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Covenant of Mayors: 2021 assessment

Climate change mitigation and adaptation at local level

Melica, G., Treville, A., Franco De Los Rios, C., Baldi, M., Monforti Ferrario, F.,Palermo, V., Ulpiani, G., Ortega Hortelano, A., Lo Vullo, E., Barbosa, P., Bertoldi, P.

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Contact information
Name: Giulia Melica
Address: Via E. Fermi 2749, Ispra (VA)
Email: Giulia.MELICA@ec.europa.eu
Tel.: +39 0332 78 9842

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https://ec.europa.eu/jrc

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Contents

Abstract

Cities and local authorities are key players in implementing the clean energy transition and addressing climate change. Since 2008, the European Commission endorses and supports their efforts through the Covenant of Mayors for Climate and Energy (CoM) and notably through the provision of capacity building, technical assistance, sharing of best practices and peer learning opportunities. This support is in line with the European Green Deal, the European Union (EU) strategy to cut emissions by 55% by 2030 compared to 1990 levels, and to reach climate neutrality by 2050 while creating jobs and growth. The initiative helps consolidate practices to monitor and report on energy consumption and greenhouse gas (GHG) emissions as well as on risks and vulnerabilities at the local level, allowing decision-makers to identify priority sectors, set emission reduction targets and climate change adaptation goals and plan relevant measures.

This report provides a scientific assessment of the CoM pillars of climate change mitigation and adaptation, based on data reported through the MyCovenant reporting platform. It describes the Covenant community, the plans submitted by signatories, examines actions and measures and gives an overview on the progress made on emission reduction comparing baseline and monitoring emission inventories.

The key findings on mitigation show that the overall commitment to reducing GHG emissions by signatories is 25.7% by 2020 and 44.5% by 2030 compared to baseline emissions. Looking at a subset of action plans with a 2020 time horizon from cities in EU-27 that also reported at least one monitoring emission inventory, on average GHG emissions were reduced by 26.1% between 2005 and 2020. On the other hand, looking at a subset of action plans with a 2030 timeline from cities in EU-27 which submitted a monitoring emission inventory, the forecast on expected achievements is not so optimistic, as their monitoring reports allow predicting a 37.8% reduction by 2030 (against 46.6% targeted reduction).

On adaptation to climate change, while committed signatories and adaptation action plans remain less numerous than mitigation ones, trends are very positive and figures are constantly growing. For example, considering the reported adaptation actions by year (2010-2020), the numbers are increasing at an exponential rate (from about 100 actions with 2014 as starting year, to over 3200 with 2020 as starting year), and the trend is projected to continue. The hazards reported the most in EU cities are floods & sea level rise, heavy precipitation, wildfires and extreme heat. The most-reported vulnerable sectors are agriculture & forestry, civil protection & emergency, environment & biodiversity, and health. Data shows potential incoherencies or “gaps” among the reported hazards and the hazards most addressed by actions.

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Executive summary

The Global Covenant of Mayors for Climate and Energy counts more than 10 500 cities and local governments that registered their commitments through the MyCovenant reporting platform. This report presents an analysis of the commitments made by those signatories, key figures based on more than 6 700 sustainable energy and climate action plans, and first results based on monitoring reports.

Policy context

Launched in 2008 with a main focus on abating energy-related emissions and targeting cities and local authorities from the EU, the CoM has grown in scope and in geographical coverage: the integration of the adaptation pillar in 2015 and the merger with the Compact of Mayors in 2017 originated the Global Covenant of Mayors for Climate and Energy (GCoM), the world's largest coalition of cities and local governments voluntarily committed to fight climate change. The EU and Global Covenant of Mayors continue to feature high in the EU policy agenda on climate and energy, and are explicitly mentioned in the European Green Deal communication, in the Climate Pact communication and, more recently, in the new EU strategy on adaptation to climate change.

In Europe, the Covenant originally required cities to commit to a minimum 20% GHG emission reduction target by 2020. In 2015, the minimum commitment was brought to 40% GHG emission reduction by 2030[1], aligned with the EU 2030 climate and energy targets. In 2021, the EU Covenant stepped up its ambition and aligned it with the EU goal to achieve climate neutrality by 2050.

Thanks to their proximity to citizens and local stakeholders, cities and local authorities are recognised by the European Commission as key partners to engage with to fight climate change locally.

Key conclusions

The CoM supports signatories' efforts through provision of guidance, technical support, sharing of best practices and peer learning opportunities. At the same time, it helps consolidate practices to monitor and report on energy consumption and greenhouse gas emissions as well as risks and vulnerabilities at the local level, allowing decision makers to identify priority sectors, set emission reduction targets and adaptation goals, and plan relevant measures.

The number of cities and local authorities committed to the GCoM and registered through MyCovenant is impressive. A large majority of them comes from the EU-27 or from other regions where the EU has been supporting the Covenant of Mayors since 2011 (notably Eastern and Southern Partnerships countries).

Most of the cities and local authorities remain committed only to 2020 mitigation targets and have not yet integrated a commitment to adaptation or renewed their pledges to 2030 or 2050.

As a result, the majority of submitted action plans has a focus on climate mitigation only and a time horizon limited to 2020. However, while committed signatories and adaptation action plans are less numerous than mitigation ones, figures are constantly growing. For example, considering the reported adaptation actions by year (2010-2020), the numbers are increasing at an exponential rate (from about 100 planned actions with 2014 as starting year, to over 3200 with 2020 as starting year), and the trend is projected to continue.

Many Covenant signatories are late on their action plans' implementation reports, in particular on quantitative reports that are needed to measure the achieved emission reduction. This might be due either to delays with action plans' implementation or to challenges in complying with the reporting timeline and requirements.

In terms of emission reduction ambition, we note that Covenant signatories collectively aim to higher emission reductions than the minimum targets set by the initiative for 2020 and 2030. In terms of emission reduction achievements, EU-27 signatories with a 2020 mitigation commitment seem to be well on track to reach their collective 2020 emission reduction target; to the opposite, for 2030 signatories a delivery gap is forecasted compared to their collective emission reduction target by 2030.

In terms of adaptation, we have noted that Covenant signatories are developing a thorough understanding of their climate risks and vulnerabilities. However, they are facing challenges in setting measurable goals prioritizing the hazards and impacted sectors to address. Consequently, the large number of planned actions

[1] For cities from Eastern Partnership countries the minimum emission reduction target is 30% by 2030.

are not directly linked to defined goals, making it challenging for signatories to measure their progress on adaptation.

In light of the increased ambition of the EU CoM soliciting signatories to reach climate neutrality by 2050 in line with the goals set in the European Climate Law, some action might be needed in order to encourage signatories to renew their commitments beyond 2020. Reinforced support could be necessary to help signatories report regularly on their action plans and to implement the actions they have planned in order to reach their mitigation targets and adaptation goals.

Main findings

The vast majority of Covenant signatories (63.2 %, covering 46 % of the signatories' population) remains committed only to the 2020 mitigation targets, while only 35.8% (representing about half of the CoM population) committed to a 2030 mitigation target combined with adaptation. The remaining 1% has a commitment to adaptation only or to adaptation combined with a 2020 mitigation target. It is nevertheless worth stressing that highly populated signatories show a distinct proclivity to commit to mitigation 2020, mitigation 2030 and adaptation.

86% of the submitted action plans only cover mitigation and about 14 % address both mitigation and adaptation, however the number of action plans with a commitment to a 2030 mitigation target and to adaptation is constantly growing.

Among the 5 991 plans with 2020 as the target year, about one third (covering nearly 40% of the population) set the minimum 20% emission reduction target required by the initiative, about 60% (covering almost half of the population) chose a target more ambitious than 20% but lower than 40%. The remaining 4% of the plans include a target of 40% by 2020 or higher. Looking at the 957 plans with a 2030 time horizon, we can see that more than 60% chose the minimum 40% target set for EU signatories, while about one fourth selected a more ambitious target, yet not as ambitious as the 55% headline target set by the EU for 2030. About 12% of the signatories set a target lower than 40%, which is allowed to CoM signatories outside the EU.

Based on data from 6 752 submitted action plans, the overall committed GHG emission reduction is 26 % by 2020 (compared to a baseline level of 965.7 $MtCO_2$-eq) and 44.5 % by 2030 (compared to a baseline level of 211.8 $MtCO_2$-eq). Looking only at signatories from EU-27, the overall committed reduction is 26.4 % by 2020 (relative to base year emissions of 797.9 $MtCO_2$-eq) and 46.6 % by 2030 (compared to a baseline level of 177.4 $MtCO_2$-eq). Almost all of the reported emissions in baseline emission inventories are related to energy use, with waste treatment playing a minor role in the inventories.

Based on a subset of 1 825 action plans in EU-27 with a commitment to 2020 followed by at least one monitoring report, it is estimated a 26.1% mean reduction from 2005 to 2020. As a result, from 2005 to 2020, cities positively exceeded their targeted mean reduction of 25%. Based on 326 action plans with a 2030 commitment and at least one monitoring report, the forecast on their expected achievements is not so optimistic, as their monitoring reports allow predicting a 37.8 % reduction by 2030.

Looking at the adaptation information coming from 953 action plans, several vulnerable population groups – including the elderly, persons living with chronic diseases, low-income households, and persons living in sub-standard housing – are exposed to climate hazards. Signatories report high-risk hazards – such as wildfires, floods & sea level rise, and heavy precipitation – that affect 18.8 million people, roughly equivalent to the populations of Sweden and Austria combined. The following sectors are the most reported by signatories in their action plans as vulnerable to their identified climate hazards: agriculture & forestry, civil protection & emergency, environment & biodiversity, and health.

However, adaptation action is growing: there are more than 10 000 reported actions so far and figures are increasing exponentially. While there is still a gap between identified risks & vulnerabilities and action taken, 53% of signatories reporting at least one high-risk hazard are also reporting already at least one matching action to address it.

Related and future JRC work

This report is part of a series of JRC reports assessing the CoM status (Cerutti et al., 2013), (A. Kona et al., 2016), (A. Kona et al., 2017), (P. Bertoldi et al., 2020), in order to track the overall progress of the initiative on the basis of action plans and monitoring reports transmitted by Global Covenant cities to the European Commission through the MyCovenant reporting platform.

Specific aspects of the Covenant are also explored in dedicated studies (e.g. multi-level governance models in the Covenant (Melica et al., 2018); review of reporting platforms (Bertoldi, Kona, Rivas, & Dallemand, 2018); projections towards Paris Agreement targets (A. Kona, Bertoldi, Monforti-Ferrario, Rivas, & Dallemand, 2018); methods on indirect emission accounting (A. Kona, Bertoldi, & Kılkış, 2019); climate mitigation policies (Palermo, Bertoldi, Apostolou, Kona, & Rivas, 2020); key factors enabling higher climate ambition (Rivas, Urraca, Bertoldi, & Thiel, 2021)).

Quick guide

This report provides a scientific assessment of the EU CoM and the GCoM by looking at data reported by signatories through the MyCovenant reporting platform until mid-May 2021. The assessment is based on climate change mitigation and adaptation plans and monitoring reports, examines planned and implemented policies and gives an overview on the progress achieved.

1 Introduction

The fight against climate change requires urgent action. The findings from the Working Group I contribution to the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) on the physical science basis of climate change highlight that the observed increase in GHG concentrations since around 1750 are unequivocally caused by human activity (IPCC, 2021). Energy production is one of the largest emitting sectors, mainly because of the reliance on fossil fuels, and therefore contributor to climate change. The report also stressed that climate change is already affecting every inhabited region across the globe and that there is growing evidence that human influence contributes to many observed changes in weather and climate extremes.

The level of awareness and concern about climate change is also growing among citizens: according to the latest Eurobarometer survey by the European Commission (EC) (European Commission, 2021), 93% of European citizens consider climate change a serious problem. 87% of the respondents think the EU should set ambitious targets to increase renewable energy and support energy efficiency. Six in ten respondents agree that adapting to the adverse impacts of climate change can have positive outcomes for citizens in the EU.

The EU recently stepped up its ambition in relation to climate mitigation: the European Green Deal Communication[2] and the 2030 Climate Target Plan[3] announced the intention of the EU to set more ambitious GHG emission reduction targets. The Climate Law[4] adopted in June 2021 set the legal objective for the EU to reach net-zero GHG emissions by 2050 and negative emissions thereafter, and an interim 55% emission reduction by 2030 compared to 1990 levels. The EU Climate law also requires Member States to establish multilevel climate and energy dialogues involving local authorities as well as other stakeholders to engage and discuss the achievement of the EU climate neutrality objective. In parallel, the EU is vying to revise its energy legislation to accelerate the transition and the uptake of renewables across the continent, including by empowering consumers and local authorities to play an active role in energy markets.

Acknowledging that the impacts of climate change are already occurring today, the new EU strategy on adaptation to climate change[5] aims to make adaptation smarter, swifter and more systemic and to increase support for international climate resilience. In this regard, it intends to support the further development and implementation of adaptation strategies and plans at all levels of governance and aims to spread adaptation awareness to every single local authority, company and household[6].

Against this backdrop, cities and local authorities are becoming increasingly aware of the key role they can play to combat climate change, being the level of governance closest to citizens and having the possibility to influence and take action on several sectors, including as regards the roll out of clean energy and energy efficiency. The EU CoM and the GCoM have been instrumental in spreading awareness on climate change among local governments and in providing methodologies and approaches to develop local climate and energy plans. For more than a decade now, cities and local authorities have been setting GHG emission reduction targets and adopted plans to tackle the key emitting sectors in their territories. More recently, they started to set adaptation goals and to adopt plans addressing the climate hazards and vulnerabilities in their territories.

1.1 The Covenant of Mayors: history, commitments and reporting requirements

The Covenant of Mayors was launched by the EC in 2008 with a target for participating cities to reduce GHG emissions in their territories by at least 20% by 2020 through the development and implementation of a Sustainable Energy Action Plan (SEAP). The initiative was very well received by cities and local governments

2 COM(2019) 640 final

3 COM(2020) 562 final

4 Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law')

5 COM(2021) 82 final

6 Among the actions from the EU Strategy of particular relevance to CoM signatories:
- increase funding opportunities to implement adaptation actions at the local scale;
- improve monitoring frameworks, develop indicators, and record data on climate-related losses (i.e., EU Risk Data Hub);
- create a "policy support facility" (CoM EU) to further support local and regional governments for a more systemic adaptation;
- further promote nature-based solutions for adaptation (biodiversity co-benefits)
- promote a socially-just transition, recognizing the higher impact of climate risks on vulnerable population groups, and avoiding reinforcing inequalities.

all over the EU and beyond, with thousands of signatories of all sizes, backgrounds and levels of experience joining enthusiastically and with regional and national authorities endorsing and supporting their efforts.

In 2014, based on the experience of the Covenant of Mayors and acknowledging the vulnerability of urban areas to the unavoidable impacts of climate change, the EC launched Mayors Adapt, a similar voluntary initiative with a focus on climate adaptation in cities.

The Covenant of Mayors and Mayors Adapt then merged in 2015, resulting in the Covenant of Mayors for Climate & Energy, which set a new target in line with the EU headline target of 40% GHG emission reduction by 2030 and integrated the adaptation pillar.

In 2017, the Covenant of Mayors for Climate and Energy and the Compact of Mayors joined forces becoming the GCoM, currently the world's largest coalition of cities and local governments voluntarily committed to fighting climate change.

As a result of the EU's commitment to reducing its net GHG emissions by at least 55% by 2030 and becoming climate neutral by 2050, in April 2021, the EU chapter of the GCoM initiative announced its renewed ambition[7], with participating cities pledging to the goal of climate neutrality by 2050 and to tackling in an integrated manner the three pillars of the initiative:

- climate mitigation;
- climate adaptation;
- energy poverty.

The key document to translate into climate action the vision of local authorities for both mitigation and adaptation to climate change is the Sustainable Energy and Climate Action Plan (SECAP). Detailed methodological guidance on how to develop a SECAP (Bertoldi, P., 2018) as well as guidelines on how to report on the SECAP (Covenant of Mayors Office, 2020) covering both mitigation and adaptation are publicly available free of charge. The energy poverty pillar is currently under development. Some key requirements of the initiative are briefly illustrated hereafter.

Within two years from signing up for the initiative, local authorities have to approve and submit a SECAP. The SECAP is the key document through which the Covenant signatory presents its vision and target, together with the measures to be implemented to achieve its climate mitigation target and adaptation goals. The SECAP covers the geographical area under the jurisdiction of the local authority and includes actions by both public and private sectors.

With regards to the mitigation pillar, the SECAP has to contain the results of the baseline GHG emission inventory, a GHG emission reduction target based on the country's or region's Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC) and a clear outline of the actions (including at least three key actions) that the local authority intends to take in order to reduce its GHG emissions. The SECAP may as well cover a longer period, in which case it is advised that the plan contains intermediate targets and goals for the year 2030.

With regards to the adaptation pillar, the SECAP includes the assessment of climate risks and vulnerabilities within the territory and a set of actions (including at least three key actions) to increase the resilience of the local authority sectors and vulnerable groups.

In January 2020, the SECAP template and related reporting guidelines were updated according to the Common Reporting Framework (CRF)[8] defined in the context of the GCoM.

Covenant signatories are required to report specific data and information on emission inventories and action plans, reflecting the content of the action plan formally approved by the local council, through one of the two officially recognised reporting platforms:

- MyCovenant[9]
- CDP-ICLEI Unified Reporting System (URS)[10]

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7 https://eumayors.eu/index.php?option=com_attachments&task=download&id=1017

8 Common Reporting Framework Available at https://www.globalcovenantofmayors.org/our-initiatives/data4cities/common-global-reporting-framework/

9 https://mycovenant.eumayors.eu/

10 https://www.cdp.net/en/cities-discloser

This report is based on data submitted through the MyCovenant reporting platform.

Box 1. 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:

1. Setting ambitious and quantified emission reduction targets;

2. Measuring their GHG emission level in a base year according to a common methodological approach;

3. Assessing climate risks and vulnerabilities in their territories;

4. Defining a strategy and concrete actions to mitigate and adapt to climate change;

5. Approving and making their action plan publicly available;

6. Regular reporting (both qualitatively and quantitatively) on the implementation of their action plan;

7. 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.

1.2 The role of the Joint Research Centre in the Covenant of Mayors

The Joint Research Centre (JRC) of the EC was entrusted since the launch of the initiative with the role of providing scientific, methodological and technical support to the EU CoM initiative to ensure its coherence with EU climate and energy policies as well as its scientific credibility.

