ENVIRONMENTAL ANALYSIS OF NURSERY PLANTS AND COMPARISON WITH OTHER PRODUCTION SECTORS

ESTIMATION OF THE CO2 SEIZURE FROM THE PRODUCTION NURSERY

A. PRODUCTION NURSERY IN RAMINI

For the calculation of the CO2 absorbed annually by the trees in the nursery, reference was made to the formula (adapted from Nicese & Lazzerini 2013):

$$CO_2\ (\text{kg/year/plant}) = \text{total dry weight} \times 0.5 \times 3.667$$

where 0.5 represents the carbon content of the dry weight of the plant and 3.667 allows the conversion of the carbon value into carbon dioxide.

For the calculation of the dry weight of stems, branches and roots, allelometric formulas based on the diameter of the plant at a height of 1.30 m were used (Nicese & Lazzerini 2013).:

trunk	$\log_{10}(y) = 2.32\log_{10}(x) - 0.95$
branches	$\log_{10}(y) = 2.35\log_{10}(x) - 1.84$
roots	$\log_{10}(y) = 1.98\log_{10}(x) - 1.10$

y represents the dry weight in kg and x the diameter at 1.30 m in cm. The total dry weight is the sum of the three values obtained.

The size of the plants initially available was the circumference class or the height class. In the first case, to obtain the diameter, the average circumference value of each class was calculated and then the value was divided by 3.14 (π). In the second case, the height class was reduced to a circumference class and then the same procedure was followed.
The dry weight calculated with the allelometric formulas must be divided by the years of age of the tree (to make the final calculation of CO2 sequestered on an annual basis); therefore this data has been estimated as well.

These formulas were used to calculate the amount of CO2 annually absorbed (kg) by the individual plant, which was then multiplied by the number of plants of the same type and species present in the nursery. Adding up these values results in the total amount of CO2 sequestered by the nursery.

The literature provides, in the case of urban trees, indicative average values of CO2 absorption, in particular 12.46 - 21.60 kg CO2/year/plant (Abacus Agronomic Report of essences, Municipality of Carimate (CO); Zirkle *et al.* 2012). In order to take into account the rapid growth of plants in the nursery sector, it was decided to also consider the average value obtained from the literature (17.03 kg CO2/year/plant). This was multiplied by the number of trees in the nursery; the result was then averaged with the final value obtained from the calculations. This way, it is possible to approach the most probable value of CO2 sequestration.

The CO2 seizure value is divided by the surface of the nursery to obtain a unitary reference value (for the full field).

It was also decided to estimate the amount of oxygen released by the plants. From the photosynthesis formula it can be seen that for each mole of CO2 absorbed is emitted a mole of O2.

Using the molar masses it is possible to obtain from the calculated kg of CO2 the quantity of O2 emitted into the atmosphere (Nowak et al. 2007). The formula used is as follows:

$$O_2 \text{ (kg/year)} = CO_2 \text{ sequestered (kg/year)} \times (MM_{O2}/MM_{CO2})$$

MM O_2 = 31.998 g/mol; MM CO_2 = 44.009 g/mol.

Considering that one person, per day, consumes about 0.80 kg of O2 (Nowak *et al.* 2007), it was also determined how many people in a year are supplied by the oxygen produced by the trees of the Mati nurseries alone.

B. PRODUCTION NURSERY IN MASIANO

In the case of shrubs, to calculate the total CO2 sequestration, the average value of the interval reported in the literature (0.27 - 0.84 kg/year/cad), equal to 0.56 kg/year/cad, multiplied by the number of plants, was used.

For the trees, the same formulas applied for the Ramini nursery have been used. Also in this case, to take into account the intense growth of the plants in the nursery, the average between this calculated value and the average value found in the literature (17.03 kg/year/cad, multiplied by the number of trees) was made. The CO2 sequestration values of trees and shrubs have been added together to obtain the total value for the portion of the pots considered; dividing then by the surface of the pots in question, the average CO2 sequestration value per square metre of the pots of the Mati nurseries has been found, necessary to extend the analysis to the remaining part of the nursery for which the inventory is missing.

Using the same formulas as above, the quantity of O2 released into the atmosphere and the number of people who breathe that same volume in a year have been calculated.

	kg CO_2 sequestered	**kg O_2 released**	**O_2 sufficient for n people**
Masiano (18.85 ha)	179744,3121	130688,2342	448
Ramini (11.11 ha)	70735,0149	51429,9122	176
	250479,3 kg CO_2	**182118 kg O_2**	**624**
	250 t CO_2	**182 t O_2**	

CALCULATION OF THE BALANCE OF CO_2 IN PIANTE MATI NURSERIES

We then proceeded with the calculation of the CO_2 balance of the Mati nurseries, obtained by the difference between the CO_2 sequestered from the plants and the CO_2eq emitted into the atmosphere during the production process by all the factors used. In order to determine the amount of emissions, average unit values were used (specific for production in containers and in the open field) taken from various bibliographic sources (Nicese & Lazzerini 2013; Lazzerini et al. 2014).

	kg CO_2 sequestered	kg CO_2eq released	difference (kg)
Masiano, open field (12.29 ha)	92090,395 44	50143,2	41947,20
Masiano, pots (3.71 ha)	87653,916 62	113155	-25501,08
Ramini (9.44 ha)	70735,014 9	38515,2	32219,81
Total	**250479,3 kg**	**201813,40 kg**	**48665,93 kg**
	250 t	**202 t**	**48 t**

<u>REMOVAL OF ENVIRONMENTAL POLLUTANTS</u>

Trees and shrubs are capable of effectively removing the various pollutants produced by human activities, thus preventing their spread into the surrounding environment and purifying the air we breathe. For this reason, it was decided to also estimate the quantity of pollutants (PM10, O3, NO2, SO2, CO) that the nursery plants are able to absorb or retain.

