S.A.P.I.EN.S

2.3 (2009)
Vol.2 / n°3 - Cities and Climate Change

Nikolas Bader and Raimund Bleischwitz

Measuring Urban Greenhouse Gas Emissions: The Challenge of Comparability

Electronic reference
Nikolas Bader and Raimund Bleischwitz, « Measuring Urban Greenhouse Gas Emissions: The Challenge of Comparability », *S.A.P.I.EN.S* [Online], 2.3 | 2009, Online since 18 December 2009, Connection on 10 October 2012. URL : http://sapiens.revues.org/854

Publisher: Institut Veolia Environnement
http://sapiens.revues.org
http://www.revues.org

Document available online on: http://sapiens.revues.org/854
This document is a facsimile of the print edition.

INSTITUT
Veolia Environnement

S.A.P.I.EN.S
VOLUME 2 ISSUE 3 2009

Surveys

Measuring Urban Greenhouse Gas Emissions: The Challenge of Comparability

Nikolas Bader and Raimund Bleischwitz[1]

College of Europe, Dijver 11, 8000 Bruges, Belgium

1. Dr. Raimund Bleischwitz is also affiliated with the Wuppertal Institute for Climate, Environment and Energy and the Universities of Wuppertal and Kassel, Germany

This paper has benefited much from a cooperation with Institut Veolia Environnement and a workshop conducted at ISPRA on May 19th 2009, as well as from an EU project called Roads2HyCom (www.roads2hy.com); we also wish to thank Stefan Lechtenböhmer, Ralph Harthan and the other anonymous reviewer for their helpful comments. A longer version of this paper is available (Bader and Bleischwitz 2009).

Correspondence to: nikolas.bader@coleurope.eu

Abstract

The paper aims to shed light on the methodological challenges of GHG monitoring at local level and to give an overview on current practices. Questions addressed are as follows: How do the methodologies which underlie different GHG inventory tools differ? What are the critical variables explaining differences between inventories? Can different GHG inventory tools be compatible—and/or interoperable—and under which conditions?

The first section discusses methodological challenges related to the formation of local GHG inventories. Rather than giving a comprehensive overview on methodological problems, this section mainly highlights some of the central methodological challenges posed by local GHG inventories. This overview identifies critical variables and clarifies concepts that are necessary for the understanding of the subsequent analysis.

In section two, some of the most advanced GHG inventory tools are analysed and the most important differences between these tools are highlighted.

The paper concludes that the methodologies are not consistent. Local GHG inventories can thus hardly be compared. The paper gives research and policy recommendations towards greater comparability and sketches the requirements of an international protocol on urban GHG inventories.

Keywords: Cities, climate change, mitigation, inventory, standard

TABLE OF CONTENTS

Received: 21 July 2009 – Revised: 26 October 2009 – Accepted: 25 November 2009 – Published: 18 December 2009.
Edited by: Gaëll Mainguy – This paper has been reviewed by Ralph Harthan and another referee

1. INTRODUCTION

The importance of cities for mitigating climate change is undisputable: More than two thirds of the world's energy was consumed in cities in 2006 and this share has been forecasted to further increase to 73% by 2030 (IEA/OECD 2008, p. 179). Accordingly, cities will have a major role to play in monitoring and reducing greenhouse gas (GHG) emissions and mitigating climate change.

If Europe wants to succeed in reducing its GHG emissions by 20% by 2020, cities will have to align their policies on that goal. Many cities are indeed willing to do so. The adoption of the Leipzig Charter on Sustainable European Cities (2007) and the launch of the Covenant of Mayors (2009) show that many cities are ready to pursue an ambitious climate policy—and may even push the EU to go ahead with its ambitious plans.

Any action to reduce GHG emissions at local level, however, requires that local governments have a good overview on the emission sources and their respective reduction potentials. Cities need appropriate tools to form a GHG emissions inventory.

This paper takes into account that indeed international city networks as well as national initiatives have developed such tools at local level, many of which are comprehensive if not sophisticated and display a great variety of different functions. Because of a growing amount of material available on how to construct and implement mitigation and adaptation policies, there is a need for comparative analysis and assessment: today, no resource provides a "road map" to these various pieces of information. Instead the profusion of information on scientific expertise, tools and best practices form a complex, yet unstructured, and somehow disconcerting, corpus.

Addressing that drawback, this article presents a comparative analysis of six different GHG inventory tools, articulated around the following questions: How do the methodologies which underlie different GHG inventory tools differ? What are the critical variables explaining differences between inventories? Can different GHG inventory tools be compatible—and/or interoperable—and under which conditions? The overarching aim of this paper is to investigate whether GHG inventories are comparable, and if not, how greater comparability could be achieved. As illustrated by the success of the Covenant of Mayors[1], most actors are seeking help and guidance to elaborate their climate plan and select suitable accounting methods.

The first section of this article discusses methodological challenges related to the formation of local GHG inventories. These methodological challenges provide a basis for the identification of the main points where differences between inventories could stem from.

In section two, critical variables for the analysis of local GHG inventory tools are inferred from section one. These critical variables guide the analysis of different GHG inventory tools and have been backed by interviews with experts and stakeholders. An overview on the main results of the analysis is provided, highlighting the methodological differences between tools that could be observed during the study. Finally, the paper discusses these results and gives research and policy recommendations.

2. IDENTIFYING CRITICAL VARIABLES

The 2006 IPCC guidelines require *national* GHG inventories to be transparent, consistent, comparable, complete and accurate (IPCC, 2006):

Transparency: There is sufficient and clear documentation such that individuals or groups other than the inventory compilers can understand how the inventory was compiled and can assure themselves it meets the *good practice* requirements for national greenhouse gas emissions inventories [...].

Completeness: Estimates are reported for all relevant categories of sources and sinks, and gases. Geographic areas within the scope of the national greenhouse gas inventory are recommended in these *Guidelines*. Where elements are missing their absence should be clearly documented together with a justification for exclusion [...].

Consistency: Estimates for different inventory years, gases and categories are made in such a way that differences in the results between years and categories reflect real differences in emissions. Inventory annual trends, as far as possible, should be calculated using the same method and data sources in all years and should aim to reflect the real annual fluctuations in emissions or removals and not be subject to changes resulting from methodological differences [...].

Comparability: The national greenhouse gas inventory is reported in a way that allows it to be compared with national greenhouse gas inventories for other countries. This comparability should be reflected in appropriate choice of key categories [...], and in the use of the reporting guidance and tables and use of the classification and definition of categories of emissions and removals [...].

Accuracy: The national greenhouse gas inventory contains neither over- nor under-estimates so far as can be judged. This means making all endeavours to remove bias from the inventory estimates [...]."

This paper focuses on comparability of *local* GHG inventories. Comparability in this context refers to comparability of results. However, *comparability of results* refers to all the remaining criteria as well. If an inventory is not as complete as another, contains less accurate estimates or is not consistent with another inventory, the results are not comparable. Transparency furthermore is the precondition for any comparison since without sufficient documentation on how the inventory was compiled it is

[1] As of November 2009, 978 cities have joined in just a few months.

impossible to assess whether the other criteria are met. The requirements of the IPCC for national inventories are accordingly also useful for the present analysis of local inventories even though it focuses primarily on comparability.

In view of assessing whether results obtained with different tools are comparable, critical variables need to be identified which allow drawing conclusions on the relative transparency, completeness, consistency and accuracy of inventories. To identify these critical variables, i.e. the possible sources of methodological differences, the main issues that the compilation of a GHG inventory raises will be discussed in the following:

- **Whose** emissions are measured?
- **What** is measured?
- **How** are emissions measured?

The selection of these major issues and challenges related to the compilation of a GHG inventory is based on a review of guidance documents from the IPCC (2006), the World Resources Institute (2002, 2004), guidance documents for specific tools as well as relevant academic research (Kennedy et al. 2009, Fedarene 2006). This paper does not aim at recommending specific methodologies. It rather highlights methodological differences which can explain why inventories are/are not comparable. Besides the identification of critical variables for the subsequent analysis, the discussion of methodological challenges may furthermore provide a first introduction into the compilation of local GHG inventories.

2.1 WHOSE EMISSIONS ARE MEASURED?

The question whose emissions are measured relates to the boundaries of the measurement. Boundaries of the measurement comprise different aspects such as territorial boundaries (e.g. boundaries of the settlement) or administrative boundaries. In some cases the data needed for the compilation of an inventory may be more easily available within specific boundaries. The issue of boundaries is therefore closely linked to the one of data availability.

