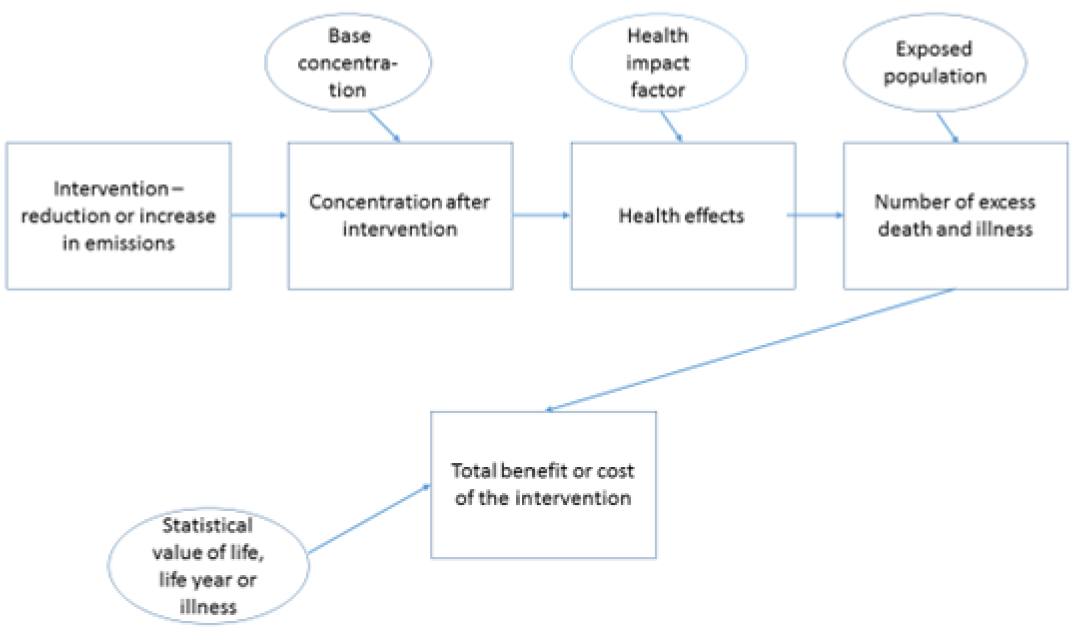


Figure 75 Impact Pathway Approach. (ExternE, 2019)

To make calculations based on the Impact Pathway Approach, we need first describe the intervention, and model/predict/observe the changes in the concentration levels of pollutants, most importantly NO_2 and $PM_{2.5}$. We describe these changes separately for each passive-control-system (PCS).

The health impact factors are obtained from epidemiological studies, or meta-analysis studies, that bring together the findings of multiple epidemiological studies. In this analysis, we use the state-of-the-art findings from the World Health Organization (2013). Health impact factors are usually expressed with concentration-response functions. Concentration-response functions tell the relative risk for different health end-points following an increase in exposure due to higher concentration levels. Relative risk needs to be multiplied with the background relevance of the end-point and the resulting health effect can be calculated. Once the background relevance is subtracted from this figure, the result is the increase in negative health impacts. This is then multiplied by the change in the concentration. Next, the result will be multiplied by the economic value of the end-point. The process is repeated for different end-points, and for all the relevant pollutants.

For end-point *i*, and for $PM_{2.5}$, the impact per person is thus calculated based on the following formula:

$$〚EV〛_{(i,PM_{2.5})} = (〚RR〛_{i,PM_{2.5}} * 〚BR〛_{i,PM_{2.5}} - 〚BR〛_{i,PM_{2.5}}) * \Delta C_{i,PM_{2.5}} * V_i \quad (20)$$

, where EV denotes the expected economic value (€) of increase in the concentration of pollutant *i*, RR denotes relative risk (unitless) of end-point *i*, BR base rate (unitless) of end-point *i*, ΔC the change in $PM_{2.5}$ concentration (ug/m^3), and V the economic value (cost in €) of health/endpoint *i*.The following table (Table 164) summarises the health end-points *i* for the pollutants considered in iSCAPE, $PM_{2.5}$ and NO_2, together with their relative risk (RR) values (Equation (20)). Based on numerous studies, they account for more than 90% of the total impact of air pollution. In the table, relative risk is unitless and defined as the ratio of the probability of the health-endpoint (i.e. mortality or various kinds of morbidity) in an exposed group to the same probability in an unexposed group; values over 1 are interpreted as higher risk of health-endpoint in the presence of increased pollutants (i.e., per 10 ug/m^3).

Pollutant metric	Health-endpoint	Relative risk (95% confidence interval) per 10 ug/m^3	Age-group
$PM_{2.5}$, annual mean	Mortality	1.062 (1.040-1.083)	>30 years
$PM_{2.5}$, daily mean	Mortality	1.0123 (1.0045-1.0201)	All
$PM_{2.5}$, daily mean	Hospital admissions due to cardiovascular diseases	1.0091 (1.0016-1.0166)	All
$PM_{2.5}$, daily mean	Hospital admissions, respiratory diseases	1.0190 (0.9882-1.0402)	All
$PM_{2.5}$ two-week-average converted to an annual average	Restricted activity days	1.047 (1.042-1.053)	All
$PM_{2.5}$, two-week average, converted to $PM_{2.5}$ annual average	Work days lost the working-age population (age 20-65 years)	1.046 (1.039-1.053)	All
NO_2 annual mean	Mortality, all causes	1.055 (1.031-1.080) on concentration >20 .	>30 years
NO_2 daily maximum 1-hour mean	Mortality	1.0027 (1.0016-1.0038)	All
NO_2 daily maximum 1-hour mean	Hospital admissions, respiratory diseases, all ages	1.0015 (0.992-1.0038)	All

Table 164 Concentration-response functions and relative risks for a 10µg increase in concentration

Out of these impacts, based on preliminary assessment and existing studies, the mortality-based end-points cover over 70% of the total impact, while end-points related to the restricted activity of work days lost represent almost 30%. Thus, focusing the analysis on these will account almost 100% of the economic value of the costs. Also, as pointed by the World Health Organization (2013), data on the hospital admission between different countries varies. However, the same applies between the definitions of work days lost and restricted activity days, thus one needs to be careful when comparing estimates from different sites. It should be noted that some of the end-points refer to chronic effects and some to acute effects. When conducting an analysis, the calculation should take into account either chronic or acute effects, not both. This is because the acute effects are modelled by increases in daily mean concentration levels, which then contribute to the annual average, and vice versa. Including both chronic and acute effects would result in double-counting (World Health Organization, 2013).

Table 165 shows the background relevance levels for the most important end-points, as well as the sources where the estimates have been obtained. Mortality rates are the most relevant end-point data. They are based on crude death rates per person in EU member states from Eurostat (2019). We use national-level statistics for iSCAPE cities, as mortality rates based on city statistics may be biased for example due to a high number of students from other cities, for example in Bologna, and differences in accounting these factors. The 1.45 multiplier to account for the increase in mortality in age groups over 30 is calculated based on mortality rates for over 30-year-old population in Finland. Thus, the assumption is that the increase is similar in other iSCAPE cities – Eurostat does not classify crude death rates per age group. For the restricted activity day (RAD) a European standard is used – as pointed out by Hurley et al. (2005), there is no common classification for a RAD, thus making the case for a uniform RAD among the iSCAPE-cities. The RAD is based on a study made in the 1990s and should be updated (Oak Ridge National Laboratory and Resources for the Future, 1994). However, it is still commonly applied figure in European studies (e.g. NEEDS, 2007, Savolahti et al., 2018). The work days lost - figure is based on OECD statistics (Organisation for Economic Co-operation and Development, 2019). Table 165 summarises the background rates for the most relevant health end-points.

Endpoint	Vantaa	Bologna+Lazaretto	Hasselt	Dublin	Bottrop	Guilford
Mortality, source Eurostat	0.0094	0.01	0.0096	0.064	0.106	0.0091
Mortality, >30 years, base level mortality *1.45, source Eurostat	0.013	0.015	0.014	0.009	0.015	0.013
Restricted activity days, common estimate for EU-countries	19	19	19	19	19	19
Work days lost, source OECD	9.85	16.8	11.2	16.9	18.3	6.5

Table 165 Most important health end-points to be used in iSCAPE economic assessment

Last, we need to use estimates of the economic value of the end-points. Again, the estimates related to the valuation related to mortality is the most relevant parameter. The are two basic approaches for quantifying the economic damage related to premature deaths. Value-of-life-year (VOLY) is based on the estimation of the life years that are lost due to premature deaths. The estimated number of these years is then multiplied with the VOLY. This approach is commonly applied in European studies, while in the U.S, Value-of-statistical-life (VSL) is the preferred method. VSL is more straightforward as it treats each premature death uniformly so that it does not require the calculation of the lost years. VSL is commonly obtained either from stated preference-based surveys (e.g. NewExt (2004)) or from revealed preference studies. (e.g. the United States Environmental Protection Agency (2017)). VOLY is then obtained by dividing the VSL by the life expectancy.

In iSCAPE, we use the VSL-based method. The reason is that we are dealing with both micro-level and macro-level solutions. On the micro-level, (e.g. a street canyon) it is not possible to calculate the number of lost life years, as it would require also micro-level demographic data (e.g. the age distribution in a specific street canyon). To keep the figures comparable, VSL is then also applied in the macro-level. However, in the sensitivity analysis, we can use previously determined benefit-ratios (Holland, 2014) between VSL- and VOLY-methods.