The amount of pollutants removed from the <u>trees</u> varies according to size. From the bibliography (Nowak 1994; F. Ferrini) reference values have been obtained for the various diameter classes, among which an average was struck to obtain a final value as representative as possible of the real situation. (In the case of the second series of values, not all diameter classes were given. For this reason, a linear regression analysis was made to obtain the missing data on the basis of those available.)

The available data therefore indicates the kg of total annual pollutants retained by the individual tree for each diameter category. Multiplying by the number of plants present for each category, it is possible to calculate the total removal by the nursery.

In the case of <u>shrubs</u>, an average of the different data found in the literature was made, referring to the removal per individual (Municipality of Forlì; Baraldi *et al.* 2018; Region of Tuscany). The average value thus determined was then multiplied directly by the number of shrubs reared.

From the values obtained through the operations, the average values of removal per hectare for the open field and for pots, necessary for the estimate of the Masiano nursery, were also calculated.

	pollutants removed (kg)
Masia no	1614,7472 85
Ramin i	668,833
Total	**2284 kg**

The bibliography (Nowak 1994) also determined the quantity of individual pollutants removed on average from nursery plants. As a percentage of the total, it results: 32.8% PM10, 14.3% NO_2, 12.8% SO_2, 36.0% O_3, 4.2% CO.

	%	kg
PM10	32.8	750
O_3	36.0	822
NO_2	14.3	326
SO_2	12.8	292
CO	4.2	96
Total	**100**	**2284**

THE ECONOMIC VALUE OF THE ACTIVITY OF THE TREES

In order to better understand and quantify the centrality of the role of plants within the urbanised context, it is usual to translate into monetary value the extent of the removal of CO_2 and pollutants.

The literature (Nowak *et al.* 2013; Interagency Working Group 2016; Wang *et al.* 2018) shows that the average social cost of carbon is 48.35 $/t CO_2eq. The social cost of carbon is the monetisation of the damage caused by climate change, as a result of the increase in greenhouse gases in the atmosphere. Among the various aspects considered are, for example: lower productivity in agriculture, higher health costs due to increased health problems, property damage as a result of more frequent floods, rising sea levels and the loss of fertile land, loss of income (related to tourism), a change in ecosystem services.

For the calculation, the cost of carbon shown above was multiplied by the total amount of CO2 that the nursery plants seize through photosynthesis and fix in their tissues. The result thus provides an estimate of the costs (and damage) avoided by society through the removal of this molecule by the plants.

In a similar way, from the various data reported in the literature, the value of the removal of pollutants (PM10, O3, NO2, SO2, CO) produced by human activities was determined, equal to 11.04 $/kg (Nowak et al. 2006; Ferrini 2009; Paoletti et al. 2011; Kim 2016). Multiplying this value by the total amount (kg) of pollutants removed from the nursery plants gives a further estimate of the benefits that derive from the presence of trees.

	kg CO_2 sequestrata	Valore economico CO_2 sequestrata (€)	kg inquinanti rimossi	Valore economico rimozione inquinanti (€)
Masiano	179744,31	7821,39	1614,747285	9433,56
Ramini	70735,01	3078,03	668,833	3907,41
Totale	**250 479 kg CO_2**	**10 899 €**	**2284 kg**	**13 341 €**

ESTIMATED VALUES FOR THE ENTIRE PISTOIA NURSERY DISTRICT

The positive role of plants grown in nurseries in mitigating some environmental problems can be extended to the entire nursery district of Pistoia, which consists of a total of 5200 ha of which 3700 ha cultivated in the open field and the remaining part (1500 ha) occupied by container production. Using as a sample the values per unit area previously calculated for the Mati nurseries, the following indicative data referring to one year were obtained:

- 63 150 t di CO_2 removed, equal to € 2 756 498;
- the net balance of CO_2 sequestered from plants is 2304 t;
- 45 780 t of oxygen released into the atmosphere, sufficient for approximately 157 000 people;
- 563 t of air pollutants potentially removed or absorbed, representing a value of € 3 293 070.

It is therefore estimated that the entire nursery district seizes an average of 12 t/ha/year of CO_2, absorbs 108 kg/ha/year of air pollutants, releasing 9 t/ha/year of oxygen..