2.1.1 DATA AVAILABILITY

The accuracy of an inventory depends to a large part on the data that feed into it. This raises the question whether cities dispose of comprehensive and reliable datasets for the compilation of a GHG inventory.

In the history of national accounting, environmental accounting is a relatively recent development. In the 1980s, Statistics Netherlands developed a "national accounting matrix including environmental accounts" (NAMEA). It combines a traditional national accounting matrix with environmental accounts in physical units. Thus it can highlight how the standard categories of national accounts (such as certain industries or household categories) impact on the environment. Since the mid 1990s Eurostat has been disseminating the practice of NAMEA accounting over the EU so that today, all member states compile NAMEA air emissions data (Moll et al. 2009; Eurostat 2004).

However, air emissions data such as NAMEA are commonly not available at regional or local level. This means that cities and regions that are planning to form GHG inventories must collect the relevant data by themselves. This is a long work intensive process. The developers of GHG inventories that were interviewed for this study (see Bader and Bleischwitz 2009) stated that the collection of data requires by far the most time of all the tasks related to the creation of an inventory. On average the compilation of a GHG inventory for cities is reported to take four to six months. This does not mean that a municipal official works six months full time on the compilation of an inventory. Some data, however, are not immediately available and cities need to wait until their request for data is processed. The overall process thus runs sometimes over six months even though the municipal official may only spend 15 to 20 days working on the inventory.

In practical terms the collection of data means gathering many different activity data such as data on the fuel consumption of a power plant, the local cement production or the electricity consumption of the territory. Some relevant activities may also take place outside the territory (e.g. waste incineration). If activity data such as the fuel use of a facility are not known a suitable option is to use data on the fuel use of comparable facilities and square footage (California Air Resources Board et al. 2008).

Given that the workload associated with the collection of local data is relatively high, some inventories derive parts of their data from national statistics, i.e. data for a specific sector are broken down from the national GHG inventory. Scaling data from national GHG inventories can be particularly interesting for a city if the relevant data are difficult to obtain at local level and are not expected to represent a great share of overall emissions.

Data collection at local level (bottom-up approach) guarantees a relatively accurate inventory. Data that are scaled from national statistics (top-down approach) have the drawback that they reflect the national average for a certain emission source but not necessarily the actual local emissions. Cities therefore face a trade-off between compiling an inventory as accurate as possible on the one hand and limiting the time needed for the undertaking on the other hand. Most local inventories are therefore based on a mix of bottom-up and top-down approach.

One of the tools analyzed (Eco2Regio) compiles an initial GHG inventory based on only two datasets: the population of the city and the number of persons employed. The tool then produces a first inventory derived from national statistics. The users then have to replace bit by bit the top-down estimate by local (bottom-up) data. The difference between the first estimate and the final inventory was with 5% on average relatively small. Yet, in some cases such a first estimate based on a limited number of data can also be very misleading. For instance, in most of the European cities and regions reported by Carney et al. (2009) industrial process emissions represent only 1-2% of total emissions. In Athens and Torino, however, these emissions represent 11% of total emissions. A top-down estimate based on a limited number of data entries must therefore be complemented by as many bottom-up data as possible to ensure that the inventory is as accurate as possible. In view of obtaining these local activity data more easily, municipal and regional authorities need to improve their data collection and management systems over time.

As the accuracy of data varies it is important to be transparent about data sources. The accuracy of data can be communicated to the public by using different data accuracy levels, also called "tiers". If for instance data are estimated on the basis of GDP and the number of employed persons this should be made transparent since this is an important information regarding the accuracy of given data.

2.1.2 DEFINING MEASUREMENT BOUNDARIES AND SCOPES

Closely linked to the question of data availability is the question of the boundaries of the inventory. Cities which plan to take inventory of GHG emissions have typically to decide whether to measure:

a) all GHG emissions that fall within the geographic boundary of the territory, including emissions from the private sector and households
b) only GHG emissions that are directly linked to activities carried out by the public authority.

Option a) will in many cases be more complicated an undertaking than option b). Yet, it allows taking inventory of the emissions of the territory as a whole. One might argue that e.g. emissions from private cars are not under the control of the local authority and should therefore not be quantified. However, even though the local

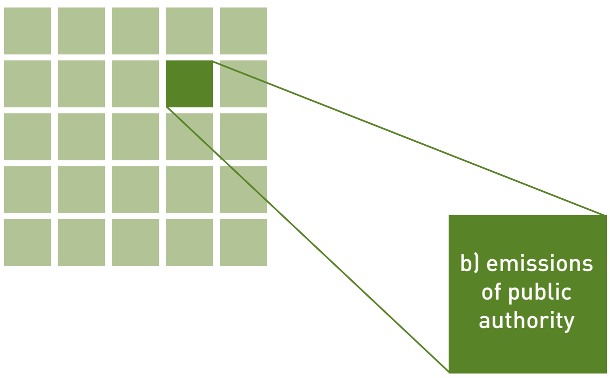

Figure 1: Emissions of public authority and whole territory
Source: own compilation, College of Europe, 2009.

authority cannot prohibit the use of private cars it can nevertheless set incentives to use them in a more efficient manner or less often, to switch to other modes of transportation or set incentives for clean cars. The examples of congestion charges in London or Stockholm have shown that public measures can have an impact on the emissions caused by private transport. Thus there is a case for measuring *all* local GHG emissions.

Option b) will arguably be in many cases less difficult to implement than option a) given that local governments have relatively good access to the relevant activity data and almost direct control over the emissions. The emissions of the public authority relate to operations, facilities or sources owned by the local authority or operations for which the city has the right to implement environmental, health or safety policies (operational control)[2].

An emissions inventory can, of course, comprise the emissions from all sectors of the territory (option a) and the emissions caused by operations of the local government (option b). An inventory that covers all emissions that fall within the geographical boundaries of the territory (option a and b) gives a more comprehensive picture of the emissions of the territory than an inventory limited to specific sectors.

In general local GHG inventories are based on the territory principle. This means that the GHG are allocated to the territory where they were emitted. GHG that were emitted within the geographic boundaries of a city must therefore be included in the inventory of this city.

In some cases, however, also GHG that are emitted outside the territory are included in the inventory because the activity principle is applied. The activity principle requires that activities of a territory that lead to GHG emissions elsewhere must also be allocated to the territory. This can be illustrated at the example of electricity consumption. Cities often import electricity from power plants that are located outside their territory. Without the demand of cities some power plants would not be built or produce less electricity and thus emit fewer GHG emissions (see figure 2). Electricity using activities which are carried out in cities can therefore cause GHG emissions elsewhere. Another case in point arises if the city administration has control of a landfill or waste incinerator outside of the city. A complete application of the activity principle would however require that all emissions caused by the production of goods that are purchased within the territory are included in the inventory (LCA, see also box on approaches to emissions accounting below). In practice this principle often applies only to specific sectors such as the electricity and heat sector.

The GHG emissions caused by activities of the territory outside its geographical boundaries are also referred to as "indirect emissions". To delineate direct and indirect emissions and avoid

[2] Reporting standards for corporations: The emissions of the public authority can, to a certain degree, be compared to the emissions of a corporation. Consequently, the basic principles of reporting standards for corporations can be applied. The "Greenhouse Gas Protocol" developed by the World Resources Institute and the World Business Council for Sustainable Development is one of the most widely used reporting standards for corporate and project emissions. The "Local Government Operations Protocol" developed by ICLEI and environmental agencies in California e.g. is also based on the GHG Protocol. It deals with GHG emissions related to government operations and is in theory applicable to all U.S. local governments (California Air Resources Board et al. 2008). The International Organization for Standardization has recently also developed a standard for corporate emissions reporting that builds on many concepts of the GHG Protocol (ISO 14064) and complements its work on a product climate footprint (ISO 14040; Buser/Lieback, 2008).

