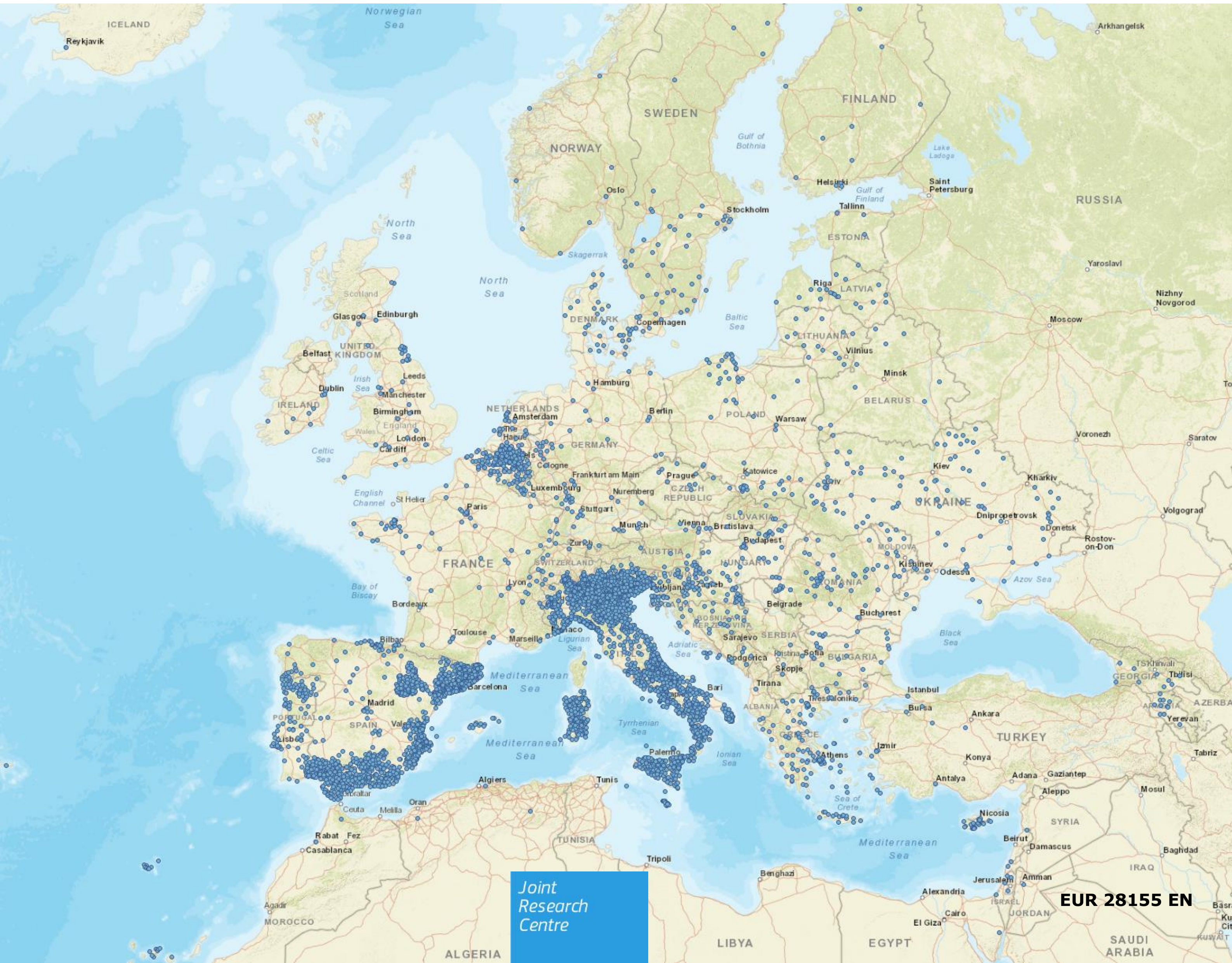
European Commission

JRC SCIENCE FOR POLICY REPORT

Covenant of Mayors: Greenhouse Gas Emissions Achievements and Projections

Albana Kona, Giulia Melica, Brigitte Koffi, Andreea Iancu, Paolo Zancanella, Silvia Rivas Calvete, Paolo Bertoldi, Greet Janssens-Maenhout, Fabio Monforti-Ferrario

2016



Joint Research Centre

EUR 28155 EN

This publication is a Science for Policy report by the Joint Research Centre, the European Commission's in-house science service. It aims to provide evidence-based scientific support to the European policy-making process. The scientific output expressed does not imply a policy position of the European Commission. Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use which might be made of this publication.

JRC Science Hub
https://ec.europa.eu/jrc

JRC103316

EUR *28155 EN*

Print	ISBN *978-92-79-63022-4*	ISSN *1018-5593*	doi:*10.2790/351463*	*LD*-NA-*28155*-EN-C
PDF	ISBN *978-92-79-63023-1*	ISSN *1831-9424*	doi:*10.2790/11008*	*LD*-NA-*28155*-EN-N

Printed in Italy

How to cite: Kona A; Melica G; Koffi B; Iancu A; Zancanella P; Rivas Calvete S; Bertoldi P; Janssens-Maenhout G.;Monforti-Ferrario F. Covenant of Mayors: Greenhouse Gas Emissions Achievement and Projections. EUR 28155 EN. Luxembourg: Publications Office of the European Union, 2016; doi:10.2790/11008

Abstract

The Covenant of Mayors (CoM) was launched in 2008 by the European Commission to support the efforts deployed by local authorities in the implementation of sustainable energy and climate policies. At 4 September 2016, 6201 local authorities from 54 countries had joined the initiative, representing 213 million inhabitants.

Today, the JRC analysis of the Sustainable Energy Action Plans points out that the CoM signatories' ambition is to reduce GHG emissions in 2020 by 27 %, well above the minimum target of 20 %.

Emission reductions for the EU Covenant signatories (31 % of the EU-28 population in 2014) may represent 31 % of the EU-28 GHG emission reduction target by 2020 compared to 2005. The analysis of the first 315 implementation reports (representing 25.5 million inhabitants) reveals that 23 % of the cut in emissions had already been achieved in 2014.

Table of contents

Acknowledgements

The authors would like to thank the Directorate-General for Energy, colleagues Eero Ailio, Sébastien Occhipenti, John Stuebler, Joanna Ziecina and Pedro Ballesteros for their continuing support and presence in the framework of the Covenant of Mayors initiative.

Special thanks to colleagues at the Joint Research Centre, especially to Heinz Ossenbrink, Diana Rembges, Jean-François Dallemand and Elisabetta Vignati, who provided strategic guidance and support during the production of the report.

We are grateful to JRC colleagues, Katalin Bódis who performed the GIS mapping, and Manjola Banja, Monica Lanzoni and Nicola Labanca for providing valuable suggestions.

Relevant contributions on reviewing this report have also been received from other European Commission colleagues including: Susana Calsamiglia Mendlewicz, Dina Silina, Alessandra Sgobbi, Sandro Nieto Silleras and Stephan Poth.

Special thanks to the Covenant of Mayors Office for managing relations with signatories and the dissemination aspects.

Executive summary

Policy context

Urban energy consumption generates about three-quarters of global carbon emissions [1]. Cities play a crucial role in terms of energy and climate policy, offering potential, comprehensive opportunities for contributing to shifting energy consumption to more sustainable pathways and creating local opportunities for investment and growth. They are also in a privileged position to meet the climate-change challenge by fostering the participation of citizens and building partnerships with local stakeholders.

In 2008, acknowledging the role of the local authorities, the European Commission (EC) launched the Covenant of Mayors (CoM) initiative to endorse their efforts in the implementation of sustainable energy policies.

Since its launch, the CoM has proved successful as the mainstream European movement involving those local authorities which commit voluntarily to contributing to the European Union's objective of reducing greenhouse gas emissions by both meeting and exceeding the target of a 20 % cut in CO_2 emissions by 2020, through better energy efficiency and the use of renewable energy sources within their territories.

The important role of the Covenant is mentioned and acknowledged in several European Commission policy documents: the Energy Efficiency Directive [1], the European Commission's Energy Union Package[2], the European Commission's European Energy Security Strategy[3], the Heating and Cooling Strategy[4] and the European Strategy for Low-Emission Mobility[5].

In 2014, in the context of the European Commission's European Strategy on adaptation to climate change[6], the European Commission launched a separate initiative called Mayors Adapt, based on the Covenant of Mayors model, with the aim of engaging cities in taking action to adapt to climate change.

Building on the Covenant of Mayors and Mayors Adapt, the new **Covenant of Mayors for Climate and Energy** was announced in October 2015 by Commissioner Miguel Arias Cañete, based on three pillars:

- Mitigation (40 % CO_2 emission reduction target by 2030)
- Adaptation
- Secure, sustainable and affordable energy.

Mayors who join the Covenant commit to taking the lead and enhancing the transparency and accountability of local climate and energy policies by:

- Setting ambitious and quantified emission-reduction targets;
- Measuring their GHG emission level in a base year, according to a common methodological approach;
- Assessing climate risks and vulnerabilities within their territories;
- Defining a strategy and concrete actions to mitigate and adapt to climate change;
- Approving and making their action plan publicly available;

[1] COM/2015/080
[2] COM/2015/080
[3] COM/2014/0330 final
[4] COM/2016/51 final
[5] COM/2016/501 final
[6] COM /2013/ 216

- Regularly reporting (both qualitatively and quantitatively) to the EC on the implementation of their action plan;
- Sharing their vision, results, experience and know-how with fellow local and regional authorities within the EU and beyond through direct cooperation and peer-to-peer exchange.

In this context, the role of subnational regional authorities is key to the implementation of climate change policies especially in small- and medium-sized cities and towns, which often lack the resources to develop and implement a Sustainable Energy Action Plan (SEAP) and can benefit from support provided at higher administrative levels.

To support the international dimension, the EC has been funding Covenant of Mayors initiatives in the EU Neighbourhood to the East, to the South and in Sub-Saharan countries. Soon it will also support the development of the Covenant in North America, Latin America/Caribbean, China and South-East Asia, India and Japan.

Covenant of Mayors commitments and achieved GHG emission reduction

At the cut-off date of the analysis, 4 September 2016, the number of CoM signatories totalled 6201[7] (96.5 % from the EU-28), covering 213 million inhabitants (85 % in the EU-28 representing 36 % of the total EU-28 population[8]).

The peculiarity of the CoM movement compared to other GHG mitigation initiatives concerns the participation of small and medium-sized towns (with less than 50 000 inhabitants) in an effort to reduce GHG emissions (89 % from the total signatories).

The signatories overall commitment to reducing GHG emissions is 27 % by 2020, i.e. 7 percentage points above the minimum requested target of 20 %.

The mitigation commitment of the Covenant signatories is mainly related to the emissions associated with energy consumption in sectors which can be influenced by the local authority (housing, services and urban transport), leaving out other emitters such as the Emissions Trading System (ETS) industry and transport outside the mandate of the local authority (e.g. highways).

Results from the 315 monitoring inventories submitted (covering 25.5 million inhabitants and mainly for the period 2012-2014) reveal an already achieved **23 %** overall reduction in emissions.

This decrease in GHG emissions between baseline and monitoring years was driven by:

- GHG emissions due to electricity consumption fell by 17 % from the baseline to monitoring years due to a less-carbon-intensive fuel mix and more efficient electricity generation power plants [2];
- GHG emissions in buildings from heating and cooling fell by 36 % from the baseline to monitoring years, driven by improved energy efficiency in buildings and consequently lower energy consumption levels, more efficient local heat production from district heating networks, and by increasing shares of renewable resources in decentralised local heating production;
- GHG emissions in the transport sector fell by 7 % from the baseline to monitoring years driven by more efficient vehicles, an increase in the share of biofuels, and the shift towards public transportation and electric mobility.

These results underline the interconnected nature of climate mitigation and energy efficiency actions adopted at the local level. The CoM signatories adopted a range of policies and measures for improving energy efficiency through building regulations, increasing the share of renewable energy, integrating district energy systems, and a

[7] 6201 signatories cover 6926 local authorities, 725 of which have adopted joint action plans, thereby resulting in fewer signatory profiles.

[8] UNDESA 2011: average from 2008-2011.

gradual transformation to more efficient and sustainable transportation. The most common policies being implemented are:

- Energy management and public procurement;
- Building standards and energy certification labelling for new and existing buildings;
- Awareness-raising and training;
- Financial incentives;
- Third-party financing;
- Urban planning: local authorities establish local mobility plans defining limited traffic zones, low emission zones, designated parking spaces for low-emission vehicles, and free parking for cleaner efficient vehicles. Furthermore, they set road pricing schemas, and integrated ticketing/charging to foster sustainable mobility.

In addition to the above policies, many municipalities have ownership or jurisdiction over local energy and water utilities, public transportation and social housing. There is a potential for improvements in energy efficiency in the provision of these services [3]. Urban energy planning throughout the development of district energy networks in high-density districts can improve the energy efficiency of urban energy systems.

The report demonstrates that the combination of effective urban energy policies and better coordination between national and local governments is crucial for the potential of the urban mitigation of climate change.

The results of this report show how climate mitigation and sustainable energy actions adopted at the local level are interconnected. The role of local authorities in leveraging sustainable development and mitigation and adaptation measures is crucial. Developing a 'sustainable energy and climate action plan' that requires the setting up of a baseline emission inventory and the adoption of policy measures is already a tangible achievement for cities. This is the first step towards an effective, transparent system for tracking progress and concrete results.

The robust open source methodological framework developed by the JRC in collaboration with city networks offers municipalities a comprehensive tool to support the development of climate and energy policies, which can be successfully replicated and adapted in other regions of the world.

1. Introduction

1.1. The Covenant of Mayors initiative: the original framework on climate mitigation

The need for immediate action at global level to reduce greenhouse gas (GHG) emissions and increase climate resilience was highlighted in the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [1] and confirmed during the 21st meeting of the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) in Paris in December 2015. The Paris agreement recognises the role of cities and other sub-national authorities and calls for these entities to scale up their efforts to reduce emissions and/or to build resilience and decrease vulnerability to the adverse effects of climate change. The European Union (EU) is leading the global fight against climate change and has made it one of its top priorities: it has committed to reducing its overall GHG emissions by at least 20 % by 2020 and 40 % by 2030 compared to 1990 levels. Besides the emissions reduction target, the EU climate and energy framework also includes a target of at least 27 % improvement in energy efficiency and a share of at least 27 % in renewable energy. This integrated policy is in line with the long-term EU objective of 80-95 % by 2050 compared to 1990.

Urban energy consumption generates about three-quarters of global carbon emissions [1]. Cities and towns are drivers of social development, economic growth and innovation and can play a crucial role in terms of energy and climate change policy, offering potential, comprehensive opportunities for contributing to shifting energy policies to more sustainable pathways and creating local opportunities for investment and growth. They are also in a privileged position to meet the climate-change challenge by fostering the participation of citizens and building partnerships with local stakeholders. In addition, cities face growing difficulties in dealing with the effects of climate change, with the transport and energy sectors likely to experience the greatest increase in damage. The increasing frequency of extreme weather events sends a signal that cities and towns must become resilient to the impacts of climate change: to maintain their competitiveness and ensure a good quality of life for their citizens, they need investments in climate-resilient spatial planning, and innovative concepts for housing or public green spaces, infrastructure and services.

Recognising the key role of cities and towns in the fight against climate change, and following the adoption of the 2020 EU Climate and Energy Package in 2008, the European Commission (EC) launched the Covenant of Mayors (CoM) initiative, to encourage local authorities to implement sustainable energy policies within their territories. By signing up to the Covenant, cities and towns voluntarily commit to a target of reducing CO_2 emissions by at least 20 % by 2020 in their respective territories: they pledge to take action in those policy areas relevant to their political mandate, focusing on improving energy efficiency and increasing the use of local renewable energy resources in sectors under their direct influence. To translate their commitment into practice, they submit and implement a Sustainable Energy Action Plan (SEAP) which outlines the key actions they plan to undertake.

In this context, the role of subnational regional authorities is key to the implementation of climate change policies, especially in small and medium-sized cities and towns which often lack the resources to develop and implement a SEAP and can benefit from support provided at higher administrative levels.

1.2. Increasing the scope and outreach of the Covenant of Mayors

The success of the Covenant of Mayors in Europe and beyond (with 6201[9] signatories and 5491 SEAPs already developed) has attracted more and more signatories from cities in other parts of the world. To support the international dimension, the EC has been funding Covenant of Mayors initiatives in the EU Neighbourhood to the East, to the South and in Sub-Saharan countries. Soon it will also support the development of the Covenant in North America, Latin America/Caribbean, China and South-East Asia, India and Japan.

Moreover, alongside actions to reduce emissions, the EU is acting to make Europe more resilient to the impacts of climate change. The EU Strategy on Adaptation to climate change, adopted in 2013, is contributing to a more climate-resilient Europe by promoting action by Member States, better informed decision-making and promoting action in key vulnerable sectors and in all relevant EU policies. To date, 21 Member States have developed a national adaptation strategy and/or plan.

In 2014, in the context of the EU Adaptation Strategy, the EC launched Mayors Adapt, a Covenant of Mayors' sister initiative that encourages cities and towns to seize the opportunities to take action on adaptation, either by developing comprehensive adaptation strategies or by integrating adaptation to climate change into their relevant existing plans.

Building on the Covenant of Mayors and Mayors Adapt, a strengthened Covenant of Mayors for Climate and Energy was launched by Commissioner Miguel Arias Cañete in October 2015, built around three pillars:

- Mitigation (40 % CO_2 emission reduction target by 2030)
- Adaptation
- Secure, sustainable and affordable energy.

The new integrated Covenant of Mayors for Climate and Energy requires cities to develop and approve a Sustainable Energy and Climate Action Plan (SECAP) presenting climate change mitigation as well as adaptation actions.

Strengthening stakeholders’ participation sets the foundation for fruitful cooperation between citizens and public administration, which may affect wider policy areas. As signatories to the CoM, cities have access to an extensive network of European cities, informative and awareness-raising events, workshops, and bilateral exchange between practitioners.

