F.P. Nicese, G. Colangelo, R. Comolli, L. Azzini, S. Lucchetti, P.A. Marziliano, G. Sanesi, 2021. Estimating CO2 balance through the Life Cycle Assessment prism: A case –Study in an urban park. Urban Forestry & Urban Greening 57 - 126869

Estimating CO2 balance through the Life Cycle Assessment prism: A case – Study in an urban park

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Abstract

In a context of progressive urbanization, urban parks can play a pivotal role in carbon sinking and stocking. The study employs Life Cycle Assessment (LCA) to evaluate CO_2e emissions and removal by plants and soil in different urban green typologies, namely afforested areas, tree rows, social allotments, lawns, hedges, referring to a life span of 50 years.

The present study aims to evaluate the carbon balance connected with planning, planting, and maintaining an urban park, the Parco Nord Milano (PNM), a green area located in the metropolitan area of Milan, Italy (Marziliano et al, 2013; Sanesi et al., 2007).

The different emission scenarios examined took into consideration planting and maintenance interventions, including the effects of equipment and vehicle choices, main operational activities, and the fate of vegetal residue from pruning, shrub and tree removal, and lawn mowing. The best performances in terms of CO_2e balance per surface unit was obtained with tree rows and afforested area typologies (- 682 and – 530 Mg CO_2e ha^{-1} $50yrs^{-1}$, respectively), while the hedges showed the worst CO_2e balance, (+ 864 Mg CO_2e ha^{-1} $50yrs^{-1}$). Different planting options, different pruning or thinning intensities or species selection can change this balance. In addition, converting residues from removed trees into wood products can improve the storage of CO_2 for long periods. LCA has proved to be an effective tool to support the planning and maintenance of urban parks and the types considered. However, rational planning must also take into account user preferences and needs, and which ecosystem services can be maximized to ensure a better quality of life.

Key words: LCA, soil, carbon, sink, ecosystem services

Acknowledgements: We gratefully acknowledge Parco Nord Milano (PNM) for the hospitality and for the help provided during data collection. Moreover, the authors would like to extend a special thanks to the anonymous reviewers for their comments and suggestions that helped improve this work.

Introduction

Over recent decades, the population living in urban settlements has increasingly grown. According to the United Nations (2016), the majority of the population (54.5%) today lives in urban areas and this phenomenon is expected to increase in coming years, with 27% of people worldwide concentrated in cities with at least 1 million inhabitants by 2030 (UN, 2016).

Many studies have reported the importance of Urban Green Spaces (UGS) in improving citizens' quality of life. Researchers usually take into consideration quantity and quality of UGS (Ostoić et al., 2017) and proximity or access (Barbosa et al., 2007; Kabisch et al., 2016), and how Green Infrastructures (GI) (Lafortezza et al, 2013; Carrus et al., 2013) are associated with improving physical, psychological and social health, and well-being (e.g. Kuo and Sullivan, 2001; Maas et al., 2006; Hartig, 2008; Mitchell and Popham, 2008; Dadvand et al., 2012; Nieuwenhuijsen et al., 2014, Carrus et al., 2015; Livesley et al., 2016; Sanesi et al., 2011). These positive outcomes are surely related to the capacity of UGS to reduce the level of pollutants in our cities (Novak et al., 2006; Escobedo et al., 2011, Bottalico et al., 2016, Bottalico et al., 2017), but there is also growing interest in studying the services provided by trees and GIs as ecosystems, as well as their effectiveness in mitigating high temperatures (Oliveira et al., 2011; Norton et al., 2015) and limiting greenhouse gas (GHG) emissions, also in terms of Life Cycle Assessment (LCA) (Oliver-Solà et al., 2007; Duan et al., 2011; Kulak et al., 2013; Smetana and Crittenden, 2014; McPherson and Kendall, 2014; McPherson et al., 2015). There are also several examples of urban forest ecosystem disservices that can negatively affect the wellbeing of humans in terms e.g of human injuries, allergenity and green waste (Escobedo et al., 2011; Tomalak et al., 2011; von Döhren and Haase, 2015; Cariñanos et al., 2017).

It is well known that parks, gardens, UGSs and GIs in general play a significant role in long-term capture and storage (sequestration) of Carbon (C) (Escobedo et al., 2010; Marble et al., 2011). Strohbach et al. (2012) considered the C sinks and sources associated with an urban green space project, taking into account the C mitigation potential of developing green spaces. Kong et al. (2014) estimated that urban turfgrass systems could shift from carbon sink to carbon source depending on maintenance management. Moreover, McPherson et al. (2015) compared the amount of CO_2 emitted with that removed from the atmosphere and stored in the biomass of some Los Angeles street trees. Several studies used models able to estimate biomass and C sink in both natural and urban forest areas (Escobedo et al., 2011; Jenkins et al, 2003; Nowak and Crane, 2002).

Nevertheless, it is quite clear that creating an UGS or a Natural Based Solutions (NBS) in a city has an "environmental cost" which can be quantified in terms of GHG (frequently in terms of CO2e), due to tree and vegetation plantings and the subsequent maintenance of the GI of the park itself (Lin et al., 2018; Kabish et al., 2016; Strohbach et al., 2012).
An important contribution in terms of C sink is represented by soil C sequestration that, on a global scale, is considered the mechanism responsible for the largest mitigation potential in the agricultural sector (Gattinger et al., 2012). Land use and land-use changes (e.g. Reg. (UE) 2018/841) are considered human activities having major impact on the soil organic carbon sink (Guo and Gifford, 2002; Poeplau et al, 2011).
LCA is a standardized methodology able to investigate the environmental impact of a product, a production process, or a system (i.e. an urban park). Such environmental impact is quantified and communicated through an official and standardized "Impact Category", the most common being Global Warming Potential (kg CO_2e.) (ISO, 2006; IPCC, 2007).
In the last decade some authors have used LCAs to evaluate different urban green typologies. Mcpherson and Kendall (2014, 2015) analyzed the way CO_2 emissions can vary according with maintenance practices of street tree lines; Strohbach and Haase (2012) verified such variations due to different tree uses (2012).
The present study aims to evaluate the C balance connected with planning, planting, and maintaining an urban park, the Parco Nord Milano (PNM), a green area located in the metropolitan area of Milan, Italy (Marziliano et al, 2013; Sanesi et al., 2007).
Our case study follows the approach of other authors using LCA in an urban green context (e.g. Mcpherson e Kendall 2014, 2015), without taking into account impact categories other than GWP, such as water eutrophication or ecotoxicity, though some of these indicators were considered in other LCA papers concerning forests (e.g. Schaubroeck et al., 2016).
With this purpose in mind, the following questions were addressed: I) Which is the best data set to evaluate the carbon balance of an urban park? II) What is the consistency of the carbon sinks and sources within the different parts of this urban green space? III) What are the possible reduced emission scenarios for a 30-year-old park like PNM, considering a 50-year lifespan perspective?
Applying different decisions in designing and maintaining an urban park such as PNM can have relevant consequences in terms of CO_2e emissions, as well as CO_2e sequestration both in the dry mass accumulated by the woody plants and in the soil organic matter.