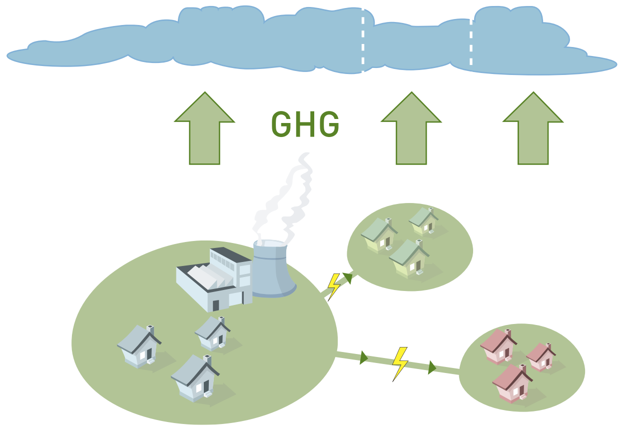

Figure 2: The generation of electricity causes GHG emissions
These emissions can be allocated as direct emissions to the territory where the power plant is located (point of generation; city A in the example described in the paragraph above). A certain share of these emissions may also be allocated as indirect emissions to the territories that import a certain share of this electricity (point of use; city B in the example described in the paragraph above).
Source: own compilation, College of Europe, 2009.

double counting, the concept of "*scopes*" is often used. The GHG Protocol Corporate Standard of the World Resources Institute and the World Business Council on Sustainable Development recommends to group emissions in three "scopes". These three scopes were designed for companies planning to take inventory of their GHG emissions. However, this classification can also be used for GHG emissions of local authorities. ICLEI has based its "International Local Government GHG Emissions Analysis Protocol" largely on the GHG Protocol.

1) Scope 1: Direct emissions, i.e. all GHG that are directly emitted within the territory, such as stationary combustion, mobile combustion, process and fugitive emissions
2) Scope 2: Indirect emissions which result as a consequence of activities of the territory such as emissions due to the generation of electricity, district heating, steam and cooling
3) Scope 3: All other indirect and embodied emissions such as landfill or compost emissions

These three scopes help to group emissions and to avoid double counting within the inventory of a territory. Yet, when several inventories are added together a problem of double counting arises. In fact, territories sometimes export electricity. This can be illustrated at the example of a power plant which is located on the territory of city A where it produces electricity. As industry and households in city A do not demand all the electricity produced by this plant a great share of the electricity is exported to city B. All the GHG emissions caused by the plant would be taken into account by city A as direct emissions (scope 1). City B would include the GHGs caused by the production of the purchased electricity as indirect emissions (scope 2) in its inventory. Thus, there would be a problem of double counting (see also figure 2).

Whether double counting is a problem depends on the purpose of the inventory. If the inventory is used for reporting purposes (such as reporting to an association of municipal authorities), the approach is commonly well defined by the relevant reporting guidelines. Some reporting guidelines are based on the conception that local inventories should be comparable with the national inventory for the United Nations Framework Convention on Climate Change (UNFCCC) and that the aggregation of all local GHG inventories of a country (i.e. all local inventories added together) should yield the same result as the national report to the UNFCCC. In this case double counting at local level should be avoided.

Other reporting guidelines may follow the approach that all emissions that can be quantified within a specific territory and which are due to the activities of the territory must be included in the inventory. In that respect the problem of double counting or the consistency with the UNFCCC does not matter given that the main aim is to form an inventory which is as comprehensive and detailed as possible. The choices behind different approaches are often normative, practical or a mix of both[3]. In theory there are many different possibilities of forming an inventory. If inventories are to be compared across cities it is, however, important that all inventories follow the same approach and the same methodology.

2.2 WHAT IS MEASURED?

Already small quantities of very potent GHGs such as nitrous oxide can have an important impact on the climate footprint of cities. The more types of GHGs and emission sources an inventory covers the more accurately it reflects the overall GHG emissions of a territory.

2.2.1 GREENHOUSE GASES

The IPCC defines greenhouse gases as "those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect" (IPCC, 2007b). A GHG inventory focuses on anthropogenic, i.e. manmade emissions. Water vapor for instance is the gas that has the greatest impact on the

[3] Approaches to emissions accounting: There are many different approaches to the formation of an inventory. Approaches based exclusively on the activity principle (sometimes also referred to as energy end use approaches) aim to take account of the energy used by final energy consumers. End use energy approaches commonly do not take account of all emissions of the energy chain such as transport losses, refinery emissions or energy conversion losses. End use energy carriers are e.g. gasoline, electricity or heat. Energy end use approaches have the advantage that data are relatively easily available. One of the most important drawbacks is that energy end use does not reflect all the emissions of the energy chain. No grey emissions are associated with electricity or heat.
Approaches based on the territory principle (sometimes also referred to as source approaches) cover manifold emission sources. In principle all GHG emission sources within the territory are covered. The emissions are allocated to the site where they occur (energy plants with emissions; imported electricity and heat without emissions). This means that also emissions which due to an activity outside the geographical boundary of the territory are covered by the inventory as long as the emission source is located within the territory (e.g. emissions related to exported electricity).
Life cycle assessment/analysis approaches (LCA). Unlike the two before mentioned approaches which normally do not take account of the emissions associated with the use of products LCA approaches aim to take account of the full environmental impact of products along their lifecycle, including the GHG emissions and the material input associated with the production of goods. LCA approaches give a relatively accurate picture of the GHG emissions of a territory. However, the inclusion of LCA data in a local GHG inventory is relatively complex, time consuming and dependent upon the accuracy of the LCA database.
In most cases inventories combine different approaches or cannot be clearly associated with one of the three approaches above.

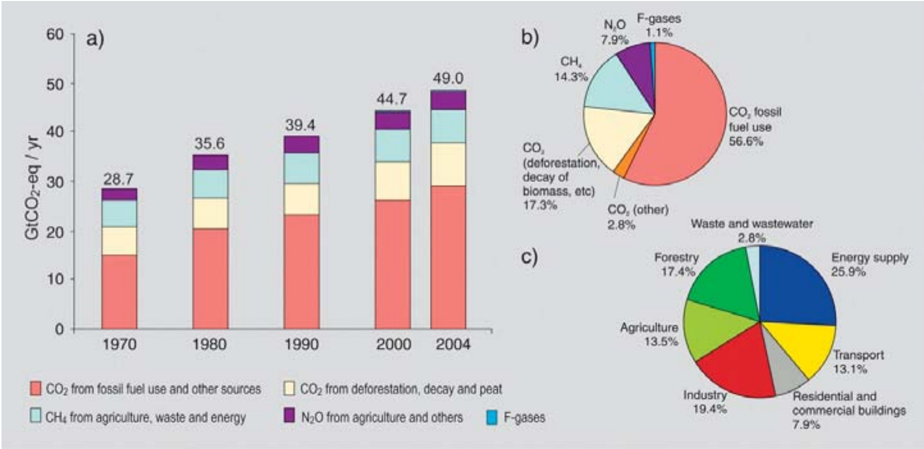

Figure 3: Global annual share and sources of GHG emissions
(a) Global annual emissions of anthropogenic GHGs from 1970 to 2004.5 (b) Share of different anthropogenic GHGs in total emissions in 2004 in terms of CO_2-eq. (c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO_2-eq. (Forestry includes deforestation.).
Source: IPCC 2007a, p. 36.

greenhouse effect. However, the atmospheric water vapor concentration is not substantially affected by human activities, thus water vapor is commonly not referred to as a major anthropogenic greenhouse gas.

Some greenhouse gases in the atmosphere are entirely manmade such as the halocarbons and other chlorine- and bromine-containing substances. The Montreal Protocol deals with these gases. The Kyoto Protocol refers to the following gases: CO_2, N_2O, CH_4, SF_6, hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). These six "Kyoto gases" are supposed to be the most important anthropogenic gases with regard to the greenhouse effect. They originate from manifold human activities and sectors (see also figure 3b).

In view of making the climate impact of different GHG comparable they are normally converted to CO_2 equivalents. CO_2 is thereby the reference gas against which other gases are measured and has a global warming potential of 1. The global warming potential represents how much a certain mass of a gas contributes to global warming compared to the same mass of CO_2. It is based on the different times "gases remain in the atmosphere and their relative effectiveness in absorbing outgoing thermal infrared radiation" (IPCC, 2007b). For instance nitrous oxide is 310 times more potent than CO_2. A ton of nitrous oxide can thus be converted to CO_2 equivalents by multiplying it by 310.

Inventories that cover different GHGs commonly display results in CO_2 equivalents. In this respect it is of crucial importance that the sources and values on which the calculation of these equivalents is based are made transparent. This can be illustrated at the example of the time horizon used for the calculation of the global warming potential. Some gases remain only for short periods of time in the atmosphere whereas other gases can remain for thousands of years in the atmosphere. Thus, different time horizons lead to different global warming potentials. Methane for instance has on average a shorter lifetime in the atmosphere than CO_2. If the calculation of the global warming potential of methane is based on a time horizon of 20 years, methane has a global warming potential of 72 (= 72 times greater than CO_2). A time horizon of 100 years yields a global warming potential of 25 and a time horizon of 500 years a global warming potential of 7.6 (IPCC, 2007c). National inventories which are compiled according to the IPCC guidelines use a time horizon of 100 years.