Being one of the earlier and larger initiatives in the world that is encouraging local authorities to take the lead on climate and energy policies, the Covenant can motivate more cities and towns of all sizes to accept being held accountable for climate action and to report transparently on their strategy and achievements.

[9] 6201 signatories cover 6926 local authorities, 725 of which have adopted joint action plans, thereby resulting in fewer signatory profiles.

Box 1. Transparency and accountability of the Covenant of Mayors: from pledges to actions

Mayors who join the Covenant commit to take the lead and enhance the transparency and accountability of local climate and energy policies by:

- Setting ambitious and quantified emission reduction targets;
- Measuring their GHG emission level in a base year according to a common methodological approach;
- Assessing climate risks and vulnerabilities in their territories;
- Defining a strategy and concrete actions to mitigate and adapt to climate change;
- Approving and making their action plan publicly available;
- Regular reporting (both qualitatively and quantitatively) to the EC on the implementation of their action plan;
- Sharing their vision, results, experience and know-how with fellow local and regional authorities within the EU and beyond through direct cooperation and peer-to-peer exchange.

1.3. The role of the JRC and the aim of the present report

The EC's Joint Research Centre (JRC) provides scientific, methodological and technical support to the Covenant of Mayors initiative. In earlier phases, the JRC developed methodologies mainly targeting the EU countries, collaborating with city networks and practitioners from local and regional authorities, energy agencies and academia. Subsequently, the JRC has adapted the Covenant's methodology to the specific situation of the EU's Eastern and Southern neighbours. This work has resulted in the publication of guidebooks on how to develop a Sustainable Energy Action Plan [4]–[9], which is currently in the process of being updated to include new aspects of the Covenant. The JRC also carries out individual SEAP analyses, providing feedback for cities and in-depth evaluations of selected SEAPs [10]. Specific aspects of the Covenant are also explored in specific studies (e.g. multi-level governance models in the Covenant [11]; and the Covenant's contribution to security of supply in countries more exposed to the risk of fuel disruption [11], etc.). Since 2013, the JRC has published a series of assessment reports on the Covenant [12]–[14] to track the overall progress of the initiative based on data from plans and progress reports transmitted by Covenant cities to the EC.

The present report assesses the overall progress of the initiative in terms of both planned and achieved CO_2 emission reduction, based on the data reported by cities up to 4 September 2016. It presents the aggregated CO_2 emissions addressed by cities' plans, the planned emission reduction by 2020, and the interim achievements to date. It also identifies the main drivers leading to the actual results and describes the main policies implemented by local authorities to reach their emission targets.

2. Approach and methodology

2.1. The Covenant of Mayors approach

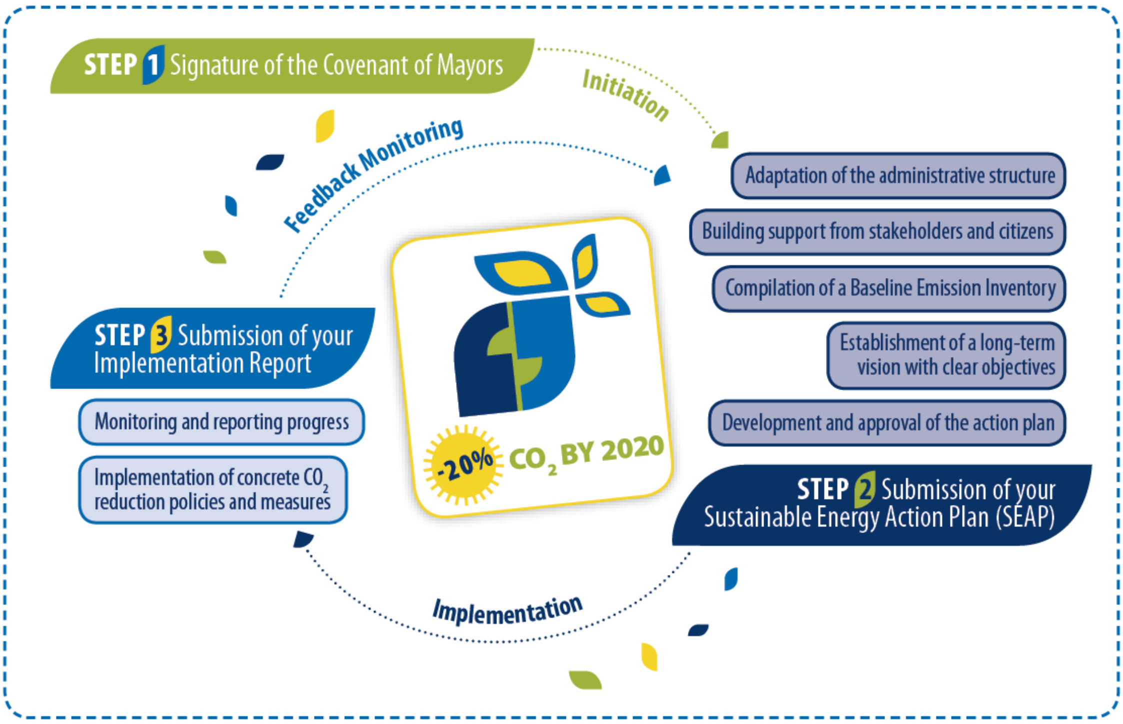
Within one year from signing up to the initiative, local authorities have to define a minimum CO_2 emission reduction by 2020 and approve and submit a Sustainable Energy Action Plan (SEAP). The SEAP is the key document through which the Covenant signatory presents its vision and target, together with the measures to be implemented to achieve its objectives. The SEAP includes the results of a Baseline Emission Inventory (BEI). Signatories are requested to submit a monitoring report on implementation of the SEAP every second year, and to complement it with a Monitoring Emission Inventory (MEI) at least every fourth year.

Specific data and information on emission inventories and action plans must be reported by the signatories via an on-line template provided on a restricted area of the Covenant web-site (http://www.covenantofmayors.eu/). This on-line template must accurately reflect the content of the official SEAP document, while the coherence of certain key figures is checked by the JRC.

Mayors commit to transpose pledges into actions by (Figure 1):

- Carrying out a BEI[10] including mainly the emissions due to energy consumption in sectors under the direct influence of the local authorities (housing, services and transport);
- Developing an SEAP within two years of joining the initiative.
- Submitting a progress report, at least every second year for evaluation, monitoring and verification purposes, including a monitoring inventory every fourth year.

Figure 1. The Covenant of Mayors step-by-step process.



Source "Reporting Guidelines SEAP and Monitoring. Covenant of Mayors 2014"

[10] Signatories joining the initiative after October 2015 must also submit a Climate Change Risk and Vulnerability Assessment and integrate the climate adaptation aspect into their plans.

In line with the established framework of the UNFCCC, project guidelines for an emission inventory within the CoM [4] broadly follow the IPCC guidelines. 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. Signatories are given various options to calculate emission inventories. They can choose either the standard IPCC approach or the life-cycle assessment (LCA) approach. In the former, emission factors are based on the carbon content of fuels [15]. Only CO_2 reporting is mandatory, as it is the most important among all the GHGs when discussing 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_2-eq.) according to their global warming potential [16].

The Covenant of Mayors methodology proposes a harmonised framework to enable local authorities, CoM signatories to produce robust and comparable inventories of GHG emissions. According to the principles laid out in the CoM, each signatory could influence the emissions produced in its territory as the result of energy consumption. The BEI is not meant to be an exhaustive inventory of all emission sources in the territory but focuses on the consumption side and on the sectors upon which the local authority has a potential influence. Notably, GHG emitted by installations covered by the EU Emissions Trading System (EU ETS) [17] should not be included.

Box 2. The Covenant of Mayors approach to building emission inventories

The Covenant of Mayors methodology proposes a consolidated and flexible framework to enable local authorities to produce robust and comparable inventories of GHG emissions.

The Covenant emission inventories serve as an instrument to support local action planning on energy. Thus, they focus on emissions mainly associated with final energy consumption (including electricity and other fuels/carriers) in sectors which can be influenced by policies implemented by local authorities (housing, services, and transport).

The BEI sets the starting point, and the subsequent monitoring inventories enable monitoring progress towards the target. The approach is based on the principles of simplicity of use, flexibility and policy relevance.

The Covenant of Mayors inventories are mapped in the main non-ETS trading sectors (such as households, transport, services) and sub-sectors, as described in Table 1 [18][11]. Direct emissions in urban areas derive mainly from two sectors: buildings and transport. In addition to these two sectors, signatories have the option to report emissions (and emission-reduction targets) for other sectors which can be influenced by the local authority (waste, wastewater treatment, agriculture and the non-ETS industrial sector). The CoM inventories also account for indirect emissions associated with the consumption of electricity and heat/cold as a final product. In this case, a certain portion of the emissions computed in the inventories and addressed via the SEAP do arise from ETS plants.

[11] Adapted from the "'The Covenant of Mayors for Climate and Energy Reporting Guidelines" '.

Table 1. Description of the on-line data on final energy consumption and related GHG emissions in the BEI template

Sector	Subsector		Description
Buildings	Municipal buildings, equipment/facilities		Energy consumption and GHG emissions in buildings and facilities owned by the local authority. Facilities refer to energy-consuming entities that are not buildings, such as wastewater treatment plants.
	Tertiary (non-municipal) buildings, equipment/facilities		Energy consumption and GHG emissions in buildings and facilities of the tertiary sector (services); e.g. offices of private companies, banks, commercial and retail activities, hospitals, etc.
	Residential buildings		Energy consumption and GHG emissions in buildings that are primarily used as residential buildings. Social housing is included in this sector.
	Public lighting		Public lighting owned or operated by the local authority (e.g. street lighting and traffic lights). Non-municipal public lighting is included in the 'Tertiary buildings, equipment/facilities' sector.
	Industries	Non-ETS	Energy consumption and GHG Emissions in manufacturing and construction industries not covered in the EU Emissions Trading Scheme (EU-ETS).
		ETS	Energy consumption and GHG emissions in manufacturing and construction industries covered in the EU-ETS. Integrating them into emission inventories is not recommended, unless such plants were included in previous energy plans and in the local authority's CO_2 emission inventories.
	Others: Agriculture/Forestry/Fisheries		Energy consumption and GHG emissions in buildings, facilities and machinery in the primary sector (agriculture, forestry and fisheries); e.g. greenhouses, livestock facilities, irrigation systems, farm machinery and fishing boats.
Transport	Municipal fleet		Energy consumption and GHG emissions from vehicles owned and used by the local authority's administration.
	Public transport		Energy consumption and GHG emissions from buses, the tramway, metro, urban rail transportation and local ferries used for passenger transport.
	Private and commercial transport		Energy consumption and GHG emissions from road, rail and boat transport in the local authority's territory which refer to the transport of people and goods not specified above (e.g. private passenger cars and freight transport).
Other	Waste management		GHG emissions not related to energy consumption, such as CH_4 from landfills.
	Wastewater management		GHG emissions not related to energy consumption, such as CH_4 and N_2O from wastewater treatment plants.
	Other non-energy related		GHG emissions not-related to energy in the territory.

Following the launch of the new Covenant of Mayors for Climate and Energy, an integrated monitoring and reporting framework with guidance[12] was released in July 2016. The Sustainable Energy and Climate Action Plan (SECAP) template and comprehensive reporting guidelines were developed together with practitioners from local and regional authorities and other key stakeholders. The framework aims to support new signatories in their energy and climate planning and to help them track progress on the implementation of their commitments. It enables signatories to report on their 2030 mitigation targets and actions and on climate adaptation.

For mitigation, the methodological approach remains the same as it was for the SEAPs, as described above, i.e. the development of a mitigation action plan is based on the BEI. At the same time, the signatories are required to review their mitigation action plans in order to include measures to achieve the 40 % CO_2 (and possibly other GHG) emissions reduction target by 2030.

For adaptation, the reporting requirements are built on the various steps of the adaptation policy cycle, such as a climate risk and vulnerability assessment (RVA), identifying, assessing and selecting adaptation options, and implementing, monitoring and assessing progress. The SECAP adaptation component is based on a comprehensive climate RVA which provides an analysis of the current situation.

The BEI and climate RVA serve as the basis for defining a comprehensive set of actions that local authorities plan to undertake in order to reach their climate mitigation and adaptation goals. Signatories commit to report on their progress every two years [18].

2.2. Statistical analysis

The CoM signatories are requested to report on their SEAP, including the BEI and planned actions, within one year after signing the Covenant. They also have to provide monitoring emission inventories every four years. The information is reported in specific on-line templates on the CoM web-site (http://www.covenantofmayors.eu/index_en.html).

Experience has shown that, due to the voluntary nature of the initiative, the difficulty of adapting sometimes local specificities to the CoM reporting framework, and the occurrence of material inputting errors, not all the data collected on the Covenant platform can be considered complete and reliable. Moreover, only a subset of the signatories which should have already provided a full monitoring report do so by the cut-off date.

For these reasons, the JRC has developed a methodology in order to:

i) Build a robust and reliable sample of GHG emission inventories by removing the outliers;

ii) Estimate GHG emission reduction for the whole set of signatories which, according to the CoM framework, should have provided at least one MEI by September 2016.

The corresponding statistical approach and projection model are described in the two following sub-sections (see Annex 1 for further details), while results are reported in chapter 3.

2.2.1. Methodology for robust statistics in the CoM

At the analysis cut-off date (4 September 2016), there was a total of 6201 CoM signatories (see section 3.1), 5491 of which had already provided a SEAP. The corresponding 'CoM dataset 2016' includes CO_2, CH_4 and N_2O gases, expressed in CO_2-eq

[12] http://www.covenantofmayors.eu/Covenant-technical-materials.htm

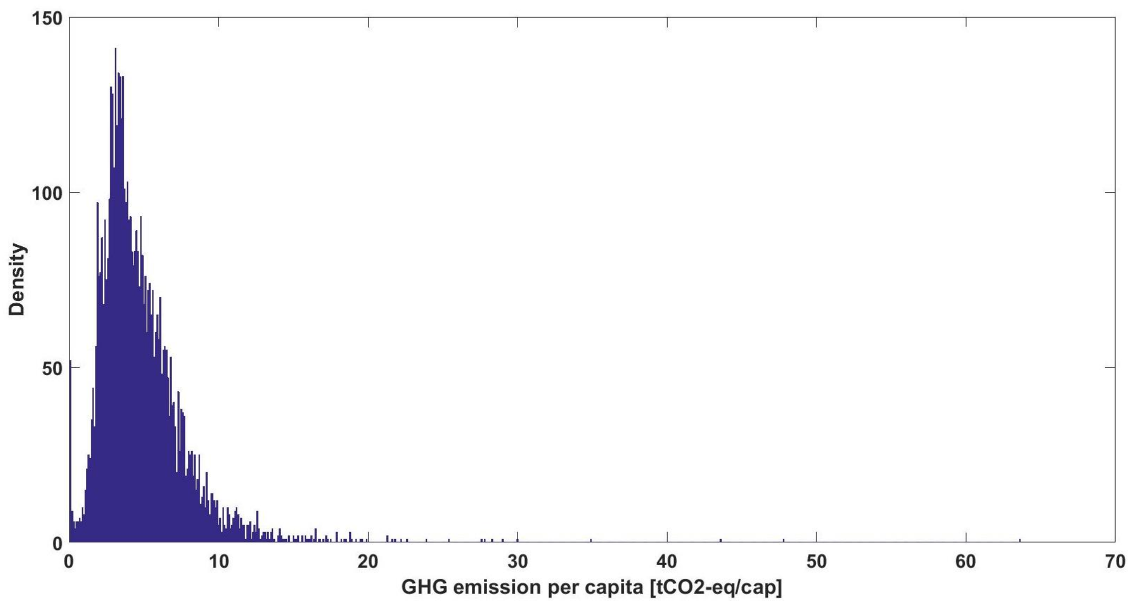
(see section 2.1). As also explained in the previous section, the inventories were built using either the IPCC or the LCA inventory approach. In order to aggregate emission data from both methods, a multiplying factor (0.885), which is considered to be representative of the fraction of direct emissions embedded in LCA inventories [12], was applied to the LCA data. Finally, since it is not possible to perform a conversion to reconcile different reporting units (CO_2 and CO_2-eq) all the data reported are considered as CO_2-eq.

As a first check, the CoM baseline emissions were compared with national emissions per capita from several international inventories (Eurostat, EEA, EDGAR[13]). Although such a direct comparison can be useful to highlight potential data inconsistencies, it can be misleading to some extent. Indeed, the CoM collects bottom-up data at local level, while the other databases collect data at national level and at the local level project their broader-scale results using a top-down approach. Therefore, per capita values can significantly deviate from national averages, especially in urban areas. Setting validity ranges of per capita emissions, based only on the national or international inventories, may lead to the exclusion of an unnecessarily high number of emission inventories or, conversely, to accepting an excessive number of outliers.

For this reason, the preference is to rely on a self-consistent methodology for the identification and exclusion of outliers, based on the statistical principles currently accepted in literature (see Annex I), using the comparison with external data sources simply as a first broad check at the national level.

Figure 2 shows the wide spread in the frequency distribution of the values of GHG emissions per capita reported in the 5491 emission inventories, which range from 0 to 63 tCO_2-eq/cap, with a mean value of 4.75 tCO_2-eq/cap.

Figure 2.GHG emissions per capita in signatories in the CoM dataset 2016



A two-step methodology has been developed in order to build a robust data sample of signatories with coherent inventories (see Annex I for further details):

[13] EDGAR is a joint project of the EU-JRC and the Netherlands Environmental Assessment Agency (PBL). It provides past and present global anthropogenic emissions of GHGs and air pollutants by country on a spatial grid.

- In the first step, a clustering of GHG emissions per capita reported in the CoM dataset by country and by population size was performed. Results were then compared to national values so as to determine the order of magnitude of the mean values per country level. Since the CoM emission inventories have different baseline years, 1990 has been chosen in this phase as the reference year for national values (see Figure 15 in Annex I).
- Subsequently, a statistical method was applied to check the internal consistency of the inventories. The method for identifying and removing the outliers is based on the Generalised Extreme Studentized Deviate procedure which is highly recommended in the literature [19]–[24]. The procedure iteratively identifies the extreme values in the dataset before choosing to remove those observations which are higher than the extreme values with a confidence level of 95 %.

