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A harmonised dataset of greenhouse gas emissions inventories from cities under the EU Covenant of Mayors initiative

A. Iancu[1], S. Martelli[1,3], A. K. Cerutti[1,*], G. Janssens-Maenhout[1], G. Melica[2], S. Rivas-Calvete[2], A. Kona[2], P. Zancanella[2], and P. Bertoldi[2]

[1]European Commission, Joint Research Centre, Institute for Environment and Sustainability, Ispra, Italy
[2]European Commission, Joint Research Centre, Institute for Energy and Transport, Ispra, Italy
[3]CORE, Chair Lhoist Berghmans, Université Catholique de Louvain, Louvain-la-Neuve, Belgium
[*]now at: Interdisciplinary Research Institute of Sustainability, University of Turin, Torino, Italy

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Correspondence to: G. Janssens-Maenhout (greet.maenhout@jrc.ec.europa.eu) and A. Iancu (andreea.iancu@jrc.ec.europa.eu)

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Abstract

The realization of national climate change commitments, as agreed through international negotiations, requires local action. However, data is still insufficient to make accurate statements about the scale of urban emissions (UNHABITAT, 2011). The need of comparable emission inventories at city level, including smaller cities, is widely recognized to develop evidence-based policies accounting for the relation between emissions and institutional, socio-economic and demographic characteristics at city level. This paper presents a collection of harmonized greenhouse gases (GHG) emission inventories (the "CoM sample 2013") at municipal level directly computed by the cities and towns that participate in the EU Covenant of Mayors initiative. This is the mainstream European movement of local and regional authorities who voluntarily commit to reduce GHG emissions by 20 % or more by 2020. The "CoM sample 2013" (http://edgar.jrc.ec.europa.eu/com/data/index.php?SECURE=123, doi:10.2904/EDGARcom2013) has been carefully checked to ensure its internal consistency and its congruity with respect to internationally accepted guide values for emission factors. Overall, it provides valuable data for the analysis of the heterogeneity of final energy consumption and greenhouse gas emissions of cities.

1 Introduction

Cities are increasingly recognised to have a high potential to drive climate change mitigation and adaptation policies and sustainable energy use. Urban areas account for about 80 % of population and 70 % of the total primary energy demand in the EU 27 (IEA, 2010; UNDP, 2012). Thus, sub-national and local actors need to be involved by central governments to properly address energy and climate change issues (Bulkeley and Betsill, 2013; Johnson, 2013).

In particular, megacities have been the focal point of air and climate research over the last decade. Although the first concern was the high level of air pollution, more

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and more co-benefits of air quality and climate change measures are considered (WMO/IGAC, 2012). Megacities became the main stage to test new emission monitoring systems and to implement local policies for emission reduction (Tollefson, 2012). However, the empirical relation between urbanization and GHG emission per capita is not conclusive. Lankao et al. (2008) suggest a positive correlation between urbanization rate and CO_2 emissions per capita, according to United Nations data, but Hoornweg et al. (2011) reviews recent literature which demonstrate that denser city centres emit half GHG per capita than suburban areas. The methodology for calculating emission inventories (production- or consumption-based) is crucial in deriving conclusions.

Production-based inventories tend to allocate GHG emissions beyond urban areas, where high emitting industries are located, such as power generation, manufacturing and waste disposal centres. As a result, emissions per capita in urban areas are lower than the national average (Dodman, 2009) and urban centres turn out to be minor contributors to total GHG emission. However, emissions from industrial, energy and transportation activities around the city are determined by citizens' lifestyle (Den Elzen, 2013). Thus, the consumption-based approach associates higher total emissions to urban areas than the production-based approach. Nonetheless consumption-based emissions per capita have been found to be lower than the national average when population density has an efficiency enhancing effect on emission generation (Rybski et al., 2013).

The need of comparable emission estimates at city level is widely recognized to allow more detailed studies. For example, the strong focus on high total emissions from megacities might hide the lower efficiency of smaller cities and their higher potential for emission reduction.

The "CoM sample 2013" presented here aims at filling this gap for the European Union. It is a collection of harmonized emission inventories at local government level (mainly municipal) directly computed by the signatories that participate in the Covenant of Mayors (CoM) project. The CoM is the mainstream European movement of local and regional authorities who voluntarily commit to reduce GHG emissions by increasing

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energy efficiency and the use of renewable energy sources on their territories. The CoM proposes a model of multi-level governance, based on the subsidiarity principle. Different institutional levels are invited to cooperate to assess local GHG emissions and design a strategy for emission reduction.

The CoM movement has already been investigated for specific actions, such as achieving energy savings by retrofitting residential buildings (Dall'O' et al., 2012), increasing the energy efficiency of public lighting (Radulovic et al., 2011) and increasing the acceptance of renewable energy within rural communities (Doukas et al., 2012), but no systematic assessment and release of emission data has been made yet.

Section 2 describes the CoM, including its geographic coverage, and other international initiatives. Section 3 presents the methodologies to compute emission inventories for the CoM and their comparison with the international approach for national emission inventories. The harmonization procedure is also reported in details. Section 4 assesses the differences between CoM and international inventories. Section 5 concludes, while Sect. 6 spells out the location of the presented dataset and the definition of variables.

2 The EU Covenant of Mayors and other international initiatives

This section describes the EU Covenant of Mayors initiative and the reporting of emission data within its framework. Similar initiatives are also presented, including the US Conference of Mayors and the C40 Cities Climate Leadership Group of the UNFCCC.

2.1 The EU Covenant of Mayors initiative

After the adoption of the EU Climate and Energy Package in 2008, the European Commission launched the CoM to endorse and support the efforts of local authorities to implement sustainable energy policies. Today, the CoM is the main European movement dedicated to local and regional authorities who voluntarily commit to meet and exceed the European Union's objective of 20 % GHG emission reduction by 2020 (Covenant of Mayors, 2009). The number of towns participating in the CoM is steadily increasing.

Furthermore, the CoM has already been extended to Eastern and Southern European neighbouring countries. While keeping the 20 % emission reduction target, it was adapted to specific characteristics of the new countries. Former Soviet countries are allowed to set an emission reduction target with respect to the level of emissions estimated in a business-as-usual scenario for 2020. Thus, their emissions can grow from their baseline level. Towns from North-African countries are explicitly requested to address the problem of water and waste management.

After joining the CoM, signatories have to:

a. Compute and submit a *Baseline Emission Inventory* (BEI) for their territories. This identifies the baseline level of GHG emissions to serve as reference for the reduction target for 2020. The BEI is based on city's energy consumption patterns (per key economic sector and energy carrier), and provides implicit evidence on the most suited actions for the city to reach its CO_2 reduction target.

b. Set an emission reduction target for a set of key sectors within the city administrative boundaries. This cannot be lower than the 20 % emission reduction target of the Europe 2020 strategy. Some cities committed to an emission reduction target higher than 20 %.

c. Develop a *Sustainable Energy Action Plan* (SEAP) to be officially approved by the local authority within a year from the date of adhesion. The SEAP describes the strategies and the concrete actions to reduce emissions and meet the committed target by 2020. As the focus of the initiative is on energy, the most common projects aim to improve energy efficiency and increase the use of renewable energy sources (RES) in buildings and transport. The SEAP also includes the timeframe of implementation and the assigned responsibilities.

All SEAPs are assessed by the European Commission's Joint Research Centre. Their compliance with the CoM principles and technical guidelines is verified, including formal criteria (i.e. the approval by an official body like the municipal council and the correctness of the reporting documentation) and, most importantly, the technical aspects of the BEI and the set of actions included in the SEAP.

By 14 March 2013, 5049 municipalities joined the CoM, covering 187.5 million citizens (of which 96 % were from the EU-27). The highest number of signatories is in Italy (2582 municipalities, corresponding to 51 % of CoM signatories) and Spain (1323 municipalities, corresponding to 26 % of CoM signatories).

Christophoridis et al. (2013) further commented the diffusion of the CoM initiative in Europe. Most of the towns are located in Southern European countries where dedicated bodies, including Covenant Territorial Coordinators (CTCs), supported cities in the process of adhesion to the CoM. The CTCs are regional authorities which voluntarily join the movement committing to promote it within their respective territory and to offer technical and/or financial support to the signatories which choose to work under their coordination.

The peculiarity of the CoM movement, compared to other GHG mitigation networks, is the elicitation of small towns' interest and engagement in the effort to reduce greenhouse gas emissions. On the 14 March 2013, 4453 small and medium size towns (with a population of less than 50 000) joined the CoM. They are 88 % of total signatories and account for 16.5 % of the total population covered by the CoM.

This suggests that small cities can also play an important role for climate change mitigation. Based on three case studies, Melica et al. (2014) indicated that the multilevel governance approach adopted within the CoM has been a key determinant to get the involvement of small towns in the movement.

