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# The greenhouse gas inventory as a tool for planning integrated waste management systems: a case study in central Italy

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ABSTRACT

This paper presents the GHG (greenhouse gas) inventory of the integrated waste management system of the Province of Siena (central Italy), for the years 2008–2011, according to the "2006 IPCC Guidelines for National Greenhouse Gas Inventories". The study presents the detailed calculation of GHG emissions from different plants (landfills, incinerators, composting plants, selection and valorization lines, etc.), which may orient emission reduction strategies and decrease the environmental impact of the waste sector. Total emissions decreased from 2009 to 2011 mainly through better management of landfills. Production of electricity from renewable (*in situ* photovoltaic panel installation) and alternative resources (incinerated waste and biogas recovery from landfills) avoids GHG emissions because it limits import of electricity from thermoelectric power stations. The experience presented in this study can be used as a waste sector model, since the evaluations can be repeated in time and concern different interacting waste disposal methodologies. Various public and private organizations may take part in the analysis, so as to calibrate the waste management system according to the results obtained by GHG inventories. The results of the analysis can be verified and validated according to international standards (e.g. ISO 14064 or 14067) by an independent organization in order to systematically facilitate the link between GHG computation and political action.



## 1. Introduction

The development of voluntary mechanisms for Greenhouse Gas (GHG) emission accounting and abatement can inspire actions for climate change mitigation, facilitating new opportunities for enterprises and public administrations (Gentil and Chistensen, 2009; Friedrich and Trois, 2010). A number of international studies have estimated GHG emissions by municipal solid waste disposal systems, applying the life cycle assessment model and the 2006 IPCC Guidelines at regional scale (e.g. Bogner et al., 2008; Mohareb et al., 2008; Gugliano et al., 2011). In Italy only a few large enterprises operating in the waste sector have performed GHG inventories of their activities and plants (see HERA S.p.A., 2003–2011 and $A_2A$ S.p.A, 2008–2011). The administrative jurisdiction of the Province of Siena (Tuscany, central Italy), in agreement with the sole waste operator within provincial boundaries, autonomously adopted the GHG inventory of the solid waste disposal plants in the local Integrated Waste Management System (IWMS – time series 2008–2011). The GHG emission assessment presented in this study is part of the "Siena Carbon Free" plan with which the Province of Siena, on the basis of the longer standing "REGES" Project - Evaluation and ISO 14064-1 validation of GHG emission reduction (2007–2015), set the ambitious goal of reaching total absorption of $CO_2$ emissions by green areas within the administrative boundaries at least to the year 2015. This territory achieved the target in 2011, recording a GHG emission reduction from each activity, thanks to interaction between scientific, political and jurisdictional actors. In addition to the economic crises, this reduction was due to the implementation of local environmental policies directed to improve the performances of the energy, waste, agriculture and industrial sectors of the Province of Siena (Bastianoni et al., 2014). One of these policies is the progressive organization of the local IWMS with an action plan that has been developing since the end of the 1990s. The GHG inventory developed here highlights both positive and negative aspects of the IWMS currently implemented in the Province of Siena, considering that the waste sector accounts for 12% of total GHG emissions of the district.

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The quantification of GHG generation for plants and waste management phases (production, collection, disposal) is aimed at encouraging responsible behavior, stimulating citizens' awareness and improving local environmental policies (REGES Project, 2008–2012; Marchi et al., 2012). The initiative can also help identify suitable emission reduction strategies aimed at reducing the impacts of waste management (Marchi et al., 2014, 2015a). For emission estimation we applied the guidelines proposed by the Intergovernmental Panel on Climate Change (IPCC) for GHG inventories (IPCC, 2006), including carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$) emissions. This method is applied to regional areas, but can also be used for smaller systems, such as industrial and business activities (see for example Priambodo and Kumar, 2001 and Bosco et al., 2008).

The aim of the study is to develop the GHG inventory as a policy tool to suggest actions for climate change mitigation and reduce the impacts of the activities performed within an IWMS.

## 2. Materials and methods

### *2.1. Integrated waste management system (IWMS) description*

IWMSs consist of comprehensive waste prevention, collection, recycling, composting and disposal programs. These include various disposal plants, which interact with each other. The IWMS of the Province of Siena consists of eight plants:

- 3 landfills (L1, L2 and L3) used for the disposal of the Municipal Solid Waste (MSW) and non-hazardous industrial waste. They are equipped for biogas recovery, which is flared or used to produce electricity. The treated waste in landfills is about 36,520 t in average per year.
- 1 composting plant (CP1) which bio-oxidises green waste and the Organic Fraction of Municipal Solid Waste (OFMSW). It is in the same district as L1, treating about 10,590 t of organic matter in average per year.
- 1 Incinerator (In1 – re-activated in 2009 after efficiency improvement) equipped with a moving grate furnace where MSW, non-hazardous industrial waste and Refuse Derived Fuel (RDF) are burned. The amount of burned waste is about 57,860 t in average per year and the heat of combustion is used for electricity production.
- 1 composting plant (CP2), 1 selection plant (SP1) and 1 valorization plant (VP1) at the same production site. They allow bio-oxidation of green waste and OFMSW, separation of undifferentiated MSW into various waste types, and differentiation of recycled waste (paper/cardboard and multi-material composed by glass, iron, aluminum, plastic and tetrapak), respectively. The average annual amount of waste treated in CP2 is equal to about 16,400 t, while in SP1 corresponds to 9170 t and in VP1 to 20,000 t.

The plants, managed by the sole operator for the Provincial area, the enterprise SIENA AMBIENTE S.p.A, are in continuous interaction via input–output flows to optimize the treatment of different waste types (Marchettini et al., 2007). These are located in strategic places in the system (Fig. 1). The disposal sites are situated for collection of good quality waste and according to the techno-economic operating conditions of the plants.

### *2.2. GHG emission accounting*

The "2006 IPCC Guidelines for National Greenhouse Gas Inventories" are an international standard methodology and include four emission sectors: 1) Energy, 2) Industrial Processes and Product Use, 3) Agriculture, Forestry and Other Land Use – AFOLU, 4) Waste (IPCC, 2006). Our analysis investigates the Energy and Waste sectors as these consider all GHG emission sources linked to the disposal plants. The GHG inventories concerned the years 2008–2011.

Total emissions to the atmosphere of $CO_2$, $CH_4$ and $N_2O$ from the plants were estimated, multiplying the activity data by the related emission factors (Note S.1 of the Supplementary on-line material). We applied Tier 2 of the 2006 IPCC methodology due to medium quality of available activity data (Note S.2 of the Supplementary on-line material). Quali-quantitative information was collected directly within the company SIENA AMBIENTE S.p.A., by a bottom-up approach. This approach enables more accurate emission evaluation than a top-down approach, in which local breakdown factors are applied.

GHG emissions are classified into direct and indirect, depending on the origin. Direct emissions take place in the sites considered (geographical criteria), and indirect emissions occur outside the disposal plants (responsibility criteria). Anaerobic degradation of organic matter in landfills, combustion of waste, bio-oxidation of organic wastes in composting and selection plants provide direct emissions. Direct emissions also derive from fossil fuels used for heating, machinery, transport of materials and energy production within the plants. Electricity imported from the national grid and fossil fuels used to transfer wastes from one plant to another (the distance between two plants and a consumption of 2.5 km/L of diesel used by trucks were considered) make up indirect emissions.

The amount of treated wastes and the other activity data of the eight solid waste disposal plants are shown in Tables S.1–S.8 of the Supplementary on-line material.

To estimate $CH_4$ emissions from decomposition of biodegradable matter in landfills, we used the IPCC Waste Model (IPCC, 2006), which considers the production of biogas generated by a wide range of waste types, characterized by specific decomposition parameters (Table S.9 and Note S.3 in the Supplementary on-line material). The biogas recovery plants installed in the three landfills capture up to 85% of the methane produced, as confirmed by Oonk and Boom (1995).

Composting and organic waste stabilization are aerobic processes and a large fraction of the degradable organic carbon in the treated material is converted into $CO_2$, which is not counted as anthropogenic emission because it is of biogenic origin. On the other hand, these processes release $CH_4$ by anaerobic sections of compost/stabilized organic waste, that are less than 1% of the initial carbon content; they also produce emissions of $N_2O$ in a range that varies from less than 0.5%–5% of the initial nitrogen content (IPCC, 2006). As proposed by the 2006 IPCC methodology, we have chosen emissions factors equal to 0.05 g $CH_4$/kg of organic waste and 0.30 g $N_2O$/kg of organic waste treated in composting and selection plants.

To determine emissions from the fossil carbon fraction of the waste burned in the incinerator, we used $CO_2$ emissions detected by continuous site-specific measures (SIENA AMBIENTE S.p.A, 2012); the $CO_2$ generated by the combustion of the non-fossil carbon fraction was subtracted (Table S.10 in the Supplementary on-line material). Anthropogenic emissions from natural gas used to maintain the combustion temperature in furnaces was also subtracted from the measured tons of $CO_2$ released by incineration (Nate S.4 in the Supplementary on-line material). Emissions due to natural gas combustion in the incinerator must be calculated separately in order to avoid double-accounting.

We decided to use the responsibility criterion for emissions related to electricity imported from the national grid. We determined an average emission factor, calculating the GHGs released for electricity production at national scale (Table S.11 in the Supplementary on-line material), divided by national grid electricity