As a result the original inventory containing 5491 entries was reduced to a clean dataset of 5403 signatories (i.e. 98 % of the original data), referred to hereafter as the 'CoM BEI dataset 2016'. Table 2 below compares the main descriptive parameters of the original and the 'clean' datasets.

Table 2. Statistical parameters of GHG emission per capita in signatories in the CoM datasets 2016

	All data CoM dataset 2016	Clean data CoM BEI dataset 2016
Number of signatories	5491	5403
Average GHG emission per capita in BEIs [tCO_2-eq/cap*year]	4.75	4.62
Total GHG Emission in BEIs [tCO_2-eq/year]	1 064 801 085	951 221 553
Total population in BEIs [million inhabitants]	187.0	183.8

The procedure adopted for data validation excludes observations that are not acceptable according to the relevant literature and international guidelines.

Investigation into the excluded inventories revealed that the majority of these signatories (72 % of the total excluded signatories) were small- and medium-sized towns (less than 50 000 inhabitants) mainly from Spain and Italy. A few signatories may have misinterpreted the type of fuel to be associated with reported data while some cities have only reported data on energy consumptions, inserting zero in the emission fields. This can relate to lack of information for specific sectors in the local territory. In addition, in some cases erroneous data might have been inserted due to misinterpretation of the units (e.g. $ktCO_2$ instead of tCO_2, kWh instead of MWh, etc.).

2.2.2. Model for GHG emission projection in the CoM

By September 2016, a total of 1779 signatories ('CoM MEI dataset 2016') should have reported on the implementation of their SEAPs by presenting a monitoring report, including an MEI (the so-called 'full report'). However, due to the fact that the reporting framework on SEAP implementation was made available to signatories later than initially foreseen, an extension of the deadline was granted until February 2017 for the submission of the full report. Therefore, only 315 signatories, i.e. 16 % of them, actually submitted a full report. This sample is called the CoM MEI 'monitoring subset'.

Given the limited number of reporting signatories, a direct extrapolation of the data provided by reporting signatories to the whole sample of 1779 signatories expected to report progress is unreliable and could easily lead to misinterpretation. Indeed, there is no guarantee that the limited subset of signatories that have actually reported their progress is representative of the whole sample in terms of, for example, population, degree of urbanisation and climate.

Therefore, a model has been developed for estimating the progress of GHG emission reduction by both reporting and non-reporting signatories. The model described hereafter is a first phase to be developed to address the limited data available during the monitoring phase. It relies on the identification of the main factors that drive the trends in GHG emissions in cities, and projects the interim results of the monitoring subset to the 1464 missing MEIs.

For the time being, studies on the correlation between direct factors that influence GHGs such as the geographic context, urban form and density, economic activities and emissions per capita in cities are under research [25]–[34]. In this model, a signatories' clustering procedure has been developed based on clustering of signatories with similar direct factors, including the geographic context (i.e. climate), the degree of urbanisation, the inventory year and the target ambition reduction.

As a first step, the CoM MEI dataset 2016 has been clustered on the basis of the main factors known to influence urban GHG emission levels[14]:

- Climate factor: Various aspects of geography such as climate affect cities' contribution to climate change. Cities in a cold climate have higher emissions related to heating, cooling and lighting in winter, while cities in warmer areas have higher electricity consumption associated with air-conditioning systems. Therefore, a clustering of cities has been performed based on climate, and signatories have been divided into climate classes (cold, intermediate and warm) on the basis of the value of the Heating Degree Days (HDD) measured in their baseline year. Boundaries among climate classes equalled 2150 and 3350 [35].

- Degree of urbanisation: Urban form and urban spatial organisation can play a crucial role in a city's GHG emissions. Dense urban settlements through the concentration of services may lead to a reduction of per-capita emissions. CoM signatories in the dataset were classified into three categories according to the harmonized definition of the degree of urbanization of Local Administrative Units for Europe [36].

- Baseline Inventory Year: Different reference years have been chosen by the signatories for the BEI (see section 3.2.1). Therefore, a clustering of signatories in two classes has been performed based on the Baseline Inventory Year (before and from 2005).

- Target ambition level: Emission reduction targets are stated in the action plans according to the BEI emissions, and are generally more ambitious for cities with a longer-standing tradition in climate and energy planning. The aggregation of cities in the two classes has been carried out based on the ambition of the emission reduction target.

Subsequently, a statistical analysis of the clusters' main parameters has been performed, and lastly, the cluster analysis has been projected into the whole CoM MEI dataset 2016 (see Annex I for more details). The results in terms of the CoM's overall potential progress towards GHG emission reduction, as of 4 September 2016, are discussed in section 3.3.

By their very nature, the results obtained are affected by uncertainty and should be considered as provisional estimates pending the submission of the actual data from the signatories.

[14] The actual influence of these factors on the emission reductions reported in the monitoring subset has been confirmed by a preliminary analysis of the variance procedure.

Table 3. GHG emissions reductions among signatories in the CoM MEI datasets 2016

	CoM MEI dataset 2016 monitoring subset	CoM MEI dataset2016
Number of signatories	315	1779
Total GHG emissions in BEIs [tCO_2-eq/year]	149 840 820	593 111 921
Total reductions of GHG emissions from BEIs to MEIs [tCO_2-eq/year]	33 780 381	129 760 534
Shares of GHG emission reductions from BEIs to MEIs [%]	23 %	22 % ± 2 %

Box 3. JRC harmonised CoM dataset 2016

Based on the reports submitted on-line by the signatories by 4 September 2016, processed using a JRC methodology for data cleaning, the following datasets have been built:

- CoM BEI dataset 2016: 5403 signatories, 183.8 million inhabitants, data on the baseline inventories;
- CoM MEI dataset 2016: 1779 signatories, including an estimated 101.9 million inhabitants, divided into two subsets:
  - The monitoring subset: 315 signatories, 25.5 million inhabitants, data on the reported monitoring inventories;
  - The estimated subset: 1464 signatories, 76.4 million inhabitants, estimated data on the inventories which were due to be submitted by September 2016.

3. Results

The different categories of signatories and commitments, as of 4 September 2016, are described in section 3.1. The findings relating to GHG emissions in the baseline year and the committed reductions by 2020, as derived from the clean CoM BEI dataset 2016, (5403 signatories) are provided in section 3.2. Analysis of the emission reductions achieved by the 315 signatories who provided monitoring reports is presented in section 3.3.2. The estimated overall potential reduction for the complete CoM MEI dataset (1779 signatories), as calculated from the projection model described in section 2.2.2, is discussed in section 3.3.3.

3.1. Signatories and commitments

At the cut-off date of the analysis (4 September 2016), there was a total of 6201[15] CoM signatories (original full dataset), covering a total CoM population of 213 million inhabitants.

As a result of new longer term target towards 2030 announced in October 2015 and the integration of adaptation in the CoM methodological framework[16], the total number of signatories was split in different categories. In fact, according to the moment of adhesion, the signatories' commitment varies and includes a combination of all three: 20 % mitigation target until 2020 (signatories of the Covenant up to October 2015), commitment to adaptation (Mayors Adapt signatories up to October 2015) and combined adaptation with mitigation target, 40 % until 2030 (the New Covenant for Energy and Climate).

Table 4 shows the number of the signatories and population covered as a function of the commitment(s) (mitigation, adaptation) and target year(s) (2020, 2030).

The majority of the signatories are the ones who committed to the initial minimum target, 20 % CO_2 reduction objective by 2020: 5910 with 204 million inhabitants, of which 5767 with 176.9 million inhabitants are committed exclusively to 2020 mitigation targets.

They are followed by 117 signatories that have committed to a 2020 mitigation target as well as adaptation action and by those signatories (26 signatories) that had previously committed to the 2020 mitigation target and now have renewed their commitment towards 2030 both in terms of mitigation and adaptation.

269 new signatories that have joined the CoM initiative after October 2015 committing to the 2030 target including adaptation.

Finally the last category consists of the 22 signatories having committed to develop an adaptation plan in the frame of the Mayors Adapt initiative but they have not yet committed to any mitigation target.

[15] 6201 signatories covering 6926 local authorities of which 725 have adopted joint action plans, thereby resulting in a lower number of signatory profiles.

[16] In October 2015 the EU funded CoM initiative announced a new longer-term vision and the inclusion of the adaptation was the result of the merging of Mayors Adapt and the Covenant of Mayors.

Table 4. Signatories and population covered by commitments and targets as of 4 September 2016

Commitments and targets		Number of signatories	Inhabitants
Only mitigation	Only mitigation 2020	5767	176 971 499
Mitigation and adaptation	Mitigation 2020 and adaptation	117	23 703 735
	Mitigation 2020 and 2030 and adaptation	26	3 345 842
	Mitigation 2030 and adaptation	269	4 837 191
Only adaptation	Adaptation	22	4 244 238
Total		6201	213 102 505

Figure 3 shows the distribution (in %) of the signatories and population covered as function of the commitment(s) (i.e. mitigation and adaptation).

The majority of the signatories are the ones who committed to the initial minimum target, 20 % CO_2 reduction objective by 2020: 5767 which are committed exclusively to 2020 mitigation targets with 93 % of the share of signatories and covering 83 % of the total population.

They are followed by 434 signatories (7 % of signatories and covering 17 % of the population) that have committed to develop an adaptation strategy or adaptation plan, 412 of which combined with a mitigation plan.

Figure 3. Share of signatories and covered population by commitments

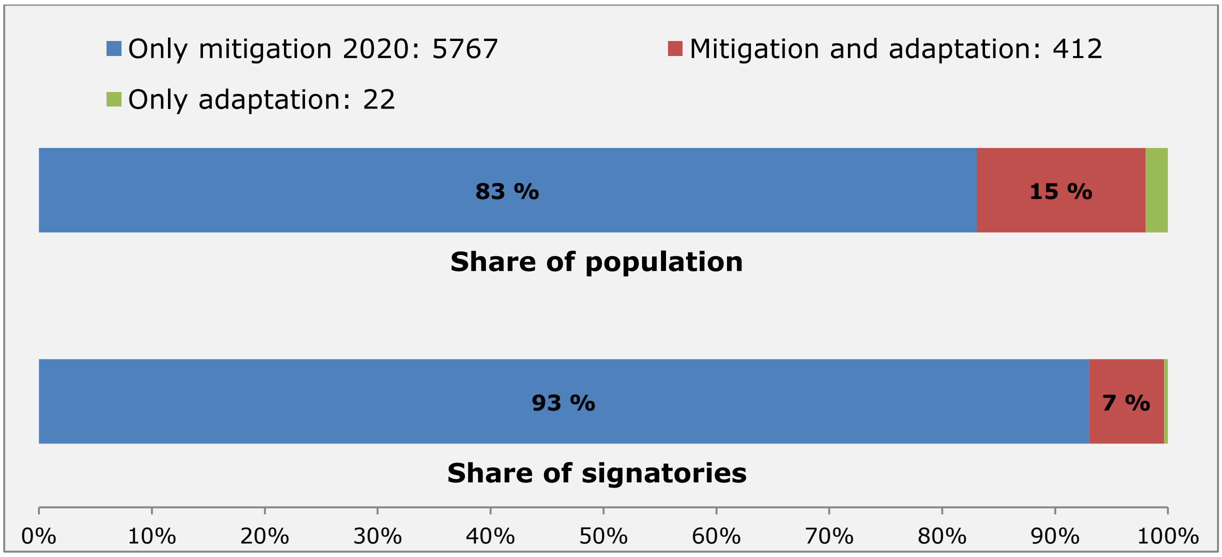


Table 5. below shows the number of signatories in the original full dataset and their population categorised by region. The large majority (96.5 %) of the signatories (5984 signatories, covering 85 % of inhabitants) are from the 28 Member States of the European Union, followed by signatories in the Eastern Partnership region (141 signatories – 2 % of signatories) representing 6 % of the total CoM population and (56 signatories – 1 % of signatories) from non-EU countries covering 7 % of the total CoM population.

Table 5. Signatories per region as of 4 September 2016

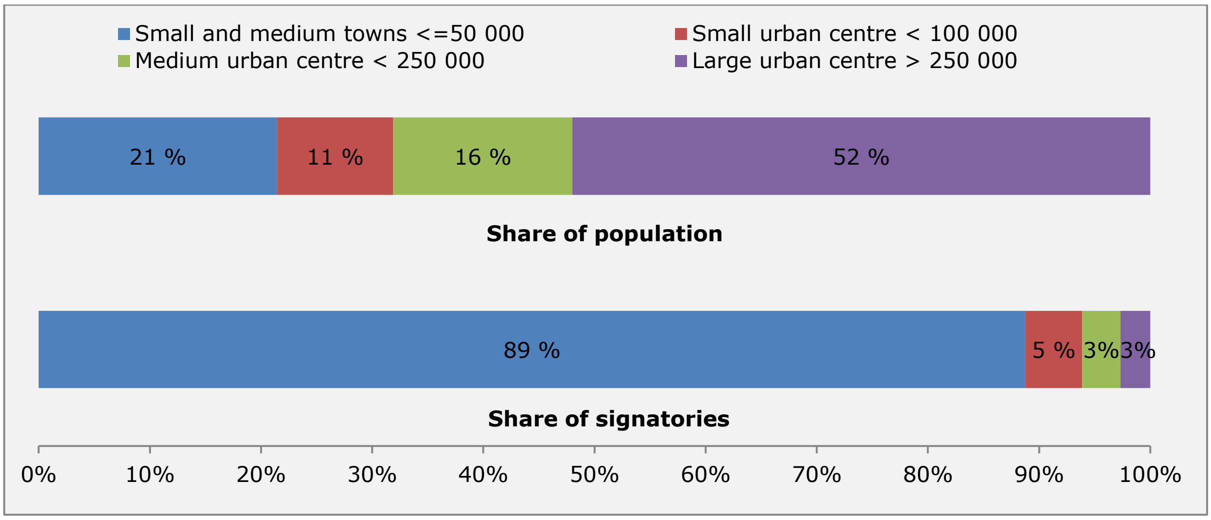
Region	Number of signatories	Signatories inhabitants
EU-28	5984	181 703 014
Europe-non-EU[17]	56	15 095 202
Central Asian[18]	4	396 386
Eastern Partnership[19]	141	13 101 972
Southern Mediterranean[20]	15	2 445 931
Rest of the world	1	360,000
Total	6201	213 102 505

The population covered by the Covenant of Mayors initiative at the cut-off date is of 213 million inhabitants. Most of them (52 %) live in large urban centres i.e. with a total population over 250 000 inhabitants (see Figure 4) and one global city: London (7.8 million of inhabitants), which alone represents 3.7 % of the total population of CoM signatories.

Most of the Covenant of Mayors signatories (89 %) are small- and medium-sized towns (SMSTs). This large involvement of small municipalities in climate change mitigation and adaptation action is one of the main specificities of the Covenant initiative. Nevertheless, SMSTs only account for a limited share of energy consumption and CO_2 emissions. Since the regional context appears to be the most important common factor for these municipalities, in order to maximise its potential, the CoM initiative encourages the development of joint action plans and promotes the role of Covenant Territorial Coordinators (CTCs) [37].

[17] Switzerland, Norway, Iceland and non-EU Balkan countries
[18] Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan
[19] Armenia, Azerbaijan, Belarus, Georgia, Republic of Moldova, Ukraine
[20] Algeria, Egypt, Israel, Jordan, Lebanon, Morocco, Palestine, Tunisia

Figure 4. Shares of CoM signatories and population as a function of the size of the urban centre as of 4 September 2016



Detailed data on number of SEAPs per country and population coverage can be found in Annex II.

Box 4. Covenant signatories and their commitments

- 6201 signatories and 213 million inhabitants by September 2016.
- 93 % are still committed exclusively to the initial target proposed (20 % reduction in CO_2 emissions by 2020);
- The Covenant is still mainly a European initiative (85 % of the population), although its extension beyond the EU-28 borders continues to grow;
- The high participation of small and medium-sized towns (89 % of the signatories) confirms the important role of small municipalities in climate change mitigation;
- In terms of population, the highest share of inhabitants (52 %) belongs to large urban centres (more than 250 000 inhabitants) and a global city (London).

3.2. Sustainable Energy Action Plans

This section analyses the baseline years (3.2.1), greenhouse gas emissions (3.2.2) and committed emission reductions by 2020 (3.2.3) reported in the CoM BEI dataset 2016 (5403 signatories), built according to the 'Methodology for robust statistics in the CoM' described in section 2.2.1.

3.2.1. Reference year for the BEIs

In the guidebook 'How to develop a Sustainable Energy Action Plan' [4] a general recommendation was made to use 1990 as the BEI year, which is the reference year for which the reduction target was defined. Nevertheless signatories are allowed to choose the closest subsequent year for which reliable data can be gathered. As a result, different BEI years have been chosen by the signatories.

These results also suggest that a significant proportion of those signatories choosing later BEI years, such as in Italy and Spain, also did the data collection more recently, i.e. after their commitment time. Indeed, data availability may be difficult due to the lack of, or incompatible electronic archiving systems, or lost knowledge following the retirement of many municipal/energy officials who were familiar with the situation in 1990. In such situations, the general recommendation to use 1990 does not apply, since the compilation of 1990 inventories would have to rely on assumptions to fill in data gaps, and therefore would reduce the accuracy of the BEI.

Using 2005 instead of 1990 at the EU level could mean a more ambitious 20 % reduction target by 2020, because of the reduction already achieved between 1990 and 2005 [38]. However, it is worth noting that this might not always be the case on national and local scales, or for a given emitting sector, according to the trends in GHG emissions since 1990

Figure 5 shows that only 2 % of the signatories chose 1990 as the baseline year, whereas most of them decided to use 2005 (34 %), 2007 (19 %), or more recent years (38 %). The 108 local municipalities which adopted 1990 as the reference year include 27 large urban centers (such as Berlin, Munich, Brussels-Capital) and cover 14 % of the total inhabitants in the CoM BEI dataset 2016. Results at the national level show that 1990 is the year ranked first in Finland (80 % of the signatories), Sweden (75 %), Germany (42 %) and Austria (23 %). From 2005 and onwards, the BEIs cover 94 % and 77 % of the CoM signatories and population, respectively.