One of the key tasks of the JRC is to assist signatories with the preparation and implementation of their action plans through the development of methodological guidebooks. With the extension of the CoM beyond the EU, the JRC has been responsible for adapting the CoM EU methodology to the environmental, economic and political conditions of other world regions (e.g. Eastern Partnership countries, (Kona A. , et al., 2018). Southern Partnership countries (Rivas, et al., 2018), Sub-Saharan Africa (Palermo, et al., 2019)). In this process, the JRC works closely with the consortium operating the EU Covenant of Mayors Office[11], with the Global Covenant of Mayors' Secretariat[12] as well as with other offices managing regional Covenants[13,14,15] with the goal of ensuring the feasibility of these methodologies. The JRC also contributes to the definition and regular update of the reporting framework.

The JRC is responsible for the evaluation of submitted action plans and the provision of feedback to signatories[16], with the objectives of verifying the compliance of the plan with the Covenant commitments, principles and methodological approaches, as well as of assessing the credibility of the action plan in relation to the set targets and goals. Through its feedback, the JRC may provide further guidance and suggestions to CoM signatories for the potential improvement of their plans. The JRC is also responsible for regularly publishing datasets of submitted action plans and monitoring reports as open data[17].

Finally, given the policy relevance of the initiative, the JRC prepares scientific publications on its outcomes and its impacts on local and EU policies in order to evaluate the policies adopted by local governments and their path towards the targets. Since 2013, the JRC has published a series of assessment reports on the Covenant of Mayors status (Cerutti et al., 2013), (A. Kona et al., 2016), (A. Kona et al., 2017), (P. Bertoldi et al., 2020) in order to track the overall progress of the initiative on the basis of action plans and monitoring reports transmitted by Covenant cities to the EC.

This report is the most recent of this series and provides a scientific assessment of the EU CoM and the GCoM by looking at data reported by signatories through the MyCovenant reporting platform. The assessment is based on climate change mitigation and adaptation plans and monitoring reports submitted by signatories, examines planned and implemented policies and gives an overview of the progress achieved.

11 https://eumayors.eu/about/support-the-community/office.html
12 https://www.globalcovenantofmayors.org/about/
13 http://com-east.eu/en/
14 https://www.com-med.org/en/
15 https://comssa.org/en/
16 Only to signatories from Europe, Eastern Partnership, Southern Partnership, and Sub-Saharan Africa.
17 https://data.jrc.cec.eu.int/collection/id-00172 ; https://data.jrc.cec.eu.int/collection/id-00354

In the context of the GCoM, the JRC collaborates with partners and other research institutions for aggregation reports[18] and co-chairs the GCoM technical working group (TWG) on data. This TWG cooperates with cities and city networks to develop an efficient and robust assessment, planning, reporting and monitoring framework by ensuring that the global initiative benefits to the maximum extent from the work, knowledge and resources placed over the years. A key output of the TWG on data has been the GCoM Common Reporting Framework (CRF)[19] (GCoM, 2018), which ensures compatible and comparable reporting approaches for signatories worldwide.

Specific aspects of the Covenant are also explored in dedicated studies, e.g., multi-level governance models in the Covenant (Melica et al., 2018); review of reporting platforms (Bertoldi, Kona, Rivas, & Dallemand, 2018); projections towards Paris Agreement targets (Kona A. , Bertoldi, Monforti Ferrario, Rivas, & Dallemand, 2018); methods on indirect emission accounting (Kona, Bertoldi, & Kılkış, 2019); climate mitigation policies (Palermo, Bertoldi, Apostolou, Kona, & Rivas, 2020); key factors enabling higher climate ambition (Rivas, Urraca, Bertoldi, & Thiel, 2021).

[18] The latest GCoM aggregation report is available at https://www.globalcovenantofmayors.org/impact2021

[19] https://www.globalcovenantofmayors.org/our-initiatives/data4cities/common-global-reporting-framework

2 Dataset construction and cleaning

Quantitative information analyses contained in this report are based on the CoM reference dataset. This dataset only includes GCoM signatories, coming from all parts of the world, who registered their commitment and reported their SECAPs through MyCovenant reporting platform (https://mycovenant.eumayors.eu/). Signatories reporting to the CDP-ICLEI URS[20] or through offline reporting tools are not part of the dataset and, therefore, not analysed in this report.

All information on their planned and measurable actions as they intend to implement them in their communities through regional and national Covenants is gathered through MyCovenant in an internal database. The overall data include the inventories (i.e., the signatories' baseline emissions and the monitoring emissions inventories, which should be submitted every two years after the submission of the SECAP), and also gather the planned actions by sectors along with all GHG emission reduction targets (for years 2020, 2030 and for long-term, approaching 2050), as well as risk and vulnerability information, goals and actions.

Assuring a good level of data quality has always been a challenging task: indeed, under the CoM framework, cities voluntarily report their own data, which naturally contains different sources of uncertainty. Such sources are of varied nature, for example, biased estimations, evident errors with respect to the CoM reporting framework, missing information or lack of coherence. From all of these possible drawbacks coming from the signatories' reported data, the JRC has acted mainly upon correcting evident mistakes, aiming at harnessing the quality of the available information on the cities' emissions and commitments. In consequence, after this JRC-harnessing process, a structured reference dataset has been published at the JRC Data Catalogue (https://data.jrc.ec.europa.eu/collection/id-00354).

The general methodology for extracting and harnessing the reference GCoM datasets from the full set of raw submissions consists of two parts, namely data extraction and data cleaning. The first part, described in the following Section 2.1, refers to the extraction and management of the data from the full MyCovenant set of submissions. The second part, which will be described in Part I – Mitigation pillar, takes more in-depth analysis, screening and cleaning the data from unexplainable outlier observations.

2.1 MyCovenant data management

All the data was extracted from the MyCovenant PostgreSQL database on May 20, 2021, making use of around 20 PostgreSQL queries. The signatories and the action plans were selected according to the following main criteria:

- Signatories with initiative status corresponding to 'published' (i.e., active, compliant with the reporting requirements) or 'on-hold' (i.e., active, but suspended due to non-compliance)
- Action plans with submission status 'submitted' or 'resubmitted'.

Different signatory profiles were excluded, notably: if they had initiative status corresponding to 'unpublished' (i.e., signatories that never concluded the registration process: 142 profiles) or 'under_evaluation' (i.e., not yet formally confirmed as signatories: 61 profiles), or if they had Covenant status null (i.e., cities and local authorities who have access to several resources on MyCovenant, but are not formally registered as signatories: 75 profiles). Besides, action plans with submission status 'under completion' (i.e., not submitted) were also excluded (2 917 plans).

Along the extraction process from MyCovenant, an important challenge consisted of linking each action plan with its commitments. A careful examination had to be performed, plan by plan, taking into account the date of submission of the plan, the level of completeness of the templates related to the plan, and most importantly, the presence of a reduction target[21]. This assignation between commitments and pillars had to be carried out manually, via an extensive and thorough exercise to minimise the risk of human errors.

The overall procedure was carried out using different types of software. The raw data extraction was performed on pgAdmin. Then, the raw data was integrated into structured tables using Python, where it was initially cleaned, also adding the extra variables for the GCoM IDs and the codes for Local Administrative Units

[20] In 2021, 121 European cities reported through CDP ICLEI URS.

[21] The presence of adaptation goals was not considered among the completeness criteria, since it was an optional information and its requirements in the reporting template was only introduced in 2020. However, the presence of at least one reported climate hazard was considered among the completeness criteria for adaptation plans. See also Section 5.2.

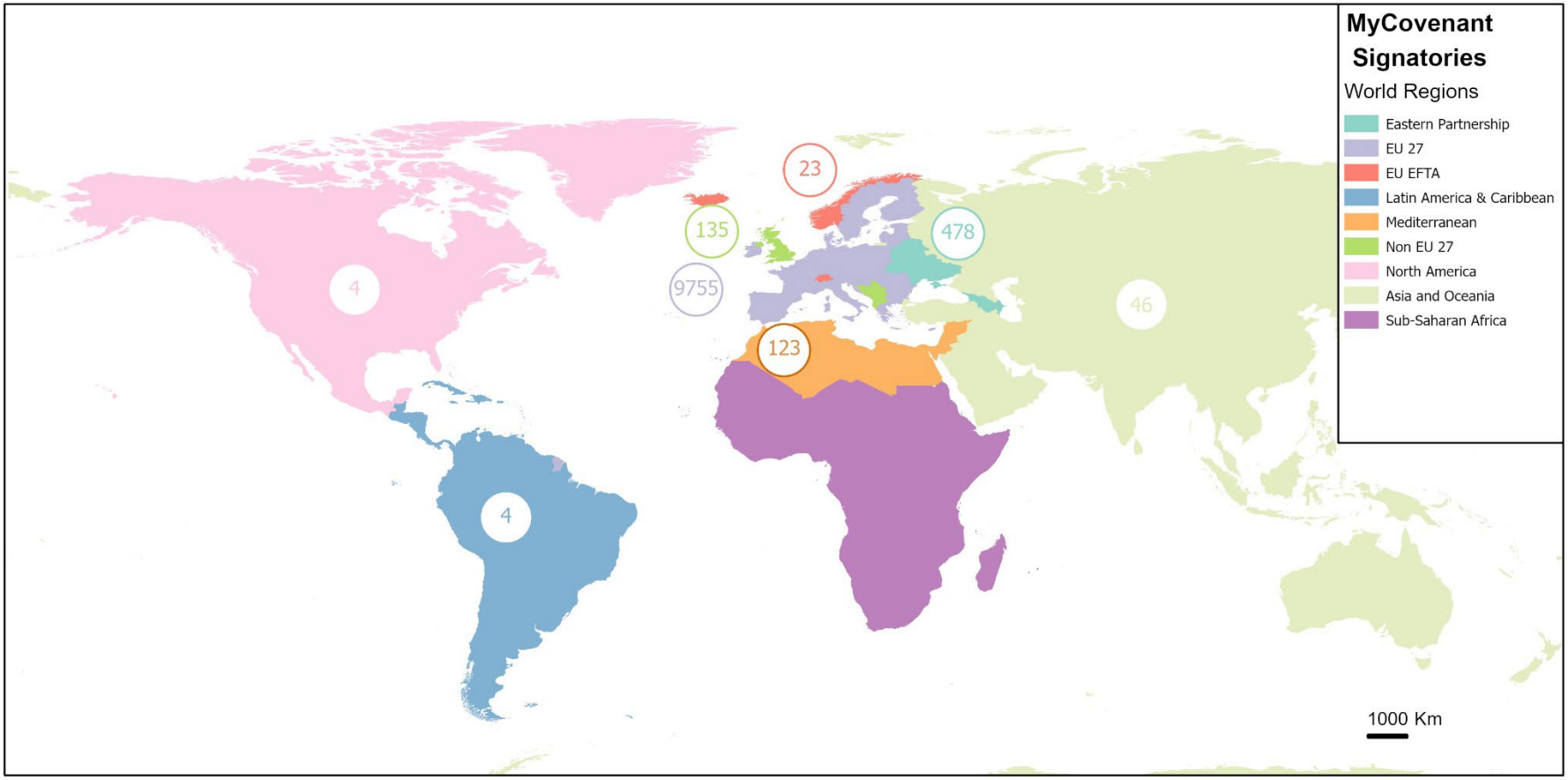
(LAU) and level 3 regions based on the Nomenclature of territorial units for statistics (NUTS3) from Eurostat. A later harnessing procedure was performed in R and Excel, as will be explained in the Mitigation (3.2.1) and Adaptation Chapters (5.2). Finally, the data was exported in Excel format for storage and publication.

Lastly, it should be stressed that the published reference GCoM dataset, titled "GCoM - MyCovenant, 2021", follows the FAIR guiding principles for scientific data management and stewardship (Wilkinson et al., 2016), being easily accessible, interoperable and reusable.

2.2 Signatories and commitments

At the cut-off date for the analysis (mid-May 2021), there was a total of 10 568 cities and local governments registered as CoM signatories through MyCovenant, covering a total population of 331.2 million inhabitants, as shown in Table 1. An overview of signatories from different world regions is presented in Figure 1.. Some of these cities and local governments have committed to submitting a joint action plan (i.e., a plan covering a group of local authorities) instead of an individual plan; thus, the number of expected action plans that should be submitted by those 10 568 signatories is 9 629.

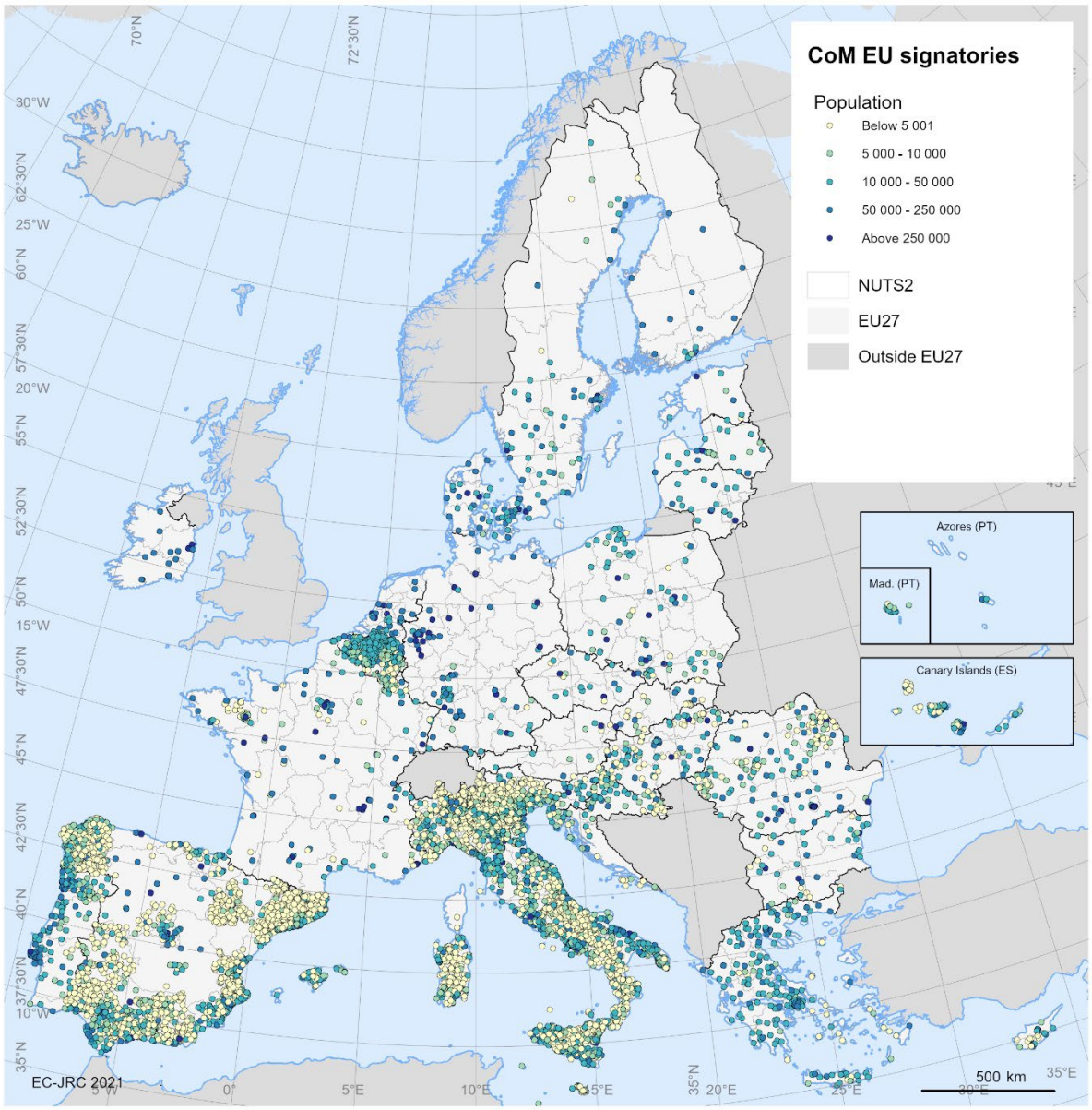
Figure 1. Overview of signatories registered through the MyCovenant reporting platform



Source: JRC elaboration based on GCoM data

As shown in Table 1, most of the signatories (9 755) come from the EU-27, covering 216.2 million inhabitants (about half of the EU population in 2020), followed by the Eastern Partnership countries (478 signatories, 32.6 million inhabitants), Europe – non-EU (158 signatories, 34.3 million inhabitants) and South Mediterranean countries (123 signatories, 12.6 million inhabitants). A smaller number of signatories come from other countries (54 signatories, 35.5 million inhabitants). Therefore, we can conclude that MyCovenant is mostly used by European signatories, as this platform was originally launched in Europe.

Figure 2. Signatories from EU-27, by population range. In the Nomenclature of Territorial Units for Statistics (NUTS) classification, NUTS2 indicates the basic regions for the application of regional policies.



Source: JRC elaboration based on GCoM data

Table 1. Overview of signatories and expected Action Plans.

Region	No. of cities and local governments committed to the CoM	No. of expected Action Plans, taking into account joint commitments	No. of inhabitants
European Union (EU-27)	9 755	8 827	216 160 693
Eastern Partnership (CoM-East)	478	478	32 611 084
Europe - Non EU-27	158	158	34 300 519
Southern Mediterranean (CoM-South)	123	112	12 563 135
Rest of the world	54	54	35 541 384
Total	**10 568**	**9 629**	**331 176 815**

Source: JRC elaboration based on GCoM data

Given that the Covenant initiative has evolved over time in line with the development in EU energy and climate policy, signatories have undertaken different commitments according to the moment of adhesion. The signatories' commitment may include a 20% mitigation target by 2020 (signatories of the Covenant of Mayors up to October 2015), a commitment to adaptation (Mayors Adapt signatories up to October 2015) and a combined adaptation with a 40% mitigation target by 2030 (the Covenant of Mayors for Climate and Energy), as well as all the combinations of these commitments. At the cut-off date (mid-May 2021), no signatories have committed yet to the renewed Covenant ambitions of 55% emissions reduction by 2030. That is likely because it was a recent update, launched in April 2021.