On the contrary, big cities (with more than 50 000 inhabitants) account for a relevant share of population in the CoM: 56.5 % of CoM population live in cities with 50 000 to 1 000 000 inhabitants, and the sole 24 cities with more than 1 million inhabitants in the CoM (e.g. London, Berlin, Madrid and Rome), represent 27 % of the total CoM population.

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Given all the above mentioned, the CoM allows to collect a unique bottom up inventory of local greenhouse gas emissions and related emission reduction potentials, as estimated by local authorities. This can be used to enhance the precision of existing emission inventories and further explore the relative importance of small and big towns in the effort for climate change mitigation.

2.2 Other international initiatives

Alternative examples of international networks of municipalities, similar to the Covenant of Mayors, are the following:

a. The C40 Cities Climate Leadership Group (C40) is an association of 58 megacities internationally (as of end-2013) which have the common purpose to locally implement sustainable climate-related policies. It covers almost 20 million tonnes of CO_2 and involves 8 % of the world population and 18 % of the global GDP. It targets a 30 % reduction of CO_2 between 2005 and 2025.

b. The US Conference of Mayors is an organisation of US municipalities that is undertaking numerous programmes, including the Climate Protection Centre. By September 2013, almost 1060 mayors of the US Conference of Mayors, representing 88.9 million people – approximately 28 % of the total US population – had signed the "US Mayors Climate Protection Agreement", thereby pledging to meet or exceed the Kyoto Protocol targets. Furthermore, the US Energy Efficiency and Conservation Block Grant (EECBG) program was conceived under the leadership of the US Conference of Mayors, making it possible for cities, counties and states to receive grants for energy-efficiency projects. Although the program is specifically dedicated to US organizations, there are signs that a broader cooperation is built. For example, Mercedes Bresso (former President of the EU Committee of the Regions) and Elisabeth B. Kautz (President of the United States Conference of Mayors) signed a Memorandum of Understanding on cooperation on climate action in 2010.

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c. The Local Governments for Sustainability project (ICLEI, 2009) is an international association of 12 megacities, 100 super-cities (with a metropolitan area population greater than 40 million), 450 large cities and 450 small- and medium- sized cities and towns in 84 countries. It addresses a broad set of projects for environmental sustainability, including resource efficiency and the low-carbon city.

d. The global Compact of Mayors in a new agreement by city networks. It was launched on the 23 September 2014 by the UN Secretary-General Ban Ki-moon and UN Special Envoy for Cities and Climate Change and former New York City Mayor Michael Bloomberg. Under this movement, ICLEI-Local Governments for Sustainability (ICLEI), C40 Climate Leadership Group (C40), United Cities and Local Governments (UCLG) commit to mobilize their members, other cities, networks and initiatives, to engage in: publically committing to strengthen their GHG emissions reductions; making existing targets and plans public; reporting on their progress annually, using a newly-standardized measurement system that is compatible with international practices.

3 Emission inventory approach within the Covenant Framework

Emissions data for towns participating in the CoM are collected in the Baseline Emission Inventory. This has to be included in the SEAP, the formal document, approved by the city council or equivalent body, which signatories have to submit within a year after joining the movement. Although specific guidelines are provided, these are very flexible and towns can adopt different methodologies to compute their baseline emissions. Nonetheless, there is a set of sectors (key sectors for the CoM) which are strongly recommended to be tackled, mainly because they fall under the regulatory control of the local administration (see following Sect. 3.2). These sectors should be the target of emission reduction, mainly through energy saving and local renewable energy development measures.

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This section reports the possible methodologies for the computation of baseline emissions within the CoM and their comparison with the common practise for other emission inventories. The rules for the selection of sectors and the definition of emission reduction targets are also spelled out. Finally, the criteria adopted to define the sample of reported emission inventories is described.

3.1 Computation of the baseline emission inventory

In line with the established framework of the UNFCCC, project guidelines for emission inventory within the CoM (Bertoldi et al., 2010) broadly follow the guidelines of the Intergovernmental Panel on Climate Change (IPCC). Similar to the UNFCCC, the recommended baseline year for reporting is 1990, or the closest subsequent year for which the most comprehensive and reliable data can be provided. Economies in transition within Annex I countries (e.g. East European countries and newly independent States) are expected to choose a year after 1990, but close to it and representative of the current situation, in order to avoid a bias related to the 1990–1991 economic breakdown. At the moment of the analysis, the baseline years which were chosen by the majority of the signatories were from 2005 to 2008.

Signatories are given various options to calculate emission inventories. They can choose the standard IPCC approach or the life cycle assessment (LCA) approach. In the standard IPCC approach, emission factors are based on the carbon content of fuels. Only CO_2 reporting is mandatory, as it is the most important among all the GHGs when talking about emissions associated with fuel combustion. Nonetheless, signatories can report emissions of methane (CH_4) and nitrous oxide (N_2O), converted into CO_2-equivalents (CO_2eq.) according to their global warming potential (GWP). CoM guidelines for emission factors are based on IPCC 2006 Guidelines (IPCC, 2006), while CO_2eq characterisation factors are based on the IPCC 4th Assessment Report (IPCC, 2007). However, local authorities can choose different emission factors, provided that they are in line with the IPCC approach. Finally, CO_2 emissions from the sustainable

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use of biomass/biofuels, as well as emissions of certified green electricity, are considered carbon-neutral on an annual basis.

With the LCA approach, the overall life cycle of the energy carrier is calculated. This approach includes all emissions within the supply chain, from extraction of natural resources to processing (e.g. refinery) transport and final use (e.g. combustion). As a result, emissions generated beyond the administrative boundaries of a town are included if they can be associated to final consumption of the city. For example, this approach leads to associate positive GHG emissions to the use of carbon-neutral fuels because of the energy carrier of the supply chain.

Other non-energy related GHG emissions such as methane from landfills and waste water management could be included in the local authority's emission reports, converted into CO_2eq.

3.2 Sectors covered

Direct emissions in urban areas derive mainly from two macro-sectors: transport and buildings. Moreover, they can be directly influenced by local policies. Thus, mayors are recommended to design a strategy for emission reduction that includes both of them. In particular, these two macro-sectors have been disaggregated into four sectors and signatories are required to include in the BEI at least three of them:

i. municipal buildings, equipment and facilities (it can optionally include municipal public lighting);

ii. tertiary (non-municipal) buildings, equipment and facilities;

iii. residential buildings;

iv. urban transport (at least including public and private transport, but it can also include municipal fleet).

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In addition, mayors have the option to report emissions (and emission reduction targets) for other sectors that fall under their jurisdiction. For example they can plan emission reduction projects for:

i. solid waste and wastewater treatment;

ii. the industrial sector, if it is not part of the EU Emissions Trading System (ETS);

iii. electricity and district heat/cold generation, from renewable and non-renewable sources.

All the sectors targeted by emission reduction projects (both mandatory and optional) contribute to the overall emission reduction target of the town. However, many signatories did not report disaggregated baseline emissions and emission reduction targets by sector because only the total emission per energy carrier and per macro-sector of activity is mandatory. Moreover, some of the high emitting sectors of a municipality (e.g. big industries and aviation) are excluded from the CoM baseline emission inventory.

As a consequence, the assessment of differences between CoM emission inventories and other inventories from the UNFCCC or from the European Commission requires careful identification and association of comparable sectors.

3.3 Comparison of different approaches for GHG emission accounting in international inventories

This section develops a comparison between the methodologies adopted in different international emission inventories to calculate the amount of greenhouse gases emitted by a region in a given time-scale. Different international emission inventories are available, including the UNFCCC National Inventories, the Global Carbon Budget, the Emissions Database for Global Atmospheric Research (EDGAR) and AR5 data (which includes the previous two and a third emission inventory based on IEA energy data). IEA and EUROSTAT provide data on both energy consumption and GHG emissions.

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In order to validate the data in the “CoM sample 2013”, CoM baseline emissions per capita were compared with the EDGAR inventory for fossil fuel emissions in the buildings sector (residential, tertiary and administrative), in the transport sector (road transport) and in the waste management sector (Fig. 4). Moreover CoM baseline energy consumption was compared with IEA energy data on final energy consumption in the building sector for different energy sources (Fig. 3). This ensures consistency between the two comparisons because IEA energy data feeds the underlying activity data of EDGAR for the energy related sectors. EUROSTAT data on energy consumption was also used to further check the robustness of results. Evidence from the comparison is discussed in Sect. 4.2.

This section is focused on the description of similarities and differences between the CoM approach to emission (and energy) accounting and EDGAR v4.2, IEA, EUROSTAT inventories (see also Olivier and Berdowski, 2001; Janssens-Maenhout et al., 2012).

EDGAR is a joint project of the European Commission DG JRC and the Netherlands Environmental Assessment Agency (PBL). It provides past and present global anthropogenic emissions of greenhouse gases and air pollutants by country on a spatial grid (EDGAR, 2011).