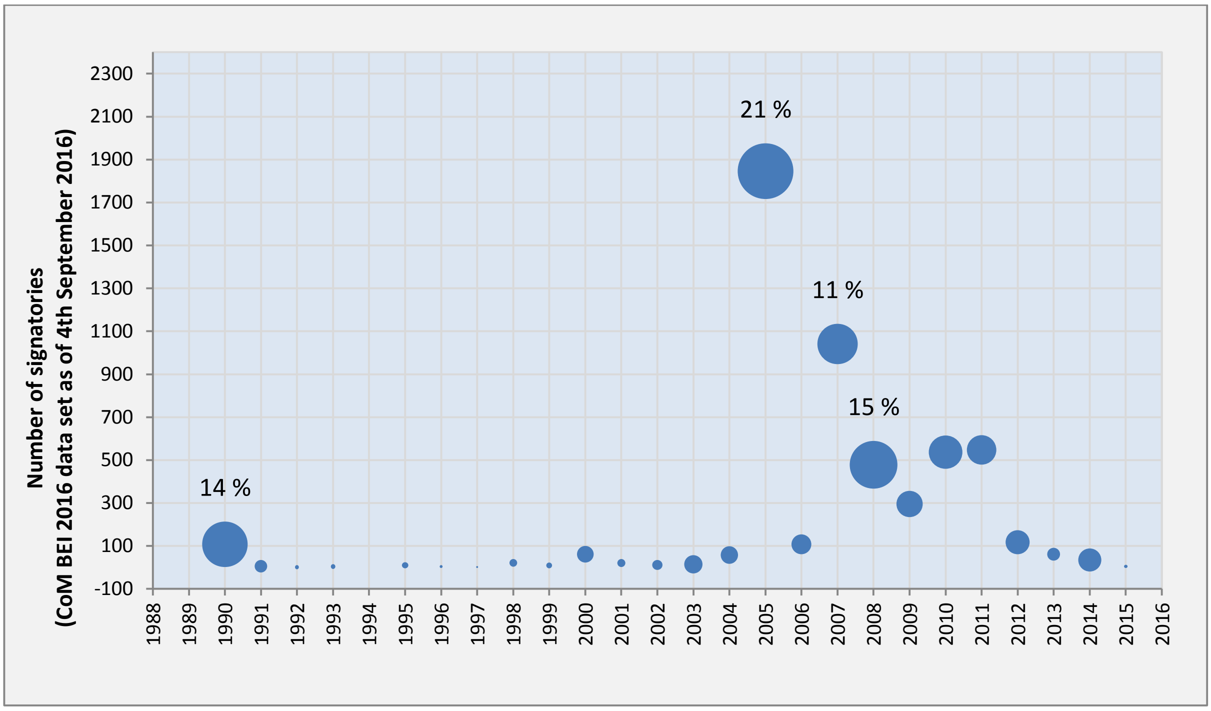
These average patterns are driven by the small and medium urban centres (97 % of the signatories, 81 % of which are located in Italy or Spain) and differ according to the size of the city and country. While only 2 % of small and medium urban centres opted for 1990, 19 % of large urban centers did. These patterns reflect the fact that the data on 1990 is not available to all municipalities, but only those which started to manage their emissions/energy consumption long before the Covenant, and already had a plan or a series of plans which they submitted as a SEAP after they had become Covenant signatories.

These results also suggest that a significant proportion of those signatories choosing later BEI years, such as in Italy and Spain, also did the data collection more recently, i.e. after their commitment time. Indeed, data availability may be difficult due to the lack of, or incompatible electronic archiving systems, or lost knowledge following the retirement of many municipal/energy officials who were familiar with the situation in 1990. In such situations, the general recommendation to use 1990 does not apply, since the compilation of 1990 inventories would have to rely on assumptions to fill in data gaps, and therefore would reduce the accuracy of the BEI.

Using 2005 instead of 1990 at the EU level could mean a more ambitious 20 % reduction target by 2020, because of the reduction already achieved between 1990 and 2005 [38]. However, it is worth noting that this might not always be the case on national and local

scales, or for a given emitting sector, according to the trends in GHG emissions since 1990.

Figure 5. Reference years in BEIs in the CoM BEI dataset 2016 (N=5403). The population covered in the corresponding SEAPs is represented in relative terms by the size of the bubble.



3.2.2. Greenhouse gas emissions in BEIs

Figure 6 shows the overall GHG emissions in the CoM macro-sectors reported in BEI data after around eight years of CoM activity. The total GHG emissions are 951 Mt CO_2-eq/year, with a preponderant contribution from the buildings (70.5 %) followed by the transport (28.3 %) macro-sectors.

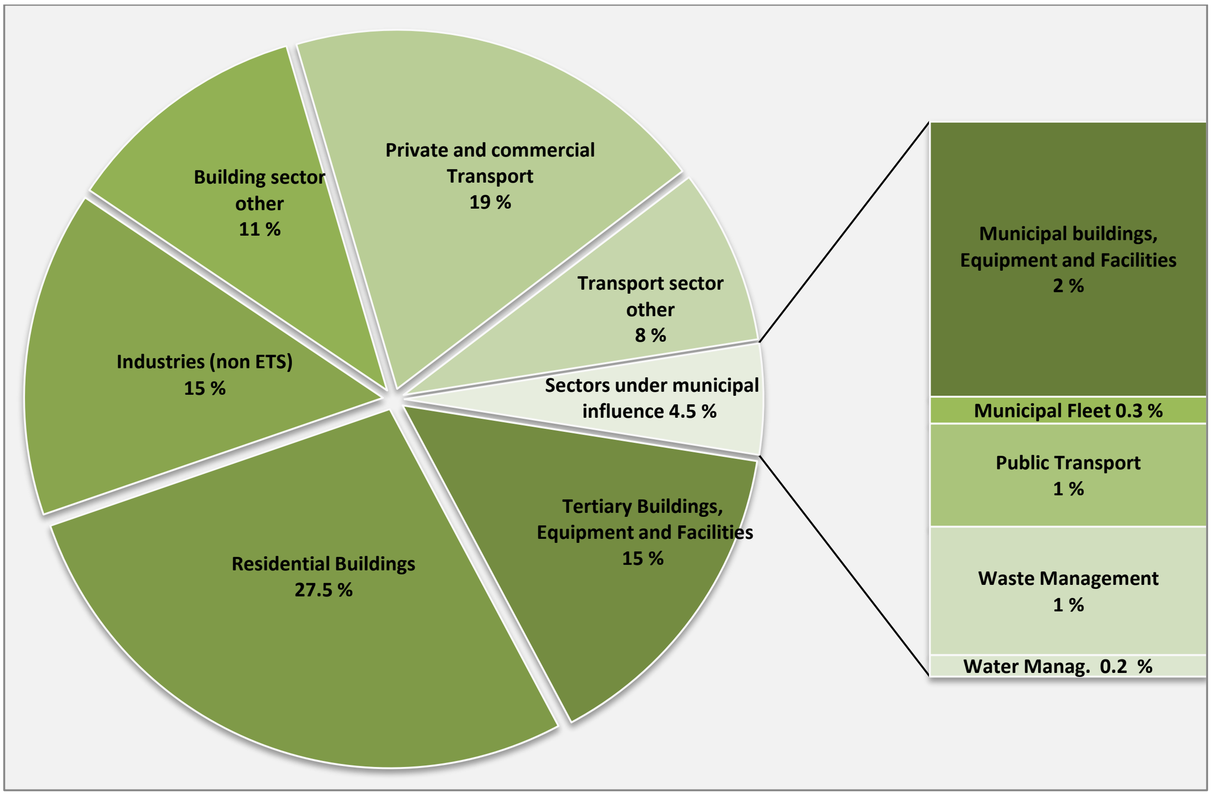
The distribution of GHG emissions into the different CoM sub-sectors (Table 1) is presented in Figure 6. The three most-emitting building sub-sectors are responsible for 27.5 % (residential buildings), 15 % (tertiary buildings) and 15 % (non-ETS industries) of the total CO_2-eq emissions, respectively. All those emissions in the building sector without a classification in a specific sub-sector are grouped under 'building sector – other', representing 11 % of the total CO_2-eq emissions.

The emissions in the transport macro-sector are largely dominated by the private and commercial transport sub-sector, which contributes to 70 % of the GHG emissions from transportation and to 19 % of total GHG emissions. All the emissions in the transport sector which are not classified in a specific sub-sector are grouped under 'transport sector – other', representing 8 % of the total CO_2-eq emissions.

The 'Sectors under municipal influence' (4.5 % of the total emissions) groups the emissions which include municipal buildings and facilities (2 %), municipal fleet (0.3 %), public transport (1 %), waste management (1 %) and water management (0.2 %).

Comparing these statistics with the previous assessment report [13] shows an increase of 39 % in the GHG emissions reported in the BEIs over the last 28 months, which reveals the Covenant's ever-increasing coverage.

Figure 6. GHG emissions in CoM sub- sectors reported in BEIs in the CoM BEI dataset 2016



3.2.3 Committed emission reductions by 2020

Statistics on emission and reduction commitment by 2020 have been calculated for the direct and indirect emissions reported by the signatories in the CoM platform. Table 6 shows the overall absolute emissions and committed reductions.

- Although minimum commitment requirement in the CoM is to reduce the emissions by 20 % by 2020, on average, the CoM signatories have committed to a significantly higher target of 27 %.
- An analysis of the share of GHG emission reduction in the different categories in urban centres based on the population size shows that more than 59 % of the reduction would result from actions/measures planned in large urban centres (of more than 250 000 inhabitants).

Table 6. Share of GHG Emission reduction: CoM BEI dataset 2016

GHG emissions in BEIs [tCO_2-eq/year]	951 221 553
Estimated GHG emission reduction by 2020 [tCO_2-eq/year]	254 545 178
Share of GHG emission reduction [% by 2020]	**27 %**

3.2.4. Performance indicators

This chapter reports the overall CoM initiative's performance on GHG emissions and reductions, as expressed in absolute and per-capita reductions. They are then reported and discussed as compared to EU emission data and reduction commitments.

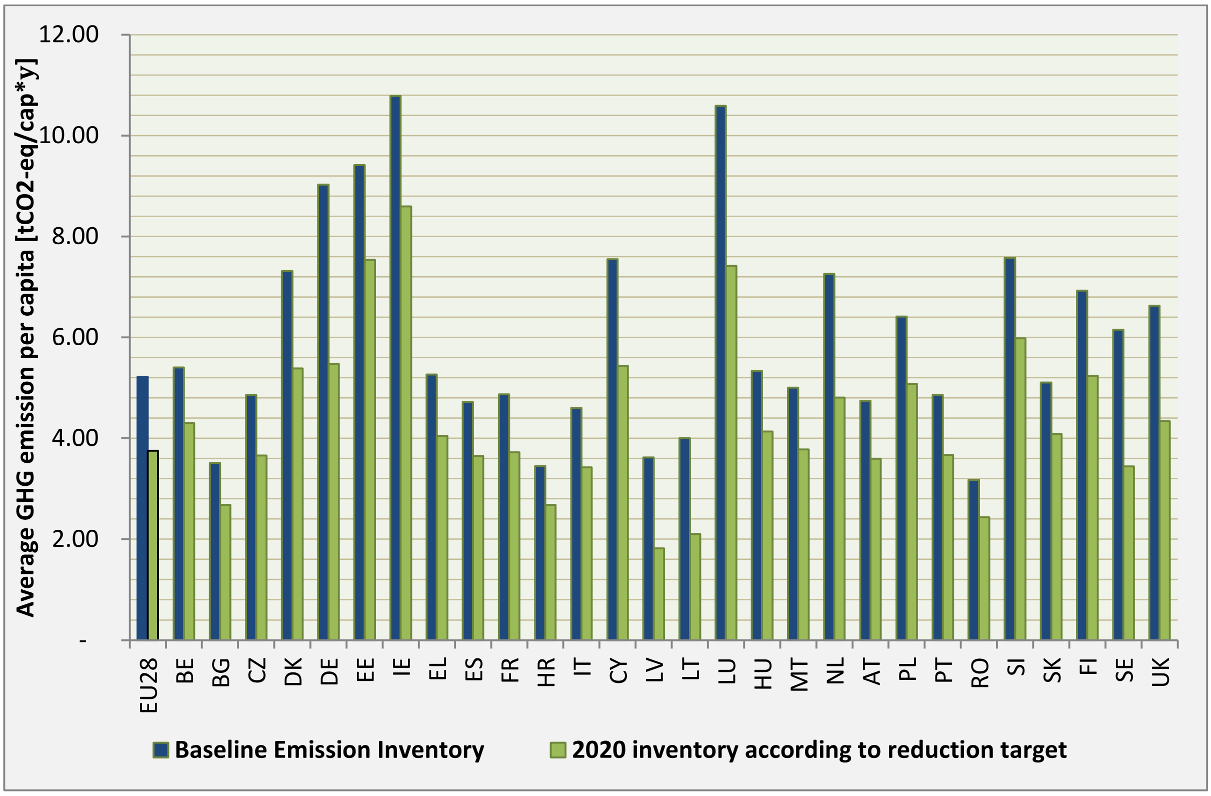
The performance indicators in Table 7 indicate the average GHG emissions per capita of 5.17 tCO_2-eq/cap*y, while the EU-28 average for GHG emissions in all sectors in 2014 [2] are 8.4 tCO_2-eq/cap*y. The average GHG emission reduction per capita by 2020, committed by CoM signatories, is 1.41 tCO_2-eq/cap*y, which corresponds to an emission reduction per capita of 27 %.

Table 7. Performance indicators on GHG emissions and reduction in CoM BEI dataset 2016

Per capita GHG emissions [tCO_2-eq/cap*y]	5.17
Per capita GHG emission reduction by 2020 [tCO_2-eq/cap*y]	1.41
Share of per capita GHG emission reduction by 2020 [%]	27 %

Figure 7 shows the GHG emissions per capita in EU Member States[21] according to the BEIs and estimated emission reductions in 2020. The figure clearly shows that Italy and Spain have an average figure for GHG emissions in BEIs and in 2020 similar to the EU-28 average values.

Figure 7 GHG emissions per capita in EU Member States according to BEIs and estimated emission reductions by 2020



[21] See http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Country_codes for the country codes.

This is due to country representativeness in terms of the signatories and population covered: 55 % of EU-28 SEAPs are from Italy, covering 24 % of the population, while 26 % of EU-28 SEAPs are from Spain, covering 16 % of the population.

Box 5. Covenant GHG emission reduction commitments by 2020

- Covenant signatories have committed to ambitious GHG emission reduction targets by 2020: the overall commitment of 27 % is almost 7 percentage points higher than the minimum target;
- Total emissions in the baseline inventories: 951 Mt CO2-eq as reported by 5403 signatories (183.8 million inhabitants);
- The buildings sector is the most representative with 70.5 % from the total emissions in the BEIs, followed by the transport sector with 28.3 %

An attempt has also been made to assess the contribution of local actions towards achieving EU GHG emission reduction targets (Table 8).

The emission reduction needed at the EU level to achieve its 20 % reduction target by 2020 has been calculated using EEA data for 2005 [2] and EDGAR [39].

- The emission reduction committed by 2020 by the CoM signatories of the EU Member States (239 MtCO_2-eq) represents 98 % of the overall reduction committed by all CoM signatories;
- By achieving their commitment, the EU Member State CoM signatories would achieve 31 % of the EU's overall emission reduction target by 2020, including all sectors (i.e. ETS and ESD).

Table 8. CoM contribution to the EU 2020 target in terms of GHG emission reductions

EU-28 2005 GHG emissions [Mt CO2-eq]	5199
EU-28 2020 GHG emission reduction target [Mt CO_2-eq]	778
CoM EU-28 2020 estimated GHG emission reduction [Mt CO_2-eq]	239
CoM potential contribution to EU-28 2020 GHG emission reduction target [%]	**31 %**

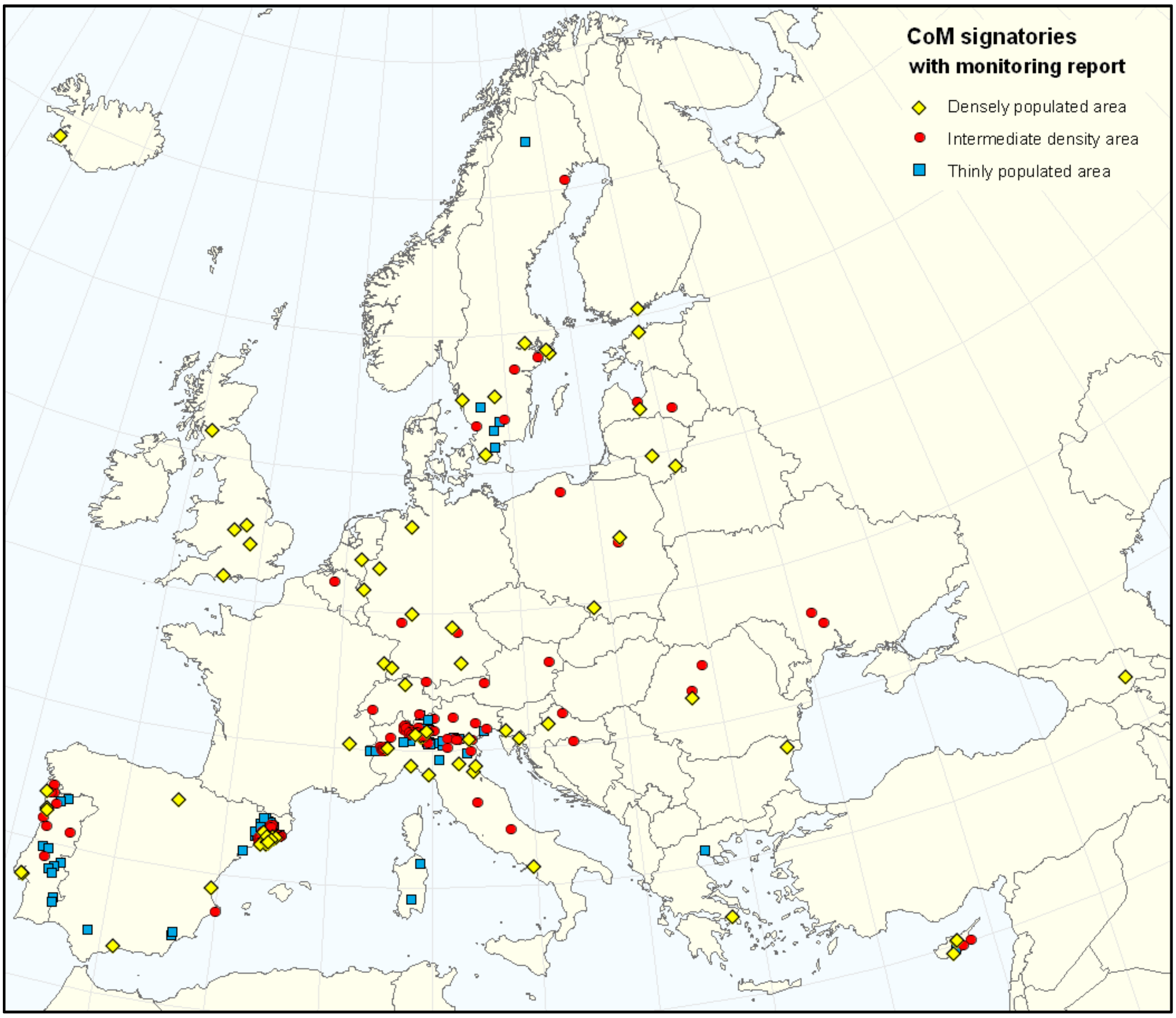
Box 6. EU28 perspective on the Covenant commitments for 2020

- 5332 SEAPs submitted from CoM signatories from the EU, covering 160 million inhabitants (97 % of the total signatories, covering 31 % of EU-28 population in 2014);
- **Emission reduction** of the Covenant signatories from the EU **may represent 31 % of the EU-28** GHG emission reduction target by 2020 compared to 2005.