Table 2 and Table 3 show the number of signatories and the population covered by region, by commitment (mitigation, adaptation) and target year (2020, 2030), respectively:

- "Mitigation 2020" refers to signatories who committed only to the initial minimum target of a reduction in GHG emissions of 20% by 2020. The majority of signatories (6 681 signatories representing 151.5 million inhabitants) are in this group.
- "Mitigation 2030 and Adaptation" refers to signatories not previously involved in the CoM 2020 initiative who directly committed to the 2030 mitigation target and to address adaptation. It includes 2 333 signatories, covering 79.4 million inhabitants.
- "Adaptation" refers to signatories that signed up only to the Mayors Adapt initiative and did not commit to climate mitigation: 20 signatories, covering 2.8 million inhabitants.
- "Mitigation 2020 and Adaptation" refers to signatories that committed to the initial minimum 20% GHG reduction target by 2020 and to adaptation, but not to the 2030 mitigation target. It includes 83 signatories, covering 12.9 million inhabitants.
- "Mitigation 2020, 2030 and Adaptation" refers to signatories committed to the 2020 mitigation target that have subsequently renewed their commitment to 2030, both in terms of mitigation and adaptation. It includes 1 451 signatories, representing 84.6 million inhabitants.

Table 2. CoM signatories by region and by commitment.

Region	Mitigation 2020	Mitigation 2030 and adaptation	Adaptation only	Mitigation 2020 and adaptation	Mitigation 2020, 2030 and adaptation
European Union (EU-27)	6 386	1 907	19	78	1 365
Eastern Partnership (CoM-East)	139	277	0	0	62
Europe - Non EU-27	90	46	1	5	16
Southern Mediterranean (CoM-South)	41	80	0	0	2
Rest of the world	25	23	0	0	6
Total	**6 681**	**2 333**	**20**	**83**	**1 451**

Source: JRC elaboration based on GCoM data

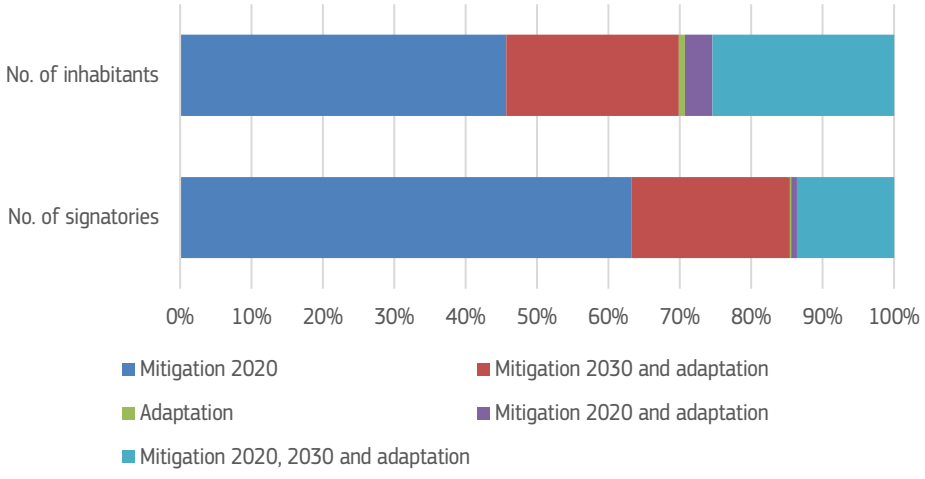
Table 3. Population covered by region and by commitment.

Region	Mitigation 2020	Mitigation 2030 and adaptation	Adaptation only	Mitigation 2020 and adaptation	Mitigation 2020, 2030 and adaptation
European Union (EU-27)	96 986 798	36 597 908	2 796 446	11 095 920	68 683 621
Eastern Partnership (CoM-East)	15 682 953	11 226 829	-	-	5 701 302
Europe - Non EU-27	22 886 255	6 153 840	45 750	1 763 531	3 451 143
Southern Mediterranean (CoM-South)	5 849 711	6 682 624	-	-	30 800
Rest of the world	10 114 400	18 709 385	-	-	6 717 599
Total	**151 520 117**	**79 370 586**	**2 842 196**	**12 859 451**	**84 584 465**

Source: JRC elaboration based on GCoM data

Despite the high number of signatories, the vast majority of them (63.2%, covering 46% of the inhabitants) remains committed only to the 2020 mitigation targets, while only 35.8% (representing about half of the CoM population) committed to a 2030 mitigation target combined with adaptation. The remaining 1% has a commitment to adaptation only or to adaptation combined with a 2020 mitigation target. It is nevertheless worth stressing that highly populated signatories show a distinct proclivity to sign for mitigation 2020, 2030, and adaptation (see Figure 3).

Figure 3. Number of signatories and population covered by commitment.



Source: JRC elaboration based on GCoM data

2.3 Submitted action plans

Following the data cleaning process described in section 3.2.1, the total number of signatories with an action plan retained in the dataset is 6 752, covering 236 million inhabitants.

Table 4 shows the number of submitted action plans by region, in total and for each commitment, while Table 5 shows the population covered in detail.

Table 4. No. of submitted action plans for each commitment.

Region	Total	Mitigation	Mitigation 2020	Mitigation 2030	Adaptation
European Union (EU-27**)**	6 393	6 363	5 763	815	818
Eastern Partnership (CoM-East)	231	231	123	112	107
Europe - Non EU-27	86	85	72	21	22
Southern Mediterranean (CoM-South)	25	25	21	4	2
Rest of the world	17	15	12	3	7
Total	**6 752**	**6 719**	**5 991**	**955**	**956**

Source: JRC elaboration based on GCoM data

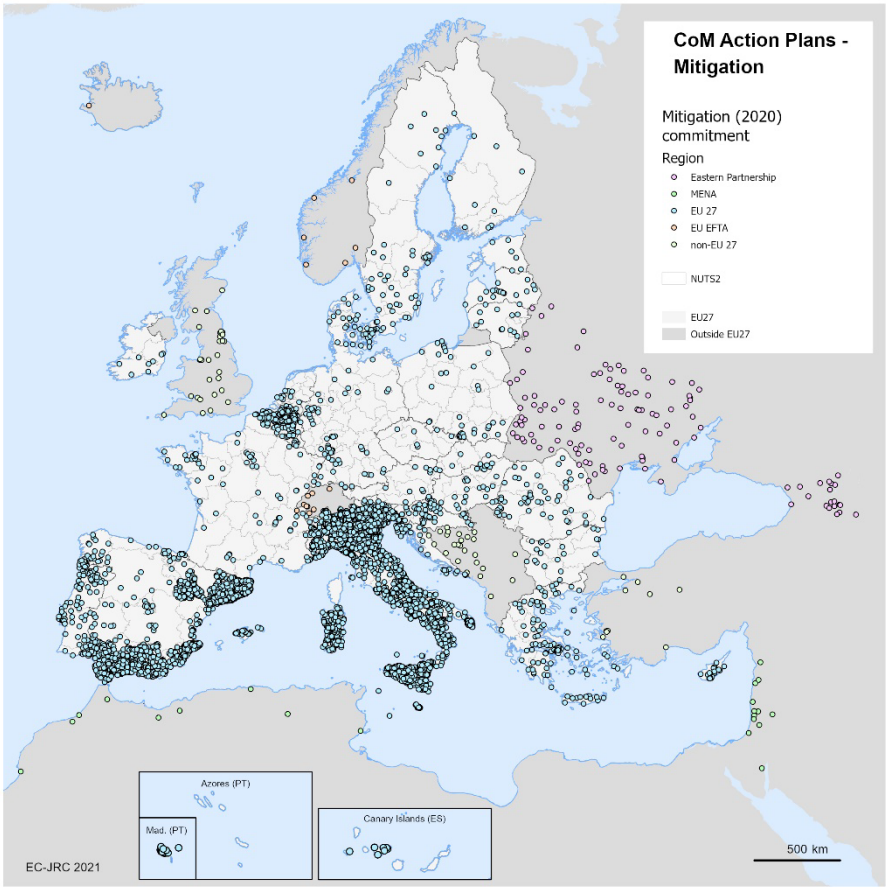
Table 5. No. of inhabitants in cities with submitted action plans.

Region	Total	Mitigation	Mitigation 2020	Mitigation 2030	Adaptation
European Union (EU-27)	171 826 538	171 290 586	154 526 287	34 409 414	36 321 870
Eastern Partnership (CoM-East)	20 350 966	20 350 966	15 091 211	5 459 368	5 286 087
Europe - Non EU-27	23 699 562	23 638 142	23 231 019	2 060 453	2 121 873
Southern Mediterranean (CoM-South)	4 250 254	4 250 254	3 876 225	374 029	126 029
Rest of the world	15 934 427	15 029 162	10 073 773	4 955 389	10 531 173
Total	**236 061 747**	**234 559 110**	**206 798 515**	**47 258 653**	**54 387 032**

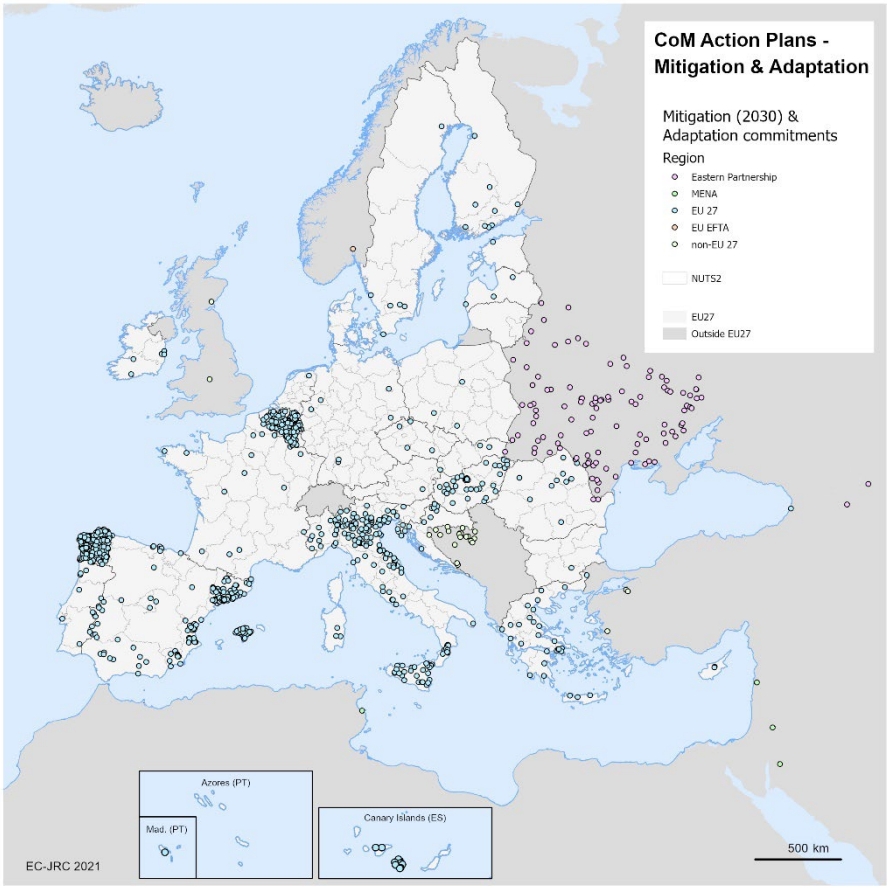
Source: JRC elaboration based on GCoM data

An overview of the signatories with a submitted action plan is provided Figure 4. Similarly to what we observed regarding the number of signatories, also the vast majority of action plans have a time horizon limited to 2020.

Figure 4. Overview of signatories with a submitted action plan covering only mitigation until 2020 (a) or both mitigation until 2030 and adaptation (b).



(a)

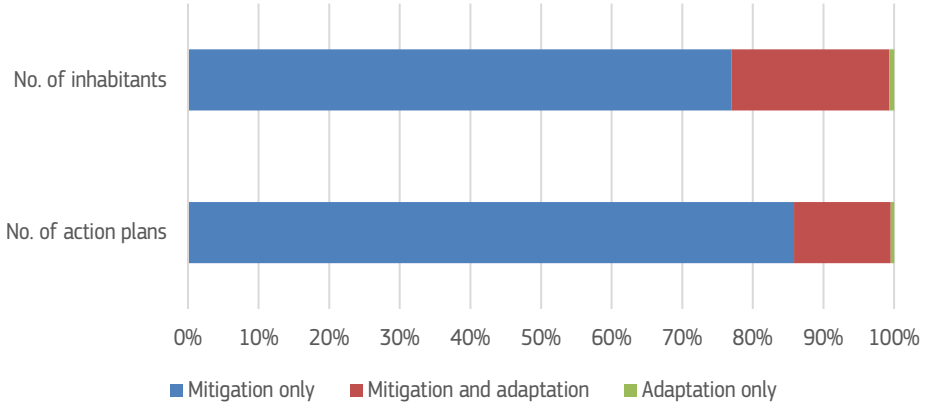


(b)

Source: JRC elaboration based on GCoM data

Looking at the action plans by pillars (Figure 5.), we note that 85.8% of the action plans (covering 77% of the population) only address the mitigation pillar and that just 13.7% of the actions plans (22.4% of the population) address simultaneously mitigation and adaptation. Less than 1% of action plans and population address the adaptation pillar alone.

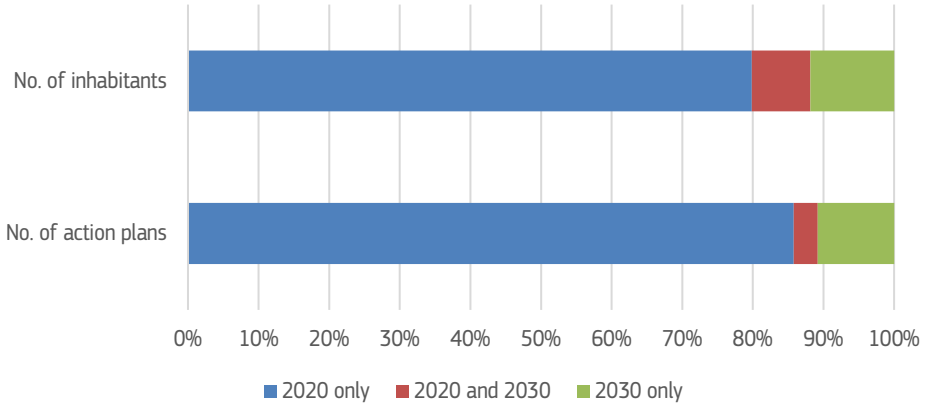
Figure 5. No. of action plans and population covered as a function of the pillar addressed.



Source: JRC elaboration based on GCoM data

Figure 6. shows the mitigation plans and the population covered as a function of the target year. We can see that 86% of the mitigation plans (covering 80% of the population) has a 2020 target only, with the remaining 14% of the mitigation plans having a 2030 target, either combined with a 2020 target (3.4% of the plans, 8.3% of the population) or not (10.8% of the action plans, 11.8% of the population).

Figure 6. No. of mitigation plans and population covered as a function of the target year.



Source: JRC elaboration based on GCoM data

2.4 Monitoring reports

Table 6 and Table 7 show that the number of signatories having submitted at least one monitoring report by the cut-off date is 2 592, covering 106.8 million inhabitants. That represents 38% of the signatories with an action plan and 45% of the population covered by action plans. The shares appear rather low and might reflect difficulties in complying with the reporting requirements or a lack of implementation of the action plans on the ground. However, it must be stressed that these percentages do not take into account how many signatories have actually reached the deadline to submit their first monitoring report.

Out of 2 592 signatories with a monitoring report, 1 370 (covering nearly 73 million inhabitants) submitted a monitoring report flagged as "complete", i.e., including at least one monitoring emission inventory. That corresponds to 20% of the signatories with an action plan and 31% of the action plans population. The other 1 222 signatories submitted a "light" monitoring report, mainly including qualitative information on the actions' implementation status.

Looking at different regions, we observe a higher share of monitoring reports over action plans from signatories from the EU-27. The CoM initiative has been established initially in the EU and has been extended later on to other regions, hence in the EU, a higher share of signatories may already be in the monitoring phase compared to other world regions (Figure 7).