In recent years, the IPCC has revised the global warming potential of GHGs every time new scientific results allowed a more precise calculation. The values for the global warming potential of gases are published in the assessment reports of the IPCC (see in particular the section of working group 1). Between 1990 and 2007, the IPCC published four assessment reports. The table below shows how the IPCC updated the global warming potential values in its different reports. Any GHG inventory should therefore be transparent with regard to the IPCC report underlying the calculation of CO_2 equivalents.

If an inventory is formed with the aim of comparing the findings with those of national inventories, then the GWP values of the second assessment report will probably be used given that until today (2009) national GHG inventories are based on these values. However, for the upcoming efforts the values of the fourth assessment report are better suited since those values can be assumed to better reflect the scientific state of the art and thus to be more accurate. The ongoing review of international science thus poses additional challenges both for national and local tools.

2.2.2 DEFINING THE SECTORS TO BE INCLUDED IN THE INVENTORY

The main objective underlying the compilation of a GHG inventory is to get a detailed overview on the emissions of the city in different sectors. On the basis of such an overview cities can then develop target-group and sector oriented action plans. In terms of GHG accounting a sector is the summation of specific emission sources. The transport sector could e.g. be defined as follows:

Transport emissions = car emissions + railway emissions + aviation emissions + motorcycle emissions + emissions from water borne navigation

A GHG inventory is constructed from the level of the lowest category, e.g. car emissions. Total emissions of a sector are

Gas	Lifetime (years)			GWP over 20 years			GWP over 100 years			GWP over 500 years		
	4th AR	3rd AR	2nd AR	4th AR	3rd AR	2nd AR	4th AR	3rd AR	2nd AR	4th AR	3rd AR	2nd AR
Co_2	Not given[1]			1	1	1	1	1	1	1	1	1
CH_4	12	12	12	72	62	56	25	23	21	7.6	7	6.5
NO2	114	114	120	289	275	280	298	296	310	153	156	170
SF_6	3 200	3 200	3 200	16 300	15 100	16 300	22 800	22 200	23 900	32 600	32 400	34 900
HFC-23	270	260	264	12 000	9 400	9 100	14 800	12 000	11 700	12 200	10 000	9 800

Table 1: Comparison of Global Warming Potential values
Global warming potential values and lifetimes of different gases in the fourth (2007), third (2001) and second (1995) IPCC assessment report, own compilation, mainly based on IPCC, 2007c[4]

calculated by adding up the emissions of several of these sub-categories. The IPCC 2006 guidelines groups overall emissions in five main sectors:

- Energy
- Industrial processes and product use
- Agriculture, forestry and other land use
- Waste
- Other

These sectors have been defined by the IPCC for national inventories. "Sub-sectors" composing the IPCC energy sector are energy industries, manufacturing industries and construction, transport as well as "other sectors" (such as the residential and the commercial/institutional sector). The remaining categories are also subdivided into different "sub-sectors". Thus the sector "agriculture, forestry and other land use" is composed of several sub-sectors such as livestock emissions (e.g. methane emissions from cattle). The five main sectors of the IPCC guidelines and their sub-sectors are supposed to cover almost all anthropogenic GHG emissions.

Cities, however, face a trade-off between completeness of the inventory (in terms of covering all the IPCC sub categories) and data availability/feasibility. Some sub-categories of the IPCC guidelines require indeed very specific information. While for a national inventory the accuracy of the data on emissions from "fishing (mobile combustion)" may be of some importance, it can be argued that in the case of a city without access to the sea or major lakes these emissions are likely to represent only an extremely small part of the overall emissions. Given that the availability of data on this or similar activities is often very limited and the share of these emissions is likely to be negligible, cities may refrain from including all possible activities in their inventory and concentrate instead on the main GHG emitting sectors in cities.

In Europe, the following sectors and IPCC sub-sectors have proven to account for the major part of GHG emissions of cities (scope 1 and 2): the residential sector, transport, industry, services, industrial processes, fugitive emissions, waste, agriculture and the energy industry. The relative importance of theses sectors for the overall emissions varies across cities. For instance the GHG emissions from "agriculture, forestry and other land use" amount in some cities to only 0,1% of total emissions while in other cities more than 10% of GHG emissions are due to this sector. Some sectors, however, such as the residential or the transport sector account for an important share of overall emissions in all cities (Carney et al. 2009). These sectors should consequently be covered by every local inventory.

In case there is good evidence of the rather limited importance of a specific sector (e.g. if emissions from agriculture are likely to lie below one percent of the overall emissions of a given city), it may be rational to neglect or only roughly estimate the respective emissions. However, without previous knowledge of the relative importance of sectors and in view of compiling an inventory as complete as possible all the main sectors should be covered. Should the first inventory reveal that some sectors are of almost no importance, the respective emissions can be only roughly estimated in the subsequent inventory. In terms of comparability it is important that sectors are defined in exactly the same way in different inventories. However, the sector definitions differ. For instance the transport sector of some inventories covers international and domestic aviation while in other inventories only domestic aviation or no aviation at all is covered. This slight difference in the definition of the transport sector can have important consequences for the comparability of inventories in case the cities in question have important international airports. Beyond the definition of sectors, the comparability of emissions also depends on structural criteria. Absolute figures for GHG emission are often not comparable even if sectors are defined in the same way since the population of the cities or the industrial production differs. In view of rendering inventories more comparable ratios are often developed (e.g. GHG emissions per square metre in the buildings sector or emissions per passenger in the public transport sector). Yet, even if common ratios are used, inventories are not easily comparable across cities. The GHG emissions of the transport sector e.g. are to a large extent dependent upon the density of the city since there is a correlation between urban population density and GHG emissions from transport. A common definition of sectors and the development of ratios for comparison are a necessary but not sufficient condition for comparison.

2.3 HOW ARE GHG EMISSIONS MEASURED?

A GHG inventory tool should provide guidance for local authorities on how to quantify emissions and make the compilation of the

[4] The IPCC does not give a single absolute value for the lifetime of CO_2 in its fourth assessment report (in the second assessment report the value of 50-200 years is given, in the third assessment report 5-200 years). This is due to the fact that a single number might lead to misinterpretation. Different removal processes of CO_2 have different uptakes. About 50% of a CO_2 increase in the atmosphere is likely to be removed after 20 years, a further 30% is likely to be removed in several centuries and the remaining 20% are likely to stay for many thousands of years in the atmosphere, see also Moore, 2008.

inventory a process as simple as possible. This refers to the quantification of emissions and the usability of the tool.

2.3.1 QUANTIFYING EMISSIONS

GHG emissions can be quantified by either directly measuring them or by estimating them[5]. Based on a review of the IPCC 2006 guidelines and guidelines from national government agencies, the World Resources Institute identifies four main quantification methods—the emission factor-based method, the mass balance method, the predictive emissions monitoring system (PEMS) and the continuing emissions monitoring system (CEMS) (World Resources Institute, 2002).

Depending on the purpose of the GHG measurement different methods may be used. For a voluntary programme which aims at gathering data on a wide range of gases and emission sources, the emission factor or mass balance method may be very suitable given the various sources. If emissions are to be measured in a regulatory framework and thus for mandatory purposes, the methods to be used may be already defined. Some protocols and programs define "tiers" to indicate different levels of accuracy. Often, three tiers are given whereby the tier three method is the most accurate and the tier one method the least accurate. The IPCC recommends to use tier two or three methods to calculate the key emission sources for a national inventory (IPCC, 2006).

The methods used may also differ according to the gas to be quantified and the emission source. However, if the main aim of the measurement is to compare emissions from the same type of technological unit in different entities, it may be advisable to use the same or at least very similar methods. If different methods lead to different degrees of accuracy the integrity of the whole reporting programme could be affected (World Resources Institute, 2002, p. 24).

Furthermore, the issue of quality control should also be taken into account when opting for one or the other method. Quality control is important for all the quantification methods. However, the time needed for quality control varies according to the method used. If human resources devoted to quality control are limited, those methods which necessitate less intensive control such as the emission factor method (possibility to double-check) may be given serious consideration.

The cost of the four methods can also vary. The CEMS provides the most accurate data but is also the most expensive option. Emission factor methods are usually the least costly option and are relatively easy to implement (World Resources Institute, 2004, p. 25).