3.3. Monitoring and implementation

This chapter presents the progress made by the signatories in terms of reporting on the monitoring of their emission inventory (3.3.1) and the emissions reduction achieved. The interim results on progress towards their reduction target (section 3.3.2) are based on currently available data from 315 signatories. They are completed with an estimation of the overall potential emission reduction achieved for the entire set of signatories (1779) which, according to the CoM requirements, should have already provided at least one monitoring report by September 2016 (3.3.3). Figure 8 shows the map of monitoring signatories with their degree of urbanisation.

Figure 8. CoM signatories with monitoring report in the CoM MEI dataset 2016



3.3.1. Progress on monitoring reporting

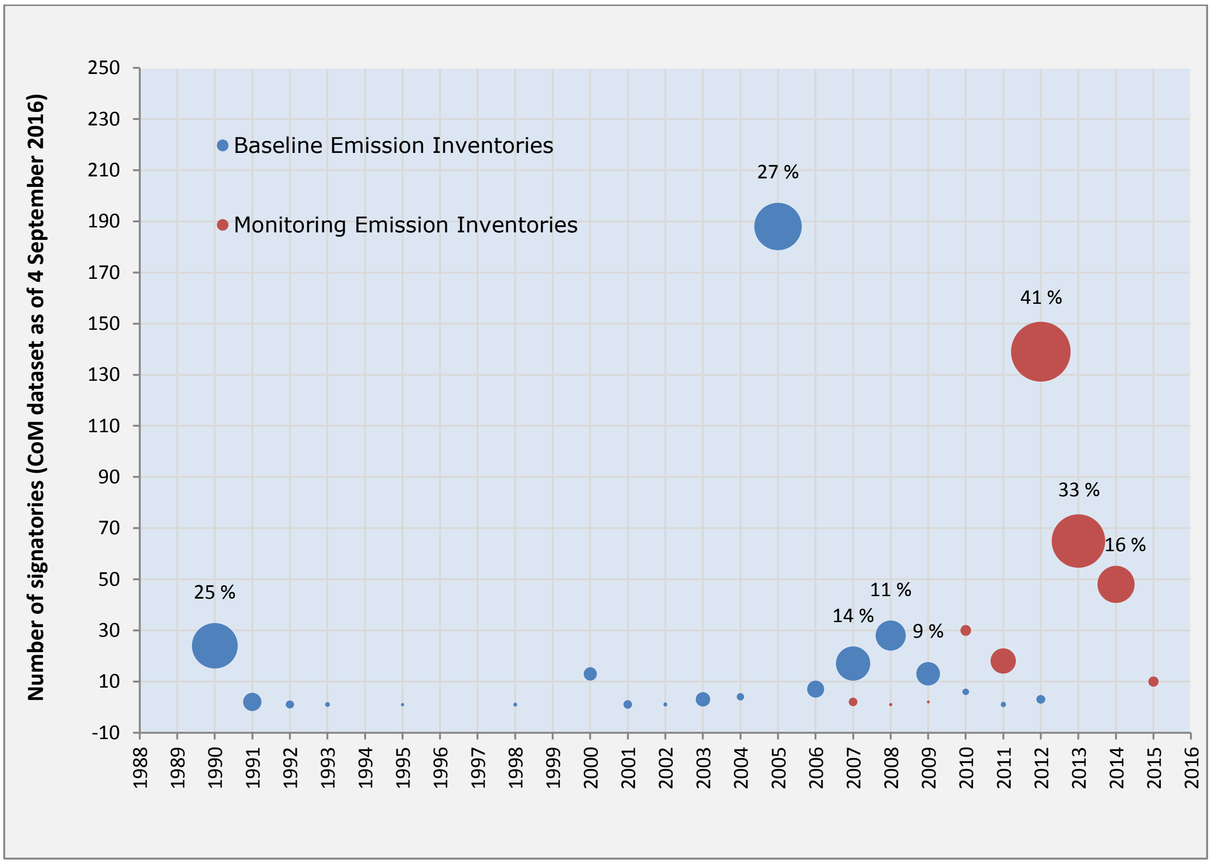
Up to September 2016, 315 signatories (6 % of signatories and 14 % of the population with a submitted SEAP) had reported on the implementation of their SEAP by presenting a so-called full report, i.e. a monitoring report including an MEI. This monitoring subset (see Table 13 of Annex II), which covers a population of 25.5 million inhabitants, only represents 18 % of whole set of signatories (1779 signatories) which, according to the CoM reporting timeline, should have already submitted at least one MEI.

For those signatories which have already presented a full monitoring report, Figure 9 shows have many have chosen which baseline and monitoring year with their respective populations (bubble size). The majority of populations (27 %) among CoM signatories have chosen the inventory year 2005 for their BEI (blue bubbles).

The MEIs already provided (red bubbles) refer mainly to the years 2012, 2013 and 2014, which represent 41 %, 33 % and 16 % of the total population in the monitoring subset, respectively.

The mean reduction target of these signatories is 30 % by 2020, which is 10 % above the minimum reduction required within the frame of the CoM protocol.

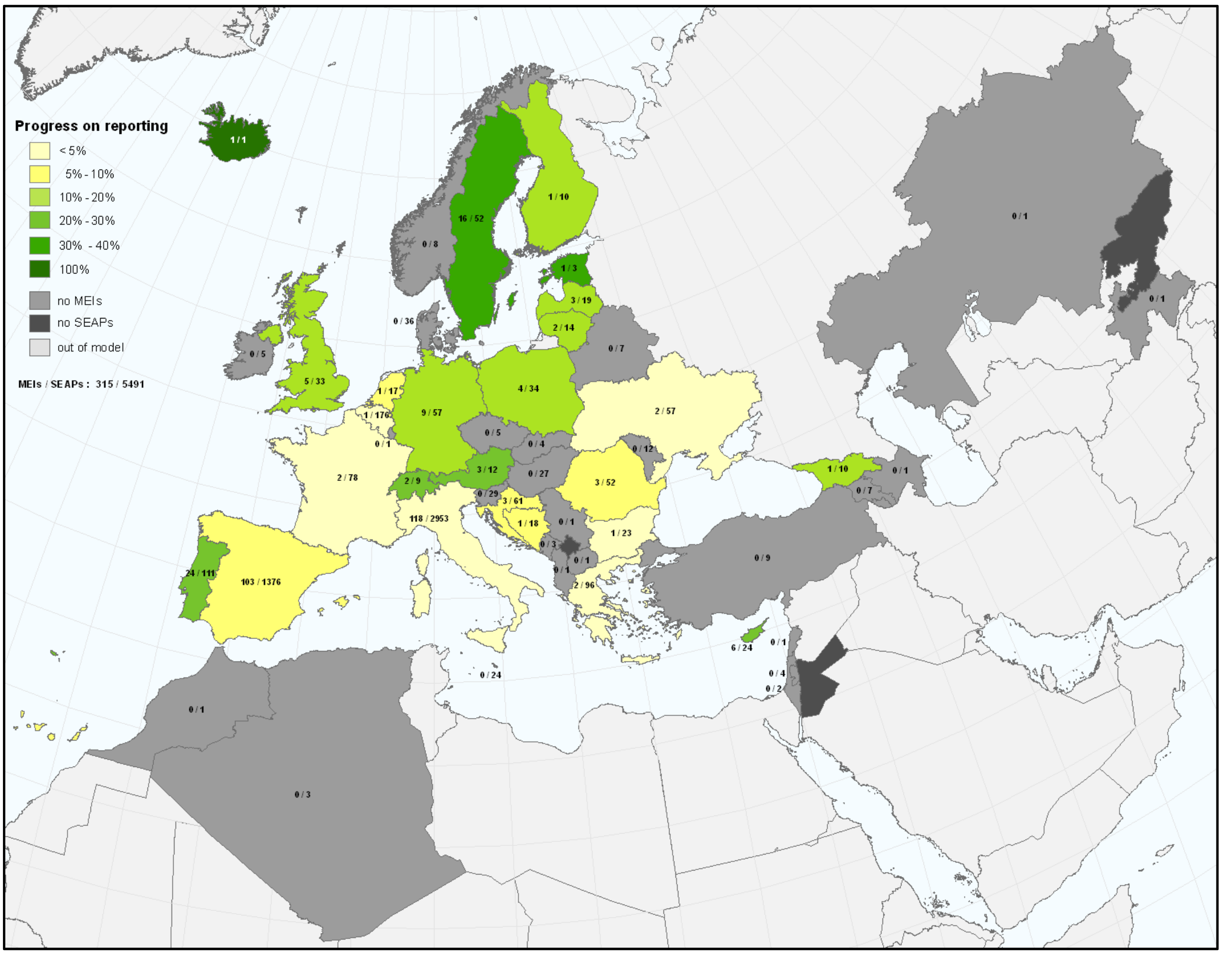
Figure 9. Years in BEIs and MEIs in CoM MEI dataset 2016 – monitoring subset (N=315)



Analysing the CoM monitoring subset of the MEI dataset (see Table 13 of Annex II) at the national level shows that Italy and Spain are the countries with the highest number of monitoring reports (118 and 103 respectively) but covering a relatively low fraction of the population (11 % and 16 % respectively). Conversely, in other countries, such as Sweden and Portugal, fewer monitoring reports have been submitted (16 and 24 respectively) but they are better represented in terms of the population covered (64 % and 21 % respectively).

Figure 10 shows the MEIs already provided by each country in terms of percentage of SEAPs submitted (CoM BEI dataset 2016). It suggests that local authorities in some countries (e.g. Italy and Spain) that have enthusiastically joined the initiative and submitted their SEAPs (thanks also to the support provided by regional authorities acting as CTCs), might now be facing some challenges in the implementation phase. The reasons for this should be further investigated in order to provide a definitive answer and to identify potential needs regarding target support by local authorities facing such a situation.

Figure 10. Share of monitoring report on number of SEAPs per country in CoM dataset 2016



3.3.2. Reported progress on the reduction of GHG emissions

The progress made by the 315 signatories which have provided at least one full monitoring report is assessed as follows: the emissions in their baseline emission inventories are compared to those reported in their latest monitoring emission inventory, having been aggregated by sector.

Table 9 and Table 10 show that the absolute and per capita reduction achieved from BEI to MEI correspond to 23 % and 26 % respectively. Although the minimum commitment for these signatories was 20 % by 2020, they have set an even more ambitious target, corresponding to a 30 % emission reduction by 2020 and are on track to reach it.

Table 9. GHG total emissions (tCO_2-eq/y) and reduction achieved (%) from the baseline to the monitoring emission year – CoM MEI dataset: monitoring subset (N=315)

	Baseline Emission Inventory (BEI)	Monitoring Emission Inventory (MEI)	Committed in 2020 (based on declared target)
GHG emission inventories [tCO_2-eq/y]	149 824 616	116 060 439	104 919 424
Absolute reduction of GHG emissions compared to BEI	-	23 %	30 %

Table 10. Per capita GHG emissions (tCO_2-eq/cap*y) and reduction achieved from the baseline to the monitoring emission year – CoM MEI dataset: monitoring subset (N=315)

	Baseline Emission Inventory (BEI)	Monitoring Emission Inventory (MEI)
Per capita GHG emissions [tCO_2-eq/cap*y]	6.13	4.55
Per capita reduction in GHG emissions compared to BEI	-	26 %

While these are encouraging results, the representativeness of the sample should be considered before drawing general conclusions for the whole SEAP sample. Indeed, on average these 315 signatories are bigger cities than those in the SEAP sample. In addition, they are often more advanced cities, i.e. with greater experience in terms of local climate and energy planning.

The results (Figure 11) show the sharpest decrease in GHG emissions since the BEI year for the building sector (27 %). The reduction in the transport sector is much less pronounced (7 %).

Figure 11. Evolution of GHG emissions per sector from baseline to monitoring emission inventories

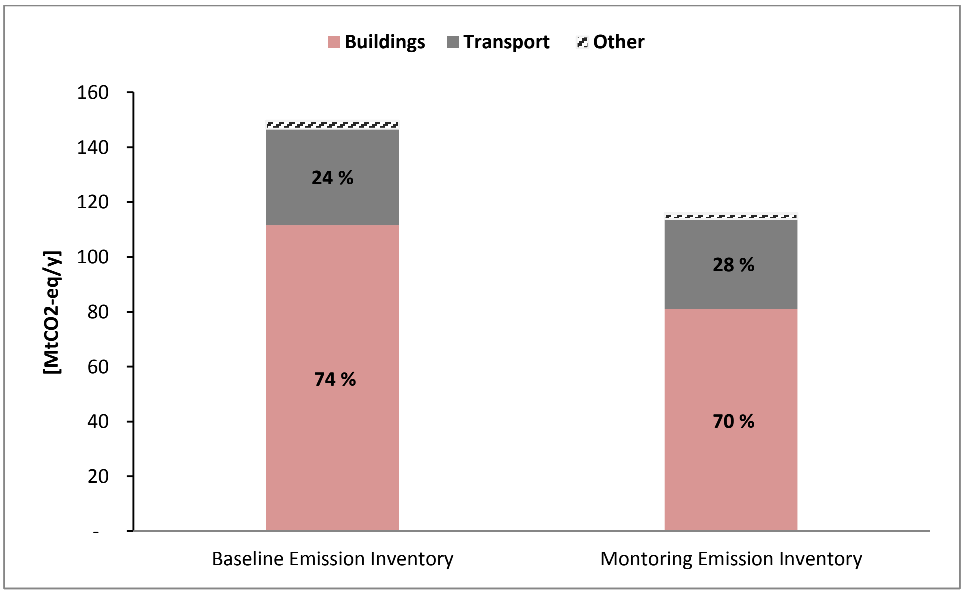
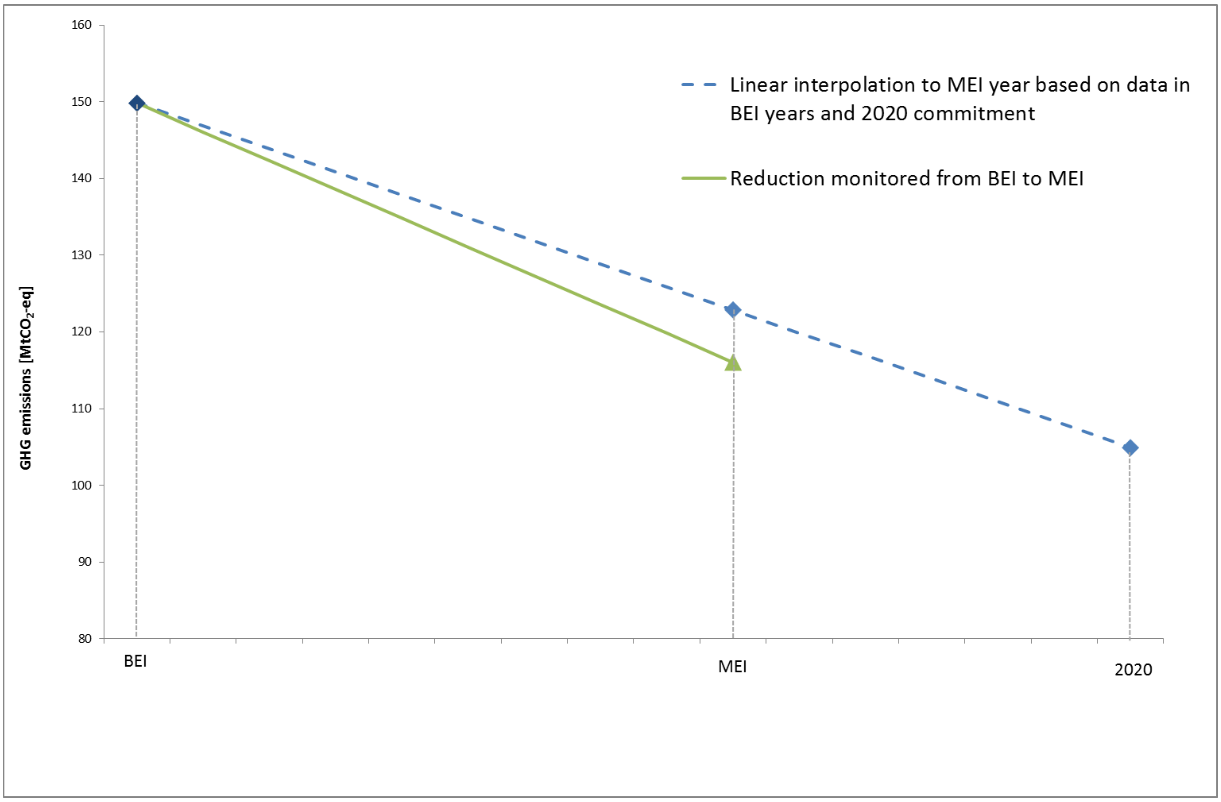


Figure 12 shows the GHG emissions in BEI years, in MEI years, and the 2020 commitment. In addition, the blue line represents the linear interpolation of the MEI years based on data from the BEI and the 2020 commitment, while the green line represents the reduction monitored based on real data from the BEI to MEI years.