The choice which VSL-estimate to use is of great importance as it has almost a linear effect on the estimated health benefits, as a reduction in the mortality explains almost 90% of the total benefits. (Buonocore et al., 2014, Heo et al., 2016). For example, Muller and Mendelsohn (2009) used an estimate of 1.2 million dollars for VSL while Heo et al. (2016) used a value of 8.6 million dollars. Just by the choice of VSL, the benefits estimated in the latter case are over 7 times higher than in the former. The recommended VSL in the U.S., given by the Environmental Protection Agency (EPA), is 10.3 million dollars. They also recommend updating it to account for inflation and an increase in income, with the income elasticity of 0.7. The most well-known research in the field Viscusi and Masterman (2017) estimated that average VSL is 12 million dollars and the median is 9.7 million dollars, which also should be corrected for inflation and income levels.

In Europe, much lower figures are applied. European Environmental Agency (EEA) recommends using uniform value across the Member States so that the life of all European Citizens is evaluated uniformly. The VSL-figures recommended by EEA area based on a project called NewExt (2004). The study was conducted in three different countries in the EU, and a mean VSL of 2 million € was obtained. The median was 0.98 million €. These figures have been applied extensively, e.g. in the CAFÉ-program or for example in the European level unit cost -studies (Amann et al., 2011, European Environment Agency, 2014, Brandt et al., 2013). In these studies, the values have been adjusted for inflation, but not for income growth. If only inflation is taken into account, the mean VSL is now 2.65 million € and median 1.3 million €. If, however, income elasticity 0.7 is applied, the values are 4.2 million € and 2.1 million €. These are theoretically more correct and closer to state-of-the-art estimates in the literature and thus applied in iSCAPE uniformly for all EU-citizens.

Other economic values that contribute to the total costs are the costs related to restricted activity days and sick days from work. For the sick days, it is common to use the hourly labour costs as a proxy for the associated loss (e.g. Savolahti et al., 2018). For example, in Finland, the average hourly labour cost is 32.72€ and the average daily hours are 7.86. The total cost related to a sick day is then 258€. (e.g. Savolahti et al., 2018). In other iSCAPE countries, the corresponding values are Ireland – 242€; Italy – 220€; Germany – 275€; UK – 216€; Belgium – 310€. For the restricted activity days, only European wide estimates are available (Ready et al., 2004). For this reason, the same value, used previously e.g. in Savolahti et al. (2018) of 154€/day is applied.

4.12.1 Non-market benefits (health)

4.12.1.1 Low boundary walls

Air quality benefits: Low boundary wall in street canyons can be used to reduce personal exposure to air pollutants on the footpaths. The wall acts as a baffle to modify the air flow pattern. The results from Gallagher et al. (2012) indicate that reductions in concentration are highest in windward of the footpath ranging from 26%-50%. On the leeward footpath, the results were mixed. McNabola et al. (2008) found reductions of 40% for perpendicular wind directions and up to 70% parallel wind directions.

The costs of these low boundary walls (LBW) include the installation costs and the required space, that is then not usable e.g. for trees or parking space.

To quantify the benefits in either term of health or money, information is needed:

1. Information on the reduced pollutant concentrations at the footpath: economically most important ones are PM2.5 and NO2 (World Health Organization, 2013).

2. about the number of daily users of the footpath and the average amount of time spent in that part of the footpath.
3. Wind conditions data
4. Land-use, and the opportunity cost of the land-use that is given up; or installation costs

Reduction in concentration

For the reduction in concentration for NO_2 and $PM_{2.5}$, we use the evidence from iSCAPE deliverable, D3.8. Two field campaigns were conducted in Dublin, Ireland. The site was Pearse Street. Presence of existing bollards for the setup of LBW and the absence of any other passive methods like parked car and trees made the location ideal for the experiment. The street canyon is characterized by a high traffic volume. Pearse Street has four lanes all going in the same direction with a total width of 16 m, and it has a North-South alignment. An LBW 18 m long and 1m high was installed along the edge of the footpath on one side of the street in the first campaign. In the second campaign, LBWs were made more continuous and longer than the previous one. Analysers were deployed at an equal distance from the existing bollards irrespective of the presence or absence of the LBW so that the concentration of the particles can be measured at the level where pedestrians walk on the footpath so that the reduction in the pollutants corresponds to the reduction in exposure.

The results of the campaigns for the reduction for NO_2 are summarised in the following figure:

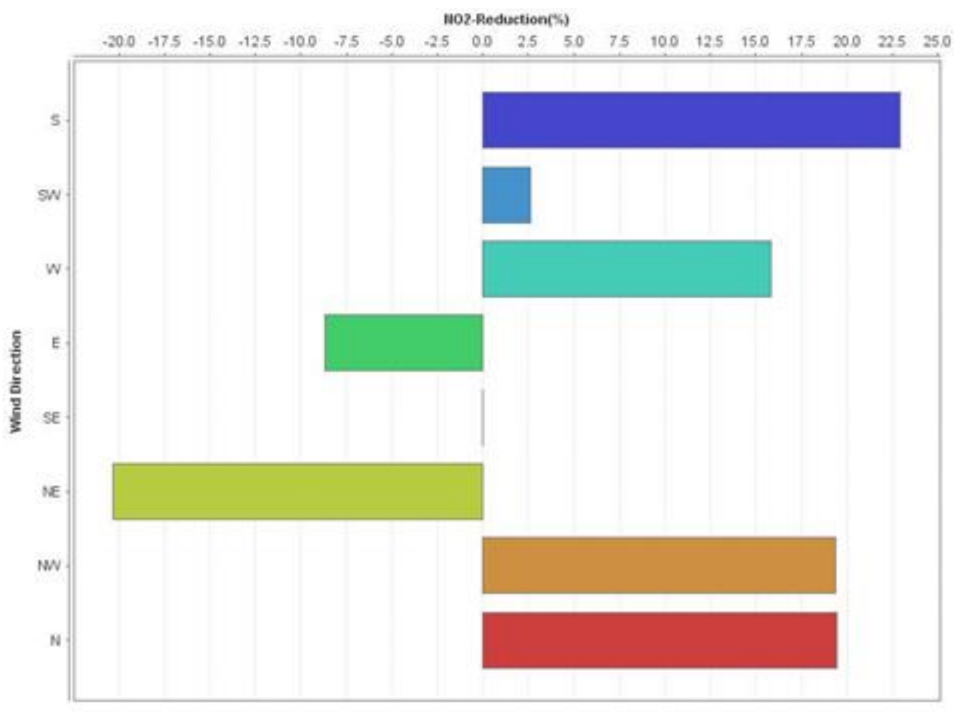


Figure 76 Reduction in NO2 behind the LBW in Dublin, source: iSCAPE D3.8

As Figure 76 shows, the reduction is highly dependent on the wind direction. Also, the report D3.8 shows the large standard deviation for the reduction; the highest uncertainty was linked to the reduction in the case of North- and West- winds. The reduction in the case of the South and the increase in the case of North-East winds were the most certain ones.

The results presented in D3.8 indicate that for $PM_{2.5}$ the LBWs were not having an effect on the dispersion of the pollutant and the average percentage difference between both the sides of the walls was almost similar for both the case when LBWs were present or not. Therefore, the walls were not effective in altering the concentration of $PM_{2.5}$ behind the walls. The results also show that the low boundary walls do not have an effect on the average concentration level of NO_2s within Dublin. However, as seen in Figure 76, they can have an effect a smaller scale on those sections of the footpath that are behind the LWB, if the LWB is installed in a footpath with high concentration levels of NO_2.

The average walking speed is around 1.4 m/s (Barton et al., 2002) so if the LBW is installed on a regular footpath, they spend in average 12.6 seconds behind the LBW. If the LBW is installed in traffic lights and can be in the waiting time, the time could amount to up to one minute or 0.017 hours. If the LBW reduced the daily maximum 1-hour mean NO_2 concentration that an individual is exposed to, it will have an effect on all-cause mortality figures. Given the wind-direction distribution in Dublin (Weatheronline, 2019), the weighted mean reduction in the concentration behind the LBW is around 8%. In the traffic Zone A, which the LBW is installed at, the mean NO_2 concentration is around 35 With a reduction of 8% this would be 32.2 Weighted with the average time spent behind the LBW, the reduction in the daily maximum 1-hour mean concentration would be around 0.01 on the regular footpath and 0.05 in the cross-section.

In economic figures, this would mean health benefits worth 0.1 € per year per person, or given the number of pedestrians, aggregate benefits worth around 570 € per year. For the cross-sections, the figures are five times higher, 0.5 € per year per person, or 2850 € per year in aggregate. If the LBW would be used for 10 years, and the interest rate was 3%, the aggregate benefits would be 4862 € in the footpath, and 24,310 € if used in the cross section of the streets.

The costs of installing the LBWs were also assessed as the installation took place in the campaign. The total installation costs of 18-meter long LWB were 4500 €. The details of the LBW are found in D3.8. Other costs could include the increased concentration of NO_2 at the road section, opportunity costs for space, aesthetic concerns and so on. During the experiment, always a low-boundary wall made out of plastic canvas was installed. The total cost of that kind of LBW was only 500€, including all accessories. However, this kind of LBW would need to be replaced more often.

There is high uncertainty related to the benefits, but much less so related to the costs. Because of this, the benefits and costs are not directly comparable (e.g. Boadway, 2006). It is safe to say, that based on the economic analysis, only those LWBs that reduce the exposure of pedestrians at the cross-sections are on a quite high certainty beneficial in aggregate. This only applies to the most polluted (NO_2) zones of the city, as only in those cases, it has an effect on the maximum NO_{2-} exposure that individuals face during the day.

4.12.1.2 Photocatalytic coating

The effects on air pollutant concentrations derived from the application of photocatalytic coatings in real urban areas have been seldom tested and results of tests conducted in indoor and outdoor environments are often contradictory. For example, Kolarik and Toftum (2012) evaluated the impact of photocatalytic paint on indoor air pollutant levels. The study showed that activation of photocatalytic paint by illumination did not have a positive effect on the perceived air quality. Conversely, Laufs et al. (2010) studied the photocatalytic reactions of nitrogen oxides for a commercially available photocatalytic TiO_2 doped façade paint and showed that photocatalytic paint can be an effective sink of NO and NO_2. Also, they simulated the impact in a street canyon and estimated that a reduction of 5% could be achieved for NO_x.