The International Energy Agency (IEA) is an autonomous intergovernmental organization established in the framework of the Organisation for Economic Co-operation and Development (OECD) in 1974. It provides worldwide detailed energy balances and CO_2 emission estimations at national level.

EUROSTAT provides data from the annual greenhouse gas inventory compiled by the European Environment Agency (EEA) on behalf of the EU. Estimates of greenhouse gas emissions are produced for a number of sources which are delineated in sectors primarily according to the technological source of emissions, as devised by the IPCC.

Common and divergent characteristics of the above mentioned databases are succinctly presented in Table 7. The approach of EUROSTAT is very similar to IEA and

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thus only minor differences can be found between the two datasets. For this reason, the comparison between approaches for emission accounting is developed in more details for CoM, EDGAR and IEA inventories.

i. The EDGAR definition of energy consumption in the tertiary, residential and transport sectors covers local, in-situ emission sources, whereas the CoM considers, not only the in-situ emissions sources but also, the emissions which occur due to the consumption of energy from carriers which could emit outside the city's territory, such as electricity and heat/cold (scope 2 emissions). Even if the consumption of electricity and heat/cold (delivered as final commodity to the user) does not imply emissions at the place of consumption, but at the production site, the CoM considers the users to be co-responsible for the production of the electricity and heat/cold during the supply chain and therefore for the corresponding emissions at the place of production. This is particularly important for those countries where electricity from fossil fuel and heat from district heating plants are widely used. For this reason, the "CoM sample 2013" was compared to international databases (see Sect. 4.2) only for those sectors and energy carriers whose emissions are related to energy produced at the place of final consumption.

   Furthermore, cities that adopted the LCA approach for emission accounting, implicitly included, in the above mentioned sectors, the emissions related to the supply chain of the fuels (see Sect. 3.1) in their inventories. In EDGAR, these emissions are allocated to other sectors (e.g. railway and marine transport, industrial processes etc.) and, sometimes, to other countries, in case the fuels used for energy production are imported. Therefore, in order to render the inventories more comparable, the emissions included in the LCA inventories of the "CoM sample 2013" were converted to direct emissions (see Sect. 3.5) for the comparison of inventories developed in Sect. 4.2.

ii. Whereas small industrial combustion is defined in EDGAR and IEA in conformity with UNFCCC's Common Reporting Format for the manufacturing industry, this can be defined in CoM as small-scale installations for the tertiary sector. Thus, total and per capita emissions and energy consumption in the tertiary sector for the CoM can be larger than in EDGAR and IEA.

iii. Whereas EDGAR and IEA aim to completely account for each sector, the CoM does allow some flexibility, and, when data disaggregated per sector is not available, the signatories can choose to report only those figures which are available, provided that the total per fuel per macro-sector is reported (e.g. an inventory might contain the total natural gas consumption and associated emissions for the entire building sector, but only those figures related to the municipal consumption of natural gas are presented in a disaggregated manner). Also, whereas EDGAR and IEA aim to completely account for all economic sectors as identified in the IPCC subcategories, the number of sectors included in CoM inventories might vary, as long as the minimum number of key sectors (see Sect. 3.2) are included.

iv. Whereas, the road transport sector in EDGAR and IEA data, as considered for the comparison in Sect. 4, includes transport on all road categories in the country, the CoM data will most certainly exclude the traffic on motorways and it could include urban rail transportation (e.g. trams, metros, local trains) and water transportation (e.g. ferries).

v. Whereas the CoM collects bottom-up data for the territory of the city, EDGAR and IEA collect data at the national level. EDGAR distributes national emissions per subsector using representative geospatial proxies at $0.1^{\circ} \times 0.1^{\circ}$ (longitude, latitude) resolution. Therefore, per-capita values can deviate significantly from national averages for those signatories with well-developed urban centres, attracting the population of the surrounding area for tertiary services.

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3.4 Emission reduction target

The emission reduction target is specified as a ratio of the expected reduction of emission by 2020 and the level of emissions in the baseline year. The emission reduction target has to be at least 20 %, in absolute or per capita terms. All signatories have to submit an official action plan with the detailed set of actions to reduce emissions, including project management information (implementation time frame, responsible bodies, costs) and impact estimations for 2020 per action and per sector (such as expected energy savings, green energy production [$MWh\,y^{-1}$] and CO_2 reduction [$t\,y^{-1}$]). At the time of the assessment, only the CO_2 reduction estimation per macro-sector was compulsory. As a consequence, the type and quality of data varies significantly across cities and requires a preliminary screening to build the reference CoM sample.

3.5 Selection of cities included in the CoM sample

The reported inventories of greenhouse gas emissions and energy consumption at municipal level are based on data provided by cities participating in the CoM. The "CoM sample 2013" is built starting from the full sample of SEAPs that were accepted before 14 March 2013. However, inconsistencies in the data led to the exclusion of some cities from the sample.

First, towns with extreme and non-reasonable declared total emissions per capita, energy consumption per capita and estimated emission reduction per capita were excluded from the CoM sample to drop possible coding errors.

Subsequently, detailed checks on the internal consistency of inventories were conducted.

As mentioned in Sect. 3.2., cities in the CoM are asked to report energy consumption and emissions per type of energy carrier, disaggregated by macro-sector (buildings, transport and others), and further subdivided by sector (i.e. consumption of diesel for municipal fleet and related emissions; consumption of gasoline for private transport in the municipality and related emissions). They should report as well subtotals by macro-sectors and sectors (across energy carriers). The declared total by sector was required not to be greater (in absolute value) than the computed corresponding figure (summing disaggregated figures per energy carrier). Detected inconsistencies greater than 5 % of the total have been manually corrected when expert judgment allowed to infer the committed mistake. Remaining cities have been excluded by the CoM sample. No consistency test has been carried out for the sectors in the group "Other" (e.g. waste and waste water treatment). Most of the emissions from these sectors derive from sources other than the energy carriers included in the CoM.

The same approach was applied to totals by energy carrier (within macro-sectors). However, reported total consumption (emissions) by energy carrier can be substantially greater than the sum of its reported components per sectors. It happens when data on consumption (emissions) is available only aggregated at the macro sectorial level and it is not possible to disaggregate it by sector. In this case, total consumption (emissions) is reported for the macro-sector, while figures for sectors are reported only if available. As a consequence, the city is not included in the sample only if the computed total is greater than the declared total, by more than 5 % (unless expert judgment allowed to infer the committed mistake and correct it).

Finally, implicit emission factors were computed dividing emissions and energy consumption as declared by subsector and energy carrier. Some of the implicit emission factors were found to be incompatible with internationally accepted reference values. Cities with implicit emission factors above 1 tonnes CO_2 eq/MWh for fuels and above 2 tonnes CO_2 eq/MWh for electricity were excluded from the sample if no reasonable justification for the choice was found and no clear mistake to be corrected was identified. Figure 5 reports the distribution of implicit emission factors for subtotals of sectors, by energy carrier, for the cities included the "CoM Sample 2013". The reference value provided in the CoM guidelines is also highlighted with a vertical line, when relevant. The figure shows that the adopted procedure for data validation excludes values that are not acceptable according to the relevant literature and international guidelines. However, dubious cases remain (outliers within the acceptable range). Few cities may

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have misinterpreted the type of fuel to be associated with reported data. Some cities have zero emissions for positive energy consumption (implicit emission factor is zero) or zero energy consumption for positive emissions (implicit emission factor is missing). This may be related to lack of information for specific categories, low incidence of the energy carrier in the sector considered, exclusion from the reduction target of emissions for the selected energy carrier (but energy consumption was reported for completeness) or mistakes. Since these cases (as highlighted by Fig. 5) do not prove to be clearly erroneous, they are not excluded from the sample. Nonetheless, they should be used with caution.

As a result, the relative difference between declared and computed totals by subsector for all cities in the sample is not greater than 5 % in absolute value. Computed totals by energy carrier do not exceed declared totals by more than 5 %. Implicit emission factors lie within an acceptable range, as derived from theory.

The distribution of signatories in the resulting "CoM sample 2013", by city size is reported in Table 2, while the distribution of signatories by country is reported in Table 1. Spain and Italy account for 80 % of the sample.

As signatories have a choice between two calculation methodologies (standard IPCC or LCA approach), baseline emissions have been transformed from supply chain emissions (LCA approach) to direct emissions (IPCC approach). In order to render the emission inventories more comparable within the sample and also with other emission databases (see Sect. 3.3), when referring to the emissions reported in the LCA inventories, a conversion factor of 0.885 was applied. That is equal to the average ratio between IPCC emission factors and the recommended LCA emission factors for energy products (Covenant of Mayors Guidelines, Bertoldi et al., 2010). This is assumed to be representative of direct emissions embedded in LCA inventories.

Finally, it is not possible to perform a conversion to reconcile different reporting units (CO_2 and CO_2eq) therefore all the data reported are considered as CO_2eq. This leads to underestimate the quantity of non-CO_2 emissions in the sample. However, the data

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still provides a reliable idea of direct emissions of towns, as CO_2 is responsible for an average of 85 % of GWP in Europe (EDGAR, 2011).