Table 6. No. of signatories with at least one submitted monitoring report

Region	Signatories with at least one monitoring report, with or without MEI	Share of monitoring reports over action plans	Signatories with at least one monitoring report with MEI	Share of monitoring reports with MEI over action plans
European Union (EU-27)	2 511	39%	1 335	21%
Eastern Partnership (CoM-East)	59	26%	20	9%
Europe - Non EU-27	18	21%	13	15%
Southern Mediterranean (CoM-South)	1	4%	0	0%
Rest of the world	3	18%	2	12%
Total	**2 592**	**38%**	**1 370**	**20%**

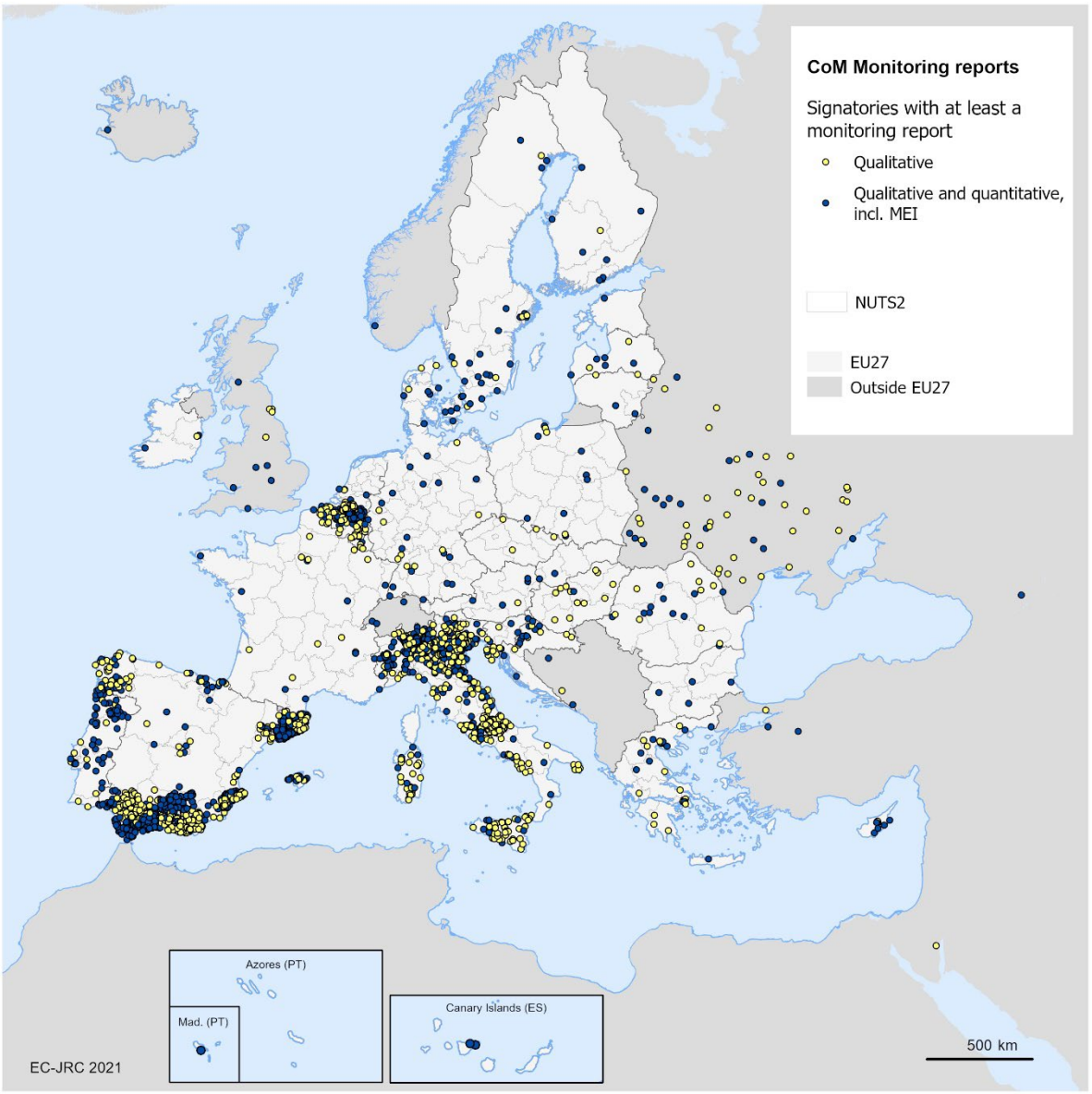
Source: JRC elaboration based on GCoM data

Table 7. No. of inhabitants in cities with submitted monitoring reports

Region	Signatories with at least one monitoring report, with or without MEI	Share of monitoring reports over action plans	Signatories with at least one monitoring report with MEI	Share of monitoring reports with MEI over action plans
European Union (EU-27)	91 773 842	53%	65 882 693	38%
Eastern Partnership (CoM-East)	8 389 037	41%	2 577 845	13%
Europe - Non EU-27	5 399 197	23%	3 818 028	16%
Southern Mediterranean (CoM-South)	63 000	1%	-	0%
Rest of the world	1 161 605	7%	709 303	4%
Total	**106 786 681**	**45%**	**72 987 869**	**31%**

Source: JRC elaboration based on GCoM data

Figure 7. Overview of signatories with at least one submitted monitoring report



Source: JRC elaboration based on GCoM data

3 Approach and methodology on mitigation

3.1 The Covenant of Mayors' approach to mitigation

A local authority willing to develop a climate mitigation plan should start by developing a Baseline Emission Inventory (BEI). The BEI quantifies the level of GHG emissions in a base year according to a common methodological approach (Bertoldi, P., 2018); it allows identifying the main emitting sectors and consequently prioritising areas for action.

Similar to the UNFCCC, the Covenant of Mayors recommends 1990 as the baseline year or the closest subsequent year for which the most comprehensive and reliable data can be provided.

Signatories are given various options to calculate their emission inventories. They can choose the standard IPCC approach[22], the Life-Cycle Assessment (LCA) approach[23] or National/sub-national emission factors which have been validated by a public body. In the IPCC approach (also referred to as the activity-based approach), emission factors are based on the carbon content of fuels. In the LCA approach, emission factors take into account the whole supply chain and not only the final combustion of fuels. Finally, signatories choosing to report according to National/sub-national emission factors will need to specify the emission factors used and provide the source/validating body.

According to the approach chosen and emitting sectors included in the inventory, signatories define the GHGs to account for: they may report only carbon dioxide emissions (CO_2) or also emissions of methane (CH_4) and nitrous oxide (N_2O), converted into CO_2-equivalents (CO_2-eq) according to their global warming potential.

The CoM inventories account for direct emissions (also referred to as Scope 1 emissions) generated within the territory of the local authority (e.g., from the combustion of fossil fuels) and for indirect emissions (also referred to as Scope 2 emissions) associated with the consumption of grid-supplied energy (electricity or district heating and cooling) irrespective of where the energy generation actually occurs.

The CoM inventories include the main sectors and sub-sectors not covered by the EU Emissions Trading System (EU ETS), as described in Table 8 [24]. Activity data and GHG emissions associated with energy supply are also calculated and reported in the context of the CoM inventories. However, they are not included in the total emissions since they are already captured through indirect emissions from grid-supplied energy. Indirect emissions associated with grid-supplied energy that is consumed in the territory of the local authority may cover electricity and heat/cold production plants involved in the ETS.

Notation keys may be used to accommodate limitations in data availability and differences in emission sources between local governments:

- "NO" (not occurring): this notation key applies to an activity or process that does not occur or exist within the city. It may also be used for insignificant sources.
- "IE" (included elsewhere): this notation key may be used for activity sectors whose GHG emissions are estimated and presented in another category in the same inventory, stating where it is added. It may be used where it is difficult to disaggregate data into multiple sub-sectors.
- "NE" (not estimated): this notation key applies to activity sectors whose GHG emissions occur but have not been estimated or reported, with a justification why.
- "C" (confidential): this notation key applies to activity sectors whose GHG emissions could lead to the disclosure of confidential information, and as such, are not reported publicly.

With the BEI results at hand, the local authority can identify the most emitting sectors in its territory and quantify the effort needed to reach the minimum target set by the initiative or possibly a more ambitious target. In addition to the BEI, CoM signatories may also calculate more recent emission inventories that would allow understanding emission trends in different sectors. Consequently, they may choose the priority areas for action, taking due consideration of the local/regional/national policy priorities and of existing opportunities available for achieving the target. The target can be set on an absolute or on a per capita basis; a third option, only given to CoM signatories from outside the EU, is to set the GHG emission reduction target based on a business as usual scenario.

[22] https://www.ipcc-nggip.iges.or.jp/EFDB/main.php

[23] For the LCA approach many datasets are available on the market.

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

Table 8. Description of the sectors and sub-sectors for GHG emission inventories in the CoM context.

Sector	IPCC (ref no.)	Subsector	Description
Stationary Energy / Buildings	1A4a	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.
		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.
		Tertiary 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.
	1A4b	Residential buildings	Energy consumption and GHG emissions in buildings that are primarily used as residential buildings. Social housing is included in this sector.
	1A1 1A2	Industries	Non-ETS: Energy consumption and GHG Emissions in manufacturing and construction industries not covered in the EU ETS.
			ETS: Energy consumption and GHG emissions to 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.
	1A4c	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.
Transportation	1A3a 1A3b 1A3c 1A3d 1A3e	Municipal fleet	All GHG emissions from fuel combustion and use of grid-supplied energy for transportation within the city boundary shall be reported and disaggregated by mode: on-road, rail, waterborne navigation, aviation and off-road: - 1A3b: on-road transportation: urban street network under the competence of the local authority; - 1A3b: on-road transportation serving a larger area and/or not under the competence of local authority (e.g., highways) may be included if mitigations actions are planned in that area - 1A3e: off-road transport: off-road traffic of vehicles/mobile machinery in any activity sector - 1A3c: rail transportation: local transport (metro, tram and local trains); long-distance trains, intercity trains, regional and cargo rail transportation may be included if mitigations actions are planned in that area
		Public transport	
		Private and commercial transport	

Sector	IPCC (ref no.)	Subsector	Description
			- 1A3d: waterborne navigation: local ferries in public and private transport acting on the local territory - 1A3a: aviation: local governments may choose to report GHG emissions from the in boundary component of domestic and/or international aviation (such as the landing and take-off cycle for aviation), or assume these are all out of boundary emissions and use the notation key "Included Elsewhere"
Waste	4A	Solid waste disposal	All emissions from solid waste that are disposed of at managed sites (e.g., sanitary landfill and managed dumps), and unmanaged sites (e.g., open dumps, including above-ground piles, holes in the ground, and dumping into natural features such as ravines).
	4B	Biological treatment	All emissions from biological treatment of waste, including composting and anaerobic digestion of organic waste.
	4C	Incineration and open burning	All emissions from waste that are burned either in a controlled, industrial, process or in an uncontrolled, often illicit, process. The former is often referred to as incineration, and the latter as open burning. Note that this excludes emissions from waste incineration for the purposes of energy generation, also known as energy recovery.
	4D	Wastewater treatment	All emissions from the treatment process of wastewater, either aerobically or anaerobically
Energy supply	1A1	Electricity-only generation	All activity data and GHG emissions from energy (both renewable and non-renewable) consumption for the purpose of generating grid-supplied electricity in power plants that solely generate electricity.
		Combined heat and power (CHP) generation	In the case of CHP plants, which generate heat and electricity simultaneously, or any other plants not listed, the amount of electricity produced, both from renewable and non-renewable energy sources shall be reported.
		District heating/cooling generation	All activity data and GHG emissions from energy (both renewable and non-renewable) consumption for the purpose of generating thermal energy in district heating/cooling plants
		Distributed local renewable energy generation	All activity data and GHG emissions from local energy generation (electricity, heat, etc.) facilities not grid-connected.

Source: Bertoldi P. (2018)

3.2 Statistical analysis

3.2.1 Harnessing the information in the GCoM datasets

The JRC-harnessing procedure followed some specific steps for enhancing the quality of the signatories' reported data. Emphasis was placed on energy consumption and supply together with their associated GHG emission inventories and on the declared actions set out to fulfil the signatories' 2020, 2030 and long-term commitments[25]. The harnessing of the supply data and mitigation actions was developed following some internal-consistency general rules that will be explained below, while for the cities' GHG emissions inventories, a more detailed analysis was performed.

For energy consumption and its associated emissions, the first task was to develop a general methodology for screening outlier energy-activity observations with respect to national (per capita) references. In this way, we compared the reported city energy activity with national energy consumption per capita reference values (Eurostat, 2021, IEA, 2021). In order to simplify the analysis, the complete methodology for screening outlier energy activity starts by grouping electricity separately from thermal carriers. For both groups, the industry sector is excluded, and national consumption references are taken for commercial and public services, road and residential sectors. After analysing the result of taking different thresholds, outliers (to the right) are tagged if the declared electricity consumption per capita is greater than five times the maximum threshold if the declared thermal activity per capita is greater than two times the maximum threshold, or (to the left) if the declared consumption per capita is less than a threshold of 0.01 (Megawatt Hour –MWh- per person per year).

In order to compute the maximum threshold for each group (by electricity and thermal carriers), countries are clustered together according to their national energy consumption per capita. The clustering technique that is applied consists of the k-medoids (Kaufman & Rousseeuw, 1990), where the selected partition is identified after minimising the dissimilarity among elements within clusters (the dissimilarity is measured as the sum of all absolute differences between the elements of clusters and their respective centroid). This method resembles the more popular one of the k-means, but it allows building partitions that are more robust to noise and outliers because it uses a median cluster centroid, referring to the most centrally located observation. Partitions of 2 to 5 clusters are considered, and a unique partition is identified according to relevant statistical indices measuring the density and separation between clusters (namely the Calinski-Harabasz, C-index, Davies-Bouldin and Dunn indices), also analysing if there are important differences between the respective thresholds and the observations being tagged as outliers. Following this approach, the chosen partition consists of two clusters with maximum thresholds of 2.95 and 13.17 (MWh per person per year), for electricity, and with maximum thresholds of 16.32 and 100.49 (MWh per person per year), for thermal carriers.

After completing the outlier screening process, a more exhaustive analysis is performed on the subset of inventories initially tagged as being outliers. Some outliers might actually be rare but correct, and if an evident error is detected, it can be corrected. For example, if the city reports in Kilowatt Hour (kWh) instead of MWh, or activity per capita instead of the overall value. Only if the reported values appear to be incomplete or to make no proper sense, like having non-positive consumption, for example, then the inventory is removed and cities are contacted to revise their reported information.

After the process, the cleaned dataset with the signatories' energy activity maintains the same number of action plans as the original one, but 20 individual emission inventories were disregarded.

Once the energy activity is cleaned from evident outliers, the emissions are estimated by multiplying the activity (MWh) times the corresponding emission factor. Cities report their own estimation of the emissions, making it necessary to validate the emission factors they used for computing their reported emissions. Those factors are validated against carrier-specific references taken from the JRC repository (Lo Vullo et al., 2020; Koffi et al., 2017). Only in case the emission factors reported by the cities are too different from the carrier-specific reference, then such a reference is taken in its place.

Regarding the internal consistency rules applied for cleaning the reported energy supply values, the following was implemented. Firstly, for local heat/cold energy and local-distributed electricity production, an implicit emission factor was computed between the reported supply and emissions, aggregating them by renewable and fossil sources. Setting lower and upper bounds for acceptable emission factors (see again

[25] For the procedure and data cleaning on adaptation information, see section 5.2.

Lo Vullo et al., 2020; Koffi et al., 2017), emissions were validated only if that implicit emission factor was less than 2 and greater or equal than 0.1 (tCO_2-eq/MWh) for fossil sources (0 for renewables). Secondly, considering renewable energy only for locally distributed electricity production, the reported energy supply was compared with energy consumption, and only if the energy produced was much greater than the consumption (over 150 times the reported consumption), it was taken out from the validated data set.

For certified green electricity purchases, the reported purchases were compared with electricity consumption, and they were validated only if the energy purchased was not greater than 1.05 times the electricity consumption.

On the commitments and mitigation actions included in the signatories' energy and climate action plans, the validation process consisted of an initial screening aiming at detecting evident inconsistencies in the reported data. After an initial assessment of acceptable commitments, they should consist of reasonable CO_2 targets, both under BEI and business as usual (BAU) scenarios, not greater than a 100% reduction of the baseline emissions. Then, following an empirical analysis, the proposed CO_2 reduction estimates were validated only if they were not greater than 2.2 times the targeted baseline emission reduction and less than the total baseline emissions. Likewise, estimated energy savings reported by the cities were checked for excluding values that were greater than 1.2 times the energy consumption. Further analysis was developed by action sectors, e.g., checking that the CO_2 reduction estimates by sector did not exceed the total reported emissions, or by computing an implicit factor between the estimates of CO_2 reduction and the sum of energy savings and production. Here, if such a factor was greater than 2 or less than 0.01 (tCO_2-eq/MWh), then the action-sector was excluded from the validated data set (again, the bounds for acceptable emission factors were based on Lo Vullo et al., 2020; Koffi et al., 2017).

Finally, regarding the actions' details, the mitigation estimated impact of CO_2 reduction was validated against the targeted CO_2 reduction estimates. It was considered, after empirical analysis, that the mitigation estimated impact could not be greater than 2 times the targeted CO_2 reduction estimates. Similarly to the validation of the mitigation sector, which was performed according to the implicit emission factor computed between the (reported) estimated CO_2 reduction and the sum of the estimated energy savings and renewable energy production, an analogous approach was followed for individual actions/measures: the action was validated only if the implicit emission factor was lower than 2 or greater than 0.01 (tCO_2-eq/MWh).

3.2.2 Statistical methods for emissions estimation and forecasting

Cities present their action plans (SEAPs/SECAPs), which include a BEI, the year against which the achievements of the emission reductions in the target year are measured. Following the plan submission, cities should present, ideally every two years, a monitoring report with its corresponding monitoring emission inventory (MEI), enabling them to follow the performance of their proposed actions according to their declared ambitions.

In order to develop the analysis of the cities achievements, emissions have to be converted into the same units (IPCC,tonnes CO_2-eq). Besides, the cities' emissions have to be estimated for a common baseline year and predicted for the target years that they have committed to. Accordingly, the baseline year is set to 2005, and for each city having presented at least one monitoring report, emissions are estimated for 2020 and forecasted to 2030.

Given the 'GCoM – MyCovenant, 2021' dataset (Baldi et al., 2021), the reported emissions can be aggregated after i) assuming that all emissions are reported in CO_2-eq, and ii) multiplying LCA inventories by a factor of 0.885, according to the fraction of direct emissions embedded in LCA inventories (Cerutti et al., 2013).

Since GCoM cities report their emission inventories for different years, estimations have to be performed to obtain the corresponding emissions on the same base year for all cities. The base year of 2005 is taken here as the general reference. For cities with a base year before 2005, the corresponding emissions for the base year 2005 are estimated by following the linear equation between the city's reported baseline inventory and its last monitoring inventory. Meanwhile, for cities with a base year after 2005, their value for a 2005 baseline inventory is adjusted according to the national per capita trend (national emissions are taken from EEA, 2021), multiplying their reported baseline inventory by a national per capita factor. Such a factor is obtained by dividing the national per capita emissions of 2005 over those in the reported base year.

On the other hand, for the years 2020 and 2030, the statistical methodology for estimating and forecasting the signatories' emissions consisted in identifying a predictive model for each city. This exercise only considers EU-27 signatories holding at least one monitoring report: 1 825 and 326 signatories with 2020 and 2030 commitments, respectively. Therefore, focusing on cities with at least one monitoring report besides

their baseline inventory, the emissions were forecasted by adjusting a model on their reported data. Such data allowed building a yearly time series, which was then modelled under a statistical methodology considering exponential smoothing, auto-regressive integrated moving average processes and artificial neural networks. In consequence, a unique model was selected for each city according to the minimum error of prediction computed for the last known emission value reported by each city. The summary of the complete methodology and the results are shown in Table A1 (see Annex 1). The proposed methodology allows controlling the uncertainty of the estimations, extracting reliable information pending the submission of the actual data from the signatories.

Lastly, the analysis of the cities' achievements for the reduction of GHG emissions is developed in absolute terms and per capita values. In order to compute the per capita scenario, the base year population of the inventory is replicated for 2005, and the 2020 and 2030 population is taken from the last available report, except if the city expects a significant change in their number of inhabitants. If the latter is the case, the population estimates for the target years are reported by the cities along with their per capita targets.