The figure shows that real monitoring data (116 Mt CO_2 eq/year) are lower than the expected value, based on the linear interpolation (123 Mt CO_2 eq/year) between the BEI data and the 2020 commitment. Therefore, those signatories that submitted a monitoring emission inventory are well on track to reach their target by 2020.

Figure 12. GHG emissions in baseline year, in monitoring year and in 2020



The reduction in GHG emissions between the baseline and monitoring emission inventories resulted from the combination of several factors such as improvements in energy efficiency, an increase in renewables, demographic growth, variations in weather conditions, economic growth, etc. The relative effects of improving energy efficiency and progress in the use of renewables are discussed below, while the demographic growth is taken into account in the calculation of the per capita indicators.

Box 7. GHG emission reduction achieved

- Overall, ***a reduction of 23 % has been achieved,*** from the baseline year inventory (BEI) to the year of the last submitted monitoring report (MEI), as reported by 315 signatories, representing 25.5 million inhabitants;

- The overall reduction occurred during a general rise in the population, hence the reduction per capita is higher (**26 %** from BEI to MEI);

- The drop in emissions is more obvious in the ***buildings sector with a decrease of 27 %*** from BEI to MEI but less pronounced in the ***transport sector with an 7 % reduction from BEI to MEI***;

- Signatories which submitted monitoring emission inventories have an overall target of 30 % for 2020 and ***are on track to reach it***.

The 23 % decrease in GHG emissions between the baseline and monitoring years was driven by (Figure 13):

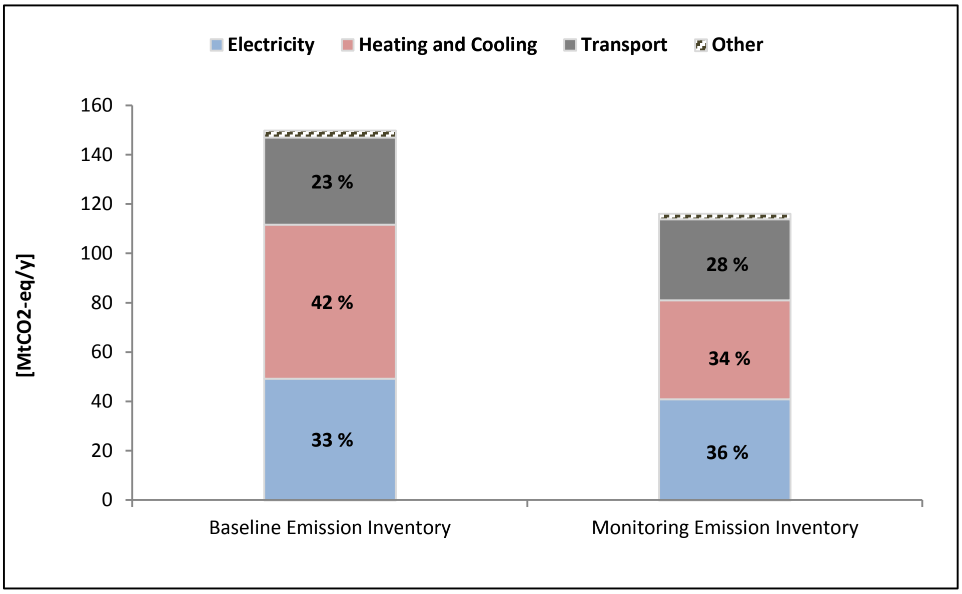
- GHG emission due to electricity consumption decreased by 17 % from baseline to monitoring years driven by a less-carbon-intensive fuel mix and more efficient electricity generation power plants [2];

- GHG emissions for heating and cooling in buildings fell by 36 % from baseline to monitoring years, driven by improved energy efficiency in buildings and subsequent lower energy consumption levels, more efficient local heat production from district heating networks, and by increasing the share of renewable sources in decentralised local heating production.

- GHG emissions in the transport sector fell by 7 % from baseline to monitoring years, driven by lower energy consumption from fossil fuels and an increase in the share of biofuels, and a shift towards public transportation and electric mobility.

These results underline the interconnected nature of climate mitigation and energy efficiency actions adopted at the local level. The CoM signatories have adopted a range of policies and measures for improving energy efficiency through building regulations, increasing the share of renewable energy, integrating district energy systems and a gradual transformation to more efficient and sustainable transportation. Below is a detailed analysis of their policies:

Figure 13. Evolution of GHG emissions per sector from baseline to monitoring emission inventories



- *Energy management and public procurement:* public authorities often prioritise the implementation of energy management systems in their buildings and facilities. Energy management and public procurement for improving efficiency are the major policy instruments used in the municipal sector and public lighting.

- *Building standards and energy certification labelling for new and existing buildings:* Covenant signatories use building codes to impose more stringent energy performance requirements than those applicable at the national level. The building codes and energy certification/labelling are the major policy instruments used by local authorities in the building sector (municipal, residential and tertiary buildings).

- *Awareness-raising and training:* local authorities organise campaigns to increase citizens' knowledge of energy issues, induce changes in behaviour, and ensure wide support for the whole process of SEAP implementation. In terms of training, local authorities develop training campaigns for civil servants, local building managers, technicians in the building sector, etc. to ensure they have the right skills to support the implementation of SEAP actions.

- *Financial incentives*: grants and subsidies are an important policy instrument used by local authorities to promote energy efficiency and the deployment of renewables in residential buildings. Typical examples of incentives include reducing municipal taxes and tariffs for improvements in energy efficiency in buildings with more stringent requirements than those required at the national level. In addition, in the local electricity and heat production sector, grants and subsidies are used to support specific technologies or pilot projects which a local authority considers to be of particular relevance for the deployment of renewable energy resources, considering its own context and objectives.

- *Third-party financing:* this financial scheme is perhaps the easiest way for municipalities to undertake comprehensive energy retrofits of their buildings, allowing someone else to provide the capital and to take the financial risk.

- *Urban planning:* local authorities establish local mobility plans defining limited traffic zones, low-emission zones, designated parking spaces for low-emission vehicles, free parking for cleaner, more efficient vehicles. Furthermore, they can set road-pricing schemes, and integrated ticketing/charging to foster sustainable mobility.
- *Other policies:* in addition to urban planning, many municipalities have ownership of or jurisdiction over local energy and water utilities, public transportation and social housing. The potential for improvements in energy efficiency exist in the provision of these services [3]. Urban energy planning throughout the development of district energy networks in high-density districts can improve the energy efficiency of the urban energy systems. Moreover, market-based instruments, such as energy efficiency obligations[22] or white certificate schemes implemented at national/regional level, represent effective policy instruments for energy consumption making an impact at the local level. Obligation schemes for energy suppliers in the CoM municipalities are a major driver for improvements in the local heat and electricity production sectors[23].

The report demonstrates that the combination of effective urban energy policies and better coordination between national and local governments is crucial for the potential of the urban mitigation of global climate change.

3.3.3. Estimated overall progress on the reduction of GHG emissions

Inventories expected by September 2016 have not yet been provided. According to the clustering model's projections (see section 2.2.2.), the signatories from CoM MEI dataset would have already achieved 22 % ± 2 % of emission reduction by 2014 (Table 11), out of the 28 % reduction target by 2020.

Table 11. GHG total emissions (t CO_2 eq/y) and estimated reduction achieved (%) from the baseline to the monitoring emission year – CoM MEI dataset (N=1779)

	Baseline Emission Inventory CoM MEI data set	Monitoring Emission Inventory CoM MEI data set
GHG emissions inventories [t CO_2-eq/y]	593 111 921	463 351 387
Absolute reduction of GHG emissions compared to BEI	-	22 % ± 2 %

In per capita terms, results (Table 12) indicate an average GHG emission per capita of 5.88 tCO_2-eq and a projected mean GHG emission reduction of 1.33 tCO_2-eq per capita, which corresponds to a 23 % reduction.

[22] Among the many policy instruments introduced in the EU to support energy efficiency, many EU Member States have introduced energy efficiency obligations, also to comply with the Energy Efficiency Directive, on energy suppliers and distributors to deliver a certain amount of energy savings.

[23] Mainly in Italy, although this policy instrument has also been adopted in Belgium (Flemish region), France and Denmark.

Table 12. Per capita GHG emissions (t CO_2 eq/cap*y) and estimated reduction achieved from the baseline to the monitoring emission year – CoM MEI dataset (N=1779)

	Baseline Emission Inventory CoM MEI data set	Monitoring Emission Inventory CoM MEI data set
Per capita GHG emissions [t CO_2-eq/cap*y]	5.88	4.55
Per capita reduction of GHG emissions compared to BEI	-	23 %

It is worth noting that these projections, which are not very different from the interim results, should be considered as provisional estimates pending the submission of the actual data from the signatories, and are, by nature, affected by an uncertainty due to the clustering modelling of the signatories.

Box 8. Projections on the potentially GHG emission reduction achieved

- 1779 signatories, covering 101.9 million inhabitants have an overall estimated reduction of 22 % ± 2 % by 2014 compared to the baseline emission inventories.

4. Conclusions

Overall considerations

This report has illustrated how the Covenant of Mayors, the world's largest urban climate and energy initiative, involving thousands of local and regional authorities, facilitates and accelerates the implementation of effective actions to fight climate change.

The Covenant of Mayors' integrated approach is in line with a number of EU priorities not only concerning mitigation and adaptation but also in terms of embracing a robust transparency framework for the implementation of the Paris agreement. It is the first initiative of its kind addressed to local authorities which requires signatories to define a binding target, commit to developing an action plan addressing mitigation and adaptation and to monitoring the results on a regular basis in order to track progress towards their targets.

Box 9. Covenant of Mayors for Climate and Energy: signatories and commitments

- ***The initiative has 6201 local authorities as signatories,*** covering 213 million inhabitants at 4 September 2016.
- S***ignificant participation by small and medium-sized towns*** (89 % of the signatories) confirms the important role of small municipalities in climate change mitigation.
- In terms of population, the ***highest share*** of inhabitants comes from ***large urban centres*** and a global city (52 %).
- The Covenant remains a mainly ***European initiative*** (85 % of the Covenant population), although its ***extension beyond the EU-28 borders*** continues to grow.

Based on a robust scientific analysis, the report has first determined and described the most appropriate methods and methodological approach used to identify the subset of cities used for the analysis. It has then analysed the results in terms of absolute and per capita GHG emission reductions resulting from the commitments and monitoring reports of the SEAPs.

Consequently, in order to forecast achieved GHG emission reductions up to 2014 for 1779 signatories, it has used the results from 315 municipalities which submitted a progress report and has projected them to other municipalities that are deemed to be in a similar phase of implementation (based on the submission date of their SEAP).

Finally, it has drawn conclusions on the main achievements in terms of reductions in GHG emissions, highlighting the main policies EU Covenant of Mayors signatories have adopted in order to achieve their targets.

Box 10. Peculiarities of the Covenant of Mayors initiative

- It is a ***multi-level governance*** model supported by a strong political commitment from mayors around Europe who are able to transpose pledges into concrete policies supporting the implementation of mitigation and adaptation climate actions in their cities.
- Implementation of the initiative and the ***voluntary commitments*** made by non-state actors is monitored and confirmed by concrete results on the ground.
- Its ***transparent system for tracking progress*** and results enhances the credibility of the commitments made by the mayors.
- It is an EU initiative which is able to show at the ***local level concrete achievements*** in GHG emission reductions and enhanced resilience/reduced risk.
- It is a ***successful on-going initiative*** that can be replicated in other geographical areas and scaled up.
- It is the first initiative to have established ***minimum targets*** and requires ***intermediate reporting*** for local authorities.

Main findings of the report

According to the moment of adhesion, the commitment made by the signatories varies and includes: a 20 % mitigation target by 2020 (signatories of the Covenant up to October 2015), commitment to adaptation (Mayors Adapt signatories) and combined adaptation with the mitigation target, and 40 % by 2030 (signatories of the New Covenant for Energy and Climate).

In terms of overall emissions reported in baseline emission inventories, the analysis shows an increase of 39 %, from 686 $MtCO_2$ to 951 $MtCO_2$, over the last 19 months, compared to the previous assessment report which indicates the Covenant's coverage is continuing to increase.

In this context, it is important to highlight the fact that, while the CoM inventories and commitment refer to only a part of the total CO_2 emissions on their territory, the EU-28 CoM signatories may contribute by 31 % to the overall EU-28 GHG emission reduction target by 2020. The results were extracted from the SEAPs submitted from the EU-28 (covering 157.6 million inhabitants) and mainly show the effect of the combined actions of local measures and national policies.

Box 11. Covenant commitments for 2020 and EU-28 perspective

- ***5403 Sustainable Energy Action Plans*** in the JRC harmonised CoM dataset 2016 (98 % of the total SEAPs submitted), covering 183.8 million inhabitants.

- ***Total GHG emissions in the baseline inventories*** in the JRC harmonised CoM dataset 2016: 951 Mt CO_2-eq and an overall estimated reduction of 254 Mt CO_2-eq by 2020.

- Covenant signatories commit to ambitious GHG emission reduction targets by 2020: ***overall commitment of 27 %,*** almost 7 percentage points ***higher than the minimum target***.

- **Emission reductions** for the EU Covenant signatories (31 % of the EU-28 population in 2014) **may represent 31 % of the EU-28** GHG emission reduction target by 2020 compared to 2005.

Analysis of the CoM monitoring dataset 2016, based on the 315 monitoring reports and 25.5 million inhabitants, confirms the findings of previous reports with achievement of a 23 % overall emission reduction in relation to the 30 % committed by 2020.

Box 12. Achieved GHG emission reduction in 2014

- ***Overall achieved reduction of 23 %*** between the baseline year and the last submitted monitoring report, based on 315 signatories with a submitted monitoring emission inventory, representing 25.5 million inhabitants.

- The drop in emissions is more pronounced in the ***buildings sector with a decrease of 27 %*** and less steep in the ***transport sector with an 7 % reduction*** from the baseline inventories to progress reporting, through a combination of effective national and local policies on:
  - *improving energy efficiency* in buildings,
  - *increasing the share of renewable* energy in local production,
  - *integrating district energy systems,*
  - *gradual transformation towards more sustainable transportation*.
- Signatories (315) which submitted monitoring emission inventories ***have an overall target of 30 % for 2020 and are on track to reach it.***
- Projecting the results achieved by 315 signatories to the 1779 reports expected, the overall ***GHG emission reduction resulted in a share of 22 % ± 2 %.***

Final conclusions

The findings confirm that the most common policies for Covenant of Mayors signatories for the transition to a clean energy future are: improving energy efficiency in buildings, increasing the share of renewable energy in local production, integrating district energy systems, and a gradual transformation towards more sustainable transportation.

The report demonstrates that the combination of effective urban energy policies and better coordination between national and local governments is crucial for the potential of the urban mitigation of climate change.

The results of this report show how climate mitigation and sustainable energy actions adopted at the local level are interconnected. The role of local authorities in leveraging sustainable development and mitigation and adaptation measures is crucial. Developing a Sustainable Energy and Climate Action Plan that requires the establishment of a baseline emission inventory and the adoption of policy measures is already a tangible achievement for cities. This is the first step towards an effective, transparent system for tracking progress and concrete results.

The robust open source methodological framework developed by the JRC in collaboration with city networks offers municipalities a comprehensive tool to support the development of climate and energy policies.

As shown by the experience of the Covenant of Mayors in the EU's Eastern and Southern Neighbourhoods, this framework can be successfully replicated and adapted in other regions of the world.

Annex I

Methodology for robust statistics in the CoM

To validate the data in CoM inventories, CoM baseline emissions per capita were compared with different international emission inventories (such as Eurostat, EEA and EDGAR). Whereas the CoM collects bottom-up data at local territory level, the other databases collect data at national level, which means that per capita values can deviate significantly from national averages, especially in urban areas. Therefore, setting simple validity ranges for the emissions per capita, based on the national values, may lead to the exclusion of a high number of emission inventories from the CoM dataset. For this reason, the comparison between the CoM database and international inventories was only used in a preliminary phase of the data-cleaning procedure and preference was given to a statistical method for selecting reliable emission inventories to produce robust data statistics on the CoM initiative.