In addition, although photocatalysis is a well-known process, its use in real weather conditions is still at the experimental stage, and the scientific literature on the subject has not yet reached a full consensus. Thus in the iSCAPE, an extensive field campaign was conducted with the aim to assess the efficiency of photocatalytic paint to reduce NO_x concentration levels in real street canyons. The campaign and the experimental setup were thoroughly described in D3.8 ("Report on neighborhood level interventions").

Similar to the setup adopted in the two summer 2017 and winter 2018 Bologna intensive experimental field campaigns to evaluate the impact of vegetation on air quality and urban thermal comfort, extensively described in D3.3 and D5.2, two similar street canyons with the same geographic NW orientation and affected by the same pollution sources (i.e., traffic) were identified between the University buildings of the Lazzaretto campus area in the outskirts of Bologna (Figure 2 and Figure 3, in D3.8). One of the two canyons was painted by PURETI on 06th August while the other was left untouched and used as reference canyon.

4.12.1.2.1 Reduction in concentration

The methodologies adopted to derive the range of reduction of NO_x pollutants achievable using the photocatalytic coatings from the observations gathered within the Lazzaretto field campaign carried out in the outskirts of Bologna in August 2018 are thoroughly described in D3.8 ("Report on neighborhood level interventions") and in D3.6 ("Report on photocatalytic coatings").

Briefly, the experimental field campaign was organized in two parallel street canyons located in the Lazzaretto campus area of the University of Bologna. Meteorological, turbulence and air quality variables including NO, NO_2 and NO_x gaseous pollutants were measured in both canyons at high-frequency resolution. After the first period of comparison of the measurements gathered in the two canyons in order to derive the presence of intrinsic differences between the two canyons, the walls and the ground surfaces of one of the two canyons were painted with the coatings, while the other was left untouched and was used as a reference. The comparison of the observations in the two canyons showed the presence of a number of confounding factors affecting the concentrations in the two canyons, including different canyon geometry and different behavior of flows. To remove the effect of these confounding factors, two more complex methodologies, one involving the comparison of concentrations in the two canyons in two adequately identified periods characterized by weak synoptic forcing before and after the coating, and one involving dispersion model simulations with the ADMS-Urban model, were utilized. The two methodologies indicated an average NO_2 reduction of 10-17% based on observations and of 8-13% based on ADMS dispersion model simulations (see D3.8 for further details).

Further, the observations conducted within the campaign were utilized to verify the model setup of CFD simulations conducted in D3.6: In particular, the model setup utilized a module to simulate the presence of the coatings in the painted canyon, which, after verification against observations, enabled us to verify the concentration reduction achievable when activating the coatings. The CFD simulations indicated even higher reductions than those derived from observations, even up to 40-50% (see D3.6 for further details).

As evidenced earlier in this report, the photocatalytic paint has – on average - potential to reduce the NO_2 concentrations by 10-17% based on observations and 8-13% based on simulations. We use this range for the reduction potential, and estimate the value of this reduction.

NO_2 will have an effect on all-cause mortality when the annual average concentration is above 20This is the case in Bologna in the winter months (average in all grids 41.5 , but not in the summer (11.5 . Reduction in daily maximum values of NO_2 exposure will also have health impacts, resulting in some avoided health impacts in the summer; however, these impacts should not be included in the economic value since there is a risk of double-counting (World Health Organization, 2013). Thus, the range of the relative reduction in the concentration of NO2 was applied to the measured semi-annual average concentration levels in Bologna and was coupled with population data. The concentration-response function was modified to take into account the fact that the reduction in health impacts is only valid during the winter months.

There are two sources of uncertainty that are quantified within the calculation. The first one is related to the actual reduction, which was estimated between 8% and 17% based on the observations. The second one is related to the concentration-response function as in Table 164. In Table 166 we present the Expected net present value, which is calculated by assuming a uniform distribution of the reduction potential (so that the expected value is 12.5%) and by using the expected value for the health response to NO_2. As recommended by (Boardman et al., 2018), we also present the worst-case and best-case. Worst-case is calculated with the 8% reduction and the 95% lower confidence interval for the health response, while the best-case is calculated by taking into account the 17% reduction and the 95% higher confidence interval for the health response.

NO2 related avoided mortality	Expected decrease in mortality, cases, 8% reduction (persons)	Expected decrease in mortality, 17% reduction (persons)	Expected economic value (million €)	Worst-case economic value (million €)	Best-case economic value (million €)
Impact	50	106	328	119	650

Table 166 Health impacts following large scale photocatalytic paint in Bologna

These reductions and the resulting savings correspond to a hypothetical scenario, in which every area (both building façade and streets) are painted with photocatalytic coating. However, as the analysis has been conducted for 1kmx1km grids in Bologna, we can also assess the benefits at the neighbourhood scale. Figure 77 shows the variation in the economic benefits in different parts of Bologna.

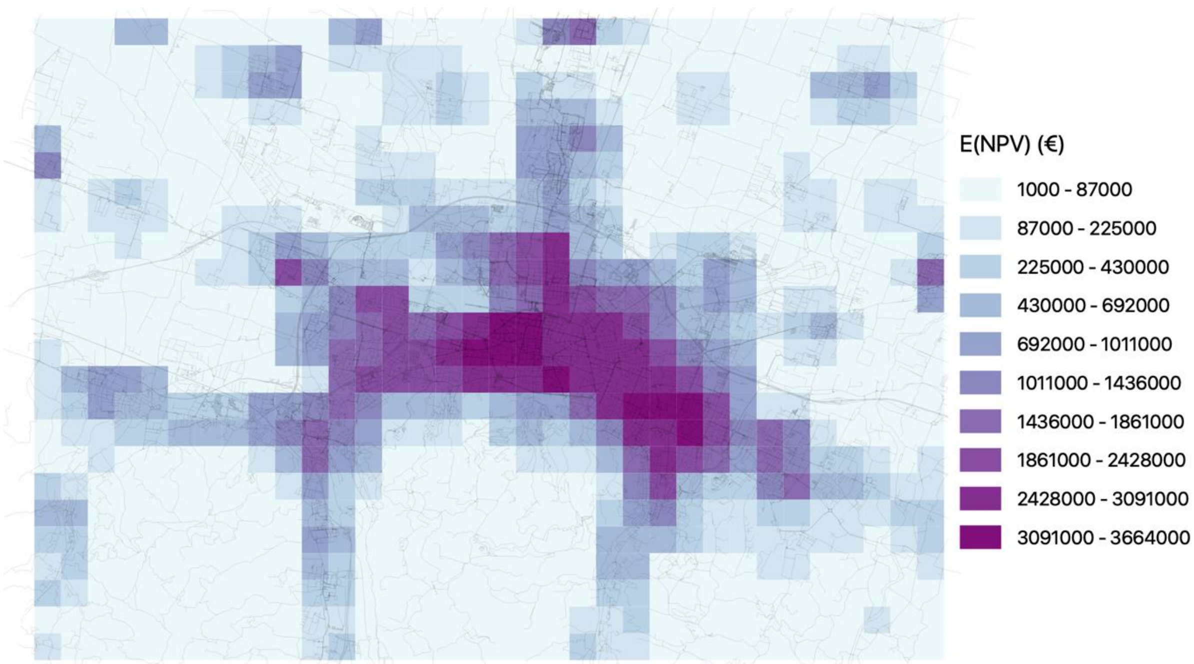


Figure 77 Economic benefits of photocatalytic paint in Bologna

Based on footprints, perimeters and approximation of building height distribution, we have estimated the total façade area in Bologna, equal to about 27145738.8 square meters.

Based on the company that produces the photocatalytic coating (PURETI, personal communication), the cost of photocatalytic coatings is equal to 1.25€ per square meter, and the painting lasts at least two years on the façade. We assume that the paint is performing at the same level throughout its lifespan. Since this cost does not include the installation costs, we used a figure of 2.5€ per square meter.

The total costs of applying the coating over the total façade area in Bologna can be then estimated to be around 68 million €. Under the hypothesis that the coatings last for two years, the costs corresponding to the annual costs need to be amortized. Considering an interest rate of 3%, the amortised cost is then evaluated to be 36 million €. Therefore, based on our analysis, the photocatalytic coating is highly beneficial, as the expected economic value per year is around 330 million €. However, again, we need to point out that the costs are far more certain than the benefits since the benefits depend on the estimated reduction potential of NO_2 and the actual relation between NO_2 exposure and mortality.

4.12.1.3 Green infrastructure - trees

For Guilford, we focus on the chronic effects, as the green infrastructure is capable of reducing the long-term average concentrations of pollutants. The effects of reduced concentration levels include PM2.5 related avoided all-cause mortality, avoided restricted activity days, and avoided loss of work days. Also, the effects of avoided respiratory and cardiovascular diseases are included but are insignificant in terms of total costs. For the NO_2, the effects include only avoided all-cause mortality.

In order to evaluate the benefits of planting vegetation in Guildford vis-à-vis reducing the traffic-related air pollutants NO_x, PM_{10} and $PM_{2.5}$ concentration and complying with the relevant standards. NO_x was converted into NO_2 with the conversion tables of Department for Environment Food & Rural Affairs (2019b). We have investigated two scenarios with and without urban vegetation for the year 2015 as described below.

2015-BASEAQ: This is the baseline case for the year 2015 with the currently estimated vegetation cover (includes grassland, deciduous and coniferous trees) around Guildford city. The air quality is estimated by a combination of dispersion and deposition of air pollutant by ADMS-Urban.