4 Results on mitigation

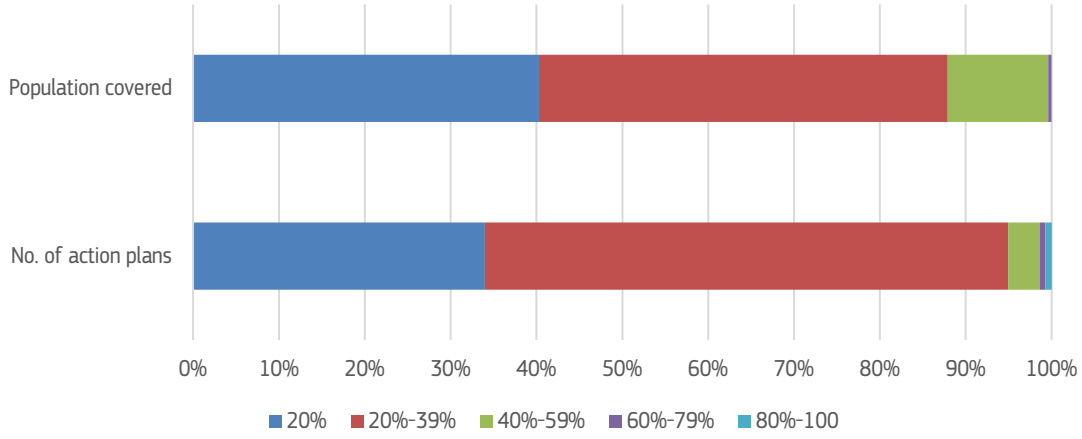
4.1 Emission reduction targets

Covenant signatories are free to set a GHG emissions reduction target more ambitious than the minimum target proposed by the initiative. As a result, we can see different levels of ambition among SEAPs/SECAPs.

Among the 5 991 SEAPs with 2020 as the target year (Figure 8.), about one third (covering nearly 40% of the population) set the minimum 20% emission reduction target required by the initiative, about 60% (covering almost half of the population), chose a target more ambitious than 20% but lower than 40%. The remaining 4% of the SEAPs include a target of 40% by 2020 or higher.

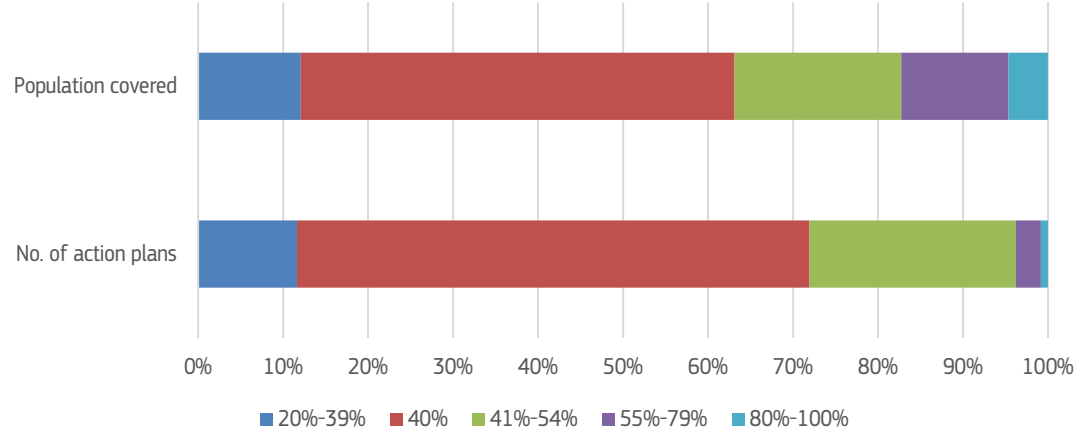
Looking at the 957 SECAPs with a 2030 time horizon (Figure 9.), we can see that more than 60% chose the minimum 40% target set for EU signatories, while about one fourth selected a more ambitious target, yet not as ambitious as the 55% headline target set by the EU for 2030. About 12% of the signatories set a target lower than 40%, which is allowed to CoM signatories outside the EU. High-population signatories showed a distinct proclivity to either high targets (above 54%).

Figure 8. Number of action plans with a 2020 horizon and population coverage as a function of the level of ambition of the target.



Source: JRC elaboration based on GCoM data

Figure 9. Number of action plans with a 2030 horizon and population coverage as a function of the level of ambition of the target.



Source: JRC elaboration based on GCoM data

Based on the targets set by cities and local authorities and the results of their baseline emissions inventories, the overall commitment by 2020 (Table 9) and by 2030 (Table 10) has been calculated. It appears that European signatories from non EU-27 countries are the ones with the higher level of ambition both by 2020 and by 2030, followed by EU-27 signatories.

Table 9. Overall commitment by 2020, based on submitted action plans.

Region	Total emissions in BEI [tCO_2eq/year]	Targeted emission in 2020 [tCO_2eq/year]	Overall committed reduction by 2020
European Union (EU-27)	797 908 020	587 318 590	26.4%
Eastern Partnership (CoM-East)	62 274 573	49 018 837	21.3%
Europe - Non EU-27	71 403 235	50 802 703	28.9%
Southern Mediterranean (CoM-South)	8 192 152	6 535 543	20.2%
Rest of the world	25 887 560	24 176 755	6.6%
Total	**965 665 540**	**717 852 428**	**25.7%**

Source: JRC elaboration based on GCoM data

Table 10. Overall commitment by 2030, based on submitted action plans.

Region	Total emissions in BEI [tCO_2eq/year]	Targeted emission in 2030 [tCO_2eq/year]	Overall committed reduction by 2030
European Union (EU-27)	177 360 220	94 786 847	46.6%
Eastern Partnership (CoM-East)	17 071 219	11 672 751	31.6%
Europe - Non EU-27	2 871 610	1 448 595	49.6%
Southern Mediterranean (CoM-South)	896 038	537 623	40.0%
Rest of the world	13 550 561	9 028 218	33.4%
Total	**211 749 648**	**117 474 033**	**44.5%**

Source: JRC elaboration based on GCoM data

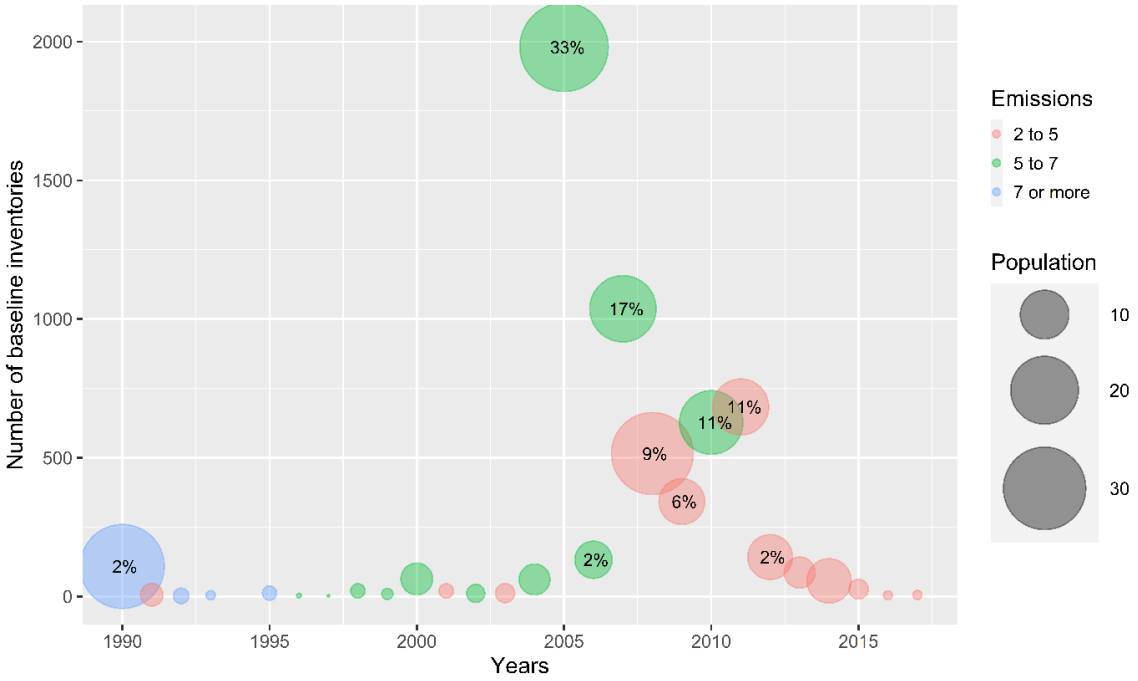
4.2 Baseline emission inventories

4.2.1 Baseline year

As mentioned previously in section 3.2.2, signatories are free to choose the base year against which their performance can be measured. Thus, different BEI years are selected, as shown in

Figure 10. and Figure 11., respectively, for 2020 and 2030 commitments. There are 1 881 signatories with 2020 commitments, the majority of which choose 2005 as their base year, representing 33% of all the BEIs (see Figure 10). This 33% represents a population of 34.6 million inhabitants, generating a medium level of emissions per capita of 5 tonnes CO_2-eq. Other frequently used base years are 2007, 2010 and 2011, including 17%, 11%, and 11% of all the plans, respectively. It is also observed that in 2008 there was a high number of inhabitants represented in 9% of all BEIs, with 29.5 million citizens, and a low level of emissions per capita, with 3 tonnes CO_2-eq. The highest level of emissions per capita appears to be associated with 1990 baseline inventories, holding 2% of all BEIs.

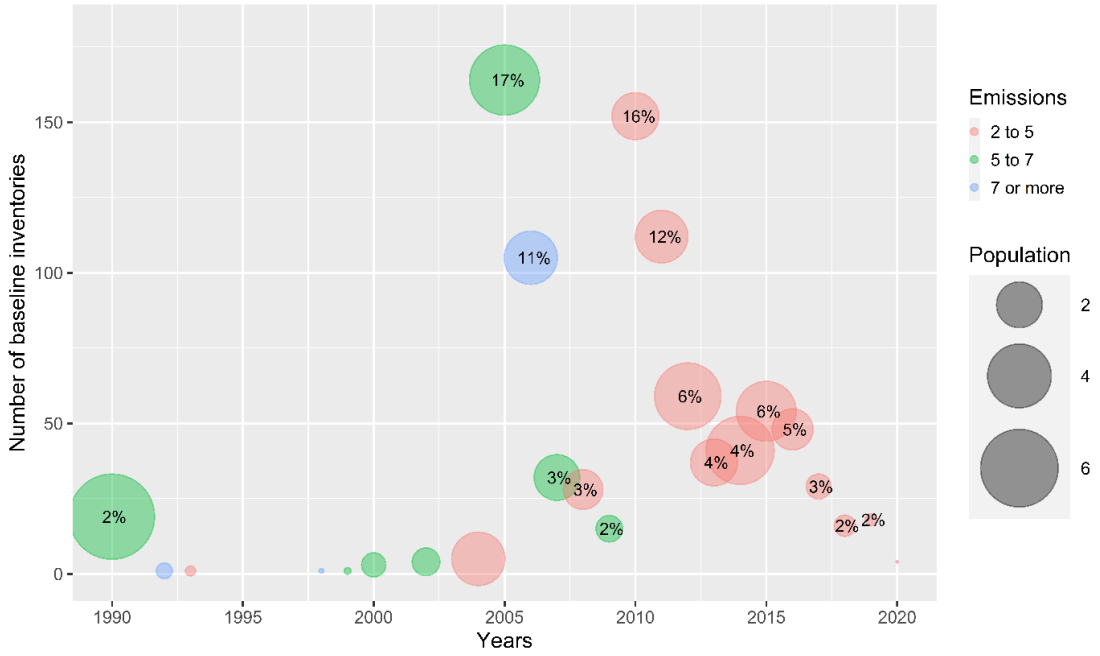
Figure 10. Frequency of BEIs for the different base years regarding 2020 commitments, along with the population (in millions) and emissions per capita (tonnes CO_2-eq) for every year.



Source: JRC elaboration based on GCoM data

Concerning 2030 commitments, there are 341 signatories, of which the majority again choose 2005 for their base year, representing 17% of all the BEIs (see Figure 11.). This 17% represents an approximate population of 4 million inhabitants with a medium level of emissions per capita (5 tonnes CO_2-eq). Other frequently used base years are 2010, 2011 and 2006, including 16%, 12% and 11% of all the BEIs, respectively. It is observed that the baseline inventories for 2006 have associated a high level of emissions per capita, while the ones for 2010 and 2011 exhibit a low level of per capita emissions. Besides, the year with the greatest proportion of population represented in the BEIs corresponds to 1990, containing 2% of all the BEIs with approximately 7 million inhabitants and a medium level of emissions per capita.

Figure 11. Frequency of BEIs for the different base years regarding 2030 commitments, along with the population (in millions) and emissions per capita (tonnes CO_2-eq) for every year.



Source: JRC elaboration based on GCoM data

4.2.2 GHG emissions in BEIs

This section provides a more detailed view of the GHG emissions declared by the signatories through their BEIs. The following table shows a finer disaggregation in terms of both sectors and energy carriers, separating commitments for 2020 (Table 11 and Table 12) from those focusing on 2030 (Table 13 and Table 14) for both EU-27 and non-EU signatories.

The largest part of emissions is reported by EU-27 signatories, namely 83% for 2020 commitments and 84% for 2030 commitments. For comparison, the overall amount of emissions declared by EU-27 SEAPs with 2020 horizon (Table 11) corresponds to about 27% of the overall EU-27 CO_2 emissions as estimated for 2019 by EDGAR (Crippa et al., 2020), showing how the CoM actually involves an important share of the GHG emission sources.

Almost the totality (>98%) of the reported emissions are related to energy use, with waste treatment playing a minor role in the inventories. Fossil fuels cause 58% of reported SEAPs 2020 emissions (56% for 2030 SECAPs), while electricity is the second carrier with 33% of reported SEAPs 2020 emissions (34% for 2030 SECAPs).

District heating follows with 6% of SEAPs 2020 reported emissions (7% for SEAPs 2030) while both renewable fuels and non-energy related emissions count for less than 2%. Such a picture does not change between EU and non-EU signatories, with the exception of non-EU SEAPs 2030, where fossil fuels play a somewhat smaller role (49% of emissions) while district heating is slightly more important (12% of emissions).

Table 11. GHG emissions reported in BEIs related to 2020 commitments – EU-27 (units tonnes CO_2eq/year).

Emissions in BEIs - 2020 SEAPs - EU-27 only

Sector	Electricity	District heating and cooling	Fossil fuels	Renewable fuels	Non-energy related emissions	Total
Industry Non-ETS	58 900 817	4 285 566	48 342 564	542 227		112 071 174
Industry-ETS	803 014	125	2 699 610	786		3 503 535
Municipal buildings, equipment/facilities	11 663 874	2 397 508	5 120 389	90 929		19 272 701
Residential buildings	80 604 304	20 899 714	105 027 511	5 042 301		211 573 831
Tertiary (non-municipal) buildings, equipment/facilities	85 150 710	8 227 641	55 100 988	298 628		148 777 967
Buildings, equipment/facilities non allocated	23 907 647	12 419 000	31 025 218	1 645 764		68 997 630
Municipal fleet	417 930	-	1 214 423	3 242		1 635 596
Public transport	2 777 264	-	4 308 997	40 944		7 127 205
Private and commercial transport	373 456	-	162 438 613	239 340		163 051 410
Transport non allocated	881 366	-	43 215 119	57 816		44 154 302
Agriculture, Forestry, Fisheries	1 739 438	305 533	4 662 533	1 665		6 709 169
Other non allocated	112 355	-	72 681	-		185 036
Waste management					9 537 237	9 537 237
Wastewater treatment and discharge					1 311 228	1 311 228
Total	**267 332 176**	**48 535 089**	**463 228 647**	**7 963 643**	**10 848 465**	**797 908 020**

Source: JRC elaboratin based on GCoM data

Table 12. GHG emissions reported in BEIs related to 2030 commitments – EU-27 (units tonnes CO_2eq/year).

Emissions in BEI - 2030 SEAPs - EU-27 only

Sector	Electricity	District heating and cooling	Fossil fuels	Renewable fuels	Non-energy related emissions	Total
Industry Non-ETS	12 980 791	1 209 071	8 531 259	161 424		22 882 546
Industry-ETS	244 538	-	14 934	1 195		260 667
Municipal buildings, equipment/facilities	2 311 010	388 427	1 013 651	4 221		3 717 309
Residential buildings	19 917 059	5 873 146	27 112 371	1 491 908		54 394 485
Tertiary (non-municipal) buildings, equipment/facilities	21 720 167	3 279 957	13 999 698	144 081		39 143 904
Buildings, equipment/facilities non allocated	360 245	11 411	1 130 735	44 855		1 547 247
Municipal fleet	22	-	482 407	4 212		486 641
Public transport	1 221 752	-	2 046 633	4 344		3 272 730
Private and commercial transport	93 766	-	38 671 008	153 721		38 918 494
Transport non allocated	38 807	-	7 461 614	12 517		7 512 938
Agriculture, Forestry, Fisheries	365 985	24 879	910 967	1 765		1 303 596
Other non allocated	102 411	98 310	39 266	62		240 048
Waste management					2 973 460	2 973 460
Wastewater treatment and discharge					706 156	706 156
Total	**59 356 554**	**10 885 202**	**101 414 543**	**2 024 306**	**3 679 616**	**177 360 220**

Source: JRCelaboratin based on GCoM data

Table 13. GHG emissions reported in BEIs related to 2020 commitments – Non-EU (units tonnes CO_2eq/year).

Emissions in BEIs - 2020 SEAPs - Non EU

Sector	Electricity	District heating and cooling	Fossil fuels	Renewable fuels	Non-energy related emissions	Total
Industry Non-ETS	13 731 603	140 022	29 929 713	38 848	-	43 840 186
Industry-ETS	114 062	1 412	94 788	-	-	210 262
Municipal buildings, equipment/facilities	2 729 516	1 273 868	1 476 113	4 536	-	5 484 033
Residential buildings	20 572 975	8 944 140	24 022 287	1 219 763	-	54 759 165
Tertiary (non-municipal) buildings, equipment/facilities	14 158 000	1 286 825	5 928 460	159 896	-	21 533 180
Buildings, equipment/facilities non allocated	2 108 566	108 849	2 638 833	33 505	-	4 889 753
Municipal fleet	11 585	-	239 292	2 271	-	253 148
Public transport	392 991	-	2 190 253	1 492	-	2 584 735
Private and commercial transport	9 481	-	25 268 471	7 836	-	25 285 787
Transport non allocated	-	-	5 188 875	1 564	-	5 190 439
Agriculture, Forestry, Fisheries	27 844	31	56 336	10 217	-	94 427
Other non allocated	1 366	-	-	-	-	1 366
Waste management	-	-	-	-	2 968 028	2 968 028
Wastewater treatment and discharge	-	-	-	-	663 010	663 010
Total	**53 857 987**	**11 755 147**	**97 033 418**	**1 479 929**	**3 631 038**	**167 757 519**

Source: JRC elaboratin based on GCoM data

Table 14. GHG emissions reported in BEIs related to 2030 commitments – Non-EU (units tonnes CO_2eq/year).