4 Assessment of data in the CoM sample

The comparison of CoM emissions and energy inventories with EDGAR and EIA data is discussed in this section. Countries with more than 10 cities in the "CoM sample 2013" (plus France that is represented by a high total population in the sample, greater than 3 million) were analysed in more detail and more extensively used for the comparisons. Results are based on cities included in the "CoM sample 2013" only.

4.1 Baseline year and methodology for emission inventory in the SEAP sample

The most common reference year for the BEI is either 2005 or 2007. Only 24 cities adopted 1990 for the BEI, as suggested in the CoM guidebook (Bertoldi et al., 2010). Moreover, there are strong differences from country to country. 1990 is the most common year in Germany and Sweden, while French cities chose more recent years as reference for the BEI (after 2000). 53 % of Italian SEAPs and almost all British SEAPs selected 2005. Furthermore, 80 % of Spanish signatories took 2007 as reference year and almost 50 % of Portuguese SEAPs opted for 2008.

Clearly, the choice of the reference year is crucial in determining the efforts required to meet emission reduction targets. For example, in countries such as Germany and Sweden, which experienced a negative trend in emissions from the beginning of 1990 (EDGAR, 2011), the choice of 1990 as reference year could be seen as a way to ease the work needed to meet the selected target. Conversely, a positive trend in emissions can be observed in most countries, until the drop related to the recent economic crisis. Therefore, the selection of a recent pre-crisis baseline year for the BEI may be related to strategic behaviour, i.e. to lower the effort required to meet emission reduction targets. Yet, this could also be related to real scarcity of appropriate data at municipal

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level: while in Nordic countries, where there is an older tradition of local GHG mitigation policies, signatories joining the CoM are already developing an action plan which generally refers to 1990 as a base year, signatories from the South often rely on more recent data, generally extracted from studies at regional level, not yearly available.

With regard to the methodology to calculate emission inventories, most SEAPs applied the IPCC approach and focused on CO_2eq (see Table 3). This can be related to the higher complexity of the LCA approach which requires computing emissions related to the supply chain of each energy product (Cerutti et al., 2013a, b).

4.2 GHG emission and final energy consumption inventory

Disaggregated emissions by macro-sector and sector are reported in Table 4. The category "unassigned emissions" report emissions that were not assigned to a particular sector, as it was not mandatory. Buildings accounts for 65 % of total emissions in the inventory, followed by the transport (31 %) and the other sectors (4 %). Overall, one third of emissions are not properly attributed to sectors within the macro-sectors. This might be due to unavailability of detailed data at the city level to meet the desired breakdown in the CoM.

Emissions reported in the BEI vary considerably from country to country. Nonetheless, a common pattern can be identified for the distribution of emissions between macro-sectors in the selected countries (Table 5). First, cities focus on the sectors that are identified as key for the CoM (see Sect. 3.2). The share of emissions reported in other sectors is always less than 1 % of total emission, with the exception of Spain (7 %). Moreover, the building sector accounts for more than half of total emissions in the inventories, with the only exception of France (32 %). Its significance grows to more than 75 % in Germany, Italy and the United Kingdom.

Average emissions and energy consumption per capita from the "CoM sample 2013" are compared to country level emissions from EDGAR v4.2 and energy consumption from IEA. The comparison with EUROSTAT yields similar result as with IEA data and it is not reported (see the similarities in emission accounting reported in Sect. 3.3).

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The comparison of emission per capita is relevant for the following sectors: residential buildings; tertiary buildings; private and commercial transport; waste management. For these sectors, emissions per capita are reported and compared to those reported at the country level from EDGAR v4.2. The per capita values in EDGAR were obtained using data gathered for CO_2, CH_4 and N_2O emissions from 1990–2008. Because not all the years are equally represented as baseline years in the CoM, the EDGAR "per capita" average, used as comparison, was calculated as a weighted average, considering yearly data from 1990 to 2008, with the weight of each year given by the sum of the inhabitants of those signatories choosing that year as baseline.

Country and sector-specific emissions *per capita* from the "Covenant sample 2013" were calculated based only on the cities that reported disaggregated emission by sector. The inclusion of cities that reported zero missions in some sectors, as a result of their decision not to disaggregate emissions, would artificially decrease the computed level of emissions per capita in some sectors.

Keeping in mind the limitations mentioned in Sect. 3.3 regarding the inter comparability of data between the EDGAR database and the CoM sample, emissions in the commercial sector are higher than the national average for those countries where very large cities have a higher share from the total population of the sample (France, Great Britain) and lower for those where the sample contains small and medium cities (Italy, Spain, Sweden). This trend was expected given the fact that large cities are usually services providers also for the population of the surrounding areas. The CoM per capita emissions for Germany are much lower than expected because many very large cities were excluded from the calculation, given the fact that they did not report data disaggregated by subsector.

The CoM average for per capita emissions in the transport sector are around 20 % higher or lower than the national average with the very notable exception of France where the emissions in CoM are almost the double of the national average and Italy where the emissions per capita are about half the national average. This could highlight some inconsistencies in the methodology for building the inventories in the transport

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sector. While the recommendation of the Covenant Guidelines is that the basis for calculating the activity data for the energy inventory in the transport sector should be the mileage in the territory and the average consumption per kilometre per type of vehicle and type of fuel, the practice shows that not all the cities follow this exact methodology. Especially the small municipalities tend to exclude the energy consumption due to the transiting traffic and to account only for those vehicles registered in their territory and only for the mileage related to those vehicles on their territory. In the case of France, the significant difference between the national and the CoM per capita emissions are due to the high value declared by big cities, which represent a high share from the sample population for France. We can speculate that these cities have more complete data regarding the traffic, including data regarding the supper emitting vehicles on their territory, and that they also act as a pole for the daily commute of a significant population living outside their territories.

Per capita emissions in the residential sector have a similar variation of ±25 % between the two datasets, with the notable exception of Sweden where the CoM average is 47 % higher than the national average.

Besides the data on emissions, a very important part of the CoM inventory is the data on final energy consumption. As a prerequisite for the emission inventory, the final energy consumption inventory follows the same structure.

CoM data on final energy consumption in the buildings sector (including all key sectors for the CoM: administrative, commercial and residential) has been compared with IEA data for 2005. This is one of the best represented base year in the CoM sample.

Final energy consumption was grouped by the four main categories of energy carriers: electricity, heat/cold, fossil fuels and renewable energy sources.

As shown in Fig. 3 regarding energy consumption per capita, CoM electricity and fossil fuel consumption per capita are comparable to the national data with a variation of maximum 43 %, the consumption of heat/cold and renewable energy sources is subject to higher variation. As expected, for heat and cold the CoM values are generally higher than the national averages. Even more, as the national per capita value for heat

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consumption is already very low in the representative countries, in comparison with the consumption of other category of energy carriers (e.g. fossil fuel), the significant share of big cities with high per capita value (in Germany and Italy), raised considerably the per capita value of the Covenant sample, reaching values of almost six times bigger than the national average (Italy).

The opposite trend is observed for the final consumption of renewable energy sources transformed in heat at the place of consumption such as: biofuels, biomass, geothermal pumps etc. For this category of energy carriers, the value reported in the CoM is much lower than the national averages. Without a more in depth analysis we cannot explain the cause of this variation. We could only assume that this parameter is very much related to the local availability of the renewable sources and that sometimes the characteristics of the supply chain of these energy carriers make it difficult for the municipalities to collect reliable data (e.g. for biomass).

Overall, even if there are some inconsistencies related to the data input or the methodologies used to gather the activity data, the Covenant values are similar to the national averages. Nevertheless, given the voluntary character of the movement and the absence of a more strict control of the data reported, the outlier values have to be considered with caution.

We can conclude that, the "Covenant sample 2013" provides valuable data to support the analysis of heterogeneity in final energy consumption and greenhouse gases emissions at city level.

4.3 Total GHG reduction potentials

The voluntary nature of the project can be seen as a limiting factor with regard to the accuracy and completeness of data collected by the CoM. Furthermore, signatories voluntarily commit to an emission reduction target which is not legally binding, so expected emission reductions might not be achieved.

In the SEAP sample, only one third of signatories (35 %) decided to adopt the minimum target of 20 % emission reduction. Most of them committed to higher targets:

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43 % of the signatories adopted a reduction target between 20 and 25 %, 10 % of the signatories targeted a reduction between 25 and 30 %, while 12 % of the signatories committed to a target of over 30 %. Figure 2 shows the total emission reduction potential by targeted emission reduction.

Big cities tend to adopt higher reduction targets than smaller cities. As a result, total emission reduction potential of the 394 towns that committed to exactly 20 % (20 Gt of CO_2eq. by 2020) is lower than total emissions that could be reduced by the 128 town that committed to more than 30 % (34 Gt of CO_2eq.).

