CO_2 budget estimation and mapping at a local scale

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Abstract

CO_2 budget is generally based on comparison between emission and uptake. In this paper, a methodology for estimating and mapping the CO_2 budget at a local scale is presented, considering various rates of uptake due to each kind of actual land use.

The methodology proposes to compare data of emission developed by Italian national regional inventory with data of uptake referred to specific land uses, which were collected from literature and optimised for local condition. In literature there are several methodologies for estimating CO_2 emission from different sources, whilst there are only a few comprehensive studies about the role of vegetation and soil for CO_2 absorption at local scales. Moreover, experimental studies often present different results, also because of the difficulty in measuring uptake and of the influence by meteorological and climatic conditions. The proposed methodology for the CO_2 budget assessment at local scale aims to provide a tool for the investigation of local situation with reference to the achievement of CO_2 emissions reduction objectives: firstly, for assessing the gap between emission and uptake at a local scale and, secondly, for supporting spatial planning towards choices that can assure a higher uptake capacity. In this paper, an example of application in five municipalities in Northern Italy is presented, where emission and uptake data are mapped with GIS, enabling to highlight the uptake deficit and the role of sustainable land use planning; indeed, the objectives of the Kyoto Protocol could be achieved, reducing emissions and/or planning land use to increase the amount of local uptake of CO_2.

Keywords: CO_2 uptake, budget of CO_2, GIS, land use.

1 Introduction

The Kyoto Protocol, signed by 195 Countries in 1997, ratified by Italy in 2002 and entered into force in February 2005, is the operational instrument of the United Nations Framework Convention on climate change. The protocol obliges Industrialized Countries and Countries with transition economies (countries in East Europe) to reduce for at least 5,2% main anthropogenic emissions of Green House Gases (GHG) during the period 2008-2012. The target for Italy is to reduce the amount of emissions of 6,5% compared to 1990 score.

At an international level, the collection and evaluation of main scientific, technical and socio-economic information about climate change is assigned to IPCC (Intergovernmental Panel on Climate Change). This Committee (created by WMO and UNEP) has the task of identifying the possible strategies of mitigation and adaptation to negative effects of climate change. Changes in atmospheric concentration of GHGs are causing a rise in global temperature, with effects on the sea level, on the frequency of extreme weather events like droughts and floods, on agriculture and biodiversity, with great impacts also on the socio-economic side (IPCC [1]). To contrast these effects, there is the need of actions aimed to reduce CO_2 concentration in the atmosphere, through the limitation of anthropogenic emissions and an increase in CO_2 uptake. One of the possible measures to contrast the green house effect is, indeed, the evaluation of possible CO_2 sinks: some studies have already been undertaken, both in Italy and in other European countries, for the estimation of possible CO_2 uptake. A significant contribution to the reduction of atmospheric CO_2 is provided by vegetation. This contribution can be forecast both at global and local scale; in particular, at local scale it is possible to establish the quantity of possible uptake related to different land uses. At present, there are only few studies that have made a review of results coming from specific studies about different kind of vegetation and land use; furthermore, available data are largely inconsistent: indeed, the capacity of CO_2 uptake is correlated with lot of variables, both climatic and geographical. The collection and processing of data is therefore important to optimize the estimation and to adapt it to Italian situation, especially for evaluations at local scale. The methodology presented in this paper provides an instrument for the evaluation of CO_2 balance at local scale and for addressing local planning choices, especially with reference to Kyoto Action Plans, that can be developed at municipality level.

2 Methodology

This study refers only to exchange of CO_2, which is alone responsible for about 60% of natural greenhouse effect; it does not consider other GHGs (e.g. CH_4 and N_2O), which contribute to the assessment of CO_2 (CO_2 equivalent), evaluated according to conversion parameters calculated considering the effect that those compounds have on greenhouse effect in comparison with the effect of CO_2 molecule, equal to 1. The methodology for CO_2 balance at local scale consists of four phases: definition and implementation of a cartographic database on land uses; estimation and mapping of uptake capacity for each land use; estimation and mapping of emissions; assessment and mapping of CO_2 balance at local scale The realization of a cartographic and georeferenced database and its implementation in areas with different land uses is based on the collection of available cartography at the best resolution available, verified through sample testing of those uses.