Material and method

A list of acronyms used in the present study is reported in Table 1.

Goal and Scope

We used the LCA approach to evaluate the CO_2e emissions due to the plantation and maintenance of a park, while the C sink was estimated by calculating the CO_2e stored both in the aboveground dry mass accumulated by the woody plants and below-ground dry mass including the soil organic matter, according with the mainstream research of LCA in urban forestry (McPherson and Kendall, 2015 and 2014; Strohbach,et al., 2012). With regard to LCA, the normative reference is represented by the International Organization for Standardization's Life Cycle Assessment, Requirements and Guidelines 14044:2006 (ISO 2006) and the British Standards Institute's specifications in PAS 2050:2011 (PAS 2050:2011).

Considering that the majority of the case studies of the park and its afforested areas is 30 years old and that all the data about plantation, maintenance (including green waste management), tree and shrub growth, and soil organic carbon stored were available, we started from these data and took into account a 20-more years time horizon, in order to have a 50-year period of park management, including its plantation to determine the total C balance and possible alternative scenarios for PNM. This approach is similar to other LCA studies (McPherson and Kendall, 2014; 2015) and consistent with the lifespan of urban trees in previous research (Roman and Scatena, 2011) The Global Warming Potential (GWP100 years) was assumed as impact category, which expresses CO_2e emissions in the atmosphere. A surface unit of 1 ha (2.47 ac) was used as functional unit, as suggested by Strohbach et al. (2012) and McPherson and Kendall (2014). The system diagram of PNM with the typology areas taken into account is reported in Figure 1.

Park Description

PNM is located on the northeast side of the metropolitan area of Milan. The park covers more than 600 ha; about 100 ha are represented by afforested areas and the remaining part is covered by other green typologies (GTs), namely lawns (211 ha), social allotments (2.10 ha), hedges (0.84 ha), tree rows (14.40 ha), recreational facilities, small lakes, grey infrastructures (schools, hospital, private airport) and agricultural areas (Marziliano et al, 2013; Sanesi et al., 2007). The first important forestation interventions date back to 1983; other large afforestation occurred throughout the 1980s and '90s. Currently, forestry plantations continue with interventions of limited extension (Sanesi et al., 2007). PNM represents a specific type of NBS (see: European Commission, 2015) and consists of reclaimed post-industrial or uncultivated lands (Panno et al., 2017; Sanesi et al., 2007).

The trees planted in PNM upon its establishment (1983) mainly reflect the Lombardy forest landscape of lowlands (i.e. *Acer* spp., *Carpinus betulus*, *Fraxinus* spp., *Prunus avium*, *Quercus cerris*, *Quercus robur*, *Tilia* spp., *Ulmus* spp.), but also some non-native species, commonly found in urban parks over the last two centuries, were introduced (e.g. *Quercus rubra*). Understory species were not part of the initial plan, but they were introduced after the first decade both in new and old afforestations, especially for shaping the boundaries of the woodlands or to 'fill' some forestry gaps. *Sambucus nigr*a, *Crataegus monogyna*, *Cornus sanguinea*, *Viburnum lantana*, and *Corylus avellana* were the most used shrub species. In 1983 (Sanesi et al., 2007) tree species were planted at a density of 1110 trees/ha; later, other trees were planted using different plantation schemes, plantation densities (up to 3000 trees/ha), and vegetation types (i.e. shrubs were introduced). Over the years, the established trees were analyzed in terms of height growth, crown width, and vertical structural models (Marziliano et al, 2013).

From 1983 to 2016, tree density decreased as a consequence of silvicultural interventions, management practices and biotic/abiotic stressors. Currently, the average number of trees per hectare is 386.

The soils belong mainly to Endoskeletic Luvisols (Epidystric, Humic) and Endoskeletic Luvic Phaeozems (Endoarenic) (IUSS Working Group WRB, 2014). The preexisting agricultural soils were modified before 1983 but their characteristics are quite homogeneous across the study site. The pH is acidic (5.5±0.4 0-10 cm, 5.7±0.4 10+ cm); the organic C content is quite high (about 1.4±0.5% in the topsoil, 0.8±0.3% in the subsoil). The phosphorus content is average (available P: 18±12 mg kg^{-1} 0-10 cm). The textural class is sandy loam in the topsoil, loamy and generally with a high gravel content in the subsoil. At a depth of about 40 cm, bulk density increases, causing problems for root growth. The most common humus form (Baize & Girard, 2009) is low acid Mesomull, with subordinate presence of acid Oligomull. The average Soil Organic Carbon (SOC) in the litter is 0.26 kg m^{-2}.

The area of PNM can be described as having mesothermal subcontinental climate conditions (transition between the Oceanic and Mediterranean climates). Air temperature is relatively mild, with the warmest month (July) averaging between 17.6 and 29.6 °C and the coldest month (January) between −2 and 4.2 °C. Average annual precipitation is equal to 943.2 mm; the precipitation pattern is characterized by two pronounced maximums during May (78 mm) and August (84 mm) and two minimums in July (60 mm) and December (63 mm). The average amount of evapotranspiration from reference crops (ET0) (Allen et al., 1998) is about 1036 mm y^{-1}, while the amount of water in the soil reaches its highest level in October and lowest in June (Sanesi et al., 2007, Mariani et al., 2016).