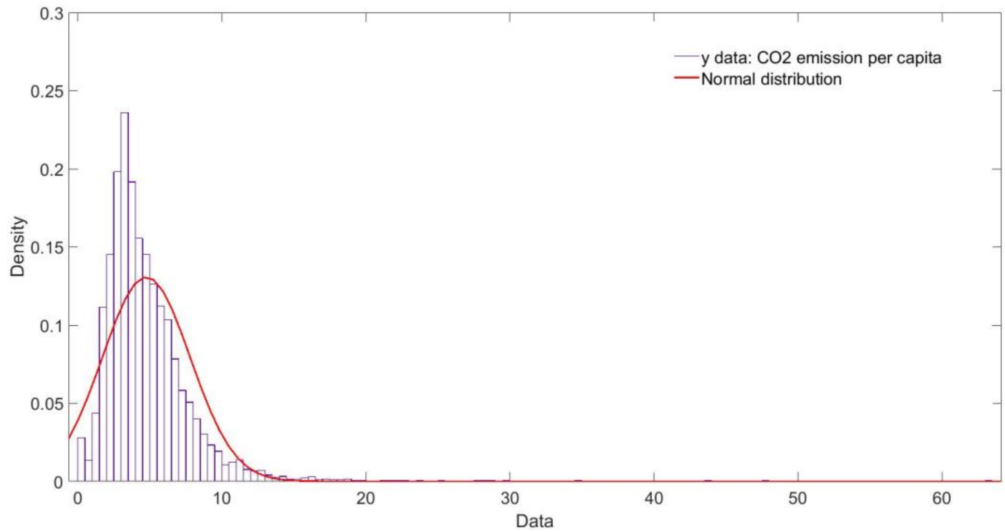
For the current report, data in the SEAPs submitted up to 4 September 2016 (the so-called CoM dataset 2016) were considered. Figure 12 shows the frequency distribution of GHG emissions per capita in the CoM dataset 2016. In the vertical axis, the number of signatories with the same range of observations is reported (i.e. GHG emissions per capita in the CoM dataset 2016). The observations range from 0 to 63 tCO2-eq/cap*y, with a mean value of 4.75 tCO2-eq/cap*y. The presence of outliers is also evident and a methodology has been developed and applied to remove them. The methodology to identify the robust data sample of signatories with coherent inventories comprises two major steps:

- This first step is necessary to determine the order of magnitude in the CoM dataset of the mean values per country level. The clustering of GHG emissions per capita by country and by population size in the CoM database emission inventories and a comparison with national values were performed. As there were different baseline years in the CoM emission inventories, 1990 has been chosen as the reference year for national values (see Figure 15. and Figure 16.).

- Subsequently, a statistical method was applied to check the internal consistency of inventories. The method for identifying and removing the outliers is based on a Generalised Extreme Studentized Deviate (ESDS) procedure which is highly recommended in the literature [19]–[24]. The procedure iteratively identifies extreme values in the dataset and then opts to remove those observations which are higher than the extreme values with a confidence level of 95 %. A detailed description of the statistical methodology is reported below.

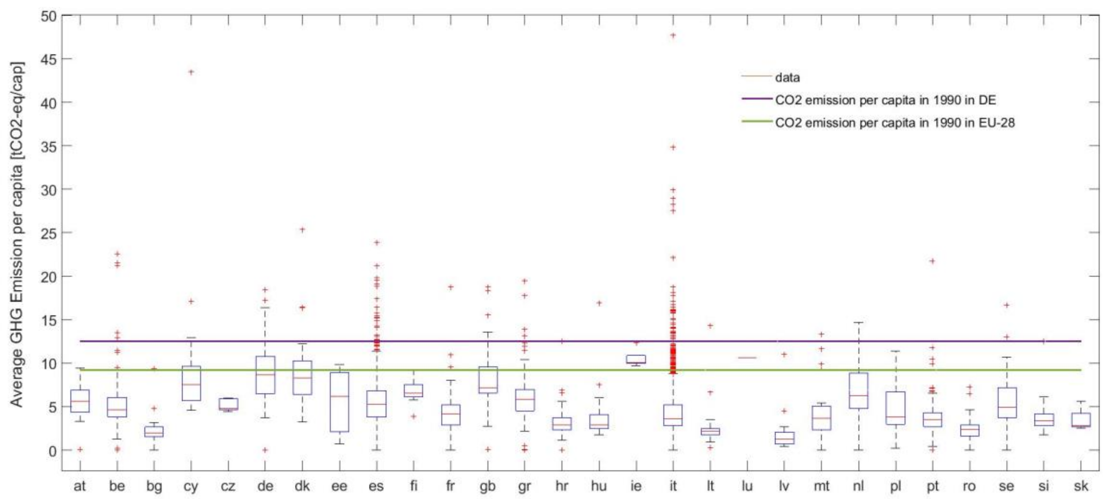
Based on the literature review of methods used for the detection of abnormal energy consumptions [19], (the ESDS), the outlier procedure proposed by Rosner is highly recommend as it works well under a variety of conditions. The methodology can be extended by including the use of skewness and kurtosis in the dataset being studied [24]. Skewness is the third moment about the mean of a given distribution, often denoted by the Greek letter γ (gamma). Skewness is a good indicator of whether or not a distribution is symmetrical around its mean, with positive values indicating top-heavy values, and negative values indicating a bottom-heavy one. Kurtosis, often denoted by γ_2 (gamma 2), is the fourth moment about the mean, which measures how strongly extreme values are represented in the distribution. The usual benchmark for kurtosis values is the normal (bell curve) distribution which is equal to 3. For that reason, to find out whether or not a distribution has more or less extreme dominance than the normal distribution, we simply subtract 3 from the kurtosis. Figure 14 shows the distribution of the observation in the CoM dataset 2016 together with the best-fitting normal distribution. The figure clearly shows that the distribution of the observations is far for normal.

Figure 14. GHG emissions per capita in signatories in the CoM dataset 2016



In Figure 15 box-and-whisker[24] plot of the GHG emissions per capita in the CoM dataset 2016 is reported, clearly showing the presence of many outliers for Italy and Spain.

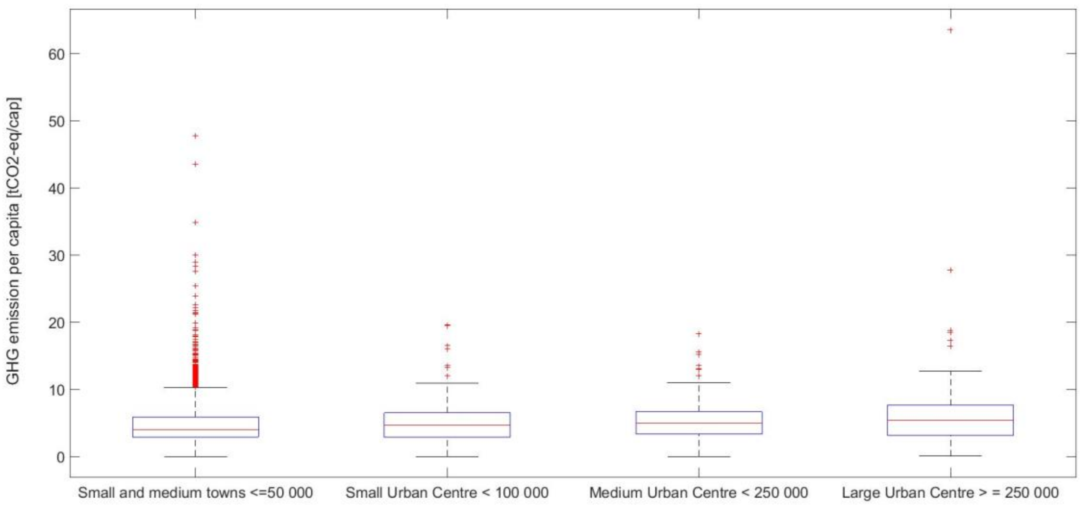
Figure 15. Box-and-whisker plot of GHG emissions per capita by country in the CoM dataset 2016



In Figure 16 the same observations are clustered by population size demonstrating that the majority of outliers are found in small and medium towns with less than 50 000 inhabitants.

[24] In descriptive statistics, a box plot or boxplot is a convenient way of graphically depicting groups of numerical data through their quartiles. Box plots may also have lines extending vertically from the boxes (whiskers) indicating variability outside the upper and lower quartiles, hence the term box-and-whisker plot.

Figure 16. Box-and-whisker plot of GHG emission per capita by country in the CoM dataset 2016



The procedure applied to identify one or more outliers from a set of n observations X represented in the flow chart is reported in Figure 17. It starts with the extraction of the whole data set, then the mean, standard deviation, are calculated at the beginning for each set of data (block 2). Secondly a Generalised Extreme Student method is applied to remove the outliers. Similar methodologies, in the literature, have been applied to detect outliers or abnormal energy consumption in buildings [19].

The extreme studentized deviate (block 3) is determined from equation. 1:

$$R_i = \frac{|x_{e,i} - \bar{x}|}{s} \tag{1}$$

where R_i is a normalised measure of how far the extreme is from the average value ($\bar{x}$) of elements in set X.
The critical value λ_i (block 3) is then determined through the following equation (equation.2):

$$\lambda_i = \frac{(n-i) * t_{n-i-1,p}}{\sqrt{(n-1)(n-1-i+t_{n-i-1,p}^2)}} \tag{2}$$

In this way a new clean dataset is selected (block (6)):

$$p = \frac{\alpha}{2(n-i-1)} \tag{3}$$

The block (4) determines that if the studentized value R_i is larger than the critical value λ_i, this value is an outlier. In block (5) all extreme values identified in block (4) are removed from the dataset and in this way a new clean dataset is selected block (6).

In block (7), a new loop starts on building a robust sample, by executing a number of cycles until the statement in block (10) is true, meaning that for the given value of $\propto$ (0.05 in this case) all the outliers has been removed. The mean, standard deviation, skewness and kurtosis of the new dataset are calculated at the beginning for each loop in block (8).
In descriptive statistics, the modified *z*-score is used to measure how far and in which direction an outlier is from the robust estimate of the mean. The modified z-score is computed in block (9) by using the equation (4):

$$z_m = \frac{(x_{e,j} - \bar{x}_{robust})}{s_{robust}} \quad (4)$$

The critical value λ_j (block 9) is computed by equation (2). The block (10) determines if the z-modified value is greater than the critical value λ_j, thus this value is an outlier. In block (11) all extreme values identified in block (10) are removed from the dataset. In this way a new clean dataset is selected (block (12)).

Model on GHG emission projection in the CoM

The model described here is a first-phase model developed to address the limited data available during the monitoring phase. As of September 2016, 315 signatories (6 % of signatories and 14 % of the population with a submitted SEAP) have reported on the implementation of their SEAP by presenting a monitoring report including an MEI (the so-called 'full report'). Based on these 315 signatories covering 25.5 million inhabitants, interim results have been reported in terms of progress towards the reduction of GHG emissions by 1464 signatories.

The CoM MEI dataset 2016 was then divided in two subsets:

1. The monitoring subset is composed of 315 signatories that submitted a full monitoring report at 4 September 2016;

2. The estimated subset refers to 1464 signatories which, according to the CoM framework, should have provided a full monitoring report as of September 2016.

The following procedure was carried out on the CoM MEI dataset 2016 in order to associate each signatory with the ancillary data required to perform the emissions projection:

1. Extraction from the Covenant of Mayors' database of the CoM MEI dataset 2016, as of 4 September 2016;

2. Harmonisation of the CoM MEI dataset 2016 with the commune centroids 2010 databases extracted from the Eurostat website[25]. The aim is to relate the signatories' administrative data at NUTS3 level with the geographical coordinates of the Local Administrative Unit (LAU) centroid;

3. Harmonisation of the CoM MEI dataset 2016 with the Degree of Urbanisation databases (DEGURBA) of the local administrative units in the EU-28 extracted from the Eurostat website[26];

4. Harmonisation of the CoM MEI dataset 2016 with the databases of the Heating Degree Days (HDD) at NUTS3 level[27], supplied by the JRC which provides near-real-time information on weather conditions across the EU.

Then the main factors were identified that drive the trends in GHG emissions.

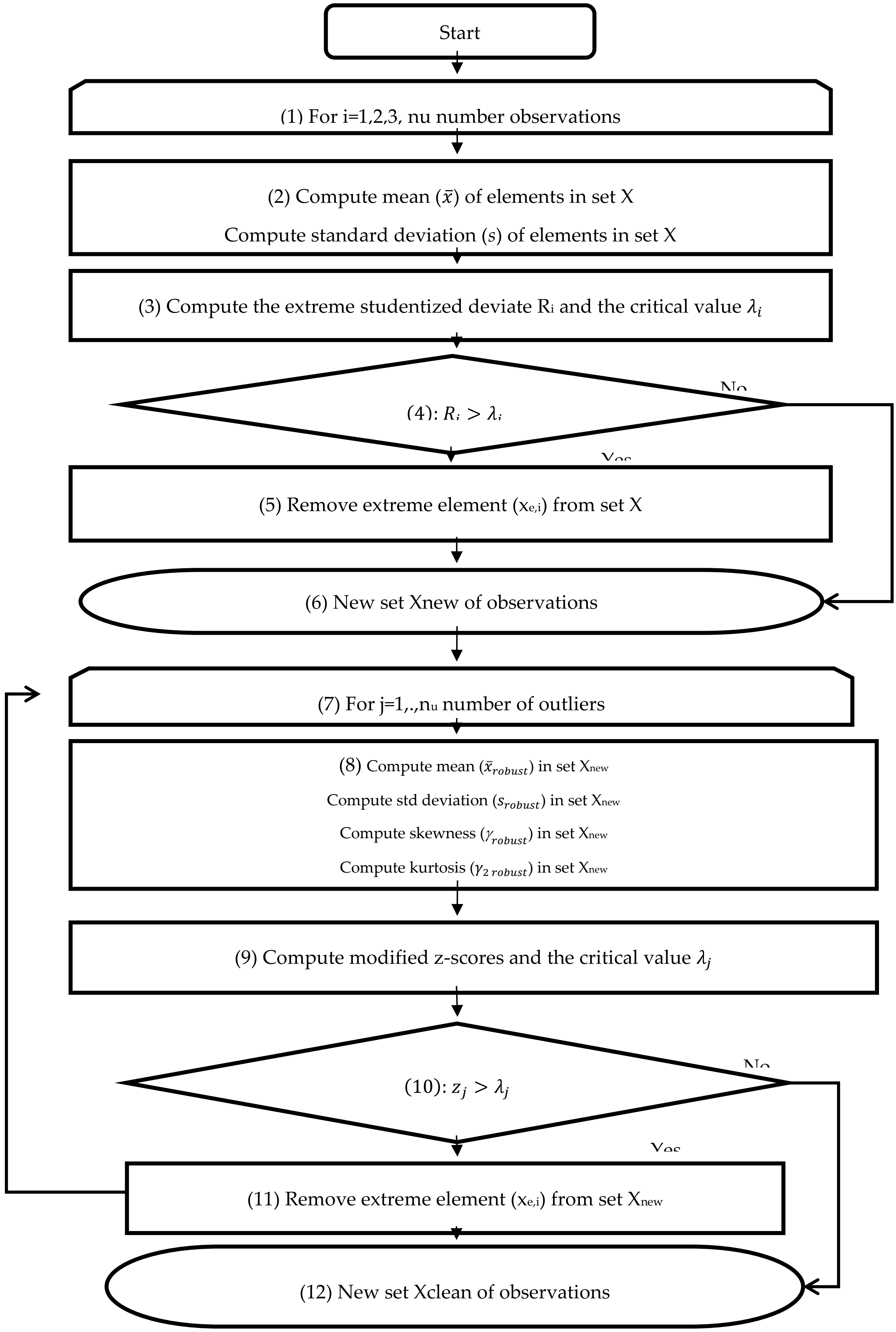
For the time being, research is being carried out into studies on the correlation between the direct factors that influence GHG emissions related to influences such as geographic context, urban form and density, economic activities, and emissions per capita in cities [25]–[34].

[25] Commune centroids 2010 (http://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units)

[26] http://ec.europa.eu/eurostat/ramon/miscellaneous/index.cfm?TargetUrl=DSP_DEGURBA of Degree of Urbanisation (DEGURBA) - Local Administrative Units

[27] http://agri4cast.jrc.ec.europa.eu/DataPortal/

Figure 17. Flow chart diagram of the selection procedure in the CoM dataset 2016



In this model, a signatories' clustering procedure has been developed based on the clustering of signatories with similar direct factors, including the geographic context (i.e. climate), the degree of urbanisation, the inventory year, and the target ambition reduction.

The actual influence of these factors on GHG emission trends was confirmed by a preliminary analysis of variance applied to the CoM MEI dataset 2016, and are briefly explained as follows:

1. Climate factor: various aspects of geography, such as climate, affect cities' contribution to climate change. Cities in a cold climate have higher emissions related to heating, cooling and lighting in winter, while those in warmer areas have higher electricity consumption linked to air-conditioning systems. Therefore, a clustering of cities based on climate has been performed as follows:
   - warmer climate (HDD < 2150)
   - intermediate climate (between 2150 and 3350 HDD)
   - colder climate (HDD > 3350)

2. Degree of urbanisation: urban form and urban spatial organisation can play a crucial role in a city's GHG emissions. Dense urban settlements with services concentrated may lead to a reduction of per capita emissions. Taking into account the harmonized definition of the degree of urbanisation based on Local Administrative Units for Europe [36], CoM signatories in the dataset were classified into categories according to those definitions. The degree of urbanisation (DEGURBA) classifies all the LAU2s (Local Administrative Units - Level 2/municipalities) into the following three categories:

   - Densely populated area: (alternate name: cities or large urban area): contiguous grid cells of 1km^2 population grid with a density of at least 1500 inhabitants per km^2 and a minimum population of 50 000;
   - Intermediate density area (alternate name: towns and suburbs or small urban area): clusters of contiguous grid cells of 1km^2 population grid with a density of at least 300 inhabitants per km^2 and a minimum population of 5000;
   - Thinly populated area (alternate name: rural area): more than 50 % of the population lives in rural grid cells.

3. Baseline Inventory Year: different years have been chosen in the dataset BEIs: most of the signatories in the monitoring sample (78 %) took 2005, 2007, or 2008 as their reference year with a 63 % share of the total inhabitants in the dataset. Therefore, a clustering of signatories has been carried out based on the baseline inventory year, as follows:

   - Earlier BEIs: Baseline Emission Inventory Years: 1990-2004
   - Recent BEIs: Baseline Emission Inventory Years: 2005-2014

4. Target ambition level: the emissions reductions targets are declared in the SEAPs, set according to the BEI, and generally are more ambitious in case of cities with a longer tradition in climate and energy planning. The aggregation of city's emission target has been done based on the assessment of the yearly emission reduction per capita Y_{Mi} calculated in equation 5 for the monitoring subset of the CoM MEI dataset 2016:

$$Y_{Mi} = \frac{\left(GHG\ emissions\ per\ capita\ _{inventories} - GHG\ emissions\ per\ capita_{monitoring}\right)}{(difference\ in\ years\ between\ inventory\ and\ monitoring\ years)} \qquad (5)$$

   Hence, the signatories of the subset where clustered in two classes:

- Moderate target: $Y_{Mi} \leq mean(Y_{Mi})$
- Ambitious target: $Y_{Mi} > mean(Y_{Mi})$

As a result of applying the Signatories' Clustering Procedure in the CoM MEI dataset 2016 – monitoring subset (315 complete inventories), 36 clusters were identified as the product of three types of climate; three types of degree of urbanisation; two types of baseline inventory years and two types of ambition reduction target. Furthermore, in order to define a robust dataset to be used as an estimator in the projections, not all the yearly emission reductions per capita were used. A range of reliable datasets on yearly emission reductions per capita has been chosen following equation 6:

$$mean(Y_{Mi}) - standard\ deviation(Y_{Mi}) \leq Y_{Mi} \leq mean(Y_{Mi}) + standard\ deviation(Y_{Mi}) \quad (6)$$

Due to the limitation of the sample in terms of frequency distribution into clusters, not all clusters are populated with data. Of the 36 clusters, only 30 have values. In addition, 7 out of 30 clusters have only one value in the cluster. Therefore, these 7 clusters will not be used in the projection exercise.