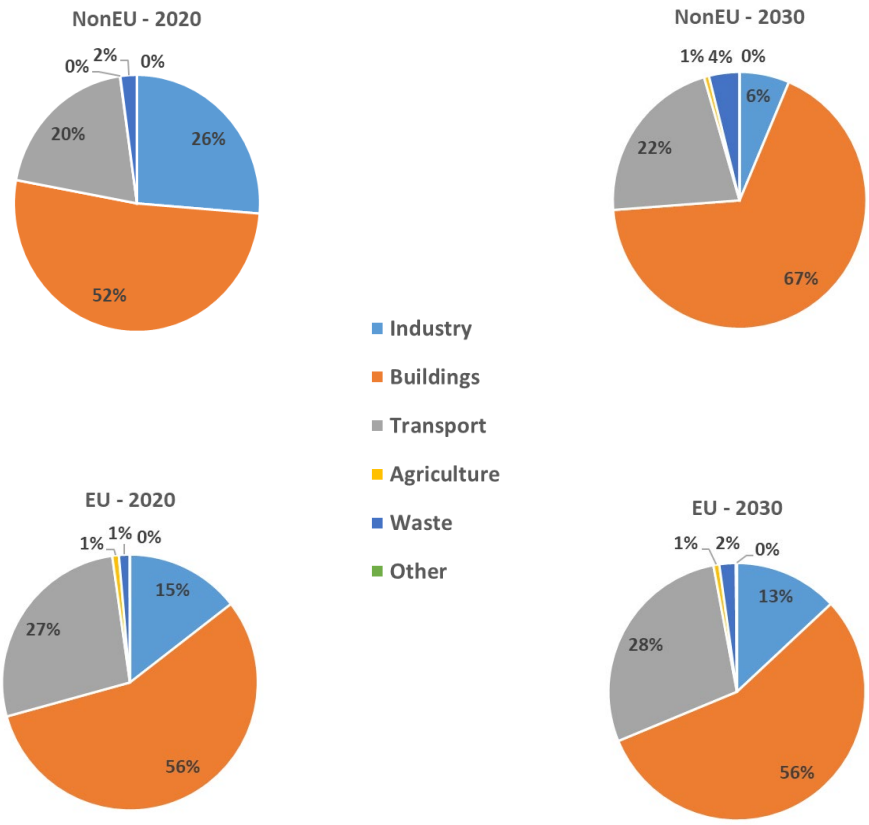
Emissions in BEI - 2030 SEAPs - Non-EU

Sector	Electricity	District heating and cooling	Fossil fuels	Renewable fuels	Non-energy related emissions	Total
Industry Non-ETS	322 907	51 374	348 525	15 744	-	738 549
Industry-ETS	1 315 859	-	129 058	1 747	-	1 446 663
Municipal buildings, equipment/facilities	907 089	870 972	389 485	98 602	-	2 266 148
Residential buildings	5 576 541	2 800 227	7 351 814	363 460	-	16 092 043
Tertiary (non-municipal) buildings, equipment/facilities	3 063 474	238 703	1 085 277	14 458	-	4 401 912
Buildings, equipment/facilities non allocated	1 178	-	436 344	-	-	437 522
Municipal fleet	5	-	83 455	2 228	-	85 688
Public transport	197 025	-	344 732	357	-	542 113
Private and commercial transport	1 583	-	6 788 074	31 701	-	6 821 358
Transport non allocated	-	-	309	-	-	309
Agriculture, Forestry, Fisheries	35 107	12 733	54 382	113 368	-	215 590
Other non allocated	1 366	-	-	-	-	1 366
Waste management	-	-	-	-	1 004 925	1 004 925
Wastewater treatment and discharge	-	-	-	-	335 242	335 242
Total	**11 422 133**	**3 974 009**	**17 011 455**	**641 665**	**1 340 167**	**34 389 428**

Source: JRC elaboratin based on GCoM data

Figure 12 shows the distribution of emissions taking into consideration a smaller number of more aggregated macro-sectors. Industry, buildings and transport regularly account for more than 95% of emissions, with buildings counting between half and two-thirds of the total. A more detailed view of these sectors is provided in the following paragraphs.

Figure 12. Distribution of emissions in BEIs by macro-sectors.



Source: JRC elaboration based on GCoM data

4.2.2.1 Buildings

Residential buildings account for more than half of emissions for both SEAPs 2020 and SEAPs 2030, with tertiary buildings being the second most important, with roughly one-third of emissions. Municipal buildings, under the direct control of the local administration, account for just about 5% of sectoral emissions.

Regarding energy carriers, the picture is very similar for both 2020 and 2030 SEAPs, with electricity and fossil fuels both accounting for 43%-45%, district heating around 10% and renewable fuels associated with just 2% of emissions. It is worth noticing that the district heating share is slightly higher, between 13% and 17%, in the case of non-EU SEAPs.

4.2.2.2 Industry

Industry emissions reported in both SEAPs 2020 and 2030 are largely dominated by the non-ETS sector, with a share between 93% to 98%. In fact, the CoM approach recommends excluding from GHG accounting the emissions associated with industries involved in the ETS (see also Table 8). From the energy carrier perspective, electricity and fossil fuels result in about 95% of emissions in all cases, with small variations for different time horizons and geographical areas. In general, electricity is more relevant for SEAPs 2030 than for SEAPs 2020, while in all cases, renewable fuels account for less than 1% of the emissions.

4.2.2.3 Transportation

Emissions from the transportation sector come from private and commercial transport, with about three-quarters of total emissions. The share of public and municipal fleets, in principle under the direct control of

local administrations, remains between 5% and 10%. A relevant share of non-allocated transport is reported, in some cases up to 20%. Fossil fuels overwhelmingly dominate the sector, constantly above 97%, with the rest of emissions mostly associated with electricity, being the renewable fuels below 0.5%

4.2.2.4 Waste (non-energy related emissions)

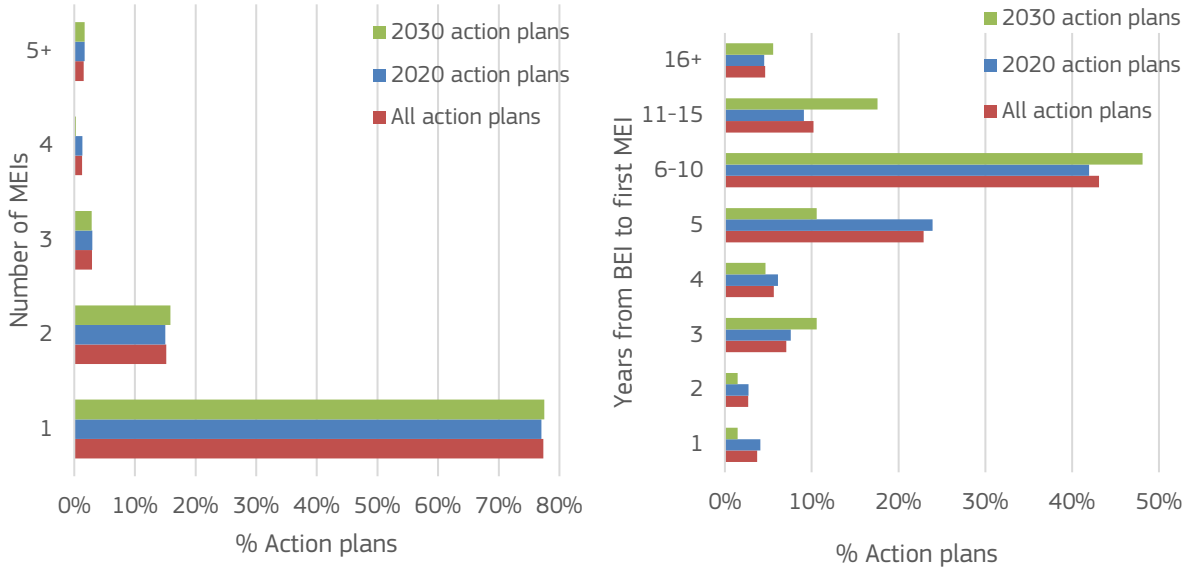
The waste sector produces non-energy related emissions, divided between actual waste management, accounting for between 80% and 85% of the emissions, and wastewater treatment producing the remaining emissions. Only in the case of 2030 committed SEAPs for non-EU signatories, such a division is slightly different, with waste treatment accounting for 75% of emissions.

4.3 Monitoring emission inventories

4.3.1 Monitoring years

Signatories are free to choose the monitoring years following their proposed action plans. Although it is recommended to have a monitoring report every two years (Bertoldi, 2018), few signatories provide a constant reporting history. Figure 13(a) shows the frequency of MEIs, where 77% and 15% of all action plans have reported 1 and 2 MEIs, respectively. Meanwhile, 43% of cities have taken between 6 to 10 years to present their first MEI, as shown in Figure 13(b).

Figure 13. For all action plans, (a) the frequency of monitoring reports and (b) the amount of years elapsed between the BEI and the signatories' first MEI.

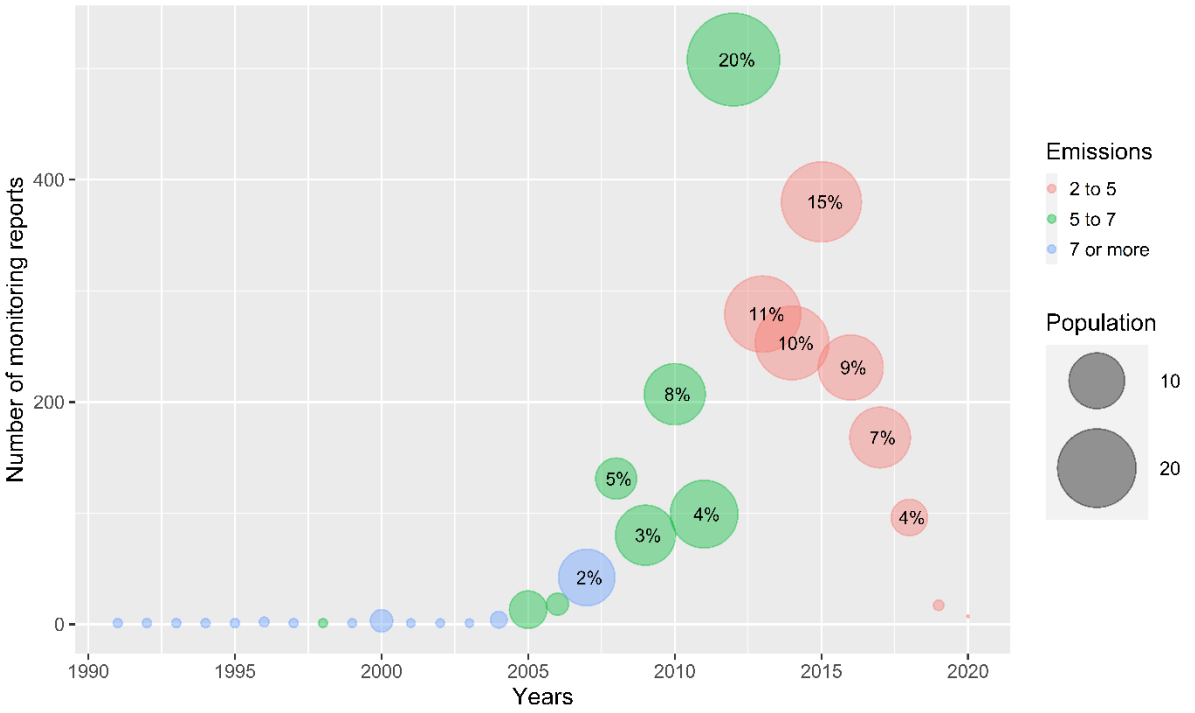


(a) (b)

Source: JRC elaboration based on GCoM data

Concerning 2020 commitments (see Figure 14), the majority of signatories choose 2012 as the monitoring year, representing 20% of all MEIs, also including an approximate population of approximately 28 million inhabitants and representing a medium level of emissions per capita. Other frequently used monitoring years are 2015, 2013 and 2014, respectively, including 15%, 11% and 10% of all the MEIs.

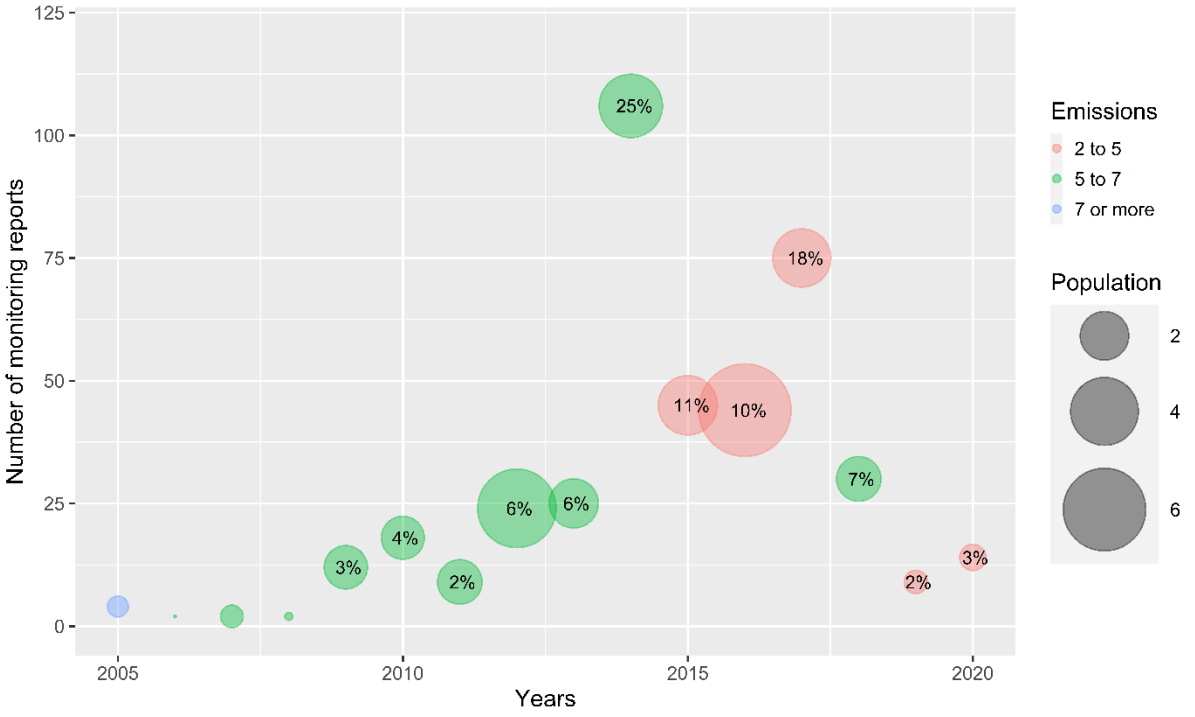
Figure 14. Frequency of MEIs for the different monitoring years regarding 2020 commitments, along with the population (in millions) and emissions per capita (tonnes CO_2-eq) for every year.



Source: JRC elaboration based on GCoM data

As for 2030 commitments (see Figure 15), the majority of MEIs (25%) have 2014 as the monitoring year, including an approximate population of 3.4 million inhabitants and representing a medium level of emissions per capita. Other frequently used monitoring years for 2030 targets are 2017, 2015 and 2016, respectively, including 18%, 11% and 10% of all MEIs. The latter, in fact, represents the highest number of inhabitants, around 7.5 million, followed by 2012 with around 5.4 million citizens.

Figure 15. Frequency of MEIs for the different monitoring years regarding 2030 commitments, along with the population (in millions) and emissions per capita (tonnes CO_2-eq) for every year.



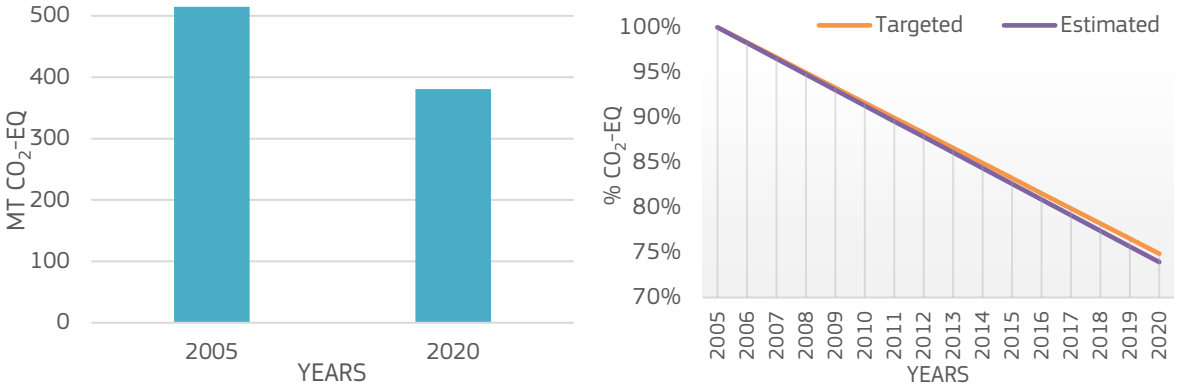
Source: JRC elaboration based on GCoM data

4.3.2 Reported progress in the European Union from BEIs to MEI

Following the statistical methodology described in the previous section 3.2.2, there are 1 825 action plans in EU-27 with a commitment for 2020, with a baseline inventory and at least one monitoring report. For this subset, it is observed that they achieved an estimated 26.1% mean reduction from 2005 to 2020[26], amounting to an absolute reduction of 134.15 Mt-CO_2 (see Figure 16(a)). As a result, from 2005 to 2020, cities positively exceeded their targeted mean reduction of 25%, by 1.1%, as shown in Figure 16(b).