Study Area

The park was classified into five main GTs for subsequent analyses (Table 1):

- Lawns (L); made up of a mix of *Lolium*, *Poa* and *Festuca*, managed with three different degrees of maintenance, typically defined by a different number of lawn mowings per year. The average rate of mowing (number per year) is three for large lawns (64 ha), eight for urban lawns (140 ha) and four for scarps (7 ha). An average of ten applications with a brush cutter (2.21 kW) for about 15 ha are assumed.

- Hedges (HE); they are another element characterizing the landscape of the park with a total length of about 8400 m. We assumed an average width of 1 m for all hedges; this led us to consider a total surface of 0.84 ha for this GT. The density of plantation (plants m^{-1}) varied according to plants growth ratio, with values of 0.5, 1, 1.5, 2, 4. The taxa present are mostly *Pyracantha* spp., *Ligustrum* spp., *Crataegus* spp., *Berberis* spp.
- Social allotments (SA); these are a particular kind of green area within the park. They are made up of 25 m^2 units and their presence influences the landscape and governance of the park, especially in some remote areas; moreover, they play an important role for social gathering. All operations are carried out by hand; the park has set rules regarding fertilization of these areas in that it can only be with organic products obtained from composted green-wastes; no pesticides are allowed.
- Tree rows (T); the rows are made up of about 9600 trees with the main taxa being *Acer* spp., *Carpinus* spp., *Quercus* spp., *Populus* spp., *Tilia* spp. The planting distance varies from 4 to 12 m, depending on the species' growth ratio. In any case, an area of 15 m^2 $tree^{-1}$ was considered, giving a total surface area of 14.4 ha. Maintenance is the same for all species, and we considered that one old tree required about the same pruning inputs (in terms of time and consumptions) as five young plants.
- Afforested Areas (FA); the tree taxa are mainly *Quercus* spp., *Carpinus betulus, Prunus avium, Acer* spp., *Tilia* spp., and *Populus* spp. at an average density of about 386 trees ha^{-1}.

A list of planting and maintenance inputs for the different GT areas is reported in Table 2. A broad system boundary was used to get a complete overview regarding CO_2 dynamics in every GT; as a consequence, the following inputs were taken into account (Figure 1): production and transport of all input materials (McPherson and Kendall, 2014, 2015), emissions from soil according to Brentrup *et al.* (2000) and Intergovernmental Panel on Climate Change (2007) (emissions of NO_2 from denitrification of fertilizers), energy (Oliver-Solà *et al*., 2007), and fuel consumptions (Strohbach et al., 2012). For the vegetal residual materials, we considered the maintenance protocol adopted by PNM (Table 3).

Carbon emissions

Life Cycle Inventory

The methodology applied was in accordance with the International Organization for Standardization's Life Cycle Assessment, Requirements and Guidelines 14044:2006 (ISO 2006) and the British

Standards Institute's specifications in PAS 2050:2011 (PAS 2050:2011). For each typology, the Life Cycle Inventory (LCI) was drawn up, differentiating the planting input data from the maintenance input. Among the planting inputs, all the emitting factors connected with plant production were included. In previous research carried out in Pistoia (the largest ornamental nursery district in Italy), the most important sources of GHG connected with multiannual plant production were clearly identified (Lazzerini et al., 2018; 2016; 2014): plastics and peat-based substrates (with potted plants), fertilizers, chemicals, energy consumption, and transport. Consequently, all these inputs, related to the plants used for PNM, were taken into account in this research. The maintenance of PNM considered in our study referred to a 50-year scenario; the inputs, calculated for each typology area, were allocated to the surface unit chosen (1 ha).

NO_2 emissions from the degradation of mineral fertilization were calculated using Intergovernmental Panel on Climate Change conversion – IPCC (2007): quantity of N (kg) used x 0.01. The NO_2 value was multiplied by 298 to obtain CO_2e conversion.

The present investigation was strictly focused on analysis of the green spaces, and so all the other infrastructures such as constructions, streets, fences, lighting, playground areas, and grey typologies were not considered; for the same reason some agricultural fields were excluded as well.

GaBi software – ver. 6.11 (Thinkstep - https://www.thinkstep.com/software/gabi-lca) was used to carry out the analysis.

Green waste management

The waste biomass is quite different among the various GTs, and PNM has adopted a specific protocol to manage these kinds of residual materials. The grass mowed in the L typology is entirely left on site as a green mulch, and we assumed that the CO_2 stored in mulch was 100% released to the atmosphere in the same year, as proposed by Kendall et al. (2015), with the exception of a percentage fixed in the SOC, as reported below. The HE are pruned twice a year, starting from the fifth year from plantation, and all the pruned material is entirely chipped and sent to a processing center about 22 km from the park, where 80% of the green waste is composted and 20% is used as bioenergy. The waste produced by the T area is managed in the same way as for HE area. With regard to the FA, the green waste comes from two pruning and thinning interventions, one made after 15 years from planting, the second after 30 years. The total amount of green waste produced is calculated per year, considering that about 10% of green biomass, such as big trunks, is left on site in order to create natural habitat for biodiversity in the forest area. The remaining parts (about 90% of the total mass) are treated in the same way as the waste material from the T area.

For the tree residue left in the forest, a period of 40 years was considered for complete mineralization

(Ammer, 1991; Ryberg et al., 2004), while for the chipped parts we assumed that all CO_2 stored is released in the same year (Kendall et al., 2015). The waste biomass coming from SA is composted within the park and distributed over the area every year; also in this case, the CO_2 stored in mulch is considered as released in the same year of its production, like in the L area.

The maintenance protocol adopted by PNM generates an estimated quantity/volume of waste products as reported in table 3:

All the data were eventually converted to Kg m^{-2} y^{-1} of fresh weight (FW) of green waste, and a complete LCA analysis of all these materials and the related processes (transport, chipping, composting, bioenergy production) was carried out.

Carbon Sink

Woody plants

The C sink was evaluated in the GTs characterized by the presence of woody species, i.e. FA, T and HE.

For FA, field data collection was performed in ten plots of 40 m × 40 m (Sanesi et al. 2007, Marziliano et al. 2013); for T, in the rows of trees present along the avenues of PNM. Within each plot and along avenues, all trees were classified according to age, stem diameter at breast height (DBH), and height (H). In total, about 1000 trees were sampled.