Overall, the GHG reduction potential of small cities (less than 50 000 inhabitants) is about 17 % (69 Mt CO_2eq.) of the projected reduction potential of the entire project. Signatories with reduced resources often choose low-cost solutions, such as awareness raising and behavioural change or they launch joint projects with neighbouring municipalities (joint SEAPs).

Expected emission reduction by city is estimated in the paper according to two methods. The first method estimates emission reduction according to the committed target, as a share of baseline emissions reported in the BEI. The second method computes the sum of expected emission reduction associated to actions planned in the SEAP. Total emission reduction according to the two procedures is reported in Table 6. Overall, cities tend to set an emission reduction target that is lower than the expected total reduction from planned actions. This can be related to a cautious approach to the flagship target, or a proactive approach to the planning of actions for emission reduction. Nonetheless, there are also cities that have not planned all the actions to be undertaken by 2020, as needed to reach the pledged emission reduction target. They planned in greater detail medium and short term actions, while they set the general strategy for subsequent years. These cities have a total expected level of emission reduction that is lower than the target, by now.

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4.4 GHG reduction potential per field of action

The data of the CoM sample does not allow to perform a detailed assessment of emission reduction potential per specific action. In fact, most SEAPs report only the estimated total emission reductions per field of action, as the estimation of emission reduction for a single action is not mandatory. Furthermore, SEAPs are elaborative instruments that plan simultaneous actions (Dall'O' et al., 2013), thus the expected effect of combined actions may not be further disentangled. Therefore, the analysis is restricted to emission reduction estimates per field of action, as reported in Table 6.

The largest share of potential CO_2 and CO_2/capita reduction is expected from the buildings sector, followed by the transport sector. A relevant number of actions are planned in the field "Working with citizens and stakeholders". Low expected emission reduction is associated to them even if the importance of raising awareness is widely acknowledged (Kousky and Schneider, 2003). It epitomizes the difficulty to quantify the reduction potential of "soft" actions that do not directly include technical measures to improve resource efficiency (e.g. Heidrich et al., 2013; Rybski et al., 2013).

5 Conclusions

The role of cities for climate change mitigation and sustainable energy use is increasing. Megacities are attracting special attention because of their high total greenhouse-gas emissions; however, literature is not conclusive on the empirical relations between urbanization, GHG emission per capita and emission reduction potential.

Individual city emission inventories are currently developed. They generally address megacities only and they do not have a uniform approach. Thus, a harmonised dataset of inventories for the comparison of emission reduction potentials across cities is further needed. Moreover, it needs not to neglect smaller towns, as frequently observed in common practice.

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The town emission inventory of the "CoM sample 2013" presented here aims at filling this gap for the European Union. It collects a harmonized version of emissions computed and reported by towns that participate in the Covenant of Mayors (CoM).

The CoM is an initiative of the European Commission to develop a decentralized approach to climate change mitigation policies. It supports the involvement of citizens in sectors included in the Effort Sharing Decision and not covered by the EU-ETS (Emission Trading Scheme). It complements international and supranational agreements for emission reduction thanks to the successful elicitation of efforts from small and medium size cities.

The high participation of small and medium size cities in the CoM, together with bigger cities, provides a new source of comparable emission inventories at city level, allowing to further explore the drivers of GHG emissions at the local level, their relative importance and the potentials for emission reduction, as identified by towns. Conversely, emissions computed by cities lead to some concern regarding the quality of data reported. This paper provides a harmonised collection of baseline emission inventories, whose internal consistency has been carefully checked, as well as their congruity with respect to internationally accepted guide values for emission factors.

The original data was, where needed, corrected according to expert judgment and scientific knowledge. Some outlier values are still present in the sample as they were not considered errors. Overall, city-level emissions and energy consumption per capita from the "CoM sample 2013" is compatible with international datasets at national level (EDGAR, IEA).

The published collection of city level emission inventories allows to assess the dependence of GHG emissions and reduction potentials with respect to city size, country specific characteristics and different multilevel governance approaches. Moreover, synthetic indicators for urban areas can be developed thanks to the detailed breakdown of emissions between macro-sectors, sectors and energy sources.

Indeed, further analysis is needed to realize the CoM potential. The steady growth of municipalities joining the CoM and the future monitoring of actions undertaken by cities

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will require empirically grounded evidence to support the assessment and improvement of local strategies for emission reduction.

6 Data access

The cleaned dataset of city level emission inventories (CoM sample 2013), as presented here, is made available at edgar.jrc.ec.europa.eu/com/data/index.php?SECURE=123. It includes the following variables, for both final energy consumption (BEI Sample MWh) and greenhouse gas emissions (BEI Sample CO_2):

The cities providing the source data via the CoM on-line template are acknowledged at http://edgar.jrc.ec.europa.eu/com/data/Sample_Covenant_of_Mayors_2013_Cities_list.xlsx.

a. city_ID_sample

b. country_code

c. Cities_name_sample- a given label, specific for each city including the country code associated with a number.

d. Year- year of the inventory

e. Seap_inventories_inhabitants

f. Table- table denomination Final energy consumption and Emissions

g. Macro_Sector_Name:

- BUILDINGS (IPCC CRF 1.A.4(×) and partially 1.A.1.a(×) including only those emissions associated with electricity and heat/cold consumption in the sectors mentioned bellow)
- TRANSPORT(IPCC CRF 1.A.3b–e(×), only the inclusion of urban road and urban rail transportation is mandatory)

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- OTHER (IPCC CRF 6A–D, inclusion of non-energy related emissions is optional)

h. Sector_Name:

i. Macro_Sector_code: a given code specific for the sample:

For the BUILDINGS macro-sector:

- municipal buildings, equipment/facilities
- tertiary (non municipal) buildings, equipment/facilities
- residential buildings
- municipal public lighting
- industries (excluding industries involved in the EU emission trading scheme - ETS)

For the TRANSPORT macro-sector

- municipal fleet
- public transport
- private and commercial transport

For the OTHER macro-sector (emissions not associated with energy consumption)

- waste management
- water management
- other emissions: all other sectors not included above
- subtotal: subtotal per macro-sector

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– total: total per inventory

j. Sector_code: a given code, specific for the sample

k. TOTAL: horizontal total emissions/energy consumption per sector/macro-sector and per total inventory

Values per energy carrier for final energy consumption (MWh) and emissions associated with it (tonnes CO_2eq $MW h^{-1}$), per sector, per macro-sector and per total inventory, for the following energy carriers:

l. Electricity (final electricity consumption)

m. Heat_cold (final consumption of heat and cold delivered as final product to the user).

n. Sum of fossils (sum of the values declared for direct fossil fuel consumption, P to W)

o. Sum of RES (sum of the values declared for direct consumption of energy from renewable resourses, X to AB)

p. Natural_gas

q. Liquid_gas (liquefied petroleum gases, natural gas liquids)

r. Heating_oil

s. Diesel

t. Gasoline (motor gasoline)

u. Lignite

v. Coal (hard and brown coal, excluding lignite)

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w. Other_fossil_fuels (all other fossil fuels not included in the categories above, including peat and non-biomass fraction of the municipal waste)

x. Biofuel (biogasoline, biodiesel)

y. Plant_oil (other liquid biofuels)

z. Other_biomass (wood and wood waste, biogas, biomass fraction of municipal waste, municipal waste, other primary solid biomass)

aa. Solar_thermal

ab. Geothermal

ac. Approach: IPCC = 1, LCA = 2

ad. CO_2_red_target: CO_2 reduction target expressed in percentages (%)

ae. Reduction target type: absolute = 1; per capita = 2

Only for the emissions table (BEI Sample CO_2):

af. Emissions_type: CO_2 = 1; CO_2eq= 2 (expressing the sum of all main GHGs, CO_2, CH_4 and N_2O, converted into CO_2eq using the GWP100 metric of the 2nd IPCC Assessment Report)

ag. Total aggregated fossil fuels: the sum of fossil emissions (as N.) except that the LCA inventories are converted into IPCC using an unique coefficient.

ah. Total aggregated emissions from all energy carriers.

In addition, estimates for 2020, regarding absolute reduction in emissions [$\mathrm{t\,y^{-1}}$], energy savings [$\mathrm{MWh\,y^{-1}}$] and green energy production [$\mathrm{MWh\,y^{-1}}$], from planned actions are reported at city level for each sector and for some key actions (SEA_sample).

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Table 1. Country breakdown of SEAPs as of 14 March 2013. Comparison between the SEAPs submitted and the SEAPs included in the CoM Sample 2013 in terms of number of SEAPs, population covered and the percentage from the total country population represented by the SEAPs. The population number is an average of the years 1990–2008 (source UNDESA, 2010).