2015-BASE-NoGIAQ: This is a hypothetical scenario for the year 2015, which assumes that there does not exist any urban vegetation and land is covered by only urban area. This case has been estimated by changing the surface roughness to zero for existing vegetation throughout the domain. In addition to surface roughness, the deposition amount over GI land is also considered as zero for existing vegetation throughout the domain. By comparing this scenario with the 2015-BASE, we will be able to estimate the air quality benefits provided by the existing GI in Guildford.

4.12.1.3.1 Modelling approach

We have assessed the potential of existing urban vegetation on air quality on the city-scale model with the help of integrated modelling approach that combines air quality maps generated through dispersion modelling by using Gaussian plume model (ADMS-Urban) and air pollutant concentration maps based on pollutant deposition over vegetation as a source in dispersion modelling. The ADMS-Urban model (version 4.1.1.0) developed by Cambridge Environmental Research Consultants (CERC) was used (Carruthers et al., 1994) to carry out atmospheric dispersion simulations through which to evaluate the dispersion of air pollutants emitted into the atmosphere from the sources considered in the emission inventory.

This detailed approach for assessing the effect of GI on air quality consists of a series of steps:

Step 1: Development of the spatio-temporal air quality maps for Guildford by using traffic emission as a prime source and other sources as background for air pollutant dispersion in ADMS-Urban.

The other influential parameters (meteorology, topography and land cover) are provided as meteorological data, terrain data and surface roughness respectively as inputs in the ADMS-Urban.

Step 2: Estimation of air pollutants deposition over the vegetation surface according to land cover, pollutant concentration (from step-1) and meteorological condition.

Step-3: Development of the spatio-temporal air quality maps by using air pollutant deposited amounts (as grid sources) in ADMS-Urban. The other influential parameters are kept the same as in step (1) as inputs in the ADMS-Urban.

Step-4: Assessment of the air quality due to the presence of urban GI by combining the air quality map from Step 1 and Step 3.

Step 5: Development of air quality for Guildford same as step-1 with altered surface roughness to take account the absence of GI.

Step 6: Comparison of the pollutant concentrations in Guildford with and without vegetation to assess the effects of a proposed vegetation planting strategy on air quality

$PM_{2.5}$ concentration was reduced in average by 3% or 0.28 The largest reduction in $PM_{2.5}$ was 1.5 and the minimum was 0.04 NO_2 concentration were reduced in average by 20% or by 2 , the largest reduction was 11.1 and the minimum was 0.6 . These were converted first into health impacts, and then into monetary values by the method introduced in this section. The main impacts and their economic value are shown in Table 167.

Pollutant and corresponding end-point	**Avoided number of end-point cases**	**Expected economic value of the avoided end-point cases (million €)**	**Lower bound estimate for the economic value (million €)**	**Higher bound for the economic value (million €)**
PM2.5 mortality	3.5	14.5	9.4	19.4
PM2.5 RAD	5740	0.9	0.8	1
PM2.5 Work	1920	0.4	0.35	0.5
NO2 mortality	10	41.9	23.6	60.9
Total (for economic figures)		57.7	34.15	81.8

Table 167 Economic value of green infrastructure to mitigate air pollution-related health impacts

As pointed out, these reductions in health end-points and resulting economic benefits correspond to the current tree coverage in Guilford. However, there is no data available on the quantity of trees in Guilford, and we have to use estimates.

If we assume that you can plant trees in Guildford in land uses marked as "Green urban areas", "Forests", "Herbaceous vegetation", "Land without current land use", and "Pastures", then the total area of the above spaces is 16079.5 hectares. (Copernicus). Typical densities range from 1000 to 2500 trees per hectare. Therefore, there are anywhere between 16 million and 40 million trees in Guilford.

Roman and Scatena (2011) have estimated that the average lifespan of a tree in urban areas is 15 years. The expected economic value over the 15 years corresponds to, with 3% discount rate, to around 700 million €. Per tree, the economic value ranges then from 17 € to 43 €. This should be compared to the value of planting trees in Guilford.

The aforementioned figures correspond to the city-scale solution. As the analysis was done separately for each grid in Guilford, we can also analyse the neighbourhood scale results. These are depicted in Figure 78. As is evident from the figure, there is large spatial variation in the economic impacts. The economic impacts are highly dependent on the population, the reduction potential of trees, and the current level of air pollution, most importantly the current NO_2 annual mean concentration.

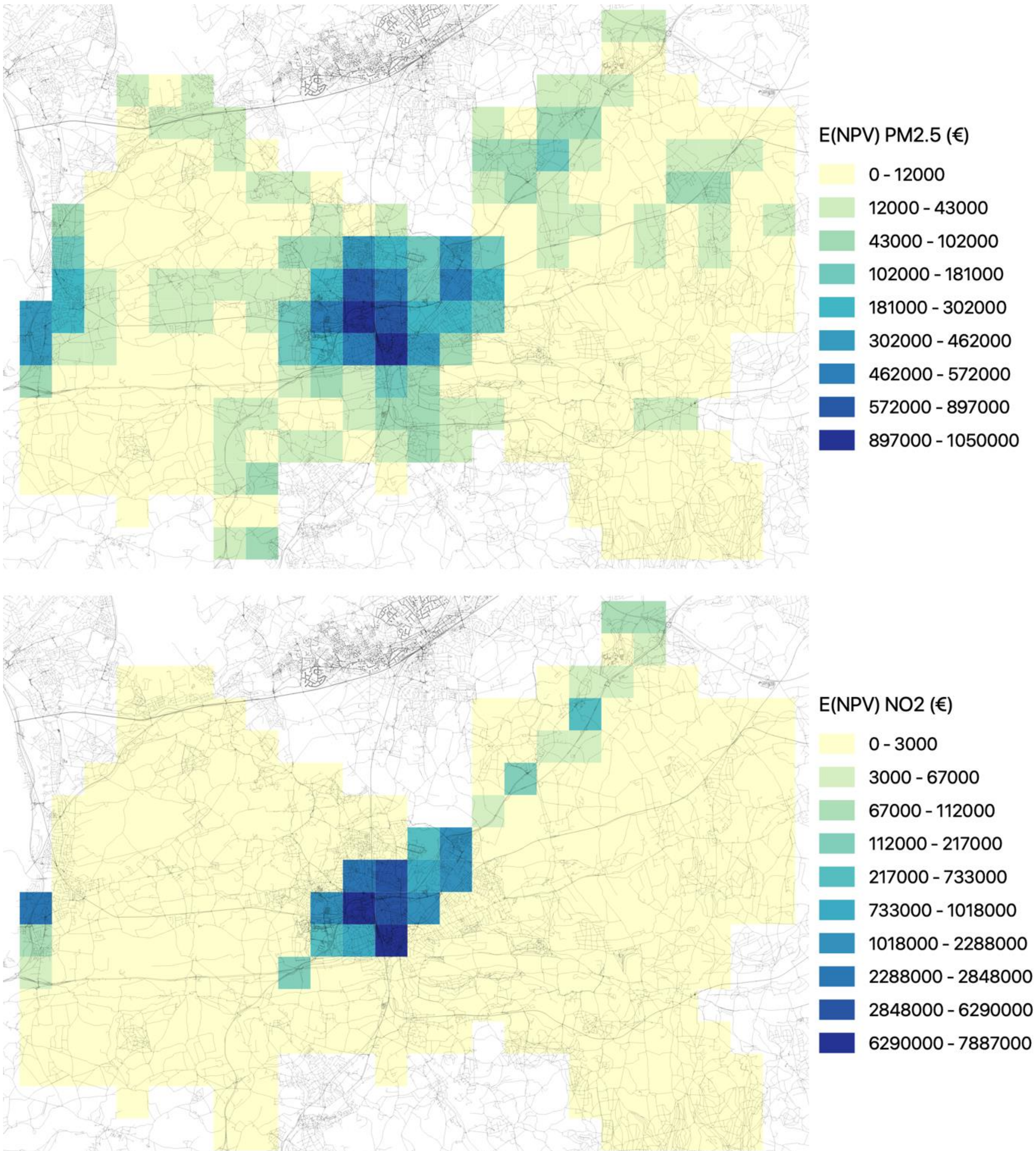


Figure 78 Economic benefits of trees in Guilford, above E(NPV) of PM2.5 related end-points, and below E(NPV) of NO2 related end-points

The reduction in NO_2 is the main component of the economic benefits, as the average NO_2 concentration is reduced by almost 20% in Guilford. Similar results to verify these kinds of effect were found in iSCAPE in simulations done in Bologna.

CFD simulations verified against observations gathered within the field campaigns in Bologna were used to analyse the effect of different tree types with various foliage density and crown distance. Briefly, the results have shown that while to a first approximation and analysing the concentrations in a single receptor site trees in street canyons have the effect of increasing air pollutant concentrations in street canyons, analysing the pollutant concentrations obtained over the whole street canyon volume trees lead to reductions in concentrations in all scenarios considered, and especially in proximity of the concentration hotspots. Reductions of about 25-30% were obtained from a thorough analysis of CFD outputs, in agreement with a detailed analysis of observations gathered in the two experimental field campaigns presented in D5.2.

4.12.2 Market benefits (real estate market)

4.12.2.1 Bologna (green infrastructure, air quality)

The market benefits of improving air quality via green infrastructure in Bologna are estimated by using a hedonic valuation approach at the neighborhood scale. The neighborhoods, in this case, are individual streets. The unit of analysis for the benefits is the average price per square meter of a neighborhood, and the model has the form

$$P/m^2 = \sum \gamma NEIGH + \sum \delta LOC + \varepsilon \quad (21)$$

where P/m2 is the dependent variable (price per square meter of property), NEIGH neighborhood attributes, LOC locational attributes, and ε is a random error term. In the above model, we include in the neighborhood (NEIGH) attributes air quality (AQ) as wintertime and summertime average PM_{10} and NO_2 concentrations (μg/m^3) and green infrastructure (GI) as a share of various natural spaces in the total area of the neighborhood. Structural attributes are absent from the analysis partly due to lack of data, but most importantly due to the fact, the unit of analysis is average neighborhood price, which renders such structural attributes not so influential for the present analysis.