Aboveground biomass was calculated applying the functional model proposed by West et al. (1999), known as the *WBE model*. In particular, the procedure uses a model based on the *power function* as suggested by the model:

$$AGB = a \cdot DBH^{b}$$

where AGB is the total aboveground biomass (Mg), DBH is the diameter at breast height (cm) and *a* and *b* are, respectively, the coefficient and exponent of scale.

According to this model, the mass would scale with the diameter with a universal exponent b = 8/3 (approximately 2.67) (West et al., 1999), irrespective of the structural and morphological characteristics of the relevant species and age (Enquist, 2002). In this study, the function has been linearized in logarithmic scale as:

$$Ln\ AGB = \ln a + b \ln DBH$$

However, in this study, for a more precise assessment of the total aboveground biomass of an arboreal population, we used more accurate values of *a* and *b*, dividing the trees in three ontogenetic stages (young, adult, mature) as suggested by Pilli et al. 2006. The allometric equations are:

$Ln\ AGB = -1.6384 + 2.08\ \ln DBH$ for Young trees (DBH<9 cm)

$LnAGB = -3.51 + 1.27\rho + 2.64\ \ln DBH$ for Adult trees (9 < DBH <15 cm)

$LnAGB = -3.12 + 1.11\rho + 2.51\ \ln DBH$ for Mature trees (DBH >15 cm)

The scaling coefficient was estimated starting from medium density (ρ) of each species, derived from literature sources (Giordano 1980, Giordano 1988).

The estimate of underground biomass (BGB) was carried out via the following equation (Galvagni et al. 2006):

$$BGB = 4.426 \cdot Age^{0.413} \cdot G^{0.463} \cdot Density^{-0.178}$$

where *BGB* is the percentage of root biomass compared to the aboveground biomass; *Age* is the age of the population (years); *G* is the basal area ($m^2\ ha^{-1}$); Density is the number of trees per hectare (n° ha^{-1}).

Finally, for Total Biomass (TB=BGB+AGB) a model to estimate the total biomass of each age was developed. In order to select the best model, the TB was estimated comparing different models with AGE as independent variable. We then evaluated the fit of the final model using and analyzing the value of root mean square error (RMSE) and the coefficient of determination (R^2) value. Based on these indicators, the following power function proved to be the most suitable:

$TB = 1.963 * AGE^{1.256}$, with $R^2 = 0.57$, RMSE = 0.376.

For the Total Biomass (TB), a projection up to 50 years of age was performed.

The total C stock stored by woody plants was determined by multiplying the total biomass (TB) by a conversion coefficient of 0.50 (Pregitzer & Euskirchen, 2004; IPCC, 2006). Instead, using the equivalence 1 $Mg\ C = 3.66\ Mg\ CO_2$ (IPCC, 2006), the equivalent amount of carbon dioxide removed from the atmosphere from plant biomass present in PNM was determined.

The total dry mass in trees turned out to be around 668 kg $tree^{-1}$ after 50 years; the number of trees/ha in the FA decreased from 386 after 30 years to an estimated number of 347 after 50 years, i.e. a global mortality rate of about 10% for the remaining 20 years. Actually, it is not easy to calculate annual tree mortality in urban and periurban landscapes because of their location in heterogeneous and highly-altered sites (Steenberg et al., 2017). Nowak (2004) reported an annual mortality rate up to 6.6% in large, established street trees, assessing that their mortality was strongly affected by tree size, tree health, tree species, and adjacent land use. In our case, with a well-established forest area, we considered the annual mortality of 0.5% quite precautionary.

The same allometric equations applied for FA were used for the trees included in the T typology. Consequently, a total dry mass of 607 kg plant^{-1} was considered and a very low mortality rate was used: 3% in 20 years (0.15% a^{-1}), considering that 30-year-old trees placed in lines within a park under nearly optimal growing conditions should have very low mortality rates for the 20 years remaining to reach the 50-year period considered in our research. Therefore, the number of plants of T typology was decreased from 9600 to 9312 and the final C accumulation was calculated using this second value.

As for the HE, C accumulation was calculated using data available in the scientific literature. For hedges growing in temperate climate, the potential aboveground carbon sequestration is approximatively 0.1 Mg C/100m y^{-1} (Baudry et al. 2000, Arrouays et al. 2002, Walter et al. 2003, Aertsens et al. 2013) and it can vary considerably in relation to the hedgerow characteristics (size, height, location) (Arrouays et al. 2002). In this study, we adopted a value of 0.06 Mg C/100 m y^{-1} to evaluate the carbon sink of this green typology. The HE belowground biomass was estimated based on a literature analysis as well. Several studies suggest that the ratio between belowground and aboveground biomass (root/shoot ratio) ranges from 0.20 to 0.80 (Canadell and Roda 1991; Cairns et al. 1997; Caravaca et al. 2003; Sanesi et al. 2013; Marziliano et al. 2015). Starting from the aboveground data, we applied an average root/shoot ratio equal to 0.40 to estimate the belowground biomass of this green typology. Information about the mortality rate of 30-year-old hedges was not available in literature so we decided to consider a theoretical 15% rate, assuming a linear relationship between number of individuals and C accumulation. This rate can be considered quite precautionary, considering that the remaining individuals in the hedge, with less competition, could grow (and stock biomass) more vigorously, limiting the C accumulation decrease due to mortality.

Soil Organic Carbon

The organic content of PNM soils (SOC, Soil Organic Carbon) was obtained from several sampling points: 10 plots of 400 m^2 in the FA, in each of which a soil profile was sampled and analyzed by horizons, and topsoil (about 0-40 cm) and subsoil (about 40-70 cm) were sampled in 15 locations; 5 sample plots in L, with composite topsoil and subsoil samples. In the laboratory, SOC was determined by a CN elemental analyzer (Flash EA 1112 NC-Soil, Thermo-Fisher Scientific). Litter, when present, was sampled on a 33x33 cm square, dried at 70 °C and weighed. It was assumed that SOC represented about 50% of soil organic matter (SOM) of the litter.