Countries	Number of SEAPs submitted	Population covered by SEAPs Submitted	% of the country population covered by the submitted SEAPs	Number of SEAPs in the SAMPLE	Population covered by SEAPs in the SAMPLE	% of the country population covered by the SEAPs in the SAMPLE
Italy	1 217	17 960 954	31 %	256	4 825 244	8 %
Spain	854	17 726 379	43 %	553	10 620 182	26 %
France	66	10 828 160	18 %	9	3 323 652	6 %
Portugal	51	3 377 245	33 %	28	2 186 940	21 %
Germany	48	15 021 766	18 %	10	7 164 571	9 %
Sweden	40	4 086 681	46 %	11	887 735	10 %
Belgium	39	2 460 089	24 %	2	1 422 134	14 %
Greece	35	1 392 697	13 %	0	0	0 %
Croatia	33	1 282 492	28 %	4	969 968	21 %
UK	26	14 009 536	24 %	12	4 275 197	7 %
Poland	25	2 838 533	7 %	2	79 634	0 %
Malta	22	104 920	26 %	2	4 931	1 %
Romania	22	2 046 555	9 %	6	670 789	3 %
Denmark	18	1 543 642	29 %	6	744 955	14 %
Netherlands	12	2 597 916	16 %	0	0	0 %
Bulgaria	7	894 502	11 %	0	0	0 %
Lithuania	7	521 077	15 %	3	462 167	13 %
Austria	6	61 425	1 %	0	0	0 %
Finland	6	1 286 270	25 %	4	991 061	19 %
Cyprus	6	172 790	18 %	2	76 890	8 %
Slovenia	5	177 726	9 %	1	33 756	2 %
Latvia	4	1 024 258	43 %	1	66 087	3 %
Republic of Ireland	3	968 630	25 %	1	506 211	13 %
Slovakia	3	101 473	2 %	1	8 700	0 %
Hungary	2	1 726 378	17 %	0	0	0 %
Czech Republic	2	23 153	0 %	1	13 136	0 %
Estonia	1	16 914	1 %	1	16 956	1 %
Luxembourg	1	2 200	1 %	0	0	0 %
Others non EU-28	39	5 896 435	–	3	1 448 381	–
TOTAL	2 600	110 150 796		919	40 799 277	

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Table 2. Distribution of the sample according to the size of the municipality in terms of total number of SEAPs and of population covered.

Signatory size category	Number of SEAPs in the sample	Percentage from the total Sample	Total population	Percentage from the total population of the sample
< 50 000 inhabitants	807	88.18 %	6 260 299	15.34 %
50 001–100 000 inhabitants	39	4.99 %	2 723 752	6.68 %
100 001–500 000 inhabitants	55	5.49 %	12 909 452	31.64 %
500 001–1 000 000 inhabitants	12	0.87 %	7 862 369	19.27 %
> 1 000 001 inhabitants	6	0.50 %	11 043 405	27.07 %

Table 3. Distribution of the sample according to the emission reporting unit (CO_2 or CO_2eq) and approach followed (IPCC or LCA) in terms of number of SEAPs, inhabitants, GHG emissions reported in BEI and the expected CO_2 emission reduction. The emission reduction estimations are calculated according to the overall target set in the SEAP and according to the sum of the targets set per sector. The latter is usually related to the estimated effect of specific actions included in the SEAP. The values of the two categories are summed into aggregated values using the 0.885 conversion coefficient for calculating the share of the direct emissions embedded within in the LCA inventories.

	Emission unit for reporting	Number of SEAPs	Inhabitants covered by the BEI	Percentage from SEAPs accepted population	GHG emissions as reported in BEI (t)	CO_2 reduction estimation for 2020, by reduction target from BEI (t CO_2eq year^{-1})	CO_2 reduction estimation for 2020 by estimated reduction in SEAP sectors (t)
IPCC approach	CO_2	332	21 069 606	51.64 %	127 182 786	38 910 414	41 912 298
	CO_2eq	564	15 411 469	37.77 %	71 630 900	17 076 056	17 746 012
LCA approach	CO_2	14	1 584 216	3.88 %	17 545 241	6 742 630	5 703 559
	CO_2eq	9	2 733 986	6.70 %	27 301 093	6 866 967	6 898 035
TOTAL aggregated values		919	40 799 277	–	238 502 692	68 030 962	70 810 721

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Table 4. Breakdown of GHG emissions by CoM sectors as reported in BEIs in SEAP sample. The values of the two categories are summed into aggregated values using the 0.885 conversion coefficient for calculating the share of the direct emissions embedded within the LCA inventories. The unassigned emissions in the macro-sector are those from inventories which provided disaggregated data only for the macro-sectors.

Sectors covered		IPCC approach (tCO_2eq)	LCA approach (tCO_2eq)	Aggregated values ($t CO_2eq$)	%
BUILDINGS, EQUIPMENT/FACILITIES	Municipal buildings, equipment/facilities	4 280 730	161 271	4 423 455	1.85 %
and INDUSTRIES	Tertiary (non-municipal) buildings, equipment/facilities	26 887 859	4 756 583	31 097 435	13.04 %
	Residential buildings	43 406 106	5 345 007	48 136 437	20.18 %
	Public lighting	731 121	31 940	759 387	0.32 %
	Industries (excluding ETS)	17 324 767	2 828 064	19 827 604	8.31 %
	Unassigned emissions in the macro-sector	42 803 118	9 309 209	51 041 768	21.40 %
	Subtotal	135 433 701	22 432 074	155 286 087	65.11 %
TRANSPORT	Municipal fleet	335 710	27 902	360 403	0.15 %
	Public transport	2 534 085	592 691	3 058 616	1.28 %
	Private and commercial transport	30 967 022	15 545 818	44 725 071	18.75 %
	Unassigned emissions in the macro-sector	23 986 551	1 216 621	25 063 261	10.51 %
	Subtotal	57 823 368	17 383 032	73 207 351	30.69 %
OTHER	Waste management	3 878 739	586 471	4 397 766	1.84 %
	Waste water management	910 922	33 331	940 420	0.39 %
	Other sectors of activities	758 112	4 411 426	4 662 224	1.95 %
	Subtotal	5 547 773	5 031 228	10 000 410	4.19 %
	TOTAL	198 813 686	44 846 334	238 502 692	100.00 %

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Table 5. GHG emissions in CoM sectors reported in BEIs (total and macro-sectors) for countries covering more than 3 % of the population of the SEAP sample.

		IPCC approach ($t\,CO_2eq$)	LCA approach ($t\,CO_2eq$)	Aggregated values ($t\,CO_2eq$)	%
France	Building sector	2 733 154	6 030 071	8 069 767	32 %
	Transport sector	1 448 458	13 070 081	13 015 480	51 %
	Others	102 224	4 777 483	4 330 296	17 %
	Total	4 283 836	23 877 635	25 415 543	100 %
Germany	Building sector	32 918 980	15 679 985	46 795 767	76 %
	Transport sector	11 394 977	3 842 712	14 795 777	24 %
	Others		247 044	218 634	0 %
	Total	44 313 957	19 769 741	61 810 178	100 %
Italy	Building sector	17 655 824	719 775	18 292 825	76 %
	Transport sector	5 273 766	468 522	5 688 408	24 %
	Others	142 534	6 542	148 323	1 %
	Total	23 072 124	1 194 839	24 129 557	100 %
Portugal	Building sector	6 357 022	0	6 357 022	58 %
	Transport sector	4 528 139	0	4 528 139	41 %
	Others	45 640	0	45 640	0 %
	Total	10 930 802	0	10 930 802	100 %
Spain	Building sector	24 290 752	2 243	24 292 737	54 %
	Transport sector	17 864 118	1 717	17 865 638	39 %
	Others	3 122 970	159	3 123 111	7 %
	Total	45 277 840	4 119	45 281 486	100 %
Sweden	Building sector	3 504 816	0	3 504 816	66 %
	Transport sector	1 840 583	0	1 840 583	34 %
	Others				0 %
	Total	5 345 399	0	5 345 399	100 %
UK	Building sector	21 988 944	0	21 988 944	77 %
	Transport sector	6 420 037	0	6 420 037	23 %
	Others				0 %
	Total	28 408 981	0	28 408 981	100 %

Table 6. Estimated GHG emission reduction potential per field of action in the SEAP sample. The emission reduction estimations are calculated according to the target set per sector, which is usually related to the estimated effect of specific actions included in the SEAP.

Fields of action	Emission reduction estimation (t CO_2eq)	Share of total estimated emission reduction	Number of actions	Share of total number of actions	Ratio of emission reduction per action (kt CO_2eq/action)
Buildings, equip./facilities, industries	32 560 394	46 %	10 910	29 %	2.98
Transport	15 920 611	22 %	4 486	12 %	3.55
Local electricity production	5 054 581	7 %	4 797	13 %	1.05
Local district heating/cooling, CHP	4 446 368	6 %	2 009	5 %	2.21
Land use planning	3 265 106	5 %	4 865	13 %	0.67
Public proc. of products/services	504 024	1 %	2 111	6 %	0.24
Working with citizens and stakeholders	3 210 397	5 %	6 959	19 %	0.46
Others	5 849 240	8 %	1 050	3 %	5.57
All actions	70 810 721	100 %	37 187	100 %	1.90

Table 7. Comparison between CoM database structure and other databases at national level.