2.1 Estimation and mapping of uptake capacity

The estimation of CO_2 uptake capacity was performed starting from studies about the evaluation of uptake for different kind of vegetation and forest species, from which field data were derived and then adapted to the local condition. From the experimental point of view, the uptake capacity can be evaluated using *eddy covariance* stations for the estimation of energy and mass (water vapour, CO_2) exchange between different vegetation and forest species and the atmosphere.

At the international level, within IPCC and particularly in the Good Practice Guidance for LULUCF, GHGs flows are measured at local scale with micro meteorological techniques. To move from a local scale to a regional one it is necessary to consider some limits connected with space-temporal variation and with long-term trends of the considered variables (Körner [2]). Nevertheless, integrating direct measures with other techniques (e.g. multi spectral remote sensing) it is possible to obtain a wider understanding about flows. Kyoto Protocol underlines the necessity to count and to certify the reduction of GHGs emissions. During COP7 in Marrakech in 2001 (7th Conference of the Parties to UNFCCC), *eddy covariance* has been pointed out as a possible long-term monitoring technique for carbon flows. This technique has been accepted as the referential methodology in various experimental activities and international networks as, for instance, Euroflux, Ameriflux and Fluxnet.

At the European level, there is a network of monitoring stations (*Euroflux,* http://public.ornl.gov/fluxnet/eurointro.cfm) for the assessment of carbon and other GHGs uptake by terrestrial ecosystems. Monitoring stations are established on 25-30m high towers and use *eddy covariance* (or *eddy correlation*) technique to measure directly the Exchange of CO_2, water vapour and sensible heat between biosphere and atmosphere. The method is based on the fact that the vertical flux of a compound in a superficial turbulence layer is directly related to the covariance of vertical velocity and to the concentration of the compound itself. Eddy correlation method implies the installation of instruments at the top of a tower which is some meters higher than the surface that emits or absorbs the gas. Measuring directly the mass and gas exchanges among the soil, the vegetation and the atmosphere, eddy covariance enables to develop specific algorithms to apply on large scales the results of point measures.

There are three main projects at a European level for the estimation of CO_2 uptake: Camels, CarboEuroflux and Nofretete. *Camels* project – Carbon Assimilation and Modelling of the European Land Surfaces (http://camels.metoffice.com/) started in November 2002, has three main aims: to estimate European carbon sinks; to deepen the knowledge about carbon uptake mechanism; to develop a theoretical model about carbon uptake cycle. This project is characterised by the effort to identify the carbon sinks accurately, combining the use of mathematical models and field observations, and to categorise carbon sinks according to land use of other environmental aspects. *CarboEuroflux* project, which is part of CarboEurope Cluster together with Camels and other projects, monitors CO_2 flow between forests and atmosphere through a monitoring network consisting in 30 sites in 11 European countries. Finally, *Nofretete* project has the aim to quantify N_2O emissions and CH_4 uptake by European forests.

At a national level, some monitoring activities about CO_2 uptake has been undertaken in Trentino province (Rigon [3]), in Modena province (Magnani *et al* [4]), in Calabria region (Marino *et al* [5]) and in Toscana region (information available at www.osservatoriokyoto.it). In Lombardy region (where the present case study has been conducted) direct measures of CO_2 exchange through *eddy covariance* technique has been performed in the period 2002-2005 in a poplar plantation in Zerbolò (Pavia), within the Regional Park Valle del Ticino, in areas with 12–15 year old trees (Matteucci *et al* [6]) and, since 2006, in areas with bare land and replanted poplars. Using the same technique, CO_2 Exchange was measured also in a short rotation poplar plantation in Vigevano (between 2004 and 2006). At present, the Joint Research Centre (JRC) of Ispra has established a system on maize and rice fields and is establishing its instrumentation on a broadleaved forest within JRC own area. Valle del Ticino Park has been selected as a test area for *JRC Kyoto Experiment.* This is one of the main phases of Kyoto Project promoted by Lombardy Region and provides a relevant contribution to the European projects mentioned before. Kyoto Project, which started in 2004 and is planned to last 3 years, aims to provide clear and accurate information needed for GHG control at regional level (e.g. raw data, scenarios, policies). The project comes up as a result of the Regional Plan for Air Quality monitoring (PRQA, 1998-2000) and is the first pilot experience for the management of GHG at a regional scale. The expected outcome of the project is the collection of methodologies, data-bases, measuring techniques and prediction models to support actions and policies for the control of GHG emissions and the prevention

Table 1: CO_2 uptake values per hectare per year.

