Landscape and Urban Planning 120 (2013) 138–146

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Carbon dioxide balance assessment of the city of Florence (Italy), and implications for urban planning

Francesco Primo Vaccari[a,*], Beniamino Gioli[a], Piero Toscano[a,c], Camilla Perrone[b]

[a] Institute of Biometeorology (IBIMET), National Research Council (CNR), Via G. Caproni, 8, 50145 Florence, Italy
[b] Department of Urban and Regional Planning (DUPT), University of Florence, Via P.A. Micheli, 2, 50121 Florence, Italy
[c] Department of Agricultural and Environmental Sciences, University of Udine, Via delle Scienze, 206, 33100 Udine, Italy

HIGHLIGHTS

- Florence's green areas offset CO_2 emissions from 2.6% (winter) to 16.9% (spring).
- Spatially CO_2 emissions decrease by 92% along an urban to rural landscape.
- Carbon dioxide balance provides innovative information tool for urban planning.

ARTICLE INFO

Article history:
Received 9 August 2012
Received in revised form 9 August 2013
Accepted 10 August 2013
Available online 16 September 2013

Keywords:
Carbon dioxide fluxes
Eddy covariance
Urban design
Urban transect

ABSTRACT

The carbon dioxide balance for the Municipality of Florence (102.3 km^2), with 29.1 km^2 of green space within the built-up city and 46.6 km^2 in the semi-rural peri-urban area, shows that collectively the green spaces offset 6.2% of the direct carbon emissions. However the green spaces in the densely built-up city only offset 1.1% of the emissions. 13.5 ktCO_2 y^{-1} are taken up by vegetation in the built-up areas and 58.7 ktCO_2 y^{-1} by vegetation in the peri-urban area. Urban green spaces are most efficient in offsetting anthropogenic CO_2 emissions during the period March to June when plant growth rates are high and emission rates are relatively low. Landscape fragmentation is highly positively correlated with total CO_2 emissions and negatively correlated with CO_2 uptake. The detailed information produced during this investigation shows that policies aimed at reducing CO_2 emissions in winter months will have a greater overall effect on total CO_2 release to the atmosphere than those aimed at increasing CO_2 uptake. Nevertheless, urban designers should consider all the benefits of urban green spaces and seek to ensure that new suburban development conserves green spaces and aims at sustainable urban design.

1. Introduction

Urban areas, defined as densely developed residential, commercial and other non-residential areas, cover a minute portion of the Earth's land surface (<3%), but host more than 50% of the population (CIESIN, 2004), thus contributing significantly to global anthropogenic emissions of greenhouse gases (GHG) to the atmosphere (Dhakal, 2010). To mitigate such emissions, several strategies aimed at improving the urban environment ecological performance have been proposed and adopted during the past decade: improving the energy efficiency of buildings (Aydin & Cukur, 2012); reducing road traffic (Reckien, Ewald, Edenhofer, & Ludeke, 2007); managing and designing existing and new urban green spaces (Pataki et al., 2011).

The role of urban green spaces, defined as all areas covered by lawns, shrubs and trees, in highly human altered ecosystems, is well recognized (Dobbs, Escobedo, & Zipperer, 2011). There is a significant amount of scientific literature underlining the benefits of urban green spaces in reducing the urban heat island by creating a cooling effect (Hu & Gensuo, 2010; Ng, Chen, Wang, & Yuan, 2012; Oliveira, Andrade, & Vaz, 2011; Onishi, Cao, Ito, Shi, & Imura, 2010; Petralli, Massetti, & Orlandini, 2011; Steeneveld, Koopmans, Heusinkveld, vanHove, & Holtslag, 2011), or in terms of avoided carbon emissions and energy use due to the cooler air temperature (Lin, Wu, Zhang, & Yu, 2011); reducing air pollution, particulates and gases (Morani, Nowak, Hirabayashi, & Calfapietra, 2011; Nowak, Crane, & Stevens, 2006; Paoletti, Bardelli, Giovannini, & Pecchioli, 2011; Tallis, Taylor, Sinnett, & Freer-Smith, 2011); filtering noise and enhancing the quality of life, in terms of psychological well-being of the citizens who live close to the green areas (Chiesura, 2004; Gidlöf-Gunnarsson & Öhrström, 2007; Hartig, Evans, Jamner, Davis, & Garling, 2003).