In conclusion, starting with the 315 complete inventories, only 263 of the monitoring subset, clustered into 23 classes, have been used in the projection exercise.

The same signatories' clustering procedure was also applied to the CoM MEI dataset 2016 – projection subset (1464 inventories) with identification of the first three drivers i.e. three types of climate; three types of degree of urbanisation; and two types of baseline inventory years in the projection sample are the same as the monitoring sample, while the clustering based on the ambition reduction target is different. The aggregation of cities' emission targets has been based on an assessment of the yearly emission reduction per capita Y_{Pi} calculated in equation 7 for the estimated subset of the CoM MEI dataset 2016. The $target_{2020}$ represents the CO_2 emission reduction target, defined in the SEAPs as the share of reduced CO_2 emissions compared to BEI emissions.

$$Y_{Pi} = \frac{(GHG\ emissions\ per\ capita_{\ inventories} * target_{2020})}{(difference\ in\ years\ between\ inventory\ years\ and\ 2020)} \quad (7)$$

Hence, the subset signatories where clustered into two classes:

- Moderate target: $Y_{Pi} \leq mean(Y_{Pi})$
- Ambitious target: $Y_{Pi} > mean(Y_{Pi})$

For each of the 1464 cities included in the CoM MEI dataset 2016 – estimated subset was estimated on the value of the emission reductions based on the following criteria:

- if the signatory was included in a cluster containing at least 2 cities from the monitoring sample, the average yearly emission reduction per capita of the monitoring subset was associated to the signatory. This procedure has been applied for 1357 signatories of the estimated subset;
- if the signatory was included in a cluster containing less than 2 cities from the monitoring subset, the linearly interpolated yearly emission reduction per capita between the baseline and the target year declared by the signatory was used. This procedure has been applied for 107 signatories of the estimated subset.

In conclusion, throughout the signatories' clustering procedure, starting with 315 complete inventories, interim provisional results on the progress towards GHG emission reduction in 2014 were projected to 1464 inventories. Only 23 clusters were used for the projection subset to estimate the yearly emission reduction per capita, while in the remaining 13 clusters the linear yearly emission reduction per capita is used. In overall the GHG emission reduction in the estimated subset resulted to a share of 22 %. However there is a degree uncertainty (± 2 %) in these projections especially because the sample from which they were derived was clustered; thus a level of uncertainty was introduced in the model. The uncertainty is calculated as the ratio between the standard deviation of the reductions and the square root of the observations [24]. The results are, by their very nature, affected by uncertainty and should be considered as provisional estimates pending the submission of the actual data from the signatories.

Annex II

Table 13. CoM signatories with a submitted SEAP (incl. BEI) and a submitted full monitoring report (incl. MEI) in the CoM dataset as of 4 September 2016

Region	Country	No. of submitted SEAPs CoM dataset 2016	Population covered in the Baseline Emission Inventory CoM dataset 2016	Number of signatories having submitted a full monitoring report	Population covered in the Monitoring Emission Inventory	Share of MEIs over SEAPs	Share of population in MEI over population SEAPs
EU-28	BE	176	5,661,567	1	82,499	1 %	1 %
	BG	23	2,251,065	1	90,000	4 %	4 %
	CZ	5	342,079	0		0 %	0 %
	DK	36	3,039,533	0		0 %	0 %
	DE	57	15,798,000	9	3,494,254	16 %	22 %
	EE	3	422,608	1	411,980	33 %	97 %
	IE	5	1,357,065	0		0 %	0 %
	EL	96	4,431,937	2	128,001	2 %	3 %
	ES	1376	25,535,260	103	4,140,329	7 %	16 %
	FR	78	14,673,075	2	103,310	3 %	1 %
	HR	61	1,911,914	3	951,478	5 %	50 %
	IT	2953	36,979,770	118	4,061,303	4 %	11 %
	CY	24	468,482	6	197,670	25 %	42 %
	LV	19	1,359,685	3	140,191	16 %	10 %
	LT	14	1,393,123	2	842,508	14 %	60 %
	LU	1	2,200	0		0 %	0 %
	HU	27	2,450,039	0		0 %	0 %
	MT	24	107,209	0		0 %	0 %

Region	Country	No. of submitted SEAPs CoM dataset 2016	Population covered in the Baseline Emission Inventory CoM dataset 2016	Number of signatories having submitted a full monitoring report	Population covered in the Monitoring Emission Inventory	Share of MEIs over SEAPs	Share of population in MEI over population SEAPs
	NL	17	3,468,572	1	166,443	6 %	5 %
	AT	12	1,691,014	3	47,881	25 %	3 %
	PL	34	3,611,352	4	1,987,540	12 %	55 %
	PT	111	5,782,660	24	1,222,987	22 %	21 %
	RO	52	3,322,492	3	178,860	6 %	5 %
	SI	29	707,506	0		0 %	0 %
	SK	4	526,932	0		0 %	0 %
	FI	10	1,594,207	1	612,594	10 %	38 %
	SE	52	3,675,294	16	2,351,146	31 %	64 %
	UK	33	17,495,217	5	2,429,057	15 %	14 %
	TOTAL EU-28	5332	160,059,857	308	23,640,031	6 %	15 %
Europe non EU	AL	1	620,000	0		0 %	0 %
	BA	18	1,246,480	1	56,727	6 %	5 %
	CH	9	772,347	2	420,084	22 %	54 %
	IS	1	116,642	1	121,116	100 %	104 %
	ME	3	173,301	0		0 %	0 %
	MK	1	600,000	0		0 %	0 %
	NO	8	1,027,069	0		0 %	0 %
	RS	1	257,867	0		0 %	0 %
	TR	9	8,498,086	0		0 %	0 %
	TOTAL	51	13,311,792	4	597,927	9 %	4 %
East Partnership and Central Asia	AM	7	1,179,157	0		0 %	0 %
	AZ	1	4,300	0		0 %	0 %

Region	Country	No. of submitted SEAPs CoM dataset 2016	Population covered in the Baseline Emission Inventory CoM dataset 2016	Number of signatories having submitted a full monitoring report	Population covered in the Monitoring Emission Inventory	Share of MEIs over SEAPs	Share of population in MEI over population SEAPs
	BY	7	325,708	0		0 %	0 %
	MD	12	304,729	0		0 %	0 %
	GE	10	1,923,700	1	1,175,200	10 %	61 %
	KZ	1	350,000	0		0 %	0 %
	TJ	1	20,153	0		0 %	0 %
	UA	57	6,772,298	2	102,700	4 %	2 %
	TOTAL	96	10,880,045	3	1,277,900	3 %	12 %
South Mediterranean	DZ	3	736,402	0		0 %	0 %
	IL	2	116,000	0		0 %	0 %
	LB	1	1,410	0		0 %	0 %
	MA	1	1,000,000	0		0 %	0 %
	PS	4	520,383	0		0 %	0 %
	TOTAL	11	2,374,195			0 %	0 %
Rest of the World	NZ	1	375,000	0		0 %	0 %
TOTAL		5491	187,000,889	315	25,515,858	6 %	14 %

References

[1] IPCC 2014, *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[2] European Environment Agency, "Total greenhouse gas (GHG) emission trends and projections," 2014.

[3] IEA International Energy Agency, "Energy Technology Perspectives 2016," *IEA*, 2016.

[4] P. Bertoldi, D. Bornas Cayuela, S. Monni, and R. Piers De Raveschoot, *How to develop a Sustainable Energy Action Plan (SEAP) - Guidebook.*, EUR 24360. Luxembourg: Publication Office of the European Union, 2010.

[5] P. Bertoldi, R. P. De Raveschoot, F. Paina, G. Melica, G. Janssens-Maenhout, O. A. Meijide, and A. Iancu, *How to develop a Sustainable Energy Action Plan (SEAP) in the Eastern Partnership and Central Asian Cities Summary.*, EUR 26741. Luxembourg: Publication Office of the European Union, 2014.

[6] A. K. Cerutti, G. Janssens-Maenhout, A. Iancu, I. Gabrielaitiene, G. Melica, P. Zancanella, and P. Bertoldi, *How to develop a sustainable energy action plan (SEAP) in the Southern Emission Inventory*, EUR 26545. Luxembourg: Publication Office of the European Union, 2013.

[7] G. Janssens-Maenhout, A. Meijide-Orive, D. Guizzardi, V. Pagliari, and A. Iancu, *An approach with a Business-as-Usual scenario projection to 2020 for the Covenant of Mayors from the Eastern Partnership*, EUR 25315. Luxembourg: Publication Office of the European Union, 2012.

[8] A. Iancu, A. K. Cerutti, G. Janssens-Maenhout, I. Gabrielaitiene, F. Paina, G. Melica, P. Zancanella, and P. Bertoldi, *How to develop a Sustainable Energy Action Plan (SEAP) in the Eastern Partnership and Central Asian Cities Part II. - Baseline emission inventories.*, EUR 25804. Luxembourg: Publications Office of the European Union, 2014.

[9] Y. Saheb, A. Kona, I. Maschio, and S. Szabo, *Guidebook How to develop a Sustainable Energy Action Plan (SEAP) in South Mediterranean Cities*, EUR 27016. Luxembourg: Publications Office of the European Union, 2014.

[10] S. Rivas, G. Melica, A. Kona, P. Zancanella, T. Serrenho, A. Iancu, B. Koffi, I. Gabrielaitiene, G. Janssens-Maenhout, and P. Bertoldi, "The Covenant of Mayors : In-depth Analysis of Sustainable Energy Actions Plans," Publication Office of the European Union, Luxembourg, 2015.

[11] A. Kona, G. Melica, I. Gabrielaitiene, S. R. Calvete, P. Zancanella, G. Janssens-Maenhout, and P. Bertoldi, *Covenant of Mayors: Fuel Switch and Sustainable Demand in signatories from "stress test" countries*, EUR 26951. Luxembourg: Publications Office of the European Union, 2014.

[12] A. K. Cerutti, A. Iancu, G. Janssens-Maenhout, G. Melica, F. Paina, and P. Bertoldi, *The Covenant of Mayors in Figures 5-Year Assessment*, EUR 25992. Luxembourg: Publications Office of the European Union, 2013.

[13] A. Kona, G. Melica, C. Rivas Calvete, P. Zancanella, A. Iancu, G. I., Y. Saheb, G. Janssens-Manhout, and P. Bertoldi, *The Covenant of Mayors in Figures and Performance Indicators: 6-year Assessment*, EUR 27110. Luxembourg: Publication Office of the European Union, 2015.

[14] A. Kona, P. Bertoldi, G. Melica, S. R. Calvete, P. Zancanella, T. Serrenho, A. Iancu, and G. Janssens-Manhout, *Covenant of Mayors : Monitoring Indicators*, EUR 27723. Luxembourg: Publication Office of the European Union, 2016.

[15] S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe, "2006 IPCC Guidelines for National Greenhouse Gas Inventories," *2006 IPCC Guidel. Natl. Greenh. Gas Invent.*, p. 6, 2006.

[16] S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller, *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. 2007.

[17] European Commission, "DIRECTIVE 2003/87/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC," *Off. J. Eur. Union*, vol. 2001, no. May, pp. 20–30, 2004.

[18] A. R. Neves, L. Blondel, K. Brand, S. Hendel-Blackford, S. R. Calvete, A. Iancu, G. Melica, B. Koffi, P. Zancanella, and A. Kona, *The Covenant of Mayors for Climate and Energy Reporting Guidelines*, EUR 28160. Luxembourg: Publications Office of the European Union, 2016.

[19] Seem., "Using intelligent data analysis to detect abnormal energy consumption in buildings.," *Energy Build.*, vol. 39, pp. 52–58, 2007.

[20] R. Bernard, "Percentage Points for a Generalized ESD Many Outlier Procedure," vol. 25, no. 2, pp. 165–172, 2016.

[21] J. M. G. T. Kenneth L. Lange, Roderick J. A. Little, "Robust Statistical Modeling Using the t Distribution," *J. Am. Stat. Assoc.*, vol. 84:408, pp. 881–896, 2012.

[22] L. Kenneth L., R. J., A. Little, M. Jeremy, and G.Taylor., "Robust Statistical Modeling Using the t Distribution."," *J. Am. Stat. Assoc.*, vol. 84:408, pp. 881–896, 2012.

[23] J. S. Simonoff, "Outlier detection and robust estimation of scale.," *J. Stat. Comput. Simul.*, vol. 27, pp. 79–92, 1987.

[24] F. Gant., *Understanding Statistics: Basic Theory and Practice. Basic Theory and Practise*. 2013.

[25] H. Bulkeley and M. M. Betsill, "Revisiting the urban politics of climate change," *Env. Polit.*, 2013.

[26] D. Dodman and W. I. Uwi, "Blaming cities for climate change ? An analysis of urban greenhouse gas emissions inventories," vol. 21, no. 1, pp. 185–201, 2009.

[27] H. Doukas, A. Papadopoulou, N. Savvakis, T. Tsoutsos, and J. Psarras, "Assessing energy sustainability of rural communities using Principal Component Analysis," *Renew. Sustain. Energy Rev.*, vol. 16, no. 4, pp. 1949–1957, 2012.

[28] D. Hoornweg, L. Sugar, C. Lorena, T. Gomez, and W. Dc, "Cities and greenhouse gas emissions : moving forward," vol. XX, no. X, pp. 1–21, 2011.

[29] C. Kennedy, N. Ibrahim, and D. Hoornweg, "Low-carbon infrastructure strategies for cities," *Nat. Clim. Chang.*, vol. 4, no. 5, pp. 343–346, 2014.

[30] C. Kennedy, S. Demoullin, and E. Mohareb, "Cities reducing their greenhouse gas emissions," *Energy Policy*, vol. 49, pp. 774–777, 2012.

[31] C. Kennedy, J. Steinberger, B. Gasson, Y. Hansen, T. Hillman, M. Havranek, D. Pataki, A. Phdungsilp, R. Anu, and V. Gara, "Methodology for inventorying greenhouse gas emissions," *Energy Policy*, vol. 38, pp. 4828–4837, 2010.

[32] K. Kern and H. Bulkeley, "Cities, Europeanization and multi-level governance: Governing climate change through transnational municipal networks," *J. Common Mark. Stud.*, vol. 47, no. 2, pp. 309–332, 2009.

[33] D. Reckien, J. Flacke, R. J. Dawson, O. Heidrich, M. Olazabal, A. Foley, J. J. Hamann, H. Orru, M. Salvia, S. D. G. Hurtado, D. Geneletti, and F. Pietrapertosa, "Climate change response in Europe : what ' s the reality ? Analysis of adaptation and mitigation plans from 200 urban areas in 11 countries," *Clim. Change*, vol. 122, pp. 331–340, 2014.

[34] S. Kilkis, "Composite index for benchmarking local energy systems of Mediterranean port cities," *Energy*, vol. 92, pp. 622–638, 2015.

[35] H. Medarac, N. Scarlat, F. Monforti-Ferrario, and K. Bódis, *Report on the impact of R1 climate correction factor on the Waste-to-Energy (WtE) plants based on data provided by Member States*. 2014.

[36] L. Dijkstra and H. Poelman, "Cities in Europe : The new OECD-EC definition," *Reg. Urban Policy*, p. 16, 2012.

[37] G. Melica, P. Zancanella, A. Kona, S. Rivas Calvete, I. Gabrielaitiene, A. Iancu, and P. Bertoldi, "The role of regions and provinces to support the participation of small local authorities in the Covenant of Mayors," in *14th IAEE European Conference. Rome, Italy,* 2014.

[38] J. G. J. Olivier, G. Janssens-Maenhout, M. Muntean, and J. A. H. W. Peters,

“Trends in global CO2 emissions 2015,” 2015.
[39] J. G. J. Olivier, G. Janssens-Maenhout, J. A. H. W. Peters, and M. Muntean, “Global trends of CO2 emissions: 2016 report, 103428 JRC/PBL report,” 2016.

List of abbreviations and definitions

BEI	Baseline Emission Inventory
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2–eq	CO_2 – equivalents
CoM	Covenant of Mayors
COP	Conference of the Parties
CTC	Covenant Territorial Coordinators
EC	European Commission
EDGAR	Emission Database for Global Atmospheric Research
EEA	European Environment Agency
ETS	Emission Trading System
ESD	Effort Sharing Directive
EU	European Union
GHG	Greenhouse gases
GWP	Global Warming Potential
JRC	Joint Research Centre
ICLEI	Local Governments for Sustainability
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
MEI	Monitoring Emission Inventory
MS	Member States
N_2O	Nitrous oxide
RES	Renewable Energy Source
RVA	Risk and Vulnerability Assessment
SEAP	Sustainable Energy Action Plan
SECAP	Sustainable Energy Climate Action Plan
UNFCCC	United Nations Framework Convention on Climate Change
UNDP	United Nations Development Programme

List of figures

List of tables

LD-NA-28155-EN-N

JRC Mission

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new methods, tools and standards, and sharing its know-how with the Member States, the scientific community and international partners.

Serving society
Stimulating innovation
Supporting legislation

Publications Office

doi:*10.2790/11008*

ISBN *978-92-79-63023-1*