Land use	**tCO_2 ha^{-1} $year^{-1}$**	**References**
Agricultural areas (corn)	0	[7]
Poplar plantations	16,05	[8]
Meadows	5,12	[9–11]
Broad-leaves forests	34,55	[12]
Coniferous forests	40,88	[12]
Mixed forests	24,19	[12]
Natural grasslands	2,93	[10]
Sterile areas	0	-
Water bodies	10,46	[13]
Artificial surfaces	0	-

of climate change effects. To match each type of land use with a value of CO_2 uptake and to map the results at local scale, the present study considers the results of the studies mentioned before and the parameters considered, in order to obtain a display diagram of CO_2 uptake rate with reference to Italian geographical and climatic characteristics. Table 1 shows the tons of CO_2 absorbed per hectare per year for each type of land use considered.

It is necessary to consider that these results are obtained matching absorption rate values and land uses considered in different studies, strictly related to measure sites, and so they have to be considered as a preliminary information, that needs further investigation. The main problem in collecting and processing data is the difficulty to find data CO_2 about fixation through the vegetation. There are indeed some factors at the woody ecosystem level that can influence the carbon budget: the density of the trees, the species of tree considered, the maturity of the plants; some climate elements such as temperature, lighting, the mean annual rainfall; the methodology used for managing the planting such as irrigation, soil organization and fertilization.

The complexity of these variables entail a great difficulty in defining a unique reference value about the absorption rate. Regarding forests, the study considers oaks, 15 year old pines and pines mixed with maple-trees for hardwood forest, coniferous forests and mixed coniferous and hardwood forest respectively. Regarding agricultural lands, the capability to storage and uptake CO_2 is related to several factors as, for instance, climate, cultivation types and techniques. Nevertheless, considering that agricultural land emits high amount of CO_2, the total budget can be considered as equal to zero. Regarding polar plantations, the CO_2 absorption rate differs depending on the period in which analyses are performed, so an average data is considered. Regarding grassland, the value included in Table 1 is the mean obtained comparing three different studies ([9–11]). Similar problems occurred evaluating lakes and rivers. In this case the study considers the net primary productivity of lakes to assign a value of uptake to the class “water areas”. Anyway, the parameters vary either in different lakes and in the same lake in different seasons. It is therefore extremely difficult to determine a reference value, unless it is an average. Finally, we decided to assign to sterile areas (e.g. landfills) and to urbanized areas a value equal to zero tons per hectare per year.

2.2 Estimation and mapping of emissions

In Italy the estimation of emissions is based on data from emission registers developed at regional scale according to Italian national law [14] about criteria for air quality evaluation. In particular, article 4 identifies emissions source inventories as the main tools for the investigation process needed for defining improvement programmes; Annex 2 lists the criteria for the inventories, that has to be followed in order to assure reliability and uniformity of the data collected. Therefore, emissions inventories represent a database of information and technological, economic and spatial data, which are collected according to verifiable and updatable methodologies and allow to identify and to map pollution sources and quantity and quality of pollutant emitted at provincial and municipality level. Using data from registers at municipality level it is therefore possible to map emissions of each municipality under investigation.

2.3 Estimation and mapping of CO_2 budget

CO_2 budget estimation consists in the comparison between emission and uptake data, the evaluation of the gap between the two values and its mapping.