CALCULATION OF THE AIR TEMPERATURE DROP

Trees, in addition to providing shade thanks to their canopies, are able to convert solar radiation into latent heat through the process of transpiration, thus contributing fundamentally to lowering temperatures in the urban context. In fact, in our cities, where a large part of the surface is covered with impermeable materials, perspiration is the main source of latent heat (Konarska *et al*. 2015).
The specific heat formula [$Q(kcal) = m(kg)*c(kcal/kg\ °C)*\Delta T(°C)$] was used to estimate the temperature drop of nursery plants. The literature has shown that 800 m2 of soil with a tree cover of 30% are capable of absorbing through perspiration 1.2 million kcal in one year (Ferrini). This figure, although slightly underestimated, has been applied to the nursery. The latent heat formula was used to determine the mass of air that is cooled by one degree from the amount of energy indicated above. The value, referred to 800 m2, was then expressed as a function of a nursery of 29 ha (the measure of the nurseries Mati). The mass value was then converted into volume by dividing it by the air density.

In order to better understand the result obtained, terms of comparison have been chosen. Calculating the volume of air occupied by an apartment of 100 m2 (on average 300 m3), we determined the number of apartments whose temperature is theoretically reduced by 1°C thanks to the transpiration operated by the plants in a nursery of 29 ha. Or, in a similar way, considering the volume of air within the canopy of the plants in a hypothetical nursery of 29 ha, we determine the number of nurseries of equal surface in which there is a decrease of 1°C in temperature. The calculation has been repeated for both comparisons, assuming a decrease of 5°C..

29 hectares of nursery absorb 435 million kcal per year.
This amount of energy subtracted allows the lowering of 1°C to an air volume equal to 1479 million cubic meters. This volume corresponds to that of about 5 million apartments of 100 m2; or to that of 1020 nurseries of 29 ha.
The same amount of energy subtracted leads to a decrease of 5°C of a volume of 296 million cubic meters of air, which corresponds to 986 thousand apartments of 100 m2 or 204 nurseries of 29 ha.

IMPACT OF THE NURSERY COMPARED TO OTHER INDUSTRIAL SECTORS

The environmental impact per unit area (kg/m2/year), in terms of CO_2eq emissions into the atmosphere, of a nursery company was compared with that of other typical industrial sectors in the provinces surrounding Pistoia (paper mills and textiles in particular).
In the case of the nursery, the values reported in the literature (Nicese & Lazzerini 2013; Lazzerini *et al.* 2014) have been used, to which reference has already been made for the calculations previously carried out. For the quantification of emissions, all the various production factors used are taken into account (such as pot plastic, fertilisers, plant protection products, diesel, electricity). Moreover, the emission value thus considered does not take into account the share of CO_2 sequestered by plant activity. For this reason, the calculation was repeated on the basis of the actual net emissions into the atmosphere of the nursery production.
In the case of other industrial sectors, environmental statements from existing companies were sought. Among the various data reported in these official documents, we have extrapolated those relating to greenhouse gas emissions into the atmosphere (and expressed as t or kg of CO_2eq) and electricity consumption (in MWh and which have been converted into CO_2eq through the conversion factor of 0.56 kg CO_2eq/kWh found in the literature). The total values determined were divided by the production area of the companies considered to obtain the final unit value (kg/m2/year).

	Emissions kg/sm/year CO_2eq
TEXTILE INDUSTRY	
greenhouse gas emissions	420
electricity	130
TEXTILE TOTAL	**550**
PAPER MILL	
greenhouse gas emissions	1367
electricity	1960
PAPER MILL TOTAL	**3327**
NURSERY	
Open field	**0,408**
Pots	**4,529**
NURSERY average	**2,469**

COMPENSATION OF CO_2 EMITTED INTO THE ATMOSPHERE

Given the significant emissions of the industrial sectors considered, plants are the only, simplest and most effective solution for reducing CO_2 emissions and containing the phenomenon of climate change. Planting trees around industrial buildings and along communication routes ensures a continuous and constant absorption of polluting molecules and helps our economic activities to move increasingly towards the sustainability criteria strongly demanded by politics and society. Trees make work environments healthier and more pleasant, also improving the productivity and well-being of individual workers. A greater presence of plants (and their proper management) produces only positive environmental and economic effects.

To calculate the number of trees needed to offset CO_2eq emissions it is necessary to know the amount of CO_2 that on average is seized by a tree in good condition in a year.

Different absorption values were used than those previously calculated for the nursery because, in urban environments, the concentration of CO_2 in the air is much higher than in a rural area and therefore the plants perform photosynthesis with much higher rates resulting much more efficient in sequestering CO_2 within a year.

The average absorption data obtained from various bibliographic sources (GAIA Project; IBIMET-CNR) are specific to the individual tree species most commonly used and most suitable for the urban environment. In order to have a more generic CO2 absorption value of reference, it was decided to calculate the average value among those given in the literature, which was equal to 86 kg CO_2/tree/year. This figure represents an average seizure referring to a period of about 30 - 40 years from planting (starting from plants of about 10 years of age).

If we divide the unit CO_2eq emissions previously calculated for the two industrial sectors by this average value, we obtain the number of trees capable of offsetting these emissions, for each square metre of production area (the figure in this form is useful for making a comparison between the various sectors. For a real offsetting study, the total emissions would be directly divided by the absorption value of the single tree).