	CoM sample	EDGAR database	IEA database	EUROSTAT database
Data on energy	–	Primary energy consumption [b]	Primary energy consumption	Primary energy consumption
	Final energy consumption[a]	–	Final energy consumption	Final energy consumption
Greenhouse Gases (GHG) included	CO_2- mandatory CH_4, N_2O optional, expressed as CO_2eq according to GWP100	All GHGs plus precursors of GHG[c]	CO_2 Partially other GHGs	All GHGs[d]
Detail of the inventory	Scope[e] 2 (mandatory) or 3 (optional)	Scope 1	Scope 1 and 2	Scope 1 and 2
Sectors included	1. Buildings, equipment and facilities: – Municipal – Tertiary – Residential 2. Public lighting 3. Industries[f] 4. Transports – Public – Private – Commercial – Municipal fleet 5. Other sectors, non energy consumption related: – Management of waste and waste water	All IPCC Source/ Sink categories	All IPCC Source categories related to energy production/consumption	All IPCC Source/ Sink categories
Time series	One year inventory within the period between 1990–2012	1970–2010 Complete time series	1971–2012 Complete time series	1990–2012 Complete time series

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Table 7. Continued.

	CoM sample	EDGAR database	IEA database	EUROSTAT database
Data collection	Mostly Bottom-up inventories (completed with national/regional averages when data at local level are not available)	Top-down, national averages National data spatially allocated to a grid of 0.1° × 0.1° using proxy data.	Top-down, national averages	Top-down, national averages
Geographical distribution	Administrative boundaries of the signatory	Worldwide coverage	Worldwide coverage	EU28 and other European countries[g]
Emission factors	IPCC default emission factors or Local Factors	EDGAR Emission factors which take into consideration also the mix of technologies, the end-of-pipe measures.[h]	Standard IPCC default emission factors	Country specific emission factors[i]

[a] Final energy consumption covers all energy supplied to the final consumer for all energy uses. The difference between total and final energy consumption is due mainly to losses in the conversion process, such as electricity generation, transport and distribution, and the part allocated to final non-energy consumption (e.g. feedstock used by the chemical industry).
[b] Primary energy refers to the energy content of the fuels calculated after any operation for removal of inert matter or impurities (e.g. sulphur from coal).
[c] For the complete list of gases included in the EDGAR database, please consult: http://edgar.jrc.ec.europa.eu/methodology.php.
[d] The so called Kyoto basket which includes six gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6). Emissions are weighted according to the global warming potential of each gas. To obtain emissions in CO_2equivalents using their global warming potential (GWP) the SAR factors of IPCC are used: CO_2 = 1, CH_4 = 21 and N_2O = 310, SF_6 = 23 900. HFCs and PFCs comprise a large number of different gases that have different GWPs.
[e] The GHG Protocol (Fong et al., 2014) categorizes direct and indirect emissions into three broad scopes:
– Scope 1: All direct GHG emissions.
– Scope 2: Indirect GHG emissions from consumption of purchased electricity, heat or steam.
– Scope 3: Other indirect emissions, such as the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting entity, electricity-related activities (e.g. T and D losses) not covered in Scope 2, outsourced activities, waste disposal, etc.
[f] Excluding industries under the EUemission trading scheme – ETS.
[g] Iceland, Liechtenstein, Norway, Switzerland, Turkey.
[h] EDGAR emission factors are based on the IPCC 2006 and 1996, scientific literature, EMEP/EEA GB'09, FOD models for landfills.
[i] The sources of the data are the national emissions reported to the UNFCCC and to the EU Greenhouse Gas Monitoring Mechanism. When necessary, the EEA aggregated and gap filled air emission data.

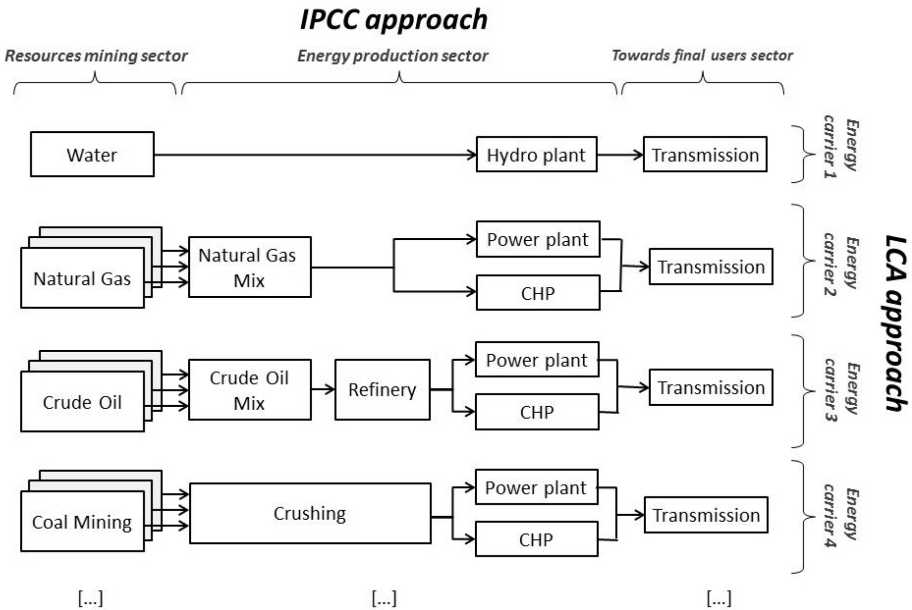

Figure 1. Graphical representation of the emission sources considered using the two approaches (IPCC and LCA) in the case of emission accounting from electricity consumption (Modified from ELCD, v.3.1, Electricity EU27 Life Cycle Inventory).

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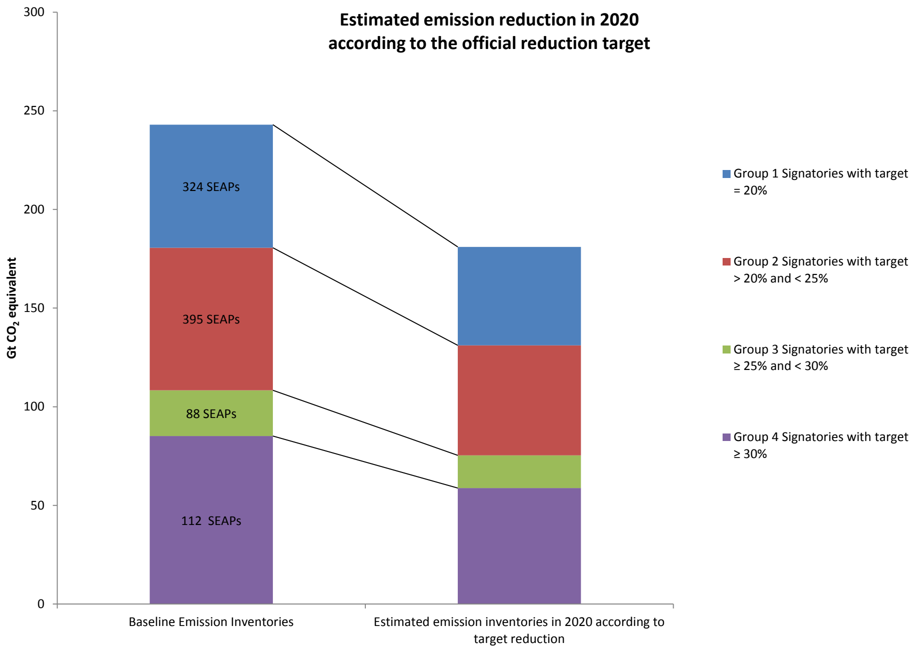

Figure 2. Graphical representation of the emission reductions according to the overall targets set. The estimated emission reduction by 2020 was calculated as percentage from the total declared emissions in BEI. SEAP sample.