The organic C content of arable soils, by way of comparison, was obtained from external soil profiles. Fifteen soil profiles (ERSAL, 1999) were considered, localized in comparable areas based on pedolandscape (fundamental plain level, gravelly-sandy texture in the depth) and equilibrium regarding the organic matter dynamic.

Calculation of the SOC content, expressed in terms of mass per surface unit, was performed by distinguishing topsoil from subsoil and taking into account the organic C percentage, gravel percentage, and bulk density.

Examination of maps and aerial photographs revealed that the prevailing land use, before establishment of PNM, was arable land. For this type of land use, calculation of the SOC content showed that topsoil holds (mean ± standard deviation) 4.61 ± 0.63 kg C m^{-2} and subsoil 1.54 ± 0.84 kg C m^{-2}, for a total of 6.15± 1.28 kg C m^{-2}.

The estimate of SOC storage 50 years from establishment of the park was performed by applying the empirical equations proposed by Poeplau et al. (2011), which for various types of land use change, provide the SOC increase or decrease compared to the initial value, taking into account texture, soil thickness, climatic conditions and age. Starting from the empirical data of the organic C content of PNM soils, it was possible to evaluate the differences between estimates and measures, so as to correct the projection after 50 years. This methodology was applied for all the GT, except for lawns (L). In this case the total SOC was increased with the amount of organic C coming from the green mulch left on the area every year; following Cutrufo et al (2015), 19% of the C present in the mulch was considered as stored in the SOC.

Results

CO_2 emissions

The five GTs considered in the present study showed emissions of CO_2e greatly differentiated in a 50-year period (Table 4). HE was by far the most CO_2e-emitting typology per unit surface area, with 126.8 kg CO_2e m^{-2}, followed by T with 12.2 kg CO_2e m^{-2}; FA showed the lowest emissions, with only 0.436 kg m^{-2}. As expected, emissions due to the planting phase were considerably lower than the emissions generated by 50 years of maintenance and, where present, green waste disposal. In particular, green waste disposal with its various interventions (chipping, transport, composting, bioenergy production) showed high emission rates, differentiated based on the various GTs. In this context, the very high CO_2e-emitting per surface unit of HE waste management is easily explained if we consider the number of pruning interventions (2/year x 45 years). In terms of a 50-year total emissions scenario, the most impacting typologies were L, T and HE (3627, 1754 and 1065 Mg CO_2e respectively). The other GTs were less impactful, due to either small surface areas (SA) or to particularly low potential CO_2e emission (FA). The total emissions of PNM were, for 50 years, about 6927 Mg CO_2e, i.e. 21 Mg CO_2e ha^{-1}.

CO_2 stored in plants

After 50 years, the woody area typologies considered (FA, T, H) were estimated to store around 53000 Mg CO_2e, which is about 472 Mg ha^{-1} considering only the areas with woody species. The resulting C sink per surface unit was quite different among the three typologies considered, with an increasing efficiency from HE to FA typologies, with T being the best (72 Kg CO_2e m^{-2}). Obviously, the most important area in terms of total C stock was by far the forest area (FA), mainly because it covers the greatest area (100 ha) (Table 5). The typologies without woody plants (L and SA) were not considered for carbon calculations.

Soil Organic Carbon

The FA estimated SOC increase, according to Poeplau et al. (2011), was 50.6% while the measured increase (including litter) was only 23.4%. Based on the ratio between measured and estimated increase (0.46), it was possible to modify the estimated increase after 50 years, calculated according to Poeplau et al. (2011): SOC between 0 and 70 cm (topsoil plus subsoil) should be 9.16 kg m^{-2} with an increase of 3.01 kg m^{-2} compared to the initial data (6.15 kg m^{-2}). According to Gasparini and Di Cosmo (2015), reporting the data obtained by the Italian National Forest Inventory, the deciduous broadleaved forest (the category more similar to PNM FA) has an average SOC content (0-30 cm) of 7.79 kg m^{-2}, a value comparable to the measured PNM value for FA (7.33 kg m^{-2}). As a comparison, in a soil with a strong accumulation of organic matter, belonging to a natural floodplain forest of Lombardy, not managed for at least 70 years, the average SOC stock was found to be 14.2 kg m^{-2} (Ferré et al., 2014).

The same procedure applied for FA was adopted for L, but in this case the ratio between measured and estimated increase was lower (0.38) than for FA. For L the amount of C stocked from the green mulch and left on the fields during the season was calculated (0.38 kg m^{-2} 50yrs^{-1}) and added to the total amount. The significant difference between the SOC estimated increase according to Poeplau et al. (2011) and the measured SOC increase could be explained by the coarse texture of the soil, which promotes a greater SOC mineralization and by the high presence, particularly in the subsoil, of the gravel, which reduces the volume of fine earth. SOC for HE was estimated taking into account the contribution of the litter, with an increase of 15% compared to L typology. SOC for T was estimated as the average between FA and L, while SOC for SA was estimated by comparison with the data (Comolli, unpublished) related to some urban allotments in Milan.

Finally, the SOC for the five GTs, estimated 50 years after establishment of PNM, is reported in Table

6. Though SA showed the highest potential, L and FA had the greatest SOC with more than 26000 Mg, almost 94 % of the whole SOC for the entire PNM.

CO_2 balance

CO_2 emissions and SOC and CO_2 in the woody plants of PNM over a 50-year period were compared in order to have a global CO_2 balance for this park (Table. 7). The table clearly shows that most of the considered GTs had a positive result in terms of CO_2. Such positive results were particularly relevant in the L, T and FA typologies, while SA gave a lower contribution to the balance, mainly because of their small surface areas. HE was the only GT showing a negative C balance, due to the waste management.

The typology that represented, by far, the main C sink for PNM (more than 70% of the total C) was FA, while the less efficient in terms of C balance per surface unit was the L typology due to its lack of woody species.