The dataset was developed specifically for iSCAPE in the steps described below:

- Collected street-level (i.e. the location of a property is given as its street and postcode and not its exact address) house sales, for a sample of months in 2017-2019 from the website www.immobiliare.it/mercato-immobiliare/emilia-romagna/bologna/. The information contains price and rent per square meter, name of the street in which the sold property is located, postcode zone, and month of the transaction.
- Collected Bologna's street network from OpenStreetMap, which, among other information, contains street names and their geometry.
- Appended the street-level transactions data to the street network geometry so that we can have a geospatial dataset of house price data.
- Appended to the above house price data the NO_2 and PM_{10} concentrations received from the environmental modelling task (see section 3.1).
- Collected land use information from the provisional CORINE 2018 data from COPERNICUS, and added fractions of all land use, including natural ones, into the above price and air quality dataset.
- Lastly, calculated distances to disamenities (e.g. airport noise and industrial facilities) from Urban Atlas 2012 and added them to the above dataset.

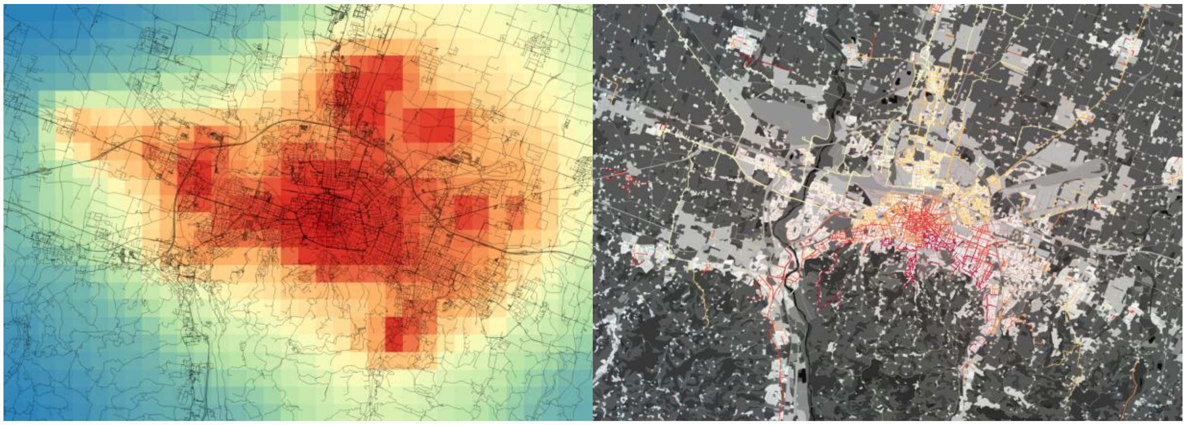


Figure 79 Main data used in the Bologna valuation study; left: pollutant concentration (in this case PM10 winter) and Bologna's street network; right: Urban Atlas and house square meter prices appended to the street network.

The above dataset was then treated as a standard hedonic dataset in order to estimate the following benefits:

- γ_{NO2}: added value of decreasing annual average NO_2 concentration by 1 μg/m^3
- γ_{PM10}: added value of decreasing annual average PM_{10} concentration by 1 μg/m^3
- γ_{GSP}: added value of increasing the land use fraction of urban green spaces in a neighborhood
- γ_{BLT}: added value of increasing the land use fraction of broad-leaved trees in a neighborhood

Variable data source **[abbreviation]**	**Unit**
Average price/m2 of neighborhood [1] (dependent variable) [Price/m2]	€/m^2
Neighborhood attributes	
Annual average concentration of NO_2 [2] [NO2annual]	μg/m^3
Annual average concentration of PM_{10} [2] [PM10annual]	μg/m^3
Continuous urban fabric [4] [fr_CLC_111]	fraction
Discontinuous urban fabric [4] [fr_CLC_112]	fraction
Industrial or commercial units [4] [fr_CLC_121]	fraction
Road and rail networks and associated land [4] [fr_CLC_122]	fraction
Dump sites [4] [fr_CLC_132]	
Green urban areas [4] [fr_CLC_141]	fraction
Sport and leisure facilities [4] [fr_CLC_142]	fraction
Non-irrigated arable land [4] [fr_CLC_211]	fraction
Complex cultivation patterns [4] [fr_CLC_242]	fraction
Land princip. occup. by agric. with sign. areas of natural veg. [4] [fr_CLC_243]	fraction
Broad-leaved forest [4] [fr_CLC_311]	fraction
Locational attributes	
Distance to the airport [3] [kmAirport]	kilometers
Distance to railways [3] [kmRailways]	kilometers
Located inside the historic center [1] [oldtown]	yes: 1; no: 0
Other control variables	
Year in which the transaction occurred [1] [Year]	-
Quarter of the year in which the transaction occurred [1] [Quarter]	multinomial (1-4)
Data sources 1. https://www.immobiliare.it/mercato-immobiliare/emilia-romagna/bologna/ 2. University of Bologna iScape partners 3. European Environment Agency (2016) 4. European Environment Agency (2019)	

Table 168 Variables of the hedonic valuation study

4.12.2.2 City scale

Since the above neighborhood-level benefits are given in square meter units, and we can upscale them to city-level by considering the volume of house sales in Bologna over a given time period. As with the case of Vantaa, this is a more fitting option for estimating the market benefits of the interventions than considering the total size of the housing stock in Bologna, since monetary value is generated by actual market transactions, whereas considering all the housing stock (whether it is involved in a transaction or not) will overestimate the total benefits.

Thus, concerning the transaction volume, (Loberto et al., 2018), based on data from the Italian real estate observatory (Osservatorio del Mercato Immobiliare - OMI), report a size of 5507 transactions during early 2015 up to the end of June 2017 (approximately 30 months) in Bologna, or approximately 2203 transactions per year. Based on the neighborhood-level information described in the previous section, we can, therefore, estimate that:

- Reducing the annual average concentration of NO_2 by 1 $\mu g/m^3$ will yield an annual added value of € 12.337 million for the whole city of Bologna, assuming that the improvement is achieved city-wide.
- Indicatively, if the above air quality improvement is achieved by increasing urban green spaces by 10% in all the streets of Bologna, the combined annual added value is estimated to € 31.062 million for the whole city of Bologna, whereas the corresponding figure for broad-leaved trees is € 16.302 million.

When reading the above estimates, one should consider that the annual volume of transactions varies from year to year because it is influenced strongly by macroeconomic conditions in Italy and internationally, as well as by local market factors such as unmet demand or oversupply of housing, and local population and/or income growth. Moreover, more precise estimates can be given by corresponding specific pollutant concentration reductions to specific green infrastructure improvements, so that the combined benefits can be refined accordingly. Nevertheless, the above figures provide a good estimate of the scale of expected market benefits (as far as those captured in real estate markets are concerned). Lastly, it should be noted that the above estimates should be discounted by approximately 10-25% because we have used asking prices, which are usually higher than the actualized prices.

4.12.2.3 Neighbourhood scale

The estimation results from the hedonic regressions are given in Figure 80 below. The coefficients of the hedonic attributes exhibit the expected signs (i.e., attributes that increase household utility have a positive sign and vice versa). We interpret the results for the subset of “short streets”, i.e. streets that are less than 600 meters long because they are firstly roughly the horizontal resolution of the air quality data performed by the Bologna team, and secondly they are not too long to represent “neighborhoods” -- see Figure 80 right. The estimates of the whole sample (Figure 80 left) are given for comparison purposes, although they largely agree with those of the subset.

```
                          Estimate Std. Error t value Pr(>|t|)
(Intercept)              37.932636   8.739402   4.340 1.43e-05 ***
Year                     -0.015712   0.004131  -3.804 0.000143 ***
Quarter                   0.004824   0.003302   1.461 0.144015
NO2annual                -0.127994   0.011283 -11.344  < 2e-16 ***
PM10annual               -0.016430   0.108661  -0.151 0.879817
oldtown                   0.142336   0.011373  12.515  < 2e-16 ***
log(kmAirport + 0.01)     0.464323   0.008270  56.148  < 2e-16 ***
log(kmRailways + 0.01)    0.045142   0.001757  25.689  < 2e-16 ***
fr_CLC_111                0.506135   0.049108  10.307  < 2e-16 ***
fr_CLC_112               -0.194726   0.044607  -4.365 1.28e-05 ***
fr_CLC_121               -0.763726   0.047309 -16.143  < 2e-16 ***
fr_CLC_122               -1.060266   0.066777 -15.878  < 2e-16 ***
fr_CLC_132               -0.649612   0.249499  -2.604 0.009232 **
fr_CLC_141                1.992596   0.069698  28.589  < 2e-16 ***
fr_CLC_142               -0.624168   0.079169  -7.884 3.38e-15 ***
fr_CLC_211               -0.541993   0.045066 -12.027  < 2e-16 ***
fr_CLC_242               -1.137340   0.079283 -14.345  < 2e-16 ***
fr_CLC_243                0.727249   0.059521  12.218  < 2e-16 ***
fr_CLC_311                0.154219   0.158209   0.975 0.329687
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.4081 on 15295 degrees of freedom
Multiple R-squared:  0.5404,    Adjusted R-squared:  0.5398
F-statistic: 998.9 on 18 and 15295 DF,  p-value: < 2.2e-16
```

```
                          Estimate Std. Error t value Pr(>|t|)
(Intercept)              39.425031   8.832652   4.464 8.12e-06 ***
Year                     -0.015744   0.004167  -3.778 0.000158 ***
Quarter                   0.004035   0.003351   1.204 0.228563
NO2annual                -0.111928   0.011795  -9.490  < 2e-16 ***
PM10annual               -0.082106   0.111947  -0.733 0.463304
oldtown                   0.140004   0.011656  12.011  < 2e-16 ***
log(kmAirport + 0.01)     0.497083   0.008617  57.683  < 2e-16 ***
log(kmRailways + 0.01)    0.045121   0.001777  25.388  < 2e-16 ***
fr_CLC_111                0.498042   0.049072  10.149  < 2e-16 ***
fr_CLC_112               -0.194450   0.044680  -4.352 1.36e-05 ***
fr_CLC_121               -0.768559   0.047675 -16.121  < 2e-16 ***
fr_CLC_122               -1.042257   0.066566 -15.658  < 2e-16 ***
fr_CLC_132               -0.590176   0.273959  -2.154 0.031237 *
fr_CLC_141                1.967982   0.069380  28.365  < 2e-16 ***
fr_CLC_142               -0.616718   0.079021  -7.804 6.38e-15 ***
fr_CLC_211               -0.535791   0.045554 -11.762  < 2e-16 ***
fr_CLC_242               -1.068705   0.080761 -13.233  < 2e-16 ***
fr_CLC_243                0.858219   0.060754  14.126  < 2e-16 ***
fr_CLC_311                0.371825   0.162801   2.284 0.022390 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.4024 on 14529 degrees of freedom
Multiple R-squared:  0.5513,    Adjusted R-squared:  0.5508
F-statistic: 991.9 on 18 and 14529 DF,  p-value: < 2.2e-16
```