3 Pilot application in Lombardy Region

The methodology was developed for a pilot application in Lombardy Region and is based on available databases at regional scale. The cartographic database is based on the maps of DUSAF project (Land Use of Agricultural and Forest Land – Destinazione d'Uso dei Suoli Agricoli e Forestali, website http://www.ersaf.lombardia.it), made by ERSAL (Regional Agency for Agricultural Development in Lombardy) and D.G. Agriculture of Lombardy Region with the aim of obtaining detailed data about land use in the Region as a support for an effective spatial planning of actions in forest and agriculture sectors. The outcome of the project, based on colour aerial photos taken in 1998-1999, is a detailed cartography with a scale of 1:10.000 about land use, with particular reference to agricultural and forest use. DUSAF classification consists of classes of macro-typology of land use (identified by a ID) which are divided into some sub-classes of single typology, identified by numbers. Since literature data refer only to a few types of land use, it was necessary to define clusters of land use, coherent with the classes on Table 1.

Therefore, data about uptake shown in Table 1 represent an estimation of a complex reality because the same value is assigned to different type of land use considering only classes instead of sub-classes. This approximation gives the first information which is useful for a total evaluation of CO_2 uptake, but needs further investigation to make the budget more accurate. For the pilot application, we used Table 1 with some adaptation to DUSAF categories. For instance, poplar plantations are representative of the whole class "agro-forestry areas", maize value is representative of the class "agricultural lands", the class "grasslands" has a single value, even if it includes water meadows, permanent meadows and pastures. Data about emissions were taken from the database INEMAR (Air Emission Inventory – INventario EMissioni Aria [15]), developed within the Regional Plan for Air Quality in Lombardy. The inventory provides emission data till the year 2003 and allows to evaluate emission in 1546 municipality of Lombardy, considering 220 type of activities and different kind of fuels. Emission estimations are based on data measured on plants, on emission factors from literature and on methodologies defined within agreements about transboundary pollution (EMEP/CORINAIR [18]). Emission data can be found in specific databases that provide information at municipality level about emission with reference to different human and biogenic activities and to different types of fuel. The comparison between uptake and emission data, expressed in terms of tons per hectare per year and georeferenced, allows to measure CO_2 budget at local scale and to map the results.

4 Results

The results presented in this paper refer to a pilot application in five municipalities, chosen because they represent a good sample of different land use in Lombardy Region. The area of study consist of 70Km^2 and is characterised by the presence of considerable pressures on the environment, due to the high level of dwelling density, to the presence of large transport infrastructures and to the high number of firms. Therefore the environment is subjected to a relevant anthropogenic impact, which is higher than the carrying capacity of the territory. Most of the area is constituted by residential areas with mixed productivity, while the rest of the territory is constituted by grasslands and arable lands. Furthermore, the territory can be an interesting to investigate of the role of woodlands, especially in relation to the presence of Monza Park, which is a urban park with an area of about 7 km^2. Figure 1 shows the detailed map of land use in Seregno municipality, obtained by clustering DUSAF classes.

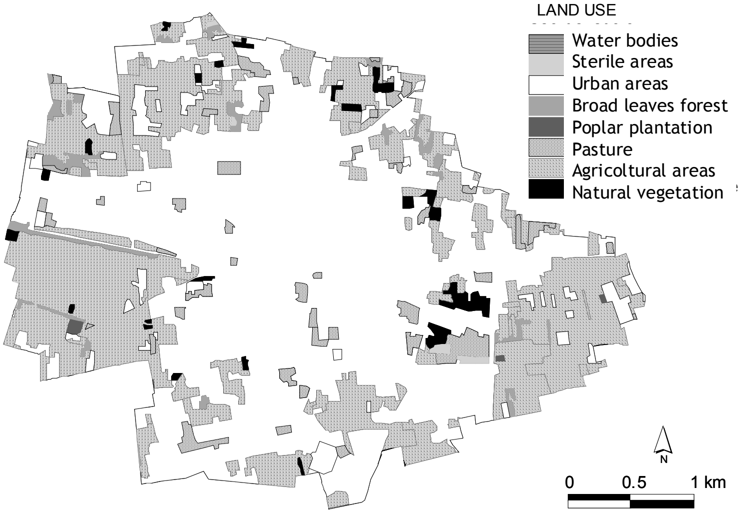

Figure 1: Land use in Seregno municipality, obtained by clustering DUSAF classes.