Discussion

The results obtained indicate that a green area like PNM, observed over a 50-years period, can represent a great C sink through either C fixation in woody plants (above and below ground) or increase in SOC. PNM showed a C sink more than 10 times higher than CO_2e emissions for the same period. The five GTs considered gave different results, in terms of CO_2e emissions and/or C sink potential; such differences were mainly due to the maintenance requirements (above all pruning) and green waste management with regard to emissions (Figure. 2), and presence of woody species (above all trees) for the C sink. Obviously, these two main factors (maintenance and C sink in trees) affected the results per unit area, while the final result (total C balance) was considerably affected by the surface areas of the various typologies, considering the important role of SOC per square meter of PNM. As a matter of fact, the analysis of SOC is not frequently considered in research papers focused on the evaluation of C balance in urban parks (Dorendorf et al., 2015) and this parameter can vary widely among different soils, land-use and land-cover types (Pouyat et al., 2006); however our results clearly show the potential of urban parks such as PNM to sequester large amounts of SOC.

The SOC estimated for the soils of PNM, at the end of the 50-year period, is aligned with the findings of various authors, considering the different pedoclimatic conditions of the areas studied. The value of about 8 kg m^{-2} of SOC for L and 9 kg m^{-2} for FA (the largest and most significant areas of PNM) can be compared to the 10 kg m^{-2} calculated for the mixed forests of parks in Seoul (Bae and Ryu, 2015), or with the values found by Pouyat et al. (2006) for some US cities. In the case of PNM, the surrounding agricultural soils have a SOC of around 6 kg m^{-2}; similar results (ratio between the SOC of parks and that of agricultural land) were found by Edmondson et al. (2012) for the city of Leicester (GB) and Vasenev et al. (2013) for the Moscow region, while taking into account the greater SOC accumulation related to a more humid and colder pedoclimate compared to that of PNM. The difference of SOC, compared to the arable crops in the vicinity of PNM, is mainly explained by two reasons: a) the lack, in the soil of PNM, of tillage which instead causes oxidation of the soil organic matter in the surrounding arable land; b) the supply of litter, which is greater in FA but not negligible in L, especially when mowings are left on the surface (Poeplau et al., 2016); in arable lands this contribution is replaced, but only to a limited extent, by organic fertilization.

The increase in SOC of urban park soils, compared to agricultural land, continues over time, even beyond the 50 years considered in our study. Therefore, there is the potential for SOC increase in urban parks to exceed those in natural grasslands or forests (Pouyat et al., 2006).

Taking into consideration that a big part of built-up areas in Italy and presumably in EU countries are unsealed and more than 80% of the total unsealed land is covered by brownfields (Sallustio et al., 2019), there is considerable potential to increase the presence of urban greenspaces. Consequently, there is similar potential to increase C sink by woody plants and soil directly in urban settlements. These green spaces can be permanent (e.g. urban parks) or temporary (e.g. forestry plantations). The second challenge is to ‘use’ the unsealed area for a fixed period of time (e.g. 10-15 years) while awaiting its final layout. With this temporary option, C sink may not only be guaranteed, but soil remediation can also be assumed (Jensen et al., 2009). In addition, though for a short period, other ecosystem services can be provided by forestry plantation, namely leisure, recreation, and biodiversity (Escobedo et al., 2011).

Green areas prove to be an effective tool to counteract, even if only partially, the emissions of CO_2 right where they are produced the most (i.e. urban settlements). The Milan metropolitan area (1620 km^2), where PNM is located, provides a total emission of 13792 Gg y^{-1} of CO_2eq, with about 1/3 of such emissions due to road transport (4223 Gg y^{-1} CO_2eq) and 1/3 due to home heating (4151 Gg y^{-1} CO_2eq) (ARPA 2016). In this case, it’s quite clear the need for less CO_2eq emitting urban mobility and heating systems, but it is also clear the positive role that the presence of Nature Based Solutions can have in this metropolitan area. Recently Schaubroeck (2018) highlighted the importance of an integrated approach to assess both human/industrial and nature-based solutions, positing that only a general sustainability assessment framework can give real answers to the need for sustaining the future wellbeing of humans.

This research has clearly shown that different planting and maintenance strategies can lead to differentiated outputs, in terms of GHG emissions and/or C sink. Actually, it is possible to reduce

CO_2e emissions from the various GTs examined with suitable planting and/or maintenance decisions (Table 7). In particular, the lengthening of wood rotation (i.e. from 50 to 70 years) as well as tree lines can consistently increase C sink potential. A further increase can be obtained by introducing natural forest regeneration in these areas. This approach, typically used in forests but more recently also in urban parks (e.g. Doroski et al. 2018), could contribute to a significant reduction in planting costs, till their complete reset. Another option to reduce GHG emissions can be through a different approach to recycling woody wastes. They could be used to make manufactured goods in which C could be stored for a very long time. Our estimates for the PNM forest areas foresee the production of good materials from the second forest thinning, and this potential could obviously be greater as trees reach the end of their life cycle. The same consideration can be made for tree lines, where trees can be managed with rotation periods longer than the standard 50 years, particularly within urban parks where there is a reduced need for pruning the canopy due to the lack of buildings and/or urban traffic. Obviously, a further contribution to the reduction of CO_2e emissions in park management will come from the adoption in time of more efficient and less emitting park maintenance machines, such as tractors and lawnmowers.

Evaluation of the C balance through a LCA analysis can be an interesting tool for planning and/or maintaining urban green spaces and parks, though it shouldn't be the only criterion. The needs of the population should be taken into account, and ecosystem services that need to be maximized should be evaluated. For instance, if the urban park is expected to mitigate either summer temperatures or urban heat island effects (Mariani et al., 2016), a cultural practice such as irrigation should be planned, in spite of a possible CO_2e increase due to such practice. Multiple types of ecosystem services, *inter alia*, wellbeing and health improvement (Sanesi et al, 2011; Panno et al., 2017) as well as biodiversity improvement (Escobedo et al., 2018) are provided by urban trees and vegetation though they can cause some ecosystem disservices, mainly linked to the pollen allergenicy (Carananos et al., 2018) and damage to people or infrastructures (Tomalak et al., 2011). All these variables can have a strong impact on planning and design of urban parks, street rows and other nature-based solutions in our cities.