When planting tree species with the highest rates of carbon dioxide sequestration (e.g. *Acer platanoides, Celtis australis, Betula pendula, Carpinus betulus, Quercus cerris, Fraxinus excelsior, Ginkgo biloba, Liriodendron tulipifera, Ulmus minor, Sophora japonica, Liquidambar styraciflua, Tilia cordata, Tilia platyphyllos)*, a smaller number of individuals is obviously necessary to achieve the same result. For this reason, the compensation calculation has been repeated considering only these most performing species, for which it has been estimated an average net absorption value of 144 kg/tree/year.

	Emissions (kg/ m^2/year)	N° trees for every productive square meter	N° of most performing trees for every productive m^2
Textile	500	6	4
Paper mill	3327	39	23

The number of plants needed for compensation is very high, so it is impossible to place them all in the vicinity of industrial sites, where in fact they would be able to best express their ability to seize CO_2 (and pollutants). However, the constant increase in the number of trees (and shrubs) in uncultivated urban and suburban green areas and the redevelopment of existing parks can only make a fundamental contribution to offsetting the emissions of our necessary industrial and commercial activities.

An example of this type of commitment is given by the GAIA Project, in the Municipality of Bologna; but there are also many companies that are individually working in this direction.

For the sake of completeness, there is also a list of tree species that are less efficient in CO_2 sequestration (GAIA Project; Qualiviva Project; IBIMET-CNR). This, of course, does not mean that these species should not be used in urban areas, as many of them have a great ornamental value or are particularly adaptable, but that they must be properly combined with the other more performing ones if the main objective is to lower the concentration of CO_2 in the air. Moreover, the pedo-climatic characteristics of the planting site are crucial: a plant that is potentially less efficient in the sequestration of CO_2 can give much better results than another that is more performing but not suitable for that particular planting site.

Among the potentially less efficient species in CO_2 sequestration, they can be indicated: *Acacia dealbata, Albizia julibrissin, Cercis siliquastrum, Corylus avellana, Crataegus monogyna, Cupressus sempervirens, Fraxinus ornus, Ligustrum japonicum, Malus spp., Koelreuteria paniculata, Parrotia persica, Prunus cerasifera 'Pissardii', Prunus serrulata, Pyrus calleryana, Sambucus nigra, Sorbus aucuparia.*

COMPENSATION FOR POLLUTANTS EMITTED INTO THE ATMOSPHERE

In a similar way to what has been said for the compensation of CO2, it is possible to estimate the number of trees necessary to absorb or retain the various pollutants released into the atmosphere by the different human activities. Therefore, dividing the total emissions of pollutants (from an industrial activity, from a city, from vehicle traffic) by the average absorption of a tree, the number of plants needed to reach compensation is estimated.

On average, a healthy mature tree absorbs about 0.42 kg of pollutants each year (considering only O_3, NO_2, SO_2 e PM10).

In the case of the highest performing species, 1.14 kg of pollutants are removed each year. Among these species can be indicated: *Acer platanoides*, *Acer pseudoplatanus*, *Liriodendron tulipifera*, *Magnolia grandiflora*, *Corylus colurna*, *Fraxinus excelsior*, *Fraxinus oxycarpa*, *Platanus* x *acerifolia*, *Quercus ilex*, *Quercus robur*, *Salix alba*, *Tilia platyphyllos*, *Tilia tomentosa*, *Ulmus parviflora*, *Ulmus procera*.

Among the species that are less capable of reducing air pollutants there are (but never forgetting the considerations made for the compensation of CO2): *Acer campestre*, *Acer negundo*, *Cercis siliquastrum*, *Koelreuteria paniculata*, *Ligustrum japonicum*, *Malus* spp., *Melia azedarach*, *Morus* spp., *Ostrya carpinifolia*, *Prunus cerasifera* ‘Pissardii’, *Pyrus calleriana*.

ANALYSIS OF VEHICLE TRAFFIC

It was decided to also analyse the vehicle traffic that can affect an industrial area and the CO2eq emissions associated with it.

The traffic data for the peak hour (7:30 - 8:30) on the East Orbital Road - Via Fermi Est intersection were obtained from the General Urban Traffic Plan of the Municipality of Pistoia. For the calculation of emissions, the average fuel consumption for each type of vehicle (l/km) and the conversion factor of fuel consumption into CO2eq emissions (kg CO2eq/l) were used.. For this second data, the diffusion of the various types of power supply for each vehicle category was considered (ISPRA 2018; Caserini et al. 2019; MIT).