The magnitude of these effects depends mainly on intrinsic factors related to urban green spaces such as: surface area, vegetation

* Corresponding author. Tel.: +39 055 3033711; fax: +39 055 308910.
E-mail addresses: f.vaccari@ibimet.cnr.it (F.P. Vaccari), b.gioli@ibimet.cnr.it (B. Gioli), p.toscano@ibimet.cnr.it (P. Toscano), camilla.perrone@unifi.it (C. Perrone).

0169-2046/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.landurbplan.2013.08.004

structure (woody, shrubs, herbaceous), species composition and location of trees in relation to the buildings (Akbari, 2002; Mirzaei & Haghighat, 2010), and on extrinsic factors such as latitude, climate, weather and typical urban forms of the cities (Sproken-Smith & Oke, 1998; Upmanis & Chen, 1999).

One well-recognized effect of urban green spaces is their contribution to mitigate GHG emissions by means of atmospheric carbon dioxide (CO_2) uptake through plant photosynthesis. Several studies have quantified the CO_2 sequestered and stored by urban green spaces (Escobedo, Kroeger, & Wagner, 2011; Jo & McPherson, 1995; McHale, McPherson, & Burke, 2007; Nowak & Crane, 2002; Zhao, Kong, Escobedo, & Gao, 2010), and the long-term direct measurements of CO_2 fluxes are acknowledged tools to assess the spatial and temporal variability of CO_2 uptake and emission in cities (Grimmond, King, Cropley, Nowak, & Souch, 2002).

Eddy covariance is a micrometeorological technique that measures the surface-atmosphere exchange of mass, energy and momentum, and is utilized since decades to assess the carbon exchange of natural and cultivated areas, contributing toward understanding the spatial and temporal variability of ecosystems productivity and their role in the global carbon cycle (Keenan et al., 2012). The eddy covariance technique has been also recently applied in urban and suburban areas (Crawford, Grimmond, & Christen, 2011; Gioli et al., 2012; Helfter et al., 2011; Kordowski & Kuttler, 2010; Pataki et al., 2009; Pawlak, Fortuniak, & Siedlecki, 2010; Velasco & Roth, 2010), allowing direct carbon fluxes of cities with different landscape or urban characteristics to be assessed.

In this article we compute the CO_2 balance of the Municipality of Florence (emissions-uptakes) by assessing the capacity of urban green spaces of offsetting the direct anthropogenic CO_2 emissions through carbon uptake. Florence was chosen as a case study, because high spatial resolution inventorial data are available and CO_2 emissions of the city center are measured with eddy covariance since 2005 (Matese, Gioli, Vaccari, Zaldei, & Miglietta, 2009). The total direct CO_2 emissions of the city have been obtained, combining measured CO_2 emissions with the Regional Emission Inventory (IRSE). Moreover, using different web-GIS databases we determined the surface areas of the various categories of urban green spaces in the city, and applying the IPCC methodology (IPCC, 2003, 2006) we assigned an annual CO_2 uptake factor to each urban green space category. The relative importance of absorbed vs. emitted CO_2 has been assessed both temporally, by means of seasonal patterns provided by direct eddy covariance flux measurements in urban (Florence) and in a Mediterranean forest (Lecceto, Siena) environments, and spatially, by computing the CO_2 balance over different areas ranging from densely urban to rural landscapes.

The paper aims to: (i) estimate the magnitude of the anthropogenic CO_2 emissions of the Municipality of Florence and of the urban green spaces CO_2 uptake; (ii) investigate source and sink spatial variability at high temporal resolution and their implications for urban planning.