The extent of the area considered and the large variety of land uses in the territory can be useful for comparison among different uptake attitudes by soil and vegetation. Figure 2 shows CO_2 uptake values for different type of land use in the municipality of Seregno; values are obtained multiplying factors in Table 1 and the extent (in hectares) of each land use class. The legend lists the areas according to their uptake capacity: from artificial lands (equal to 0) to broad-leaves forests (33,55 t ha^{-1} $year^{-1}$).

The comprehensive value of CO_2 uptake at municipality level was estimated adding up the contribution of each class of land use. To compare the uptake capacity of several municipalities, an uptake value per hectare per year was calculated for each municipality; these values are mapped in Figure 4.

CO_2 emissions estimations is based on INEMAR data for each municipality and each CORINAIR group of activities (e.g. Combustion in energy and

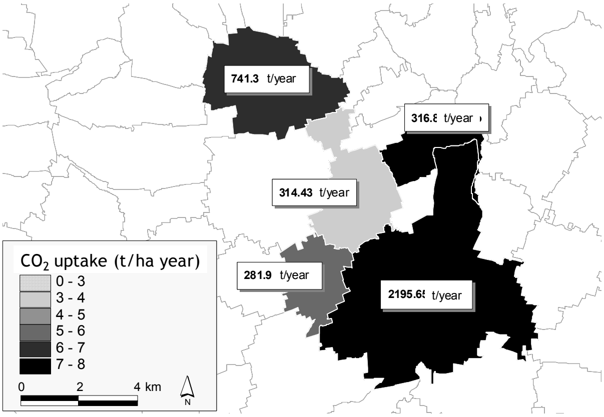

Figure 2: CO_2 uptake values at municipality level (CO_2/ ha year).

Table 2: Contribution (ktonCO_2 /year) from different activity groups to CO_2 emissions in the area of study.

Activity group	Biassono	Lissone	Monza	Muggiò	Seregno	Total
Non-industrial combustion plants	18.1	58.8	257.26	41.59	68.76	444.51
Combustion in manufacturing industry	9.62	26.1	63.59	17.44	27.2	143.95
Production processes	0.38	1.18	4.14	0.72	1.35	7.77
Extraction and distribution of fossil fuels	0	0	0	0	0	0
Solvent and other product use	0	0	0	0	0	0
Road Transport	8.7	43.65	165.82	19.75	39.59	277.51
Other mobile sources and machinery	1.22	2.04	5.93	1.25	1.86	12.3
Agriculture	0	0	0	0	0	0
Other sources and sinks	0	0	0	0	0	0
Waste treatment and disposal	0	0	19.18	0	0	19.18
Total	**38.02**	**131.79**	**515.92**	**80.75**	**138.75**	**905.22**

transformation industry, Road Transport, Agriculture, etc.). Data about the five municipalities under investigation are listed in Table 2.

Data show that the major contribution to the total amount of CO_2 emissions comes from Non-industrial combustion activities, which generates 444,51 kton (49,1% of the total) and from Road transport, which generates 277,51 kton (30,7% of the total) (Figure 3).

As for the uptake, also total emission values for each municipality can be expressed as a mean emission value per hectare per year, allowing one to compare the rate of emission per hectare for each municipality (Figure 3).

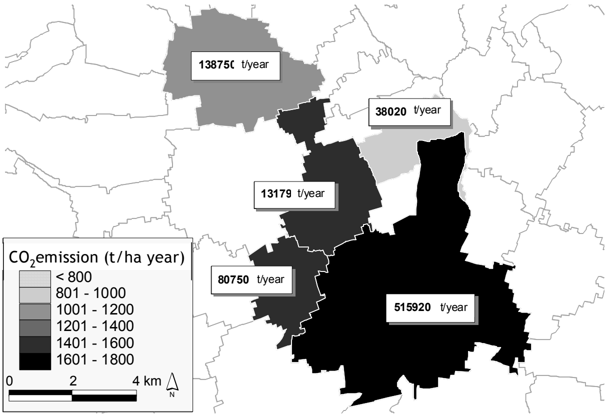

Figure 3: CO_2 emissions in 2003 (ton per hectare per year): total value for each municipality.