Figure 80 Hedonic regression estimates for the whole sample (left) and a subset of streets less than 600 meters (right); the unit of the estimates is € thousand per square meter.

From the variables of interest, the price effects of NO_2, urban green spaces, and broad-leaved trees are statistically significant at the 99.9% 99.9% and 95% confidence interval, respectively, which means that their price effects can be interpreted as being different than zero, even after estimation uncertainty has been taken into account. The effect of PM_{10} is not statistically significant and is not interpreted here.

More specifically:

- Decreasing the annual average concentration of NO_2 in the neighborhood by 1 μg/m^3 yields an added value of 112 €/m^2 (+/- 12 €/m^2 uncertainty) to the average house price of a typical neighborhood, controlling for all other price determinants.
- In the case of PM_{10}, the corresponding benefit is 82 €/m^2, but this estimate is not statistically significant.
- Assuming that this air quality improvement happens by adding 100% green infrastructure, then there is an additional added value of 1698 €/m^2 (+/- 69 €/m^2 uncertainty) for urban green spaces and of 372 €/m^2 (+/- 163 €/m^2 uncertainty) for broad-leaved trees, controlling for all other price determinants.
- Note that this is unrealistic, however, because in practice green infrastructure can increase only by so much in a neighborhood; a more meaningful example would be a 10% increase, which would yield added value of 170 €/m^2 for urban green spaces and 37 €/m^2 for broad-leaved trees (more realistic examples can be given for air quality as well).
- Applying the above marginal benefits to a 50 m^2 apartment, the indicative benefit is estimated to € 5600 increase in its value for reducing the annual average NO_2 concentration in its neighborhood by 1 μg/m^3. If that improvement is done by a hypothetical increase of green infrastructure by 10% in the neighborhood, then the total combined benefit is estimated to € 14100 for the case of urban green spaces and € 7400 for the case of broad-leaved trees.

It should be noted that estimating the added value of reducing the summertime and wintertime concentration of NO_2 and PM_{10} is not possible, because their effects were found statistically insignificant and in some cases, the signs of the coefficients were also counterintuitive. We, therefore, opted for analyzing the annual averages, which performed better in the hedonic regressions, perhaps indicating that the air quality conditions at the season of the transaction are not so influential; what affects the housing market is rather the long-term perception of air quality in a neighborhood (rather than short-term variability).

4.12.2.4 Vantaa (green infrastructure, air quality)

We adopt a hedonic valuation approach to estimate the market benefits (shadow prices or marginal willingness to pay) of improving air quality and green infrastructure. We estimate these benefits by using a detailed (spatially, temporally, thematically) housing transactions dataset that took place throughout Vantaa during 2000-2011. The hedonic valuation is implemented through a spatial error econometric model that includes structural (i.e. internal to the property), neighborhood (e.g. environmental and social conditions) and locational (e.g. proximity to services) attributes of properties and is of the form:

$$P/m2 \; = \sum \beta STR + \sum \gamma NEIGH + \sum \delta LOC + \lambda u + \varepsilon \qquad (22)$$

where P/m^2 is the dependent variable (price per square meter of property, STR denotes structural attributes, NEIGH neighborhood attributes, LOC locational attributes, u is a spatially autocorrelated error term, ε is a random error term, and β, γ, δ are the regression coefficients that give the shadow prices or marginal willingness to pay for their corresponding hedonic attributes. In the above model, we include in the neighborhood (NEIGH) attributes air quality (AQ) as annual average $PM_{2.5}$ concentration (μg/m^3) and green infrastructure (GI) as proximity within 100 meters to green spaces, and more specifically:

- $\gamma_{AQ}AQ$, with γ_{AQ} indicating the marginal benefit of decreasing $PM_{2.5}$ by 1 μg/m^3, and
- $\gamma_{GI}GI$, with γ_{GI} indicating the marginal benefit of locating or leaving green infrastructure within 100 meters of residential properties.

These marginal benefits are measured in € per square meter (of residential property) and are interpreted in section 4.12.2.5 below in a number of complementary ways. For a fuller description of this methodology refer to D5.6.

The data used for the hedonic analysis are entries from a large real estate transaction dataset, based on voluntary regular submissions of a consortium of Finnish real estate brokers, and maintained by the Technical Research Centre of Finland (VTT). The records include the selling price, debt component, maintenance cost, postal address, listing details (the date listed and sold), and structural attributes of sold dwellings in selected Finnish cities during 1971-2011. The acquired data were subsequently geocoded and converted into a GIS database by FMI. Based on the coordinates, neighborhood and environmental characteristics were added to the structural characteristics for a subset covering the period 2000-2011. The price and other monetary variables were detrended by adjusting for inflation with 2011 as the base year. The figures and table below describe the variables of the analysis.

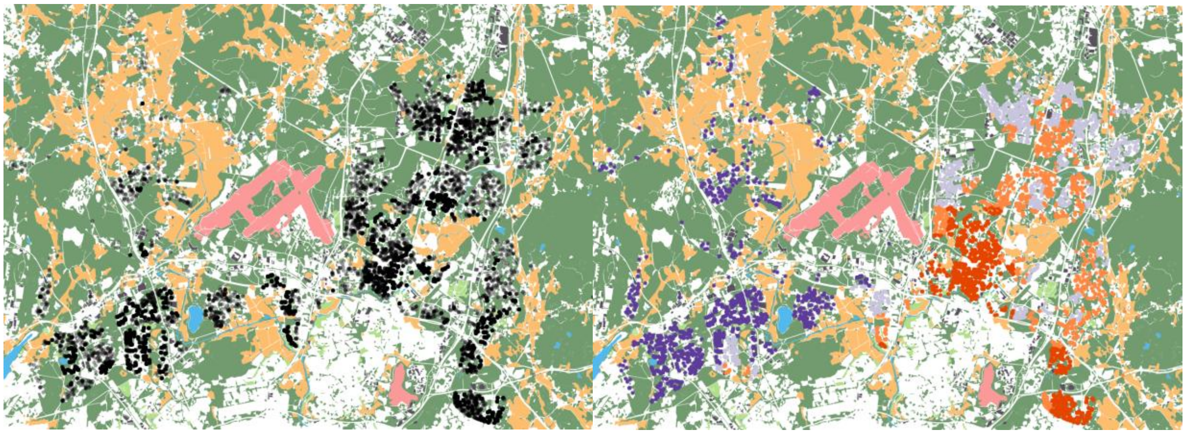


Figure 81 Main data used in the Vantaa valuation study; left: main land uses included in the analysis (background polygons) and the sample of transaction points (foreground points); right: land uses (background) and annual average PM2.5 concentrations for the transactions points, split into quartiles.

Variable data source **[abbreviation]**	**Unit**
Price per square meter of dwelling (dependent variable) 1 [RPRIC_M2]	€ thousand / m^2
Neighborhood attributes	
PM2.5 annual average concentration 2 [PM25]	µg / m^3
Situation near green infrastructure 3 [GreenInfra]	within 100 m: 1 otherwise: 0
Proximity to industrial sites 3 [Indust500m]	within 500 m: 1 otherwise: 0
Locational attributes	
Proximity to the nearest administrative hub 3 [I(HubDist/1000)]	kilometers
Structural attributes	
Property is situated in its own or rented from city plot 1 [Ownplot]	own plot: 1 rented from the city: 0
Age of dwelling 1 [Age]	years
Number of rooms 1 [Rooms]	Multinomial (1-9)
The floor of the property relative to total floors (if in an apartment block) 1 [Floor]	Fraction (0-1)
Bad condition 1 [Bad_Cond]	yes: 1; no: 0
Weeks on sale 1 [I(Daysonsale/7)]	-
Monthly maintenance fee 1 [Vastike_mk]	€ / m^2
Debt component 1 [I(Velkaosuus/Asuinala)]	€ thousand / m^2
Other control variables	
Spatial error term (not interpreted in this study) 4 [Lambda]	€ /m^2
Time trend for the 2000-2011 period 1 [Year]	year
Transaction occurred in quarter 2 1 [QuarterQ2]	yes: 1; no: 0
Transaction occurred in quarter 3 1 [QuarterQ3]	yes: 1; no: 0
Transaction occurred in quarter 4 1 [QuarterQ4]	yes: 1; no: 0
Data sources 1. Votsis and Perrels (2016) 2. van Donkelaar et al. (2018), van Donkelaar et al. (2016) 3. CSC - IT Center for Science Ltd (2015) 4. Econometric analysis of the sample	

Table 169 The variables of the hedonic valuation; in green the two variables of interest

4.12.2.5 City scale

The estimation results of the final spatial econometric model (intermediate models and testing are available upon request by the FMI team) are given in Figure 82 below. All hedonic attributes of the final model have the expected signs (i.e. they have the expected negative or positive price effect) and are statistically significant (i.e. different from 0 also when uncertainty is taken into account). The regression diagnostics do not indicate any specification or estimation problems, given that the estimation is performed on all submarkets of Vantaa during a whole 11-year cycle.