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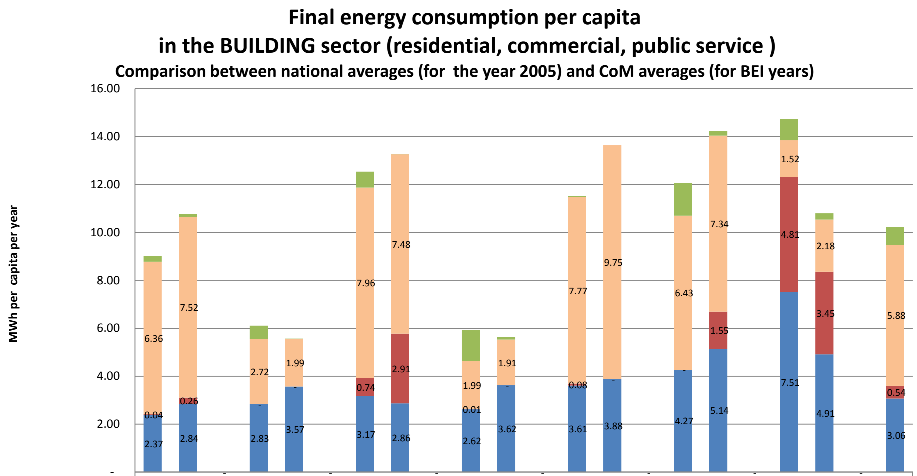
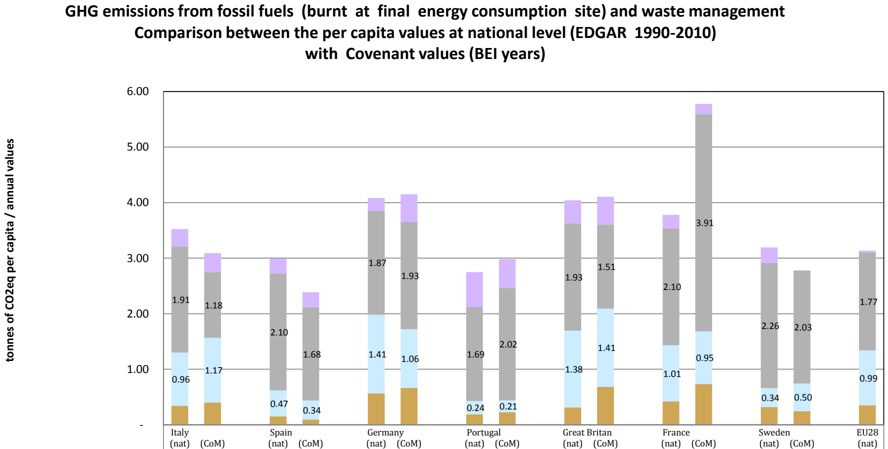


	Italy (nat)	(CoM)	Spain (nat)	(CoM)	Germany (nat)	(CoM)	Portugal (nat)	(CoM)	Great Britan (nat)	(CoM)	France (nat)	(CoM)	Sweden (nat)	(CoM)	EU28 (nat)
RES consumption	0.24	0.14	0.56	0.01	0.66	0.01	1.31	0.11	0.06	-	1.35	0.19	0.88	0.26	0.75
Fossil fuel consumption	6.36	7.52	2.72	1.99	7.96	7.48	1.99	1.91	7.77	9.75	6.43	7.34	1.52	2.18	5.88
Heat/Cold consumption	0.04	0.26	-	-	0.74	2.91	0.01	-	0.08	-	-	1.55	4.81	3.45	0.54
Electricity consumption	2.37	2.84	2.83	3.57	3.17	2.86	2.62	3.62	3.61	3.88	4.27	5.14	7.51	4.91	3.06

Figure 3. Final energy consumption at per capita level in the BUILDING sector. Comparison between national averages (for the year 2005, source IEA, 2011) and the CoM averages. The per capita average in CoM is calculated for the BEI year, which is chosen by each signatory from the period between 1990 to 2010.



	Italy (nat)	Italy (CoM)	Spain (nat)	Spain (CoM)	Germany (nat)	Germany (CoM)	Portugal (nat)	Portugal (CoM)	Great Britan (nat)	Great Britan (CoM)	France (nat)	France (CoM)	Sweden (nat)	Sweden (CoM)	EU28 (nat)
Waste management	0.31	0.34	0.27	0.27	0.23	0.50	0.63	0.52	0.42	0.50	0.24	0.18	0.28	-	0.03
Transport	1.91	1.18	2.10	1.68	1.87	1.93	1.69	2.02	1.93	1.51	2.10	3.91	2.26	2.03	1.77
Residential Buildings	0.96	1.17	0.47	0.34	1.41	1.06	0.24	0.21	1.38	1.41	1.01	0.95	0.34	0.50	0.99
Commercial and administrative buildings	0.34	0.40	0.15	0.09	0.57	0.66	0.19	0.23	0.31	0.68	0.42	0.73	0.32	0.25	0.35

Figure 4. GHG emissions from fossil fuels (burnt at final energy consumption site) and waste management. Comparison between the per capita values at national level (EDGAR1990–2010) with Covenant values (BEI years). The per capita average in EDGAR is a weighted average for the period 1990–2010, the weighting factor for each year being the percentage of the population in the SAMPLE which chose that year as a BEI. The GHGs analysed at national level are CO_2, CH_4 and N_2O. The per capita average in CoM is calculated for the BEI year, which is chosen by each signatory from the period between 1990 to 2010.

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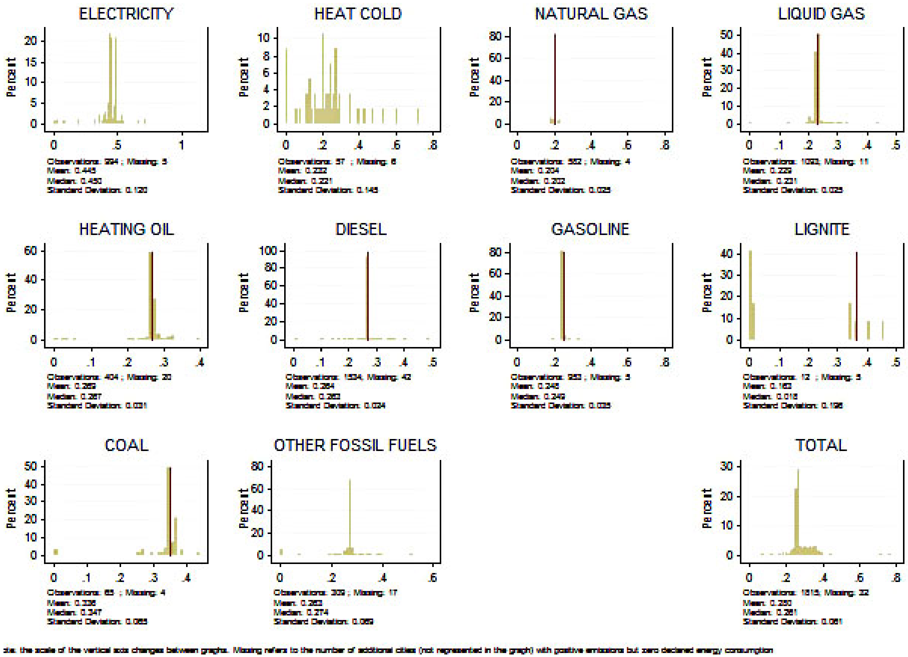

Figure 5. Distribution of implicit emission factors and summary statistics for "CoM sample 2013". The emission factors, expressed in tonnes of CO_2eq/MWh, were calculated based on the data on final energy consumption and the emissions associated to it and compared, when adequate, with the IPCC default values (vertical red lines).

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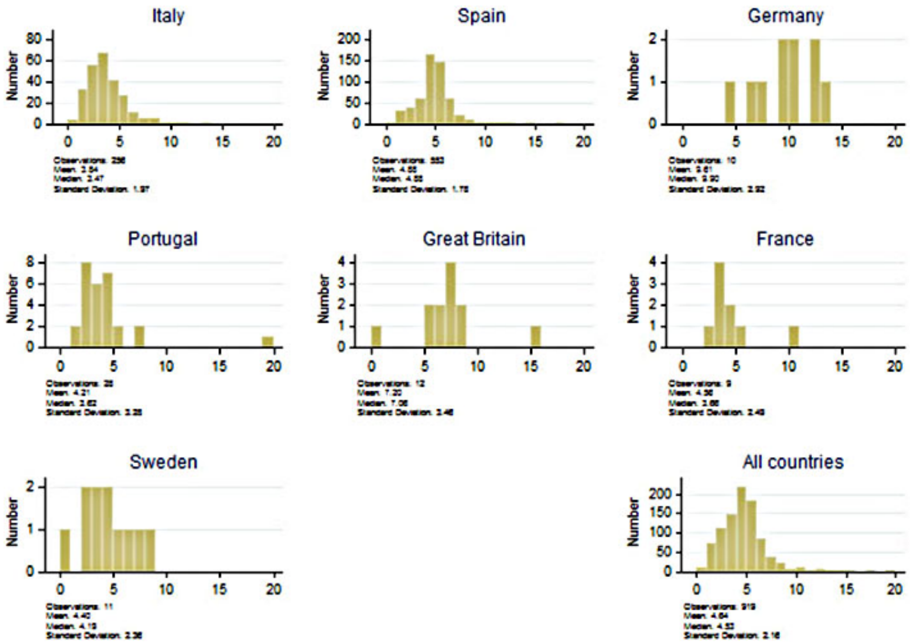

Figure 6. Distribution of total emission per capita (tonnes of CO_2eq) at city level and summary statistics for the "CoM sample 2013", representative countries and the entire sample.

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