From the product between the fuel consumption per km and the conversion factor, the CO_2eq emissions for each km travelled are calculated. Multiplying this last data by the number of vehicles passed, we obtained the amount of emissions for the only vehicles that during the peak hour, in one day, pass through the junction above in the industrial area of Pistoia (the calculation was made considering the emissions related to 1 km covered). From this daily data we have then moved to the annual one.

	km/l	l/km	conversion factor kg CO_2/l (average)	kg CO_2/km	number of vehicles (7:30-8:30)	kg CO_2eq emitted during rush hours on 1 km
Car	15	0,07	2,29	0,153	1508	230,22
Lightweight commercial vehicles	12	0,08	2,48	0,207	213	44.02
Lorry	4,8	0,21	2,63	0,548	113	61,91
Tractor trailer	3,4	0,29	2,63	0,774	10	7,74
Bus	4	0,25	1,90	0,475	3	1,43
Motorcycle	31	0,03	2,33	0,075	64	4,81
Daily Total					1911	**350 kg**
Yearly Total						**105 738 kg**

Considering, as above, an average annual absorption of 86 kg CO2 per plant, the number of trees capable of offsetting the emissions of the single peak hour on the intersection Via Fermi - Tangenziale Est, is equal to 1230. Using only the species with the highest seizure rates (on average 144 kg CO2/hub/year) then 734 trees would be needed.

Here, too, similar considerations apply as in the case of offsetting industrial emissions. The number of plants needed for offsetting is very high, which makes it possible to understand how every free space should contain healthy plants capable of counteracting the harmful effects of greenhouse gas accumulation.

With this study we just want to show how the nursery sector, which of course must continuously improve to solve its problems, presents itself as a strategic sector to counter the negative effects of the accumulation of greenhouse gases and climate change because it produces plants that among the many benefits, as mentioned, are able, if well managed, to absorb significant amounts of CO2 and pollutants contributing to greater livability of urban agglomerations.

ANALYSIS OF OTHER CONTEXTS

Agriculture

The ornamental nursery tends to have emission values, for the production in open field, equal to or lower than those of the traditional agriculture. Container production, on the other hand, is characterised by higher emissions (due to the higher inputs required and the use of pots and peat plastics) than agricultural processes, even though the cultivation of vegetables in greenhouses, for example, has much higher emission values.

Maize cultivation, on average, has CO_2eq emissions around 3.15 t/ha/year (Desjardins *et al.*; CRPA 2013; Solazzo *et al.* 2015). The absorption of CO_2 during the cultivation period, including the share stored in the soil, is equal to 39.5 t/ha (PSR Umbria).

The cultivation of table tomatoes, in open field, has average greenhouse gas emissions around 12.6 t/ha. But if production takes place in greenhouses, heated with conventional methods,

then emissions rise to 587 t/ha. Heating is in fact the item that weighs most on the balance of emissions (Ntinas *et al.* 2016; Ronga *et al.* 2019).

Wood

A forest absorbs on average 13.4 t/ha/year, a value which also includes the part stored in the soil (APAT 2002; Scarfò & Mercurio 2009; Lorenz & Lal 2010). Comparing various data found in literature, the average amount of air pollutants removed annually from wooded areas was also determined: 31 kg/ha/year of PM10, 13 kg/ha/year of NO2, 6 kg/ha/year of SO2 and 45 kg/ha/year of O3 (Marando *et al.* 2016; Song et al. 2016; Fusaro *et al.* 2017; Eom *et al.* 2017; Nowak *et al.* 2018).

City

In Italy (Cittalia 2010), the average CO_2eq emissions of a metropolitan city are 1261000 t per year (equivalent to 51 t/ha/year), to which corresponds an average annual emission value per capita of 1.805 t.

They have been taken into account for the calculation of the emissions:

- domestic gas consumption, which represents 37.7% of the total;
- domestic electricity consumption, which accounts for 30.8%;
- private passenger transport, equal to 31.2% of the total;
- waste production and treatment (0.3% of the total).

A worldwide study (C40 Cities 2018), which considers many more parameters (emissions related to: households, commercial areas, public services, public and private transport, food supply, restaurants, hotels, recreational and cultural areas, clothing, communications, health, education), estimates for European cities average per capita emissions of about 12 tons per year.

With regard to emissions of pollutants in urban areas, the ISPRA 2015 data have obtained the following annual average values: 395 t PM10, 2973 t NOx, 626 t SOx, 8744 t CO. Urban green areas have the capacity to sequester about 3 tonnes of CO2 per hectare per year. The uptake of air pollutants by greenery is much more variable, but values around 25 kg/ha seem reliable (Nowak 1994; Scott et al. 1998; Selmi et al. 2016).

ISTAT data (2016) shows that, in Italy, green areas in cities occupy an average of 2.7% of the surface area of the territory.

Industry

From the IRSE (2010) data of the Region of Tuscany it can be deduced that the entire industrial sector of the Region has the following annual emission values in the atmosphere:

CO	20 967 t/year
CO_2	13 272 178 t/year
NO_x	11 531 t/year
PM10	2 318 t/year
SO_x	7 848 t/year
CO_2 eq	13 367 569 t/year

The emissions into the atmosphere relative to the industrial sector of the Province of Pistoia alone have therefore been determined:

	t/year	% Pistoia emissions on total Tuscany Region
CO	104	0,5
CO_2	201835	1,5
NO_x	406	3,5
PM10	26	1,1
SO_x	457	5,8
CO_2 eq	202772	1,5

Considering that in the Province of Pistoia, commercial and industrial areas occupy 1475 ha, equal to 1.53% of the total provincial area, this data has been used to estimate the emissions of pollutants per unit area for the industrial sector:

	kg/ha/year emissions from industrial areas Province of Pistoia
CO_2	136 831
CO_2 eq	137 466
CO	71
NO_x	275
PM10	18
SO_x	310

PLANTS TO CONTAIN NOISE POLLUTION

The use of vegetation strips along the roads is a possible solution for noise reduction. In addition to the effect of the distance between the source and the receiver (the so-called normal attenuation), the presence of plant elements also introduces phenomena of absorption and, above all, the diffusion of sound waves.