[26] It is important to note that signatories choose any base year, and that this analysis sets the base year to 2005, which in fact can be farther away, or closer, to the target year. In case the actual base year occurs before 2005, the signatory's ambition (measured by the annual rate of reduction) will be higher (with respect to their chosen base year) when measured from 2005. Conversely, if the actual base year occurs after 2005, the signatory's ambition will be lower (with respect to their chosen base year) when measured from 2005.

Figure 16. (a) Total reduction of GHG emissions in EU-27 action plans for 2020 commitments and (b) trajectories of the 2020-targets and estimated emissions for EU-27 action plans.

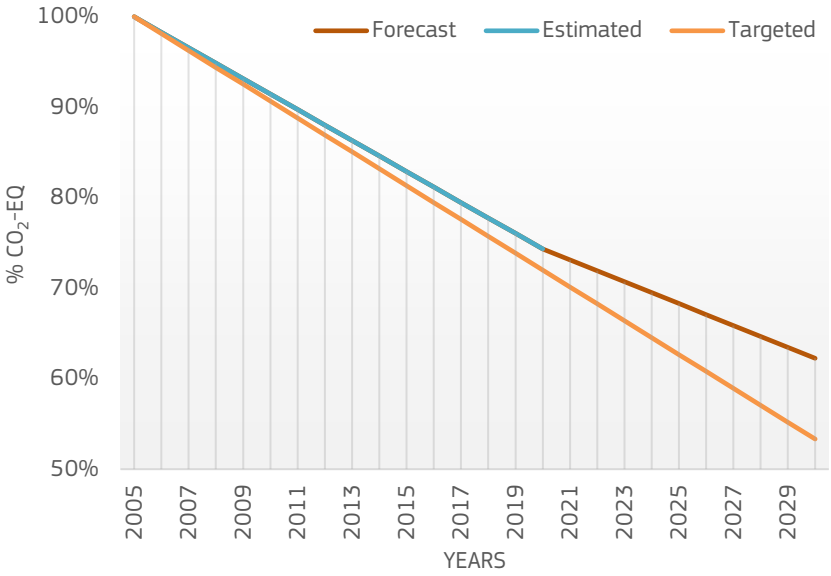


(a) (b)

Source: JRC elaboration based on GCoM data

On the other hand, there are 326 cities that signed a commitment for 2030, presented a baseline inventory and followed it by at least one monitoring report. These signatories have the ambition of reducing their emissions, on average, by 46.6%, setting the base year to 2005. Nonetheless, the forecast on their expected achievements is not so optimistic, as their monitoring reports allow predicting a 37.8% reduction by 2030 (see Figure 17). That would entail an absolute GHG emissions reduction of 41.72 Mt-CO_2.

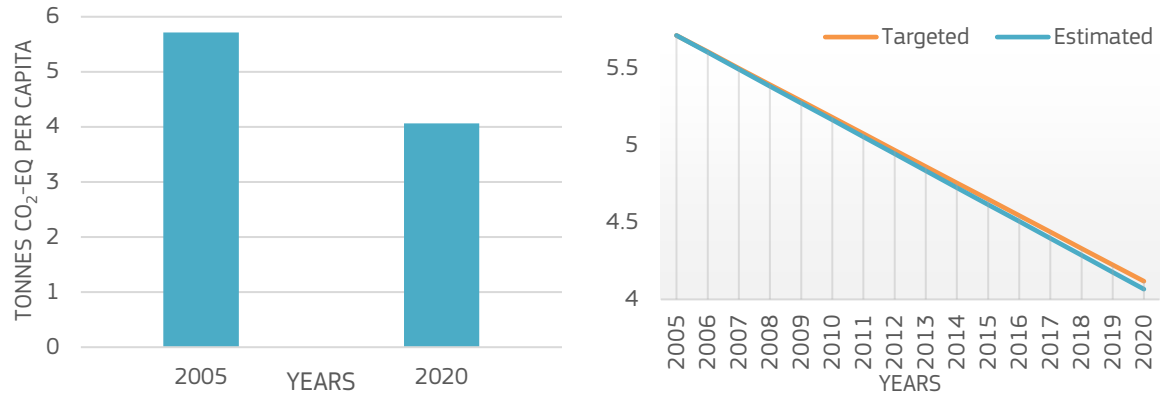
Figure 17. Trajectories of forecasted emissions and 2030 targets in EU action plans.



Source: JRC elaboration based on GCoM data

Extending the previous analysis to a *per capita* frame and taking into account the statistical methodology described in the previous Section 253.2.2, cities in EU-27 signing a commitment for 2020 achieved an estimated 29% reduction in the volume of their per capita emission inventories. The total GHG emissions reduction sums up to 1.65 tonnes-CO_2 per capita (as shown in Figure 18 (a)), positively exceeding by 1% the targeted mean reduction of 28% (for the period between 2005 and 2020), as shown in Figure 18(b).

Figure 18. (a) Per capita reduction of GHG emissions in EU-27 action plans for 2020 commitments and (b) trajectories of the 2020-targets and estimated per capita emissions for EU-27 action plans.

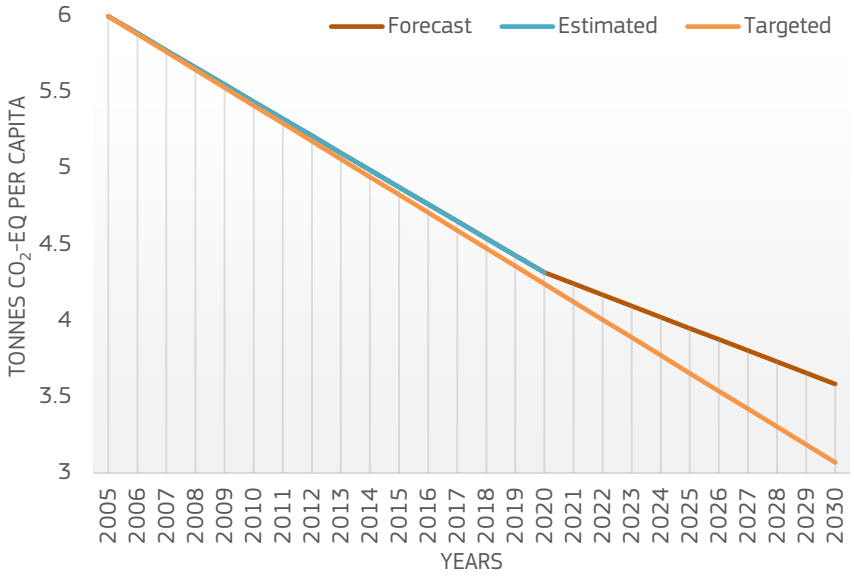


(a) (b)

Source: JRC elaboration based on GCoM data

As for cities committed to reducing their emissions in 2030, they are expected to accomplish a 40% reduction in tonnes-CO_2 per capita, hence achieving a total reduction of 2.4 tonnes-CO_2 per capita. Despite being an important effort, it falls short when compared to the cities' declared ambitions, aiming at a 49% reduction between 2005 and 2030. The trajectory of the cities' emissions against their proposed target is shown in Figure 19.

Figure 19. Trajectories of forecasted emissions per capita and 2030 targets in EU action plans.



Source: JRC elaboration based on GCoM data

4.4 Climate change mitigation actions and measures

In order to be able to submit their online template, Covenant of Mayors' signatories are required to list at least three mitigation actions/measures from their action plan. However, manylocal authorities prefer to report a more comprehensive list of actions, not only three; therefore, the analysed dataset contains **182 959 mitigation actions/measures** from signatories located in Europe and beyond, committed to 2020 and/or 2030 targets. That corresponds to an average of **27 mitigation actions/measures per action plan**.

The reporting template allows categorising the actions by the sector they address, the specific area of intervention and the type of policy instrument they rely upon. It also allows indicating the initiator of the actions, considering that a local action plan may also, to a certain extent, rely on measures decided by other levels of governance, such as the national or the regional one. This section describes the mitigation actions/measures based on the categories assigned by signatories.

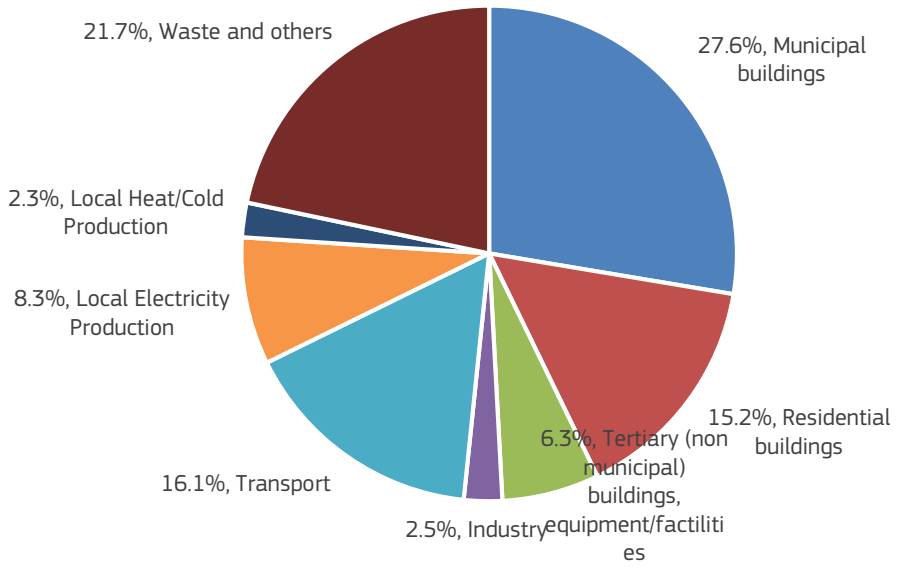
4.4.1 Actions/measures by sector

Mitigation actions/measures should target as a priority the most emitting sectors as per the baseline emission inventories. Based on the macro-sector they address, the actions/measures analysed can be grouped as follows:

- Stationary energy: 94 488 actions/measures
- Transport: 29 432 actions/measures
- Local energy production: 19 336 actions/measures
- Waste and others: 39 703 actions/measures

As shown in Figure 20, the preferred sectors for planning climate mitigation actions/measures seem to be those related to stationary energy: municipal, residential and tertiary buildings together with industry account for more than half (52%) of the actions listed in MyCovenant. The transport sector, accounts only for 16% of the planned actions/measures, despite representing 26-27% of emissions in the BEIs. About 10% of the actions are aimed at reducing emissions through local energy production (electricity and/or district heat/cold). Finally, 21.7% of the actions address waste and other sectors. That category is quite broad, as it also includes actions that were reported through a previous version of the online template, which included other sectors subsequently discontinued (e.g., awareness-raising and training, land use planning regulation, initially treated as "sectors" were later on classified as "policy instruments").

Figure 20. Share of mitigation actions/measures by targeted sector.



Source: JRC elaboration based on GCoM data

4.4.2 Actions/measures by area of intervention

The CoM reporting template allows signatories to classify their actions targeting each sector according to the specific area of intervention they tackle. This section analyses separately the four macro-sectors, as the areas of intervention are very different among them:

— Stationary energy

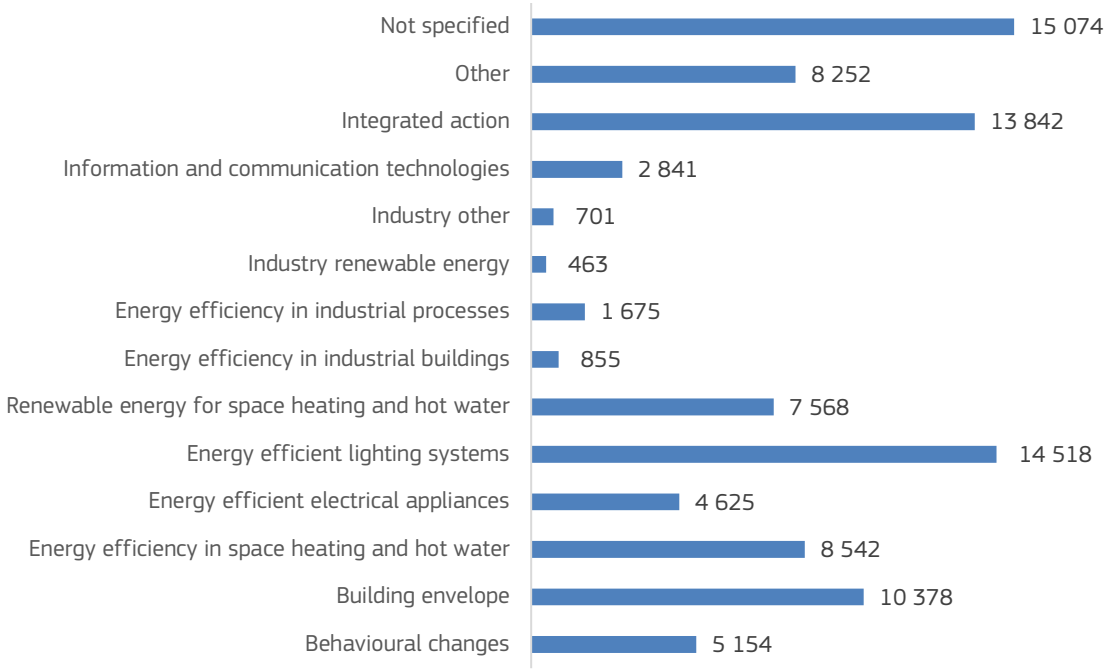
— Transport

— Energy production

— Waste and others

The stationary energy sector is addressed by 94 488 actions/measures: the majority of them aim at improving the energy efficiency of lighting systems, building envelopes, space heating and hot water systems, as well as electric appliances (Figure 21). Many measures are also aiming at promoting renewables for space heating and hot water (notably through solar thermal collectors and biomass boilers). A lower share of actions/measures targets the industrial sector, mainly aiming at improving energy efficiency in industrial processes. Many actions are classified as "integrated action", meaning that they target in a holistic way the building system. A small share of actions concern information and communication technologies (ICT), for example, remote management systems and energy management software for municipal buildings and street lighting. About one-fourth of the actions/measures were reported under the category "Other" or not specified.

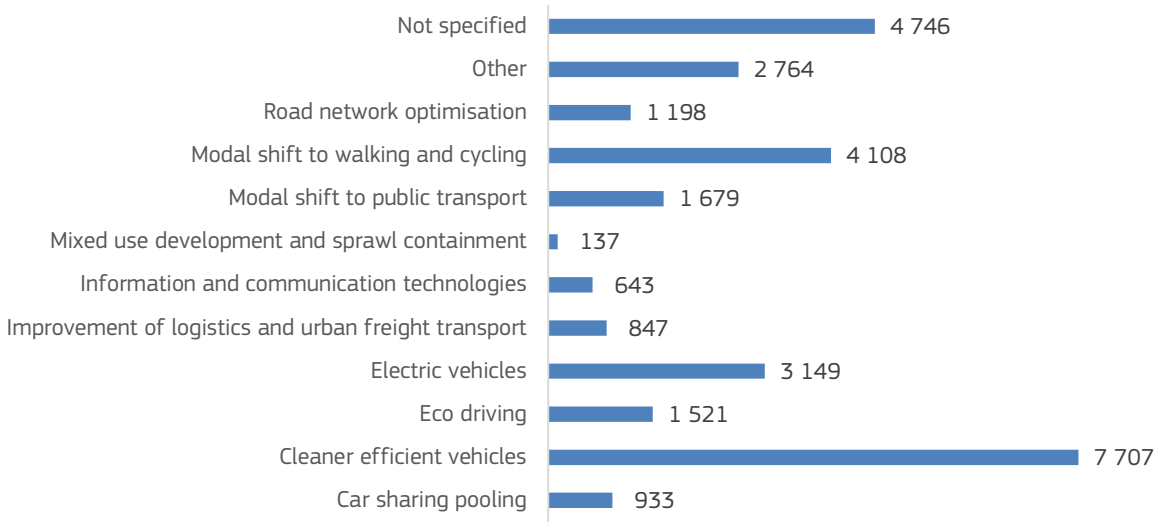
Figure 21. Stationary energy sector – Actions/measures by area of intervention.



Source: JRC elaboration basedon GCoM data

In the transport sector (Figure 22), the large majority of the 29 432 total planned actions concerns cleaner/efficient vehicles and electric vehicles (more than 10 800 measures), showing that local authorities rely to a great extent on the gradual improvement of the fleet of vehicles, which are bound by European standards, and might also depend on national incentives and economic performance. Local authorities then try to encourage a shift towards active mobility (with more than 4 100 measures classified as a modal shift to walking and cycling) or towards public transport (more than 1 600 measures) and to promote eco-driving (1 500 measures).

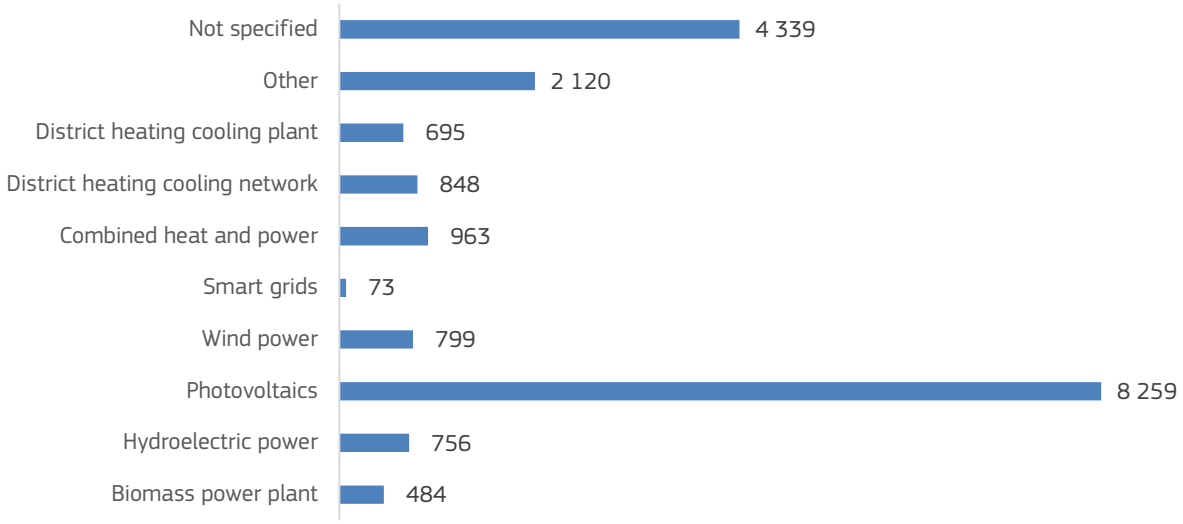
Figure 22. Transport sector - Actions/measures by area of intervention.