For the above described advantages (quality control, costs) the emission factor based approach is by far the most widely used quantification method for local GHG inventories. The accuracy of the emission factor based quantification depends on the one hand on the accuracy of the emission factor value itself[6] and on the accuracy of the activity data (see also section on *Data availability*) on the other hand. One of the tools analysed, the GRIP tool, therefore recognizes differences in activity data quality and makes these transparent. The most certain data are highlighted in green, intermediate quality data in orange and lower quality data in red. Besides the criterion of accuracy the criterion of transparency is thus also of paramount importance with regard to quantification methods since it enables the public to learn more about the accuracy of data. The latter should of course be as accurate as possible. However, the most accurate data are often also those data that are most difficult to obtain. City officials that are planning to compile a GHG inventory face therefore a trade-off between the accuracy of the quantification and its feasibility.

2.3.2 FUNCTIONS AND USABILITY OF THE TOOL

Whether or not a local authority is successful in compiling a GHG inventory depends to a large extent on the usability and functions of the tool. As shown above, it is a rather technical and sometimes difficult undertaking to form an inventory. A user friendly interface, well written guidance documents, trainings and the feasibility to update the tool according to recent scientific findings are therefore very important factors for the success of this undertaking. The criteria of "usability"—though not explicitly mentioned in the IPCC guidelines—certainly is of crucial importance for the further dissemination of tools across cities.

Good usability and specific functionalities render comparisons easier. Inventory tools may e.g allow for selecting specific sectors

[5] Quantification methods:
- Emission factor-based method: This method is often used to estimate the emissions of large entities, such as cities or countries but it can also be used for small entities. The "emission factor" is a coefficient which quantifies the emissions per activity. Site specific data on the exact quantity of GHG emissions are not needed. Instead, data samples are used that represent the amount of GHG emissions released when a certain activity is carried out under specific operation conditions. The factor-based approach can be written as follows: E = A * EF, where E represents the emissions, A represents the activity data (e.g. fuel consumption or production output) and EF represents the emission factor (expressed as a specific value in e.g. t CO_2/TJ or kg CO_2/t). The precondition for using this method is of course that emission factors have been calculated for the activity to be measured. As operation conditions differ across countries/sites it may be necessary to calculate site-specific or local emission factors to improve the accuracy of the measurement.
- Mass balance method: The basic idea of this method is to follow the mass flow of an element such as carbon or oxygen through a process. This method can be used if the input/output streams as well as the chemical reactions of a process can well be identified (e.g. for stationary combustion technologies). Its general equation reads as follows: Input = Output + Emissions.
- Predictive emissions-monitoring system (PEMS): This method comprises elements of the direct measurement and the calculation based approach. It requires that for the unit in question a correlation test is made to determine the relationship between process parameters and the level of GHG emissions. The determined correlation serves as input for mathematical models which calculate the released emissions for a given process.
- Continuous emissions-monitoring system (CEMS): The CEMS approach is based on direct measurement of emissions. It allows obtaining very accurate and real-time data.

[6] Emission Factors: Many tools provide emission factors in view of rendering the compilation of the inventory easier. GHG emissions can thus be calculated by multiplying specific activity data (e.g. total gasoline consumption within the territory) by the corresponding emission factor. The IPCC provides default emission factors. The use of these default emission factors would represent a tier 1 approach, i.e. the least accurate emission estimation.
A more accurate tier 2 approach requires that default emission factors are replaced by country specific emission factors which take account of country specific data. For instance a country specific emission factor for fuel combustion would take account of the average carbon content of the fuel, fuel quality, carbon oxidation factors and the state of technology development.
A tier 3 approach would in addition take account of operation conditions, the age of the equipment used to burn the fuel, control technology, operating conditions, the fuel type used and combustion technology. Such an approach represents the most accurate emission quantification. However, for many local territories the use of a tier 3 approach might be too complex. For big plants data on plant-specific CO_2 emissions are increasingly available.
It is good practice to use the most disaggregated, site and technology specific emission factors available (IPCC, 2006). If a local authority has access to country and regional emission factors for key activities, then the regional emission factors should be preferred.

Variable	Example of variation	Requirement affected by variation
GHG measured	Only CO_2 is measured ⇔ all GHG are measured	completeness, comparability, consistency
Global warming potential values	Global warming potential values derive from second IPCC assessment report ⇔ values derive from fourth IPCC assessment report	comparability, consistency, accuracy
Boundaries	only operations controlled by the public authority are covered ⇔ all GHG emitting activities of the city are covered	completeness, consistency, comparability
Scope of the measurement	measurement takes only direct emissions into account ⇔ measurement takes direct, indirect and life cycle emissions into account	completeness, consistency, comparability
Sector definitions	different definition of specific sectors such as the transport sector	completeness, consistency, comparability, accuracy
Quantifying emissions	default emission factors and top-down data are used ⇔ regional/local emission factors and local activity data are used	accuracy
Guidelines	guidelines/handbooks are available and make the methodology underlying the inventory transparent	transparency
Functions/usability	simple user-interface and various functions that allow e.g. to form ratios; different language versions available	comparability

Table 2: Overview on critical variables
Source: own compilation, College of Europe 2009.

which are comparable with those of other cities and create ratios (provided of course that the methodology underlying the inventory of the other city is the same). The overall GHG emissions of a city with heavy industry cannot be compared with the overall emissions of a city based on services. However, the residential sector or the transport sector may well be comparable.

The main purpose of local GHG inventories is to help cities and regions to reduce emissions. The condition sine qua non of any action plan is that the local government has a good overview on the overall emissions and the emissions per sector. This should be the basic functionality of every tool. Yet, some additional functionalities can be of great added value. Some tools can e.g. be used to analyse the impact of different measures. City officials may e.g. have the following question: How many tons of CO_2 equivalents could we save if we improved the insulation of buildings? How many tons of CO_2 could we save if, alternatively, we installed more modern gas heating systems in buildings? Some tools allow for comparing the effect of both options. Many others functionalities are of course also conceivable.

A further possible difference is the general usability of the tool. For instance, the user interface of a tool can have the form of Excel sheets or be Windows like, the latter being presumably more user friendly, even more so if it can be accessed via the internet. The tool may furthermore offer a helpdesk. Some tool developers provide very detailed and well written guidance documents which explain the methodology, the calculation of emission factors and the compilation of the inventory. In some cases the developers of the tool offer also training courses for users.

Finally, the price of the tool can also have great influence on the decision of a local authority to compile an inventory. The price may include the software package for an unlimited timeframe or it may limit the use of the tool to a specified timeframe (e.g. licence for 1 year). Additional costs to be taken into account are the costs of trainings (if offered), other forms of support and the costs related to the working time of the official who uses the tool. The latter is likely to be the biggest cost factor in most cases. Thus the overall cost of compiling an inventory is to a large part linked to the duration of this process and the relevant working time needed.

3. ANALYZING GHG INVENTORY TOOLS

The previous chapters have highlighted several methodological challenges related to the compilation of local GHG inventories. It has been shown that there is no single and best approach to the preparation of an inventory. Local inventories can be formed according to many different principles and methodologies are therefore likely to differ. Critical variables where differences in results may stem from are displayed in table 2.

The choice whether e.g. only direct or also indirect emissions are taken into account (scope of the measurement) has major consequences for the outcome of the inventory process. An inventory that takes only direct emissions into account is neither consistent nor comparable with an inventory that takes direct and indirect emissions into account. The above listed variables allow therefore checking whether inventories are complete, consistent, accurate and transparent and thus comparable in the end. Furthermore, the variable of usability was introduced. Usability is not directly linked to the requirements of the IPCC. However, at local level the usability of a tool and the time needed for the compilation of an inventory are crucial factors and should therefore be taken into account.

In view of identifying possible methodological differences between inventories the above listed variables (table 2) were applied to the analysis of six different GHG accounting tools and methodologies. The tools share the following characteristics:

- they are widely used in at least one European country,
- they are among the most advanced GHG inventory tools currently available,
- they have been developed and/or disseminated by non-profit organizations with expertise in this field such as national and international city organisations or energy agencies.