CO_2 budget at local scale was then calculated according to two methods: firstly, as the difference between total uptake and total emissions per year and, secondly, as the difference between uptake per hectare per year and emission per hectare per year (results of the first phase are shown in Table 3). The first calculation has the aim to assess the gap between emission and uptake for each municipality; the second one has the aim to evaluate the balance between emission, uptake and land use.

Figure 4 shows the map of CO_2 budget, considering the total deficit and the budget per hectare.

Table 3: Emissions, uptake and CO_2 budget for the five municipalities under investigation.

Municipality	**Total emissions (E) (tCO_2 /year)**	**Total uptake (A) (tCO_2 / year)**	**Budget (A-E) (tCO_2 $year^{-1}$)**
Biassono	38.020	316	-37.703
Lissone	131.790	314	-131.475
Monza	515.920	2.195	-513.725
Muggiò	80.750	281	-80.468
Seregno	138.750	741	-138.008

The comparison between the total data and the data per hectare allow to highlight some aspects connected to land use. Monza municipality, for instance, has a deficit of 513.724 tons of CO_2 per year, which means that for every hectare 1.671,52 tons of CO_2 has to be compensated; whereas Biassono municipality has to compensate only 846,80 tons of CO_2 per hectare (due to the different balance between low and mean uptake capacity land uses).

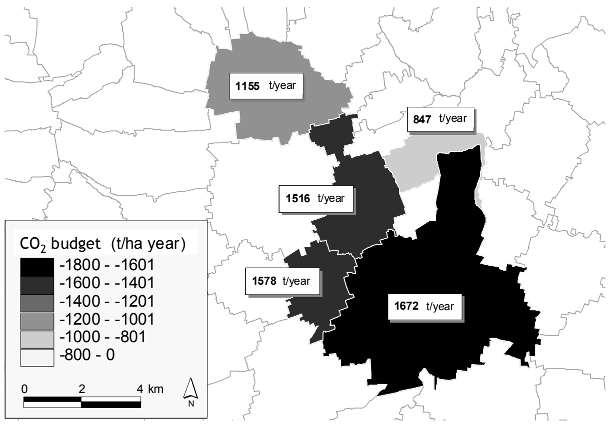

Figure 4: CO_2 budget in the five municipalities.

For this reason, it is important to correlate the budget values to the actual land use in the area considered: Monza area, which includes the Park, has a higher uptake capacity than other areas which have an higher extension of urban areas, i.e. could be expected to have a more efficient budget. Nevertheless, Biassono area has to compensate a lower amount of CO_2 deficit, due to the fact that this municipality has lower emissions per hectare and a good mean of uptake capacity. Analysing emission and uptake data, it is possible to note that there is a difference of two orders of magnitudes between them: regardless of the intrinsic variability of source data used for the estimation, there is anyway a relevant difference between CO_2 emission and CO_2 uptake capacity.

5 Discussion

The application of the methodology to the five municipalities considered helped to underline some critical aspects that need further investigation. For instance, it is necessary to integrate the cartography provided by DUSAF (with a scale of 1:10.000) with more detailed data provided by every municipality involved in the study. This improvement would allow to consider also urban green areas with little extension and to analyse agricultural lands according to the type of cultivation actually carried out in the area, considering the specific uptake capacity of different kind of cultivations. Moreover, the role of agricultural lands should be further investigated, especially considering the fact that, they can have a good uptake capacity but can also be a source of CO_2 emissions (IPCC [16]).

Furthermore, the budget is influenced by seasonal factors; an important improvement of the methodology could be based on the evaluation of emission and uptake related to seasonal factors, considering for instance that the uptake by an agricultural land occurs in different phenological phases (Evans [17]). However, it has to be considered that CO_2 budget (and, generally, the budget of all GHGs) is calculated on an annual basis and this is the reason why annual crops are considered as invariant with reference to CO_2 emission and uptake. Another field of investigation should regard also reservoirs and water areas, which has wide ranges of variability, due to seasonal variation of the productivity.

Finally, if we consider the possibility to implement the methodology in other contexts, for instance in protected areas, the resolution needed could refer to the type of plant species that are present in the area and to their density. In this case, detailed information about the vegetation and its uptake capacity would be needed, even if it has to be considered that data currently available in literature come from areas with different weather conditions and then could alter the estimation of the amount of CO_2 uptake.

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