There is a direct correlation between noise attenuation and the thickness, length and height of the plant barrier. In general, vegetation bands with a thickness of 30 m or more are capable of significantly reducing noise: according to data reported in the literature from 4 - 8 dB A to 10 dB A (Cook & Haverbeke 1992; Fang & Ling 2003, 2005; Van Renterghem et al. 2015). If the same green belt is placed on an embankment, then the sound reduction can reach values of 10 - 15 dB A (USDA). A well-done hedge of trees and shrubs can reduce noise pollution by 0.1 - 0.2 dB per metre of thickness (in the case of low-frequency and high-frequency noise, respectively).

Other studies show that a 20 - 30 m thick barrier is optimal for reducing traffic noise (both from cars and heavy vehicles) on a major road in rural areas. The edge of the hedge should be 15 - 25 m from the centre of the road and the trees should be 14 m high. In the case of an urban area, a thickness of 6 to 15 m is sufficient to significantly reduce traffic noise. If shrubs with a height of 2 - 2.5 m are placed, followed, in the background, by a row of trees with a height of 6 - 15 m, optimum results are obtained. Also in urban areas, the best distance between the noise source and the first row of shrubs is 3 - 8 m. In cities, a hedge of dense shrubs and trees of moderate height is an adequate noise barrier.

It has been calculated that a 15 m thick hedge with optimal characteristics attenuates traffic noise like a rigid artificial noise barrier.

When it comes to choosing the most suitable species, well-branched shrubs with dense foliage provide excellent results. Also in the case of trees, tall species with dense, leathery foliage and uniform vertical leaf distribution are the most efficient. A multi-layered barrier, with a combination of lower shrubs and trees, is best able to attenuate the noise. However, the creation of a barrier that

is as dense and continuous as possible is the most important aspect. This is why evergreen or persistently leafy species are among the most functional. In general, leaves are capable of attenuating noise more frequently than 1000 - 2000 Hz.
The length of the hedge must, of course, be equal to that of the road on which you want to obtain protection (to have attenuation, the noise receiver must never see the cars, the plant barrier is not able to interfere with the sound waves that with oblique trajectory reach the receiver). If the receiver is on time, the length of the hedge must be at least twice the distance between the noise source and the receiver. In cases where it is not possible to use trees for height issues, it should not be forgotten that even a solution of herbaceous species combined with shrubs creates a soft surface that can attenuate the noise more than satisfactorily (Cook & Haverbeke 1992; Fang & Ling 2003, 2005; RISVEM 2008; Van Renterghem et al. 2015).

BIBLIOGRAPHY

APAT. 2002. Assorbimento e fissazione di carbonio nelle foreste e nei prodotti legnosi in Italia. Rapporti 21/2002.

Baraldi Rita, Facini Osvaldo, Neri Luisa, Carriero Giulia. 2018. Relazione Parco Storico Bosco Albergati. Gruppo di Ricerca IBIMET-CNR. https://www.boscoalbergati.it/wp-content/uploads/2018/10/IBIMET-CNR-Relazione-BOSCO-ALBERGATI-25-07-18.pdf

Benincà Gino, De Franceschi Giacomo. 2017. Regolamento per la quantificazione delle misure di compensazione delle emissioni di gas climalteranti degli allevamenti zootecnici intensivi.

Buffoni A., Toccafondi P., Pinzauti S. Progetto di fattibilità di un sistema del verde di mitigazione da inquinamento. Comune di Forlì, settore Ambiente.

Burgo Group S.p.A. 2018. Dichiarazione Ambientale: Cartiera di Toscolano – Cartiera di Verzuolo – Cartiera di Villorba. Triennio 2018–2020.

C40 Cities. 2018. Consumption-based GHG emissions of C40 cities.

Caserini Stefano, Baglione Paola, Cottafava Dario, Gallo Michela, Laio Francesco, Magatti Giacomo, Maggi Valter, Maugeri Maurizio, Moreschi Luca, Perotto Eleonora, Pizzol Lisa, Semenzin Elena, Senese Antonella. 2019. Ingegneria dell'Ambiente, **6** (1): 43–59.

Cittalia. 2010. Rapporto Cittalia 2010. Anticipazioni. Due campi di calcio a testa per ridurre l'inquinamento di CO_2 dei cittadini nelle aree metropolitane.

Comune di Caorso. Valutazione emissioni di CO_2 ed opere compensative. PUA – Area di Trasformazione P05 –Sub Comparto A Lotto C – Mercedes Benz Italia S.p.A.

Comune di Carimate. 2017. Relazione agronomica abaco delle essenze.