The six analysed tools are: CO_2 Grobbilanz, Eco2Regio, GRIP, Bilan Carbone, CO_2 Calculator and the tool of Project 2 Degrees. The CO_2 Grobbilanz has been widely used in Austria and was developed by the energy agency of the Austrian regions (Energieagentur der Regionen); Eco2Regio was developed by Ecospeed and has been widely used in different European countries (Germany, Switzerland, Italy) by members of the international city network "Climate Alliance"; GRIP, a tool developed by the University of Manchester, has been used in metropolitan regions in several European countries; Bilan Carbon, developed by the French energy/environmental agency ADEME, has been used by numerous French cities and local governments; the CO_2 Calculator, developed by the Danish National Environmental Research Institute, COWI and Local Government Denmark, has been widely used in Denmark; the tool of Project 2 Degrees was developed by the Clinton Climate Foundation, Microsoft and the international city alliance ICLEI and has been used by some members of the C 40 city alliance.

The analysis of these tools is based upon the methodological guidance documents, test versions of the tools and semi standardised interviews with their developers. In the following only a synopsis of the main results of the analysis, i.e. the main differences between the tools, is shown. A more detailed analysis of each tool and further information on the interviews can be found in Bader and Bleischwitz (2009).

3.1 GREENHOUSE GASES

The number and type of greenhouse gases included in the different inventories varies widely. Three out of the six tools take account of all the six gases of the Kyoto Protocol. Two tools allow taking account of carbon dioxide, methane and nitrous oxide. The values for one tool are in brackets because the number of GHG included in the inventory depends on the version of the tool which is used. The basic version of the tool in question is the most widely used version and covers only carbon dioxide. The advanced versions, however, cover all the six Kyoto gases (see table 3).

An inventory that covers only carbon dioxide can be internally consistent if all the other inventories which serve as basis for comparison apply the same methodology and also cover carbon dioxide only. However, in many cases a comparison of different inventories is not possible given that already the number of GHG varies.

With regard to the requirement of completeness an inventory covering all the six Kyoto gases is certainly preferable to an inventory that covers carbon dioxide only. However, the collection of activity data that allow including all the six gases is time intensive. Thus there is a trade-off between the completeness and the feasibility of an inventory. The "CO_2-Grobbilanz" e.g. is often used by small towns and even villages where carbon, dioxide, methane and nitrous oxide commonly represent almost the totality of GHG emissions. The inclusion of all the six Kyoto gases was therefore perceived too complex and not necessary an undertaking. In this case, the requirement of completeness was put into the context of feasibility and the needs of the territory. While for big cities and regions the inclusion of all the GHG in the inventory may often be necessary and feasible (human resources available), this is not always the case for smaller territorial units.

	CO_2	CH_4	NO_2	SF_6	HFCs	CFCs	Other
CO_2 Grobbilanz	•	•	•				
ECO2Region	•	(•)	(•)	(•)	(•)	(•)	
GRIP	•	•	•	•	•	•	
Bilan Carbone	•	•	•	•	•	•	•
CO_2 Calculator	•	•	•				
Project 2 Degrees	•	•	•	•	•	•	

Table 3: GHG covered by the inventory
Source: own compilation, College of Europe 2009.

3.2.2 GLOBAL WARMING POTENTIAL VALUES

The tools differ also with regard to the global warming potential values that underpin the calculation of CO_2 equivalents. The most widely used global warming potential values are still those of the IPCC's second assessment report of 1995 (see table 4). This is mainly due to the fact that the Kyoto Protocol of 1997 and therefore also the respective national inventories are based on these values. One tool is pre-loaded with the values of all the three last assessment reports. The developers of this tool, however, recommend using the values of the 1995 report given their widespread use on national level (in table 4 the other values are therefore in brackets). Two tools use the values of the third assessment report for the calculation of CO_2 equivalents whereas only one tool is based on the fourth assessment report.

The relatively widespread use of the values of the second assessment report is due to two reasons. First, the inventories using these values are consistent and, second, to a certain extent also comparable with national inventories. However, with regard to the requirement of accuracy it can be assumed that the most recent values, i.e. those of the IPCC's fourth assessment report, are the most accurate ones. Thus there is a certain trade-off between comparability and consistency with the national inventories and the relevant IPCC guidelines on the one hand and accuracy on the other hand.

	2nd Report (1995)	3rd Report (2001)	4th Report (2007)
CO_2 Grobbilanz		•	
ECO2Region	•		
GRIP	•		
Bilan Carbone			•
CO_2 Calculator		•	
Project 2 Degrees	•	(•)	(•)

Table 4: Global Warming Potential Values used
Source: own compilation, College of Europe 2009.

3.2.3 BOUNDARIES AND SCOPES

The analysis shows that the inventories are normally consistent with regard to the boundaries of the measurement. The tools are all geared towards the measurement of the emissions of the whole territory. In principle all the six tools can limit their measurement to the emissions of the public authority only. However, the user guides and developers of the tools recommend taking account of the emissions of the whole territory.

The picture is somewhat different when it comes to the scope of the measurement. In this respect the methodologies and recommendations differ in several respects. Three tools do not take account of LCA emissions whereas the other three tools allow in principle to include LCA emissions. However, for none of the analysed tools the inclusion of LCA emissions in the inventory is compulsory. Thus, some inventories may include no LCA emissions at all whereas other inventories may include LCA emissions of a limited number of goods or services or even the LCA emissions of a whole basket of goods and services which reflects the average purchases of the local population. An inventory that includes also the LCA emissions of goods and services purchased within the territory can be deemed more complete than an inventory that does not. Yet, all these emissions are normally not part of the national inventories which are based on the territory principle. Thus there occurs a trade-off between consistency and comparability with national inventories on the one hand and completeness on the other hand.

The tools and methodologies furthermore differ with regard to the allocation of indirect emissions due to electricity and heat. Table 5 shows that the emissions related to electricity generation are either allocated to the point of use or to the point of generation. One tool leaves the choice as to the allocation of electricity emissions to the user and offers both options (in brackets). Two tools cover both, emissions from the point of generation and emissions from the point of use. Two tools allocate emissions to the point of use and one tool allocates emission to the point of generation.

In this context consistency is of paramount importance given that in many cities the share of indirect emissions due to the use of electricity and heat (generated outside the territorial boundaries) is rather big. If an inventory is to be consistent with the IPCC guidelines, only emissions at the point of generation should be taken into account. However, inventories which also cover indirect emissions at the point of use can be deemed more complete. The trade-off between consistency/comparability with national inventories and completeness arises here again.

	Point of use	Point of generation
CO_2 Grobbilanz	•	
ECO2Region	(•)	(•)
GRIP	•	
Bilan Carbone	•	•
CO_2 Calculator		•
Project 2 Degrees	•	•

Table 5: Allocation of electricity emissions
Source: own compilation, College of Europe 2009.

3.2.4 EMISSION SOURCES AND SECTOR DEFINITIONS

The emission sources covered differ between tools. Some tools cover the energy sector only whereas other tools cover almost all the five categories as defined by the IPCC (industrial processes and product use, agriculture, forestry and other land use, waste, other). The choice which emission sources to include in a local inventory seems to depend to some extent also on the main emission sources of a territory. The category "land use, land use change and forestry (LULUCF)" for instance is only covered by one of the six inventory tools. This probably reflects the assumption that the LULUCF category may only represent a very small share of municipal emissions in Europe.

An inventory which does not cover the LULUCF category may well be complete if within the respective territory the emissions from land use, land use change and forestry are negligible. However, sometimes the inventory reveals that the emissions in question are greater than expected. The question whether the feasibility of an inventory and thus its limitation to the most "important" categories should be favoured or whether the completeness of the inventory and thus the inclusion of all main categories should be preferred finds no easy answer. In general whole categories should only be excluded from the inventory if good evidence of the minor importance of these categories exists. In the absence of good evidence of the relative importance of emission sources it is certainly rational to include all categories.

The definitions of specific sectors (which normally lie below the level of the IPCC categories) are an additional source of divergence. This can be illustrated at the example of the transport sector. In some cases only the transport of persons and the freight transport on road is taken into account while in other cases all the modes of transport (road, rail, marine and air transport) are covered for both persons and freight. To this adds a slight methodological difference: The estimation of road transportation emissions can be based either on the average mileage of vehicles or on fuel consumption. Both methods are commonly used by local authorities. The choice of the method depends mainly on data availability.

3.2.5 INTERNATIONAL COMPARABILITY AND USE

The question as to whether an inventory can be compared internationally refers to the issue of international standards. As described above there is no widely accepted international standard or protocol for GHG monitoring at local level yet. In the absence of any such standard most of the developers of inventory tools/methodologies have taken the IPCC methodology for national inventories as guideline. However, as shown in the sections above developers of tools for the local level often face trade-offs between consistency with the IPCC methodology and completeness, feasibility and to a certain extent also accuracy of the local inventory. Given that the IPCC guidelines have not been developed for the local level tool developers have therefore made some adaptations to it.