The research succeeded in answering all the questions that were initially posed. I) All the C sources and sink were carefully identified and calculated, making it possible to identify the most relevant CO_2 emission and sequester factors, in order to have a sort of guideline for better environmental performance of this park (in terms of sustainability) in a decision-support system. II) The consistency of the different green typologies in terms of C source and sink were clearly defined, either per unit area or for the total surface; obviously the FA showed the highest environmental performances due to its specific land-use (a forest area full of trees with reduced maintenance). III) The possible reduced emission scenarios for this 30-year-old park are clearly connected to specific strategies for the different GTs (Tab.8). They are mainly based on a controlled reduction of maintenance, lengthening of life span, and a reuse strategy for residual materials. Eventually, even a different strategy of designing and planning the various GTs could be taken into account.

Conclusion

The evaluation of C balance through a LCA analysis applied to the different planting and maintenance phases of an urban park has clearly shown how the different green typologies present in the park can have very different impacts. Moreover, LCA has shown how every single step concerning maintenance, including the way the green wastes are used or recycled, can affect this C balance. Therefore, LCA can represent an interesting and precious tool to analyze in detail the different phases in the life of a park in terms of environmental sustainability.

Within parks, urban forests represent the green typology with the highest potential in terms of C sink, while tree lines can be either relevant C sources if pruning is intensively and often applied, or efficient C sink with reduced maintenance for a lifecycle longer than 50 years. Even lawns can play a dual role depending on the maintenance practices applied. As a matter of fact, lawns can store a high quantity of SOC, but such potential is partially balanced by the emissions due to the use of machines for field maintenance (lawnmowers and brush cutters).

LCA is confirmed to be an important tool to evaluate environmental impacts, although when applied to parks or, more in general, to public spaces or other NBS categories, it should be flanked by other evaluation criteria. The needs and preferences of park users should be taken into account as well. For this reason, it is crucial to take an analytical approach in which the various ecosystem services and possible trade-offs are considered.

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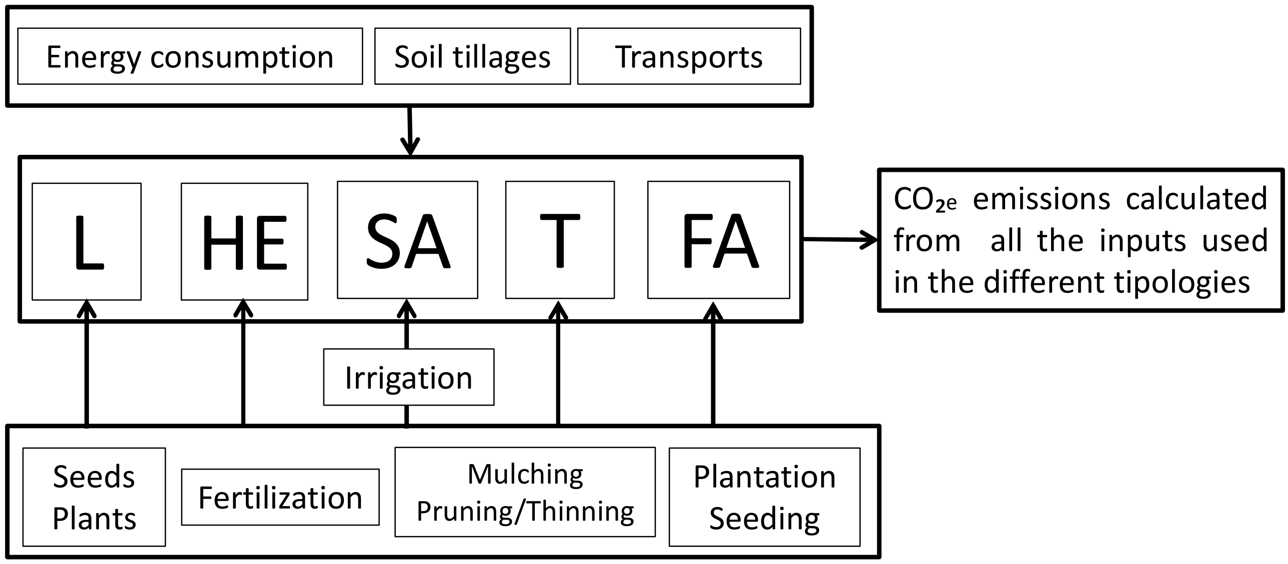
Figure Legends

Fig. 1 – LCA system diagram of Parco Nord Milano (PNM), with the five different green typologies considered.

Fig. 2: CO_2e emissions for the different GTs (50 years) calculated for the whole area (A) and per surface unit (ha) (B).

Fig. 1



(L = Lawns; HE = Hedges; SA = Social Allotments; T = Trees; FA = Forest area)

Fig. 2

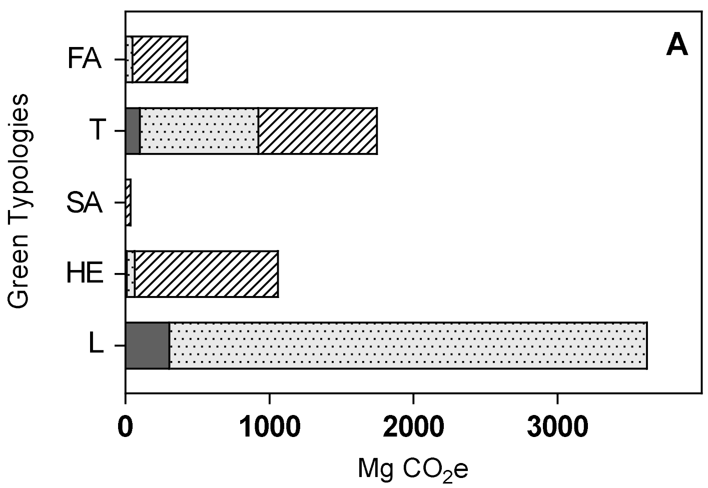


Table 1: List of acronyms used in the present study

Acronyms	Explanation
FA	Afforested area
L	Lawns
HE	Hedges
SA	Social Allotments
T	Tree rows
AGB	Above Ground Biomass
BGB	Below Ground Biomass
DBH	Diameter at breast height (130 cm)
GHG	Green House Gas
GI	Green Infrastructure
GT	Green Tipology
GWP	Global Warming Potential
H	Height
LCI	Life Cycle Inventory
NBS	Nature Based Solution
PNM	Parco Nord Milano
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
UGS	Urban Green Structure

Table 2: List of planting and maintenance inputs, complete rotations included, for the different GT areas considered.