Source: JRC elaboration based on GCoM data

Looking at the 19 336 measures addressing the supply of energy (Figure 23), we can see a strong push towards photovoltaic (8 259 measures) – probably thanks to its decreasing costs and growing accessibility. In contrast, other technologies for renewable energy production seem to receive less attention from local authorities.

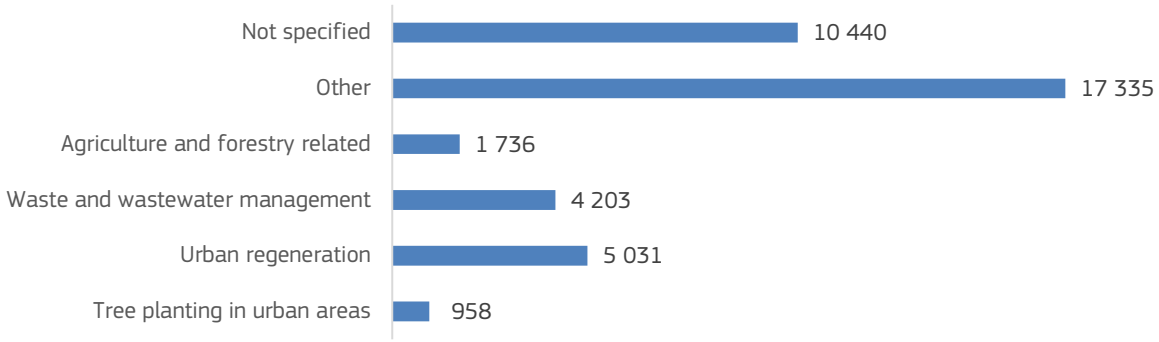
Figure 23. Energy production sector – Actions/measures by area of intervention.



Source: JRC elaboration based on GCoM data

The last sector, including waste and others (Figure 24), is more heterogeneous and includes many actions that were not classified under the proposed categories. Its importance is likely to grow in the future, with cities currently expanding the scope of their action plans to include more emitting sectors (e.g., agriculture, forestry and other land use, or industrial processes and products use) in an effort to reach climate neutrality goals.

Figure 24. Waste and other sectors - Actions/measures by area of intervention.



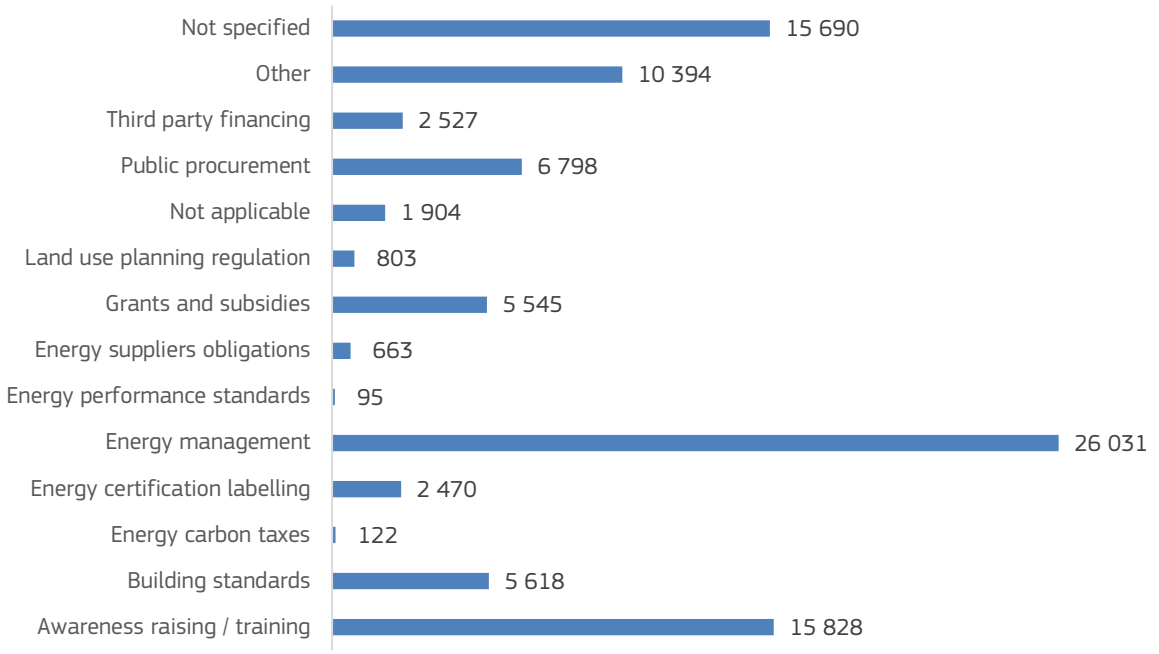
Source: JRC elaboration based on GCoM data

4.4.3 Actions/measures by policy instrument

Similarly to what is observed for the "area of intervention" categories, also the "policy instrument" categories vary depending on the sector. Therefore, in this section, we grouped the actions falling under the same macro-sector for analysis purposes.

Figure 25 shows the policy instrument assigned to actions/measures targeting the stationary energy sector. The energy management policy instrument is associated with 26 031 reported actions (27%), mainly addressing municipal buildings. The second preferred instrument is awareness-raising and training (15 828 actions), targeting, in particular, the residential buildings sector, but also municipal and tertiary buildings. Public procurement is also a quite common instrument (6 798 actions), followed by building standards (5 618), grants and subsidies (5 545) and energy certification/labelling (2 470). Other instruments seem less popular in local mitigation plans.

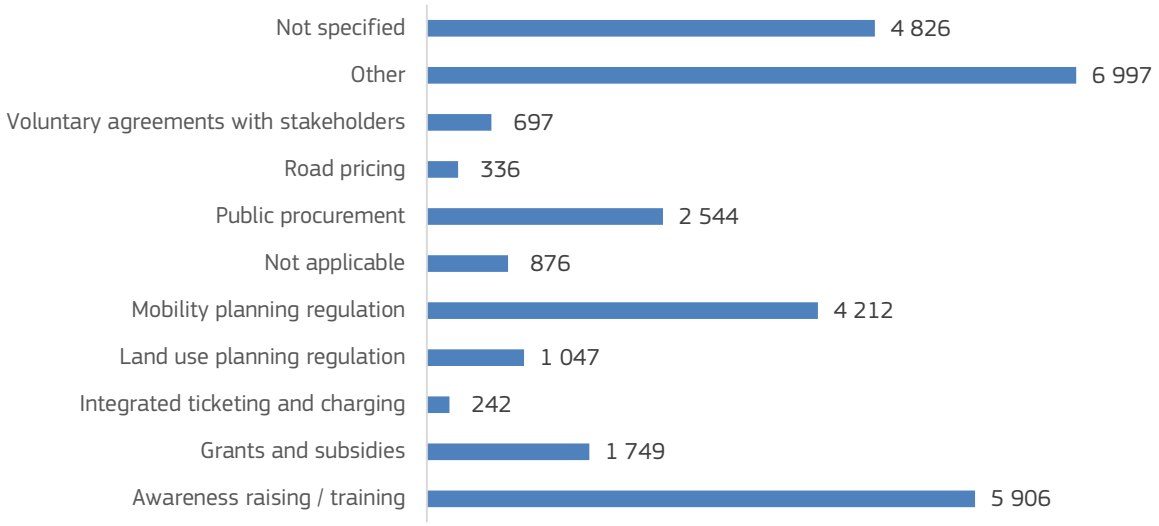
Figure 25. Stationary energy sector - Actions/measures by policy instrument.



Source: JRC elaboration based on GCoM data

In the transport sector (Figure 26), the preferred instrument is awareness-raising and training (5 906 actions out of 29 432), followed by mobility planning regulation (4 212 actions), public procurement to renew municipal fleet and vehicles used in public transport (2 544 actions), and grants and subsidies (1 749 actions, which may include tax reduction or subsidies for more efficient vehicles or incentives for the purchase of electric bikes). Instruments classified as road pricing and integrated ticketing and charging are less numerous, probably because they mainly apply to larger urban centres that represent a small number of Covenant signatories, compared to the high number of small towns. A very high number of actions/measures are not classified under any of the proposed policy instruments.

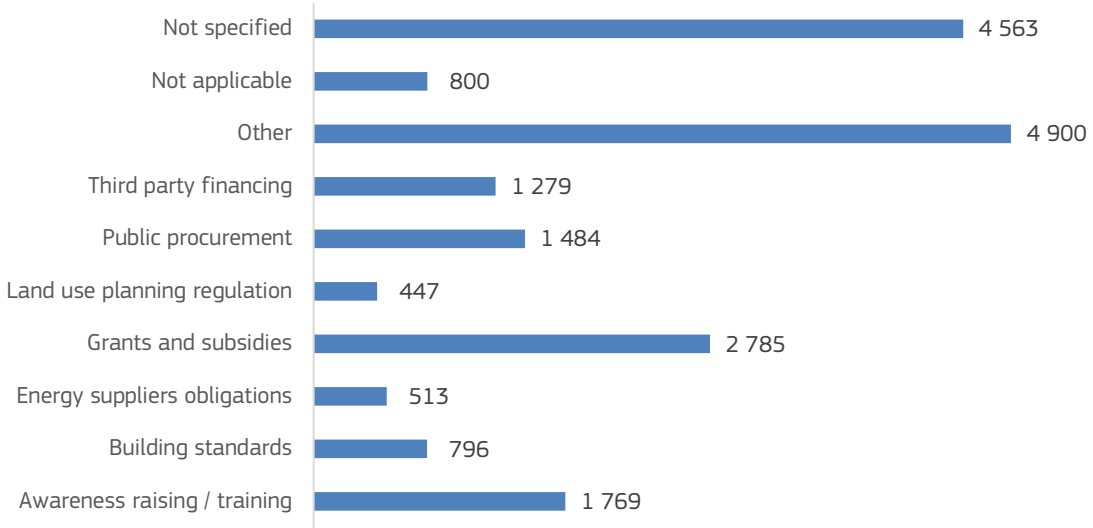
Figure 26. Transport sector - Actions/measures by policy instrument.



Source: JRC elaboration based on GCoM data

In the energy production sector (Figure 27), the most common policy instrument (when indicated) are grants and subsidies (2 785 actions out of 19 336), followed by awareness-raising and training (1 769 actions), public procurement (1 484 actions), third party financing (1 279 actions), building standards (796), energy suppliers obligations (513), and land use planning regulation (447).

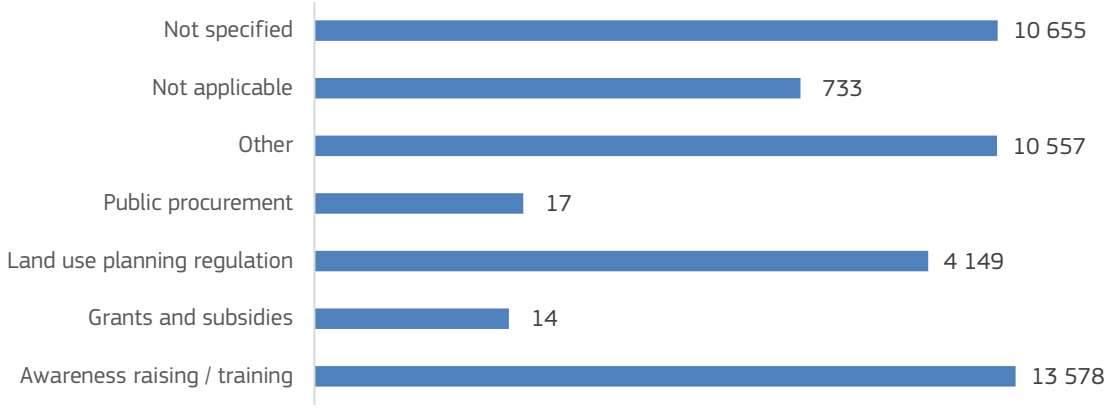
Figure 27. Energy production sector – Actions/measures by policy instrument.



Source: JRC elaboration based on GCoM data

Finally, the sector "waste and others" (Figure 28) includes two main policy instruments (when reported): awareness-raising and training (13 578 actions) and land use planning regulation (4 149 actions).

Figure 28. Waste and other sectors - Actions/measures by policy instrument.

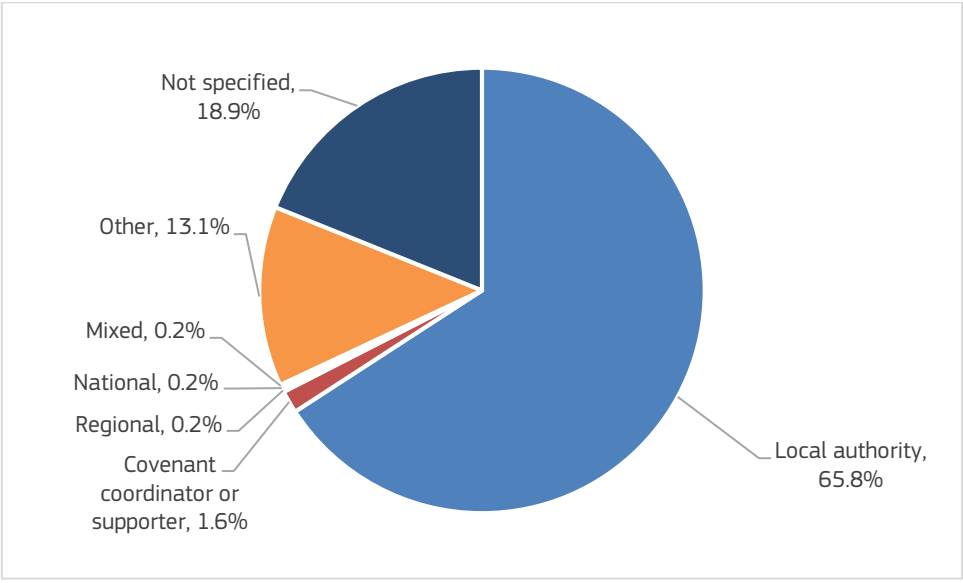


Source: JRC elaboration based on GCoM data

4.4.4 Actions/measures by origin of the action

Covenant signatories are also invited to indicate the level of governance initiating each action/measure. This allows appreciating if the local authority is actually taking the lead in the effort to reduce emissions in its territory or rather counting on the effect of actions decided by other authorities. About two thirds of the actions/measures are declared as being initiated by the local authority, while for almost one third the initiator is either "other" or not specified (Figure 29).

Figure 29. Share of actions/measures by action initiator.



Source: JRC elaboration based on GCoM data

5 Approach and methodology on adaptation

5.1 The Covenant of Mayors' approach to adaptation

The adaptation pillar was first introduced through Mayors Adapt, launched in 2014 by the EC as a parallel initiative to the CoM. In 2015, the EC merged the two initiatives into the CoM for Climate and Energy in an effort to promote an integrated approach to climate and energy action. From 2015 onwards, adaptation and, therefore, the Mayors Adapt initiative are entirely integrated into the Covenant of Mayors for Climate and Energy, and local authorities are committed to both mitigation (2020 and/or 2030 target) and adaptation.

By joining the initiative, signatories commit to voluntarily developing a comprehensive local adaptation strategy or integrating adaptation into ongoing development plans, as well as reporting their progress every second year.

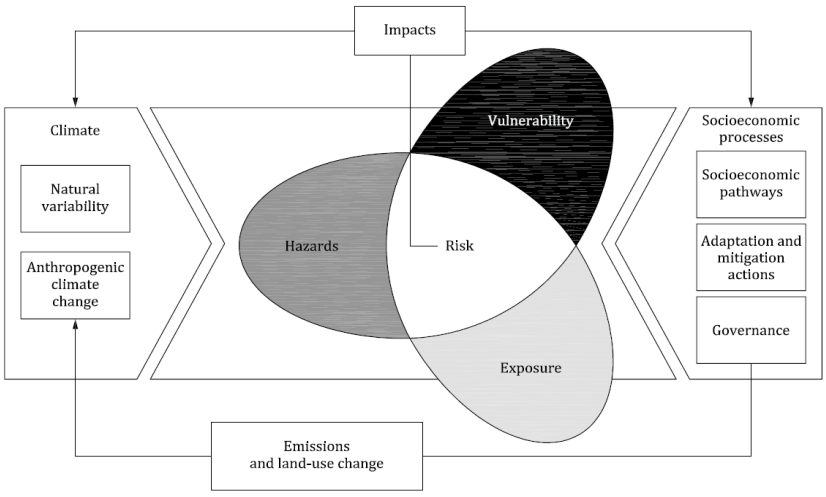
In January 2020, the reporting requirements changed, removing some mandatory information (i.e., Adaptation Scoreboard at the Registration stage) while introducing others (i.e., Adaptation goals). The reporting guidelines are in line with the Common Reporting Framework (CRF) by GCoM also for the adaptation pillar.

The current approach followed in the adaptation pillar of the Covenant of Mayors include:

- Committing to climate adaptation
- Identifying adaptation goals
- Conducting a Risk and Vulnerability Assessment (identifying the most relevant climate hazards and most vulnerable sectors)
- Defining adaptation actions
- Monitoring progress

The approach used for conducting a Risk and Vulnerability Assessment (RVA) follows the framework and core concepts of the IPCC AR5 (Figure 30). The risk of climate-related impacts results from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems. Changes in both the climate system (left side in Figure 30) and socioeconomic processes, including adaptation and mitigation (right side), are drivers of hazards, exposure, and vulnerability.

Figure 30. Illustration of the core concept of risk (AR5), based on IPPC AR5[27].



Source: IPPC AR5

[27] IPCC, 2014: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1 132 pp.

5.2 Datasets and data analysis

A similar approach to the one described in section 3.2.1 was used for harnessing data on climate change adaptation from MyCovenant. For adaptation information, additional quality scrutiny steps were required on the information provided with a text, such as the adaptation goal and the action titles, short description and outcome reached[28]. Because MyCovenant does not prevent submission in languages other than English, signatories often submitted info in their national or local language (e.g., Catalan), despite English being a mandatory reporting requirement[29]. The language barrier, therefore, affected the quality scrutiny process and data analysis for adaptation.

Table 15 shows the number of signatories committed to adaptation (either from the previous Mayors Adapt initiative