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-148.48566821	2.81844240	-52.6836	< 2.2e-16	***
I(Velkaosuus/Asuinala)	0.31819890	0.00992316	32.0663	< 2.2e-16	***
Vastike_mk	-0.00453600	0.00124041	-3.6569	0.0002553	***
Rooms	0.06634727	0.00621575	10.6741	< 2.2e-16	***
Age	-0.00664444	0.00043546	-15.2585	< 2.2e-16	***
Floor	0.05756263	0.01198984	4.8009	0.0000015791554850	***
Bad_Cond	-0.18907420	0.00872490	-21.6706	< 2.2e-16	***
Ownplot	0.16966452	0.02346171	7.2315	0.0000000000004776	***
Year	0.07496230	0.00140282	53.4368	< 2.2e-16	***
QuarterQ2	0.02547103	0.00994817	2.5604	0.0104560	*
QuarterQ3	0.06105004	0.01022131	5.9728	0.0000000023318845	***
QuarterQ4	0.05832056	0.01048945	5.5599	0.0000000269894009	***
I(Daysonsale/7)	-0.00526084	0.00034631	-15.1914	< 2.2e-16	***
I(HubDist/1000)	-0.01775800	0.00611105	-2.9059	0.0036622	**
Indust500m	-0.08744647	0.01874439	-4.6652	0.0000030830641651	***
GreenInfra	0.09555397	0.02955193	3.2334	0.0012232	**
PM25	-0.03955878	0.01928907	-2.0508	0.0402826	*

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Figure 82 Estimation results of the spatial error hedonic model (variable abbreviations in Table 169)

The variables of interest “$PM_{2.5}$” (annual average $PM_{2.5}$ concentration in μg/m^3) and ‘GreenInfra’ (location within 100 meters of green infrastructure) are statistically significant at the 99% and 95% confidence level, respectively. The estimated price effects (‘Estimate’ in Figure 82 above) are in the units of € thousand per square meter, and they represent the benefits that a unit improvement in air quality and green infrastructure will bring to home-owning households, given a ‘typical property’ in Vantaa.

More specifically, if annual average $PM_{2.5}$ concentration is reduced by 1 μg/m^3, the added value is estimated to 39.56 €/m^2 +/- 19.29 €/m^2, controlling for all other determinants of prices. Moreover, if the air quality improvement is achieved by adding or preserving green infrastructure so that one typical property is brought or preserved within 100 meters of the green infrastructure, then we expect an additional benefit of 95.55 €/m^2 +/- 29.55 €/m^2, controlling for all other determinants of prices.

Considering then, the total volume of transactions of our sample, all the properties that have been sold and their square meter sizes, as well as an average-sized property in Vantaa, the above estimates translate to the following city-scale benefits:

- The added value of € 48 million over an 11-year period (coinciding with an equilibrium cycle in the housing market) from improving air quality by 1 μg/m^3 lower annual average $PM_{2.5}$ concentration. This corresponds to an added value of € 4.4 million annually.
- Per transaction, the same improvement in air quality adds € 2620, to which we should add a green infrastructure benefit of € 6306, which makes the combined benefit of improving air quality through green infrastructure approximately € 8926 for a typical property.
- Considering the ENVIMET simulations for a single building block, which show a smaller than the one-unit reduction of $PM_{2.5}$ annual average concentration, the added value for the 11-year cycle would be € 170,000, which corresponds to € 16 thousand per year. Note, however, that this is only indicative and assumes that the small improvement of air quality from green infrastructure simulated for one block can be directly transferred to the city scale.

- Considering the simulations carried out for Guildford, extensive implementation or preservation of green infrastructure implies an added value of € 13 million for the 11-year cycle, which corresponds to € 1.2 million annually.

4.12.2.6 Neighborhood scale

The results for neighborhood scale are shown in small areas (in Finnish “pienalueet”). The neighborhoods (small areas) are distinguished from HSY’s 2018 land use data and are then connected with the neighbourhood-specific housing market transactions, the added value of the transactions and average floorspace in that neighborhood. These are calculated based on FMI/VTT housing transactions dataset (for years 2000-2011). The marginal willingness to pay (WTP) for one unit (μg/m^3) decrease in PM2.5 air pollution concentration for the whole Vantaa is 39.56 €/m^2 and the WTP for house locating in the proximity to green infrastructure in Vantaa is 95.55 €/m^2 based on the regression analysis above (Figure 82). WTP for air quality improvements and proximity to green infrastructure are held as constants while the number of transactions, added the value of transactions and the average floorspace change depending on the neighborhood when calculating the economic impact of air quality and green infrastructure on the housing market in different neighborhoods in Vantaa. The resulting values are shown in Table 170.

Neighborhood	Number of transactions	Added value for 11 years (€)	Average floorspace (m2)	Annual added value (€)	Added value per transaction in the 11 year period (€)	Added value from typical property (€)	Added value from green infrastructure for one transaction (€)
Askisto	66	243525	93	22138,64	3689,773	3679,08	8886,15
Asola	95	292904	78	26627,64	3083,2	3085,68	7452,9
Hakkila	158	422383	68	38398,45	2673,31	2690,08	6497,4
Hakunila	840	2010530	61	182775,5	2393,488	2413,16	5828,55
Hämeenkylä	1056	2076470	50	188770	1966,354	1978	4777,5
Hämevaara	92	375587	103	34144,27	4082,467	4074,68	9841,65
Havukoski	1082	2283830	53	207620,9	2110,749	2096,68	5064,15
Helsingin pitäjän kirkonkylä	11	62782	144	5707,455	5707,455	5696,64	13759,2
Hiekkaharju	489	1165030	60	105911,8	2382,474	2373,6	5733
Ilola	159	653856	104	59441,45	4112,302	4114,24	9937,2
Itä-Hakkila	164	599026	92	54456,91	3652,598	3639,52	8790,6
Jokiniemi	332	773039	59	70276,27	2328,431	2334,04	5637,45
Jokivarsi	43	215327	127	19575,18	5007,605	5024,12	12134,85
Kaivoksela	704	1311700	47	119245,5	1863,21	1859,32	4490,85

Keimola	4	16655	105	1514,091	4163,75	4153,8	10032,75
Kiila	23	81020	89	7365,455	3522,609	3520,84	8503,95
Kivistö	149	657642	112	59785,64	4413,705	4430,72	10701,6
Koivuhaka	58	248078	108	22552,55	4277,207	4272,48	10319,4
Koivukylä	256	683876	68	62170,55	2671,391	2690,08	6497,4
Korso	711	1958640	70	178058,2	2754,768	2769,2	6688,5
Kuninkaala	148	555512	95	50501,09	3753,459	3758,2	9077,25
Kuninkaanmäki	109	453869	105	41260,82	4163,936	4153,8	10032,75
Länsimäki	609	1372190	57	124744,5	2253,186	2254,92	5446,35
Länsisalmi	1	3679	93	334,4545	3679	3679,08	8886,15
Lapinkylä	53	239813	114	21801,18	4524,774	4509,84	10892,7
Lentokenttä	0	0	0	0	0	0	0
Leppäkorpi	344	1036310	76	94210	3012,529	3006,56	7261,8
Linnainen	21	105901	127	9627,364	5042,905	5024,12	12134,85
Luhtaanmäki	4	15349	97	1395,364	3837,25	3837,32	9268,35
Martinlaakso	1281	3028380	60	275307,3	2364,075	2373,6	5733
Matari	208	753642	92	68512,91	3623,279	3639,52	8790,6
Metsola	540	1492570	70	135688,2	2764,019	2769,2	6688,5
Mikkola	397	787931	50	71630,09	1984,713	1978	4777,5
Myllymäki	11	65709	151	5973,545	5973,545	5973,56	14428,05
Myyrmäki	1577	3295860	53	299623,6	2089,956	2096,68	5064,15
Nikinmäki	176	774742	111	70431,09	4401,943	4391,16	10606,05
Ojanko	2	8228	104	748	4114	4114,24	9937,2
Päiväkumpu	168	757616	114	68874,18	4509,619	4509,84	10892,7
Pakkala	879	1967420	57	178856,4	2238,248	2254,92	5446,35
Petikko	14	67569	122	6142,636	4826,357	4826,32	11657,1
Piispankylä	150	328949	55	29904,45	2192,993	2175,8	5255,25
Rajakylä	440	1417100	81	128827,3	3220,682	3204,36	7739,55
Rekola	135	569037	107	51730,64	4215,089	4232,92	10223,85
Riipilä	22	112387	129	10217	5108,5	5103,24	12325,95
Ruskeasanta	341	1134850	84	103168,2	3328,006	3323,04	8026,2
Seutula	33	102146	78	9286	3095,333	3085,68	7452,9
Simonkylä	725	1800870	63	163715,5	2483,959	2492,28	6019,65

Sotunki	12	49451	104	4495,545	4120,917	4114,24	9937,2
Tammisto	466	1218680	66	110789,1	2615,193	2610,96	6306,3
Tikkurila	464	897811	49	81619,18	1934,938	1938,44	4681,95
Vaarala	403	1213620	76	110329,1	3011,464	3006,56	7261,8
Vallinoja	47	164384	88	14944	3497,532	3481,28	8408,4
Vantaanlaakso	303	967537	81	87957,91	3193,191	3204,36	7739,55
Vapaala	503	1266410	64	115128,2	2517,714	2531,84	6115,2
Varisto	179	587940	83	53449,09	3284,581	3283,48	7930,65
Veromies	1	2690	68	244,5455	2690	2690,08	6497,4
Vestra	15	65946	111	5995,091	4396,4	4391,16	10606,05
Viertola	697	1766270	64	160570	2534,103	2531,84	6115,2
Vierumäki	121	433132	90	39375,64	3579,603	3560,4	8599,5
Viinikkala	2	14874	188	1352,182	7437	7437,28	17963,4
Ylästö	218	937818	109	85256,18	4301,917	4312,04	10414,95

Table 170 Neighborhood scale statistics of air quality and green infrastructure impacts on the housing market in Vantaa.