The brackets in table 6 (IPCC column) indicate that the various inventory methodologies are broadly consistent with the IPCC guidelines. However, only one methodology is almost completely consistent with the IPCC guidelines. Differences with the IPCC methodology relate to all the points highlighted above: the number and type of GHG included, the scope of the measurement, the emission categories covered by the inventory or the global warming potential values used.

Other standards and protocols that were developed by other actors than the IPCC (see table 6) do not seem to be widely accepted. During the interviews with developers of inventory tools the IPCC guidelines were indeed very often quoted as the main source of reference although adaptations have been made in almost all cases.

	GHG Protocol	ISO	ICLEI	IPCC
CO_2 Grobbilanz				(•) a
ECO2Region	(•) a	(•) a		(•) b
GRIP				(•) c
Bilan Carbone		•		
CO_2 Calculator				•
Project 2 Degrees	•	•	•	(•) d

Table 6: Consistency with international standards

Source: own compilation, College of Europe 2009.

a) The CO_2 Grobbilanz allocates electricity to the point of use and not the point of generation. The CO_2 Grobbilanz furthermore differs from the IPCC guidelines inasmuch as it does not take account of industrial processes, solvent use and land use sinks.

b) The inventories following the recommendations of the Climate Alliance are not consistent with the IPCC guidelines. However, the ECO2Region tool allows also for the compilation of inventories that are consistent with the IPCC guidelines. With regard to the GHG Protocol and the ISO standard, the ECO2Region tool allows for displaying results for scope 1 and 2.

c) GRIP inventories allocate electricity to the point of use and not the point of generation. Otherwise they are consistent with the IPCC guidelines.

d) Project 2 Degrees states that the inventory is consistent with the IPCC guidelines. However, also indirect emissions are taken into account.

3.2.6 USABILITY AND LANGUAGES

The analysis of the functionalities and the usability of the different tools has yielded rather positive results. All but one tool offer dynamic user interfaces. Most of the tools are furthermore accessible through the web and provide numerous additional functionalities such as the calculation of ratios or even scenario development.

For the international dissemination of these tools, their availability in different languages is of crucial importance. A single tool that is adopted by many important actors internationally could, in theory, even become a reference methodology and enable international comparison. This presupposes, however, that such a tool can be used in many different world regions, hence is available in different language versions. None of the tools above fulfils this condition. Tools that are available in English have certainly good starting conditions. Yet, many of the city employees in non-English-speaking countries would presumably encounter difficulties if they had to work with guidance documents in English. The compilation of a GHG inventory is a rather technical and demanding exercise. Having to do this in a foreign language would render the task more difficult.

Table 7 shows that one of the six tools is available in four different languages while another tool is planned to be released in several languages. A tool that is available in English, German, French and Italian can potentially be very widely disseminated on European level. At this point of time it is, however, still too early to say whether we are witnessing an international convergence towards a small number of tools that are available in several different languages or whether there is a trend towards a greater number of country specific tools.

	English	German	French	Italian	Danish	Other
CO_2 Grobbilanz		•				
ECO2Region	planned	•	•	•		
GRIP	•					
Bilan Carbone			•			
CO_2 Calculator					•	
Project 2 Degrees	•		planned			planned

Table 7: Languages of the tools; source
Source: own compilation, College of Europe 2009.

4. CONCLUSION

4.1 DISCUSSION AND ASSESSMENT

This paper has shown that many advanced tools already exist in different European countries and worldwide, highlighted the main methodological challenges of local GHG accounting and has presented an analytical framework for the assessment of inventory tools and methodologies.

The analysis was very much developer-driven, so as to understand the underlying methodologies and their differences. Surprisingly many tool developers contacted were not aware of the work currently undertaken on this topic and sometimes did not even know of the existence of other tools (on the assumption of their tools being one of the first of their kind). This may be explained by the fact that most of the tools were developed only in recent years and often in isolation to other similar initiative. The time seems therefore right to draw first conclusions on the state of the art and discuss possible future developments.

In general, the methodologies underlying the different tools are relatively similar. Almost all tool developers stated that they tried to align their methodology with the IPCC guidelines. Moreover, also in fields which are not directly related to the IPCC recommendations tools have many points in common. For instance all the local inventories cover normally the emissions of the whole territory and not only the emissions of the public authority. The tools are relatively easy to use and offer many additional functions (ratio calculation, graphs etc.). Furthermore, tools are often pre-loaded with country specific emission factors and users are trained on how to refine the analysis with regional emission factors and how to obtain local activity data.

One of the most important commonalities of the different tools is their great **transparency**. The methodologies on which the tools are based are normally very transparent. On the webpages of the tool developers/promoters, guidance documents are available which explain in detail the compilation of the inventory.

Nevertheless, the analyzed tools differ also in some important aspects:

Completeness: Estimates are not always reported for all relevant categories of sources and sinks, and gases. Some tools cover only the energy category of the IPCC guidelines whereas other tools cover all the categories. Furthermore, sector definitions vary and the number and type of GHG covered differ across tools. Inventories are often limited to a small number of gases and sources because the benefit of a more complete inventory is deemed out of proportion to the effort. This may indeed be the case for relatively small local territories with limited human resources and time available for the compilation of an inventory and a limited number of emission sources. However, greater territories often do have the resources to form a more complete inventory and should dispose of tools that allow them to form an inventory as complete as possible.

Consistency: All the tools are internally consistent, i.e. they allow for compiling inventories which are consistent with historic inventories formed according to the same methodology. Most of the tools have been developed and/or are used by city associations to ensure that their members use the same methodology and that results are comparable. However, inventories of different city associations are normally inconsistent with another due to methodological discrepancies. This can be illustrated at the example of the scope of the measurement which greatly varies across inventories and the respective tools.

Accuracy: The accuracy of an inventory depends mainly on the data that feed into it and thus on data availability at local level on the one hand and support of the users and advice on how to find data on the other hand. All tools allow for working with top-down and bottom-up data. However, not all the tools make the data sources transparent. In many cases it is not clear to the outsider whether an inventory is based on data that are scaled down from national statistics or whether bottom-up data are used.

In the light of these differences with regard to completeness, consistency and accuracy it can be concluded that today's inventories compiled with different tools are hardly **comparable**. Though all the methodologies are generally modelled according to the IPCC guidelines, they differ in many respects.

There is undoubtedly a *trade-off* between two needs: On the one hand there is a need for inventories to be as accurate and comprehensive as possible in view of selecting the most efficient measures for emissions reduction. On the other hand the formation of an inventory must not be an end in itself. The ultimate goal should be to reduce emissions. In this respect the time spent on the compilation of a GHG inventory should be reduced to the minimum so that human resources can be used for the implementation of emission reducing measures. Unfortunately, less time city officials spend on the compilation of an inventory less accurate it will be and thus less useful for policy formulation. This trade-off lies at the heart of any attempt to render inventories more comparable or interoperable. Any attempt to render local GHG inventories interoperable will have to deal with this issue. A practice oriented solution to this problem would necessitate feedback and involvement of users and is a task of further applied research.

4.2 TOWARDS GREATER COMPARABILITY

It should be stressed that the main question is not whether greater comparability is desirable. On the contrary, most actors interviewed during this study would arguably welcome any development towards greater comparability. The degree of urgency with which climate change needs to be tackled and the long lifespan of urban infrastructure means that cities need to take well-informed and effective decisions quickly. Greater compatibility or interoperability of tools would render it easier to compare results and thus facilitate this process.

The crucial question is how far actions towards greater "comparability" should go. Should they lead towards a precise agreement on how inventories are to be formed? Should they, on the contrary, just lead to a broad set of common guidelines?

Better comparability could be achieved in three different ways:

1) enabling communication between existing tools
2) development of an international protocol
3) adoption of a common tool

Firstly, after the identification of the main variables between tools, a platform could be established. This platform could allow different tools to dialogue with others. Relative comparability would be ensured by "providing translation" between existing tools. This would not require that cities or city associations abandon their already established reporting guidelines. The platform could investigate the main differences between tools and their consequences for the measurement of GHG emissions from different types of urban areas and sites. For instance a methodology that takes account of emissions from international aviation will lead to relatively high emissions in a city with a big international airport. A document could e.g. explain that tool A is very similar to tool B. Yet, if the city in question has an important international airport, tool A leads to a greater total than tool B since it includes emissions from international aviation whereas the former does not. Enabling communication between tools necessitates, however, close cooperation of all the relevant experts and quantitative research on the impacts of different urban structures on the results obtained with different tools.