Comune di Pistoia. 2017. Aggiornamento del Piano Generale del Traffico Urbano (PGTU) e definizione del Piano Urbano della Mobilità Sostenibile (PUMS).

Cook David I., Haverbeke David F. 1971. Trees and Shrubs for Noise Abatement. Historical Research Bulletins of the Nebraska Agricultural Experiment Station (1913–1993)

CRPA. 2013. Emissioni in atmosfera: l'impronta che non si vede. Programma di sviluppo rurale dell'Emilia Romagna 2007-2013.

Desjardins R.L., Worth D.E., Vergé X.P.C., VanderZaag A., Janzen H., Kroebel R., Maxime D. Smith W., Grant B., Pattey E., Dyer J.A. Carbon Footprint of Agricultural Products - A Measure of the Impact of Agricultural Production on Climate Change. Agriculture and Agri-food Canada.

Eom Ji-Young, Jeong Seok-Hee, Lee Jae-Seok. 2017. Assessment of absorption ability of air pollutant on forest in Gongju-city. Journal of Ecology and Environment 41:41.

Fang, C.F., Ling, D.L. 2003. Investigation of the noise reduction provided by tree belts. Landscape Urban Plan. **63** (4): 187–195.

Fang, C.F., Ling, D.L. 2005. Guidance for noise reduction provided by tree belts. Landscape Urban Plan. **71**: 29–34.

Ferrini F. 2009. L'albero in città: risorsa o criticità? https://www.ilverdeeditoriale.com/pdf_verde/Albero%20in%20citt%C3%A0%202009.pdf

Fusaro Lina, Marando Federica, Sebastiani Alessandro, Capotort Giulia, Blasi Carlo, Copiz Riccardo, Congedo Luca, Munafò Michele, Ciancarella Luisella, Manes Fausto. 2017. Mapping and Assessment of PM10 and O_3 Removal by Woody Vegetation at Urban and Regional Level. Remote Sens. **9**: 791.

IBIMET–CNR. Forestazione urbana: schede. http://www.bo.ibimet.cnr.it/repository/forestazione-urbana-schede/view

Interagency Working Group on Social Cost of Carbon, United States Government, 2016. Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866.

IRSE. 2010. Settore Energia, tutela della qualità dell'aria e dall'inquinamento elettromagnetico e acustico: Inventario regionale delle sorgenti di emissione in aria ambiente – IRSE aggiornamento all'anno 2010. Regione Toscana, Direzione Generale Politiche Territoriali Ambientali e per la Mobilità. http://www.regione.toscana.it/-/inventario-regionale-sulle-sorgenti-di-emissione-in-aria-ambiente-irse

ISPRA. 2018. Tabella dei parametri standard nazionali per il monitoraggio e la comunicazione dei gas a effetto serra ai sensi del Decreto Legislativo n. 30 del 2013.

ISTAT. 2016. Statistiche focus – Verde urbano anno 2014. https://www.istat.it/it/archivio/186267 Jersey

Mode S.p.A. 2015. Dichiarazione ambientale. Regolamento CE n°1221/2009.

Kim G. 2016. Assessing Urban Forest Structure, Ecosystem Services, and Economic Benefits on Vacant Land. Sustainability, **8**: 679.

Konarska Janina, Uddling Johan, Holmer Björn, Lutz Martina, Lindberg Fredrik, Pleijel Håkan, Thorsson Sofia. 2015. Transpiration of urban trees and its cooling effect in a high latitude city. Int J Biometeorol. DOI 10.1007/s00484-015-1014-x

Lazzerini G., Lucchetti S., Nicese F.P. 2014. Analysis of greenhouse gas emissions from ornamental plant production: A nursery level approach. Urban Forestry & Urban Greening, **13**: 517–525.

Lorenz K., Lal R. 2010. Carbon Sequestration in Forest Ecosystems. Springer.

Marando Federica, Salvatori Elisabetta, Fusaro Lina, Manes Fausto. 2016. Removal of PM10 by Forests as a Nature-Based Solution for Air Quality Improvement in the Metropolitan City of Rome. Forests **7**: 150.

MIT. Costo chilometrico medio relativo al consumo di gasolio delle imprese di autotrasporto per conto terzi. http://www.mit.gov.it/documentazione/autotrasporto-merci-conto-di-terzi-valori-indicativi-di-riferimento-dei-costi-di

Nicese F.P., Lazzerini G. 2013. CO_2 Sources and Sink in Ornamental Plant Nurseries. Proc. II IS on Woody Ornamentals of the Moderate Zone. Acta Hort. **990**, ISHS 2013.

Nowak D.J. 1994. Air Pollution Removal by Chicago's Urban Forest. In: McPherson, E.G., Nowak, D.J., Rowntree, R.A. (Eds.), Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project. USDA Forest Service General Technical Report NE-186, Radnor, PA, pp. 63–82.

Nowak D.J., Crane D.E. 2002. Carbon storage and sequestration by urban trees in the USA. Environmental Pollution **116**: 381–389.

Nowak D.J., Crane D.E., Stevens J.C. 2006. Air pollution removal by urban trees and shrubs in the United States. Urban Forestry and Urban Greening **4**, 115–123.