Typology Area	Type of data	LCA Inputs
L	Planting	Production of seed mixes and transport (50 km); fertilizer (12%N-20% P_2O_5-15% K_2O) production and transport (100 km); tractors (73.55 kW and 51.50 kW of power) for milling, sowing and fertilization; fork lift (64 kW of power) to unload materials.
	Maintenance	Tractor (73.55 kW of power) with mower (6 m), a tractor (51.50 kW) with mower (4.5 m) and two lawnmowers (18.39 and 36.77 kW); ten brush-cutter applications (2.21 kW).
	Residues	The entire green waste is left on ground and mulched.
HE	Planting	Plant production and transport (100 km); hydraulic digger (power 13.50 kW) for excavation; organic fertilizer (7% N-7% P_2O_5 -7% K_2O) production and transport (100 km).
	Maintenance	Gasoline-powered hedge trimmers (0.75 kW of power) for pruning, twice a year, first pruning after 5 years from plantation.
	Residues	Total biomass chipped (power 5.22 kW) and transported to the processing center, 22 km round trip with a medium truck.
SA	Planting	Tractor (power 100 kW) for soil milling.
	Maintenance	Tap water supply (2 m^3 $year^{-1}$ per unit 25 m^2).
	Residues	The waste biomass is locally composted and mixed with soil in the allotments.
T	Planting	Tree production and transport (325 km); tractor (power 100 kW) for ploughing; hydraulic digger (power 13.50 kW) for excavation; organic fertilizer (7% N-7% P_2O_5-7% K_2O) production and transport (100 km); timber pole production and transport (50 km); fork lift (64 kW of power) to unload materials.
	Maintenance	Pruning with gasoline-powered chainsaws (power 2.21 kW).
	Residues	Total biomass chipped (power 5.22 Kw) and transported to the processing center, 22 km round trip with a medium truck.
FA	Planting	Tree production and transport (50 km); tractor for ploughing (power 100 kW); hydraulic digger (power 13.50 kW) for excavation; organic fertilizer (7% N-7% P_2O_5-7% K_2O) production and transport (100 km).

Maintenance	Gasoline-powered chainsaws (power 2.80 kW) for silviculture activities 4ha y^{-1}.
Residues	10% of the biomass (trunks) left on site; 90% chipped (power 5.22 Kw) and transported to the processing center, 22 km round trip with a medium truck.

(L = Lawns; HE = Hedges; SA = Social Allotments; T = Tree rows; FA = Afforested area)

Table 3: List of interventions planned by PNM in each GT for the maintenance of the park. The data concerning the green waste produced are reported in terms of fresh weight (FW).

GT	Area (ha)	Interventions	Data from PNM	Kg m^{-2} y^{-1}
L	211	Mowed several times per year	5 t ha^{-1} y^{-1} fresh mulch	0.50
HE	0.84	Pruned twice a year	5 kg m^{-1} y^{-1} dry mass	9.00
SA	2.10	Green residues yearly removed	13 m^3 ha^{-1} y^{-1} fresh waste	0.40
T	14.40	Pruned 4 times in 50 years	152 Kg $plant^{-1}$ $50yrs^{-1}$ dry mass	0.40
FA	100	Two interventions (15/30 years)	28.63 m^3 ha^{-1} $50yrs^{-1}$ fresh wood	0.02

Tab. 4 - CO_2e emissions calculated for the different GTs, referred to a 50-year period

GT	Area (ha)	Source (Kg CO_2e m^{-2})				Total emissions ($Mg\ CO_2e$)
		Planting	Maintenance (50 years)	Green Waste	Total	
L	211	0.148	1.571	--	1.719	3627
HE	0.84	2.002	6.700	118.100	126.802	1065
SA	2.10	0.008	0.138	1.960	2.106	44
T	14.40	0.753	5.700	5.730	12.183	1754
FA	100	0.011	0.045	0.380	0.436	436
Total	328.33					6926

Tab. 5 - Estimated Carbon storage in woody plants (trees and hedges) after 50 years.

GT	Total Area (ha)	Carbon sink (Kg CO_2e m^{-2})	Total Carbon Stock (Mg CO_2e)
L	211	0	0
HE	0.84	33.450	281
SA	2.10	0	0
T	14.40	72.000	10355
FA	100	42.430	42430
Total	328.33		53066

Tab. 6 - SOC and CO_2e stock measured and calculated for each GT

GT	SOC measured (kg m^{-2})	SOC 50 years after the initial situation (kg m^{-2})	SOC Increase compared to the initial situation (kg m^{-2})	CO_2e increase (kg m^{-2})	Total CO_2e stock (Mg)
L	6.83	8.18	2.03	7.43	15677
HE	7.85	8.05	1.90	6.95	58
SA	9.21	13.43	7.28	26.64	559
T	7.21	8.48	2.33	8.53	1228
FA	7.59	9.16	3.01	11.02	11020
Total					28518

Tab. 7 - Estimated C balance (Mg CO_2e) in the different GTs and in the whole PNM after 50 years. (negative/positive data are for uptake/emission CO_2e)

GT	Total Area (ha)	Source			Sink		Balance	Balance/ha
		Planting	Maintenance	Green waste	Soil	Plants		
L	211	312	3315	--	15677	0	- 120450	- 57
HE	0.84	17	56	992	58	281	726	864
SA	2.1	0.2	3	41	559	0	- 515	- 245
T	14.4	108	821	825	1228	10355	- 9829	- 682
FA	100	11	45	375	11020	42430	- 53018	- 530
Total	328.33						- 74686	

Tab. 8: Strategies to reduce CO_2e emissions in the various GTs.

GT	Strategy
L	Different maintenance options (e.g. height and number of lawn cuts)
HE	Different species (e.g. slow growing), different pruning approach (reduction in pruning intensity and cycle)
SA	Different maintenance options (e.g. water quantity and quality)
T	Different species (slow growing), different pruning approach (reduction in pruning intensity and cycle), longer life span (e.g. 80 years)
FA	Different regeneration options (e.g. natural seed regeneration), different thinning options, longer life span (e.g. 80 years), different use of residual material (round wood for park facilities and furniture)