Secondly, an international reporting protocol could either be adopted or developed. For an international protocol to be developed, current practices and methodologies first need to be discussed by the main actors and assessed by an authoritative review process. For instance it may be possible to define a rather simple reporting protocol which covers only the most important GHG as well as a number of well defined emission sources. The tools could offer extractions for this basic standard while allowing cities also to compile more sophisticated inventories (that cover more GHG and e.g. also LCA sources).

This paper has highlighted crucial points for any such protocol and provides a basis for first recommendations. Our conclusion is that where possible local inventories should follow the IPCC guidelines since these are globally accepted. However, some adjustments to the needs of the local level must be made. The establishment of a global protocol for the compilation of local GHG inventories seems feasible (see also Kennedy et al. 2009). It requires that developers and users of GHG accounting tools find agreement on the following points:

1. **Gases to be measured:** Some inventories take account of CO_2 only, others cover CO_2, methane and nitrous oxide while other inventories cover all of the six gases of the Kyoto Protocol or even several more. A protocol could require that emissions be reported for at least the three most important GHG, i.e. CO_2, methane and nitrous oxide. Thus the greatest share of CO_2 equivalent emissions is covered by local inventories. The inclusion of further gases should be encouraged, even more so if evidence of the relative importance of a specific gas for the overall emissions exists (e.g. chemical industry emitting HFC).
2. **The global warming potential values to be used:** The values used for the calculation of the global warming potential of gases differ. Some inventories use values of the second, some of the third and others of the fourth assessment report. On the basis of these values CO_2 equivalents are calculated. In the light of the requirement that inventories should be as accurate as possible and assuming that the latest IPCC values are the most accurate values available, a protocol could recommend the use of the most recent IPCC values. Currently (2009) this would be the values of the fourth assessment report. As more accurate values are published by the IPCC, these values should be used.
3. **Emission sources:** The emission generating activities, to be included in the inventory. For instance, some inventories take account of emissions from international air and maritime transport while others do not. In general an inventory should be as complete as possible. It is therefore advisable that emissions from domestic and international aviation as well as maritime transport are included. An alternative option would be to include only landings and take-off for international aviation as well as all emissions from domestic aviation to be in line with the IPCC guidelines.
4. **Sector definitions:** sectors are defined as the aggregation of specific emission sources. The emissions of the transport sector could e.g. be defined as aviation emissions + emissions of cars + emissions of trucks + emissions of buses + emissions of railways etc. Sector specific emissions can only be compared if the sectors are defined in exactly the same way, i.e. cover the same emission sources. In this case the IPCC guidelines could provide a common base for local inventories.
5. **The scopes of the measurement:** It is not always clear which scopes inventories cover. Most of the tools take account of direct and indirect emissions. However, emission sources that fall into these categories can differ between tools. Few inventories take also account of life cycle emissions of purchased goods. With regard to the requirement of completeness local inventories should cover also indirect emissions due to electricity and heat production (also referred to as "scope 2 emissions"). The inclusion of life cycle emissions should be encouraged and could be reported separately.

Tier methods to be used: The accuracy of the different quantification methods is normally classified in three tiers, tier 1 methods being the least accurate methods. Local GHG inventories commonly quantify GHG emissions with emission factor based methods. The accuracy of the method depends on the emission factors and the activity data used. Region specific emission factors and activity data are more accurate than country specific emission factors and should preferrably be used. It is furthermore advisable that inventories make the degree of certainty/uncertainty transparent. For instance one of the analysed tools uses colour codes to highlight the accuracy of data.

Thirdly, a common tool could be adopted or developed. A common tool would involve a common user interface, a common standard, common guidance documents and common administrators. Thus, it would require more harmonization than an international standard and would tend to replace existing tools.

These three alternatives differ substantially with regard to the implementation process and their goal but they are nonetheless not mutually exclusive: convergence of existing tools could result in a common tool and/or serve as a base to develop an international protocol. A prerequisite for any of these three methods is the involvement of the main actors, i.e. the users and developers of tools. It is very unlikely that there will be a common tool, a common standard or communication between tools if the developers and users are not willing to support this process and are not involved in it. In order to move on, a well-structured, transparent and user-driven discussion on tools and methodologies, experiences, and results is certainly desirable. It would enable a better understanding of the differences and similarities between tools and would provide the requirements for better comparability. Thus, the platform with international legitimacy suggested above is a central pillar for further action.

REFERENCES

ADEME (2006). Analyse ADEME de l'expérimentation du Bilan Carbone® Collectivités – Synthèse du retour d'expérience.

ADEME (2007a). Bilan Carbone® Entreprise et Collectivités. Guide méthodologique – version 5.0 – objectifs et principes de comptabilisation.

ADEME (2007b). Bilan Carbone® Entreprise et Collectivités. Guide des facteurs d'émissions – version 5.0 – Calcul des facteurs d'émissions et sources bibliographiques utilisées.

Bader N. & R. Bleischwitz (2009). Comparative Analysis of Carbon Inventory Tools, Bruges, 2009 http://www.coleurop.be/content/development/references-academiccooperation/GHGinventories_finalreport.pdf

Buser J. et al. (2008). Der Product Carbon Footprint (PCF) – CO_2-Bilanzierung für Produkte, Der Umweltbeauftragte, 16, pp. 5-6.

Bußwald P, et al. (2006). CO_2 Assessment Tool for Communities, EnviroInfo 2006 Conference Graz, Austria.

California Air Resources Board, ICLEI, California Climate Action Registry, the Climate Registry: Local Government Operations Protocol. For the quantification and reporting of greenhouse gas emissions inventories, Version September 2008.

Carney S. et al. (2009). Greenhouse Gas Emissions Inventories for Eighteen European Regions, EUCO_2 80/50 Project Stage 1: Inventory Formation. The Greenhouse Gas Regional Inventory Protocol (GRIP).

Fedarene (2006). Greenhouse Gas Regional Observatory, 2006, paper available at: http://www.fedarene.org/publications/Projects/GHG-Observatories/Chapitre1.htm

Eurostat (2005). NAMEA for Air Emissions Compilation Guide, Doc. EA1/016/10.1/, Version November 2004.

ICLEI (2008). International Local Government GHG Emissions Analysis Protocol (Release Version 1.0).

IEA/OECD (2008). World Energy Outlook 2008. Part 1.

IPCC (2006). IPCC Guidelines for national GHG inventories, Geneva.

IPCC (2007a). Climate Change 2007: Synthesis Report, Geneva.

IPCC (2007b). Annex I (glossary) to the fourth assessment report, Geneva.

IPCC (2007c). Working Group 1: The Physical Science Basis of Climate Change. Fourth assessment report, Geneva

Kennedy, C. A. et al. (2009). Greenhouse Gas Emission Baselines for Global Cities and Metropolitan Regions, paper presented at the 5th Urban Research Symposium: Cities and Climate Change – Responding to an Urgent Agenda, Marseille, June 28-30 2009.

Moll S. & D. Watson (2009). Environmental Pressures from European Consumption and Production. A study in integrated environmental and economic analysis, ETC/SCP working paper.

Moore P (2009). Carbon is forever, in: Nature, published online on 20 November 2008, article available at: http://www.nature.com/climate/2008/0812/full/climate.2008.122.html

Project 2°C (2008). Project 2° Administrators and Users Guidance Manual, Version 1.

World Resources Institute (2002). Designing a customized greenhouse gas calculation tool, Washington.

World Resources Institute (2004). World Business Council for Sustainable Development: Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard, available at: http://www.ghgprotocol.org/standards

INTERNET-ANALYSED TOOLS

CO_2-Grobbilanz (Climate Alliance Austria; in German only) http://co2rechner.klimabuendnis.at/

Eco2Region (developed by Ecospeed and used by the Climate Alliance; in German only): http://eco2.ecospeed.ch/reco/index.html

GRIP – Greenhouse Gas Regional Inventory Protocol (University of Manchester, Tyndall Centre and UK Environmental Agency) http://www.grip.org.uk

Bilan carbone (developed by ADEME; in French only): www.ademe.fr/bilan-carbone

CO_2 Calculator (Danish National Environmental Research Institute, Local Government Denmark and private company COWI; in Danish only) http://www.miljoeportal.dk/CO2-beregner/

Project2Degrees (ICLEI, Microsoft and the Clinton Climate Initiative): http://www.project2degrees.org