Nowak David J., Greenfield Eric J., Hoehn Robert E., Lapoint Elizabeth. 2013. Carbon storage and sequestration by trees in urban and community areas of the United States. Environmental Pollution, **178**: 229–236.

Nowak David J., Heisler Gordon M. 2010. Air Quality Effects of Urban Trees and Parks. National Recreation and Park Association: Research Series | 2010.

Nowak David J., Hirabayashi Satoshi, Doyle Marlene, McGovern Mark, Pasher Jon. 2018. Air pollution removal by urban forests in Canada and its effect on air quality and human health. Urban Forestry & Urban Greening **29**: 40–48.

Nowak David J., Hoehn Robert, Crane Daniel E. 2007. Oxygen Production by Urban Trees in the United States. Arboriculture & Urban Forestry, **33** (3): 220–226.

Ntinasa Georgios K., Neumaira Maximilian, Tsadilas Christos D., Meyer Joachim. 2016. Carbon footprint and cumulative energy demand of greenhouse and open-field tomato cultivation systems under Southern and Central European climatic conditions. Journal of Cleaner Production. doi: 10.1016/ j.jclepro.2016.10.106

Paoletti Elena, Bardelli Tommaso, Giovannini Gianluca, Pecchioli Leonella. 2011. Air quality impact of an urban park over time. Procedia Environmental Sciences, **4**: 10–16.

Politec Technology Srl. 2017. Calcolo della carbon footprint per l'abbattimento delle emissioni tramite piantumazione.

Progetto GAIA: http://lifegaia.eu/

Progetto Qualiviva: http://www.vivaistiitaliani.it/qualiviva/consultazione-shede-tecniche

PSR Umbria. Realizzazione di un modello per la quantificazione della riduzione di CO_2 in agricoltura. PSR Umbria 2007-2013 asse 1 mis. 124; Cooperazione per lo sviluppo dei nuovi prodotti, processi e tecnologie nei settori agricolo e alimentare e in quello forestale.

Regione Toscana. Linee Guida per la messa a dimora di specifiche specie arboree per l'assorbimento di biossido di azoto, materiale particolato fine e ozono. http://www.regione.toscana.it/documents/10180/4058647/Allegato+1+Linea+guida+Piantumazione+31_10_2018.pdf/c99d86e0-811d-44da-836e-adb6f255f28c

RISVEM. 2008. Manuale RISVEM. Linee guida tecnico-operative per la pianificazione, progettazione realizzazione gestione di spazi verdi multifunzionali.

Ronga Domenico, Gallingani Tommaso, Zaccardelli Massimo, Perrone Domenico, Francia Enrico, Milc Justyna, Pecchioni Nicola. 2019. Carbon footprint and energetic analysis of tomato production in the organic vs the conventional cropping systems in Southern Italy. Journal of Cleaner Production **220**: 836–845.

Scarfò F., Mercurio R. 2009. Il calcolo dei crediti di carbonio: il modello CO2FIX v. 3.1 applicato ad una faggeta sotto Forest Management nel sud Italia. Forest@ **6**: 215–228.

Scott Klaus I., McPherson E. Gregory, Simpson James R. 1998. Air Pollutant Uptake by Urban Forest. Journal of Arboriculture, **24** (4): 224–234.

Scott Klaus I., McPherson E. Gregory, Simpson James R. 1998. Air pollutant uptake by Sacramento's urban forest. Journal of Arboriculture **24** (4): 224–324.

Selmi Wissal, Weber Christiane, Rivière Emmanuel, Blond Nadège, Mehdi Lotfi, Nowak David. 2016. Air pollution removal by trees in public green spaces in Strasbourgcity, France. Urban Forestry & Urban Greening **17**: 192–201.

Solazzo Roberto, Tomasi Licia, Donati Michele, Arfini Filippo. 2015. Il contributo del Greening alla riduzione delle emissioni di CO_2. Agriregionieuropa, **11** (41).

Song Cholho, Lee Woo-Kyun, Choi Hyun-Ah, Kim Jaeuk, Jeon Seong Woo, Kim Joon Soon. 2016. Spatial assessment of ecosystem functions and services for air purification of forests in South Korea. Environmental Science & Policy **63**: 27–34.

USDA. GUIDELINES / 6.0 Aesthetics & Visual Quality. 6.4 Buffers for Noise Control. https://www.fs.usda.gov/nac/buffers/guidelines/6_aesthetics/4.html

Van Renterghem Timothy, Attenborough Keith, Jean Philippe. 2015. Designing vegetation and tree belts along roads. Environmental methods for transport noise reduction, eds. M. E. Nilsson, R. Klæboe, and J. Bengtsson Oxford, U.K.: Spon Press 2014.

Wang P., Deng X., Zhou H., Yu S. 2018. Estimates of the social cost of carbon: A review based on meta-analysis. Journal of Cleaner Production, **209**.

Zirkle G., Lal Rattan, Augustin Bruce, Follett R. 2012. Modeling Carbon Sequestration in the U.S. Residential Landscape. In: Lal R., Augustin B. (Eds), Carbon Sequestration in Urban Ecosystems. Springer, pp. 265–276.

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