The above results are shown also in maps below (Figure 83 and Figure 84). The value of air quality improvements in housing market is shown in Figure 84. The higher values are associated to the areas close to the two hubs Myyrmäki and Tikkurila, while the more natural and agricultural areas have lower added values. In Figure 84, the added value from proximity to green infrastructure is shown for one housing market transaction (left side) and the average value of air quality improvement for a typical property in the neighborhood is shown (right side).

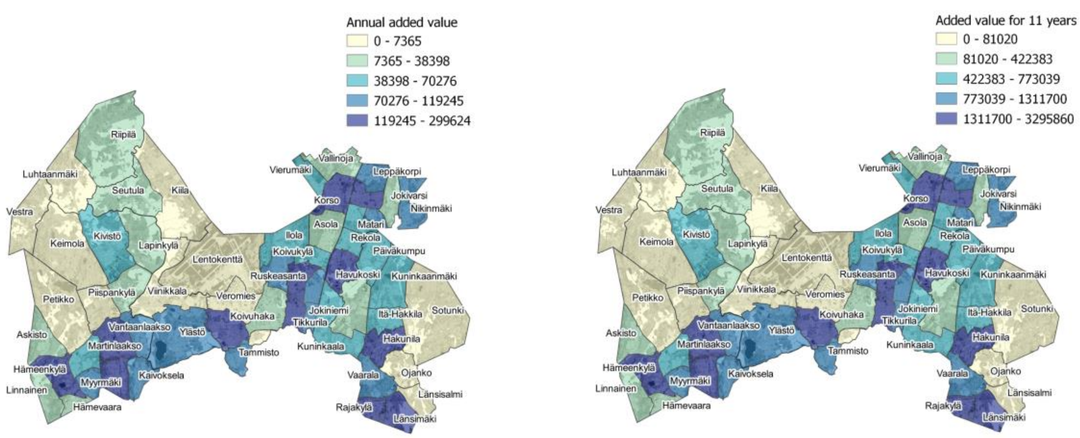


Figure 83 Annual added value (left) and added value for the 11 year period (right) from air quality improvement in 2011 €..

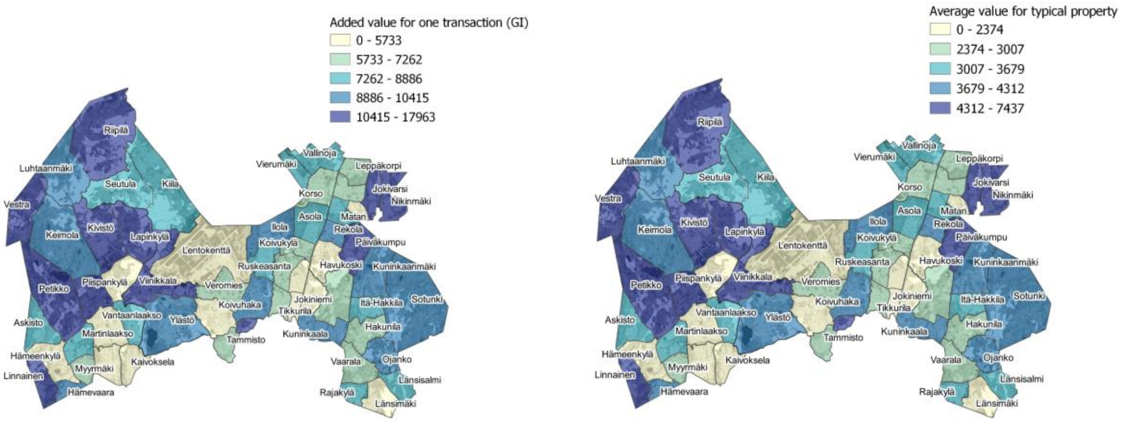


Figure 84 Added value from green infrastructure for one transaction (left) and average air quality improvement value for a typical property (right) in 2011 €.

5 Conclusions

The present report has evaluated the iSCAPE interventions, including physical, behavioural and engagement interventions, from an environmental and socio-economic perspective. The following conclusions have been reached:

- Planting of trees in street canyons can, for certain geometries, lead to reduced average concentrations of up to 44% with differences between vegetation geometries (size, species, the distance between trees) accounting for up to 22% differences. This was shown for one specific street canyon in Bologna, Italy for one meteorological situation.
- A specific proposed urban development in the city of Bottrop, Germany was analysed using ENVI-Met, and the application of simulations as part of an urban planning process was discussed. The change in air temperature and physiological equivalent temperature as a result of the proposed planning was shown to be rather low with temperature changes up to 0.3 C and changes in physiological equivalent temperature up to 12 degrees.
- The statistical modelling for the city of Dublin, Ireland estimated that widespread implementation of low-boundary walls could lead to a reduction of 12% for NO_x, 10% for $PM_{2.5}$ and 13% for PM_{10}. This was estimated to correspond to respectively 53 disability-adjusted life years because of changes in NO_x and 18 disability-adjusted life years because of changes in $PM_{2.5}$.
- For the city of Guildford, the UK, the Gaussian plume modelling for the year 2039 showed that increasing the area of deciduous trees would lead to increases in air pollution concentrations, due to reduced deposition during the winter. Increasing the area of coniferous trees could lead to further air pollution reductions of up to 2.7%, whereas replacing the existing trees with grassland could lead to increased air pollution of up to 13.8%. Similar, albeit smaller, trends were shown for the scenarios covering planting of vegetation close to the major roads.
- For the city Vantaa the results reached with ENVI-met v4 simulation software showed rather small: for PM2.5 differences between areas with and with green infrastructure were about -0.1% for the green infrastructure area, for NO2 the result was -1.5%, and for PM10 almost neglectable (-0.03%).

- The activities by the Bologna LL, including the “Let’s plan the green together” and the citizen science workshops, have been able to stimulate curiosity and interests among citizens and policy-makers about air quality and its challenges into the urban environment. In particular, participants better understood the relevance of greening to support air pollution reduction in urban areas.
- The activities conducted by the Bottrop LL, including the Wandering Tree Parade, the CS workshops and the meeting with stakeholders and policymakers were able to increase awareness of citizens, policy-makers, and stakeholders about the adoption of trees into urban planning practice.
- The activities by Dublin LL, including the fieldwork campaign, the activity with school children, the CS workshops and the meeting with local stakeholders, contributed towards a better understanding of LBWs’ relevance in Dublin. They also stimulated the interest of pupils in taking action towards reducing air pollution and improving air quality.
- The activities conducted by the Guildford LL, including the Waterloo festival, the activities with local associations, the CS workshops and the meeting with stakeholders and policy-makers, were able to involve different associations among local communities in better understanding the necessity for green infrastructure in Guildford. In addition, the activities had a relevant impact in terms of multi-level policies, in particular by contributing to national policies for the consideration of green infrastructure into national urban planning.
- The activities conducted by the Vantaa, including the activity with pupils and high school students, the CS workshops and the meetings with policy-makers, supported the integration of iSCAPE climate change data in future urban planning in Vantaa. They were also useful for students to better understand future climate challenges
- Finally, the Behavioural intervention study stimulated participants to reflect on their needs for travelling by cars and for adopting alternative routes and transportation modes. This led participants to decide for a shift from car to the bike when possible or to undertake less polluted routes for their everyday commuting.
- General conclusions can be also retrieved. On the one side, there has been a general increase in awareness around air quality issues among all participants (individuals, policy-makers, and stakeholders) into the cities involved in the iSCAPE project and for all the activities conducted by each LL. On the other side, it must be said that the activities mainly involved participants that had already high concerns about environmental issues and human values, for which medium-high scores were recorded. Notwithstanding this, their current pro-environmental behaviour did not always correspond to these high scores and rather recorded medium and sometimes low scores. In this way, the work to be done is to provide an understanding of the main challenges for these people to truly undertake pro-environmental behaviours, and of the main strategies and actions to be put in place to stimulate such behaviours.The economic analysis, using the hedonic pricing method, for the city of Vantaa, Finland showed an added value of 39€/m^2 for each microgram the $PM_{2.5}$ concentration was reduced. Likewise, an added value of 95€/m^2 was shown for houses within 100m of green infrastructure. It was likewise shown that the effect is largest for the areas close to the urban hubs and smaller for more agricultural areas.
- The economic analysis of the low-boundary wall showed a monetised benefit of up to €4862 on the footpath and €24310 for a low-boundary wall close to an intersection. This should be compared with an installation cost of the wall of €4500.

- The economic analysis of the deployment of photocatalytic coating in Bologna, Italy estimated the costs of widespread deployment to 36 million €, which should be compared to an estimated benefit of 330 million €.
- The economic analysis of trees in Guildford, UK showed a benefit of 58 million € per year, corresponding to 17 to 43 € per tree over their lifetime. Next, to these benefits, other benefits of trees should be taken into account.
- The economic analysis, using the hedonic pricing method, for Bologna, Italy, showed an added value of 112€/m^2 for decreasing the NO_2 concentration with 1 microgram per cubic meter.

In this way, the iSCAPE-project has advanced the general understanding of the advantages of using physical, behavioural and engagement interventions for air pollution exposure mitigation.

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