2. Materials and methods

2.1. Study area

Florence (Lat 43° 46′ N; Long 11° 15′ E) (Fig. 1), has a typical medieval heart and the renaissance city was built on the ruins of a Roman town, in a river valley surrounded by hills. The Municipality extends over 102.3 km^2, with a total surface area of urban green spaces of 75.7 km^2 formed by two main categories: those in densely built-up zones, defined here as Urban Green areas (UG) extending over 29.1 km^2, and Peri Urban green areas (PU), defined here as urban areas of low-density housing extending over 46.6 km^2. In addition to these two main categories, there are also a total of 11,541 isolated Urban Trees (UT), many of them along avenues and streets. They include 8326 trees, managed directly by the Municipality (UT_{MF}), and 3215 trees owned by other public institutions or by private (UT_O).

The UG areas can be classified in two main categories: those managed by the Municipality of Florence (UG_{MF} = 7.7 km^2), for which a detailed database of morphometric parameters is available, and those represented by parks and urban green spaces managed by other public institutions and by private, defined here as other urban green space (UG_O = 21.4 km^2).

The PU areas surrounding the city are: agricultural fields on the valley floor, typically horticultural with a predominant component of herbaceous plants (PU_H) and extending over a total area of 9.5 km^2; agricultural fields on the hills around Florence, typically orchards, vineyards and sparse olive trees with a predominant component of woody plants (PU_W), extending over an area of 33.4 km^2; natural forests (PU_F) extending over 3.7 km^2.

According to the Florence Master Plan the total urban green spaces will be enhanced by 2.3 km^2 (UG_{SP}), and 28,450 isolated urban trees (UT_{SP}) will be planted or replaced.

The types of urban green spaces and tree numbers have been obtained by overlapping different GIS layers of the Municipality of Florence (Open data http://datigis.comune.fi.it) (Fig. 2). In particular the web-GIS supplied layers for the UG_{MF} and UT_{MF} categories, that they were created in 1990 with the purpose of managing the urban green spaces. These layers are continuously updated and they provided some fundamental information for our research, such as plant species composition in each type of area, the age of the trees, and morphometric information such as diameter at breast height (DBH). The other urban green space categories were determined by overlapping the GIS layers provided by the Florence Master Plan that take all the other categories into account; unfortunately these GIS layers did not provide detailed information about plant species. All the maps created with this overlapping were subsequently validated through digital orthophotos.

2.2. The IRSE data

The IRSE emission database is based on the Corinair methodology (EEA, 2007) and was developed by the Regional Administration of Tuscany (IRSE, 2010). It contains yearly amounts of pollutants emitted since 1995, spatially disaggregated at 1 km^2 resolution, on the basis of spatial proxies of emission intensity. Emission sources are classified according to the European standard nomenclature '97 called SNAP (Selected Nomenclature for Air Pollution), and include three categories: (i) diffuse: that are not localized, but distributed on the territory; (ii) punctual: that are geographically localized; (iii) linear: related to linear infrastructure such as roads and railway lines. In our study, by overlapping the administrative borders of the Municipality of Florence with the IRSE spatialized data, we determined the annual direct CO_2 emissions (Fig. 3). In practice we considered only the CO_2 emissions within the city boundaries (Scope 1, defined by Kennedy et al., 2010) and recently adopted in the Global Protocol for Community-Scale Greenhouse Gas Emissions (C40 & ICLEI, 2012C40, ICLEI, World Resources Institute, 2012).

2.3. Urban and forest CO_2 flux measurements

Two eddy covariance sites have been used in this study to measure CO_2 fluxes. The first was installed in September 2005 at the Ximeniano Observatory (Lat 43° 47′ N; Long 11° 15′ E) (Fig. 1), in the city center where fluxes are entirely governed by anthropogenic emissions, considering the lack of green space in the flux footprint (Matese et al., 2009). Observed CO_2 fluxes are therefore always a net source throughout the year, of 309 (±42) $tCO_2\ ha^{-1}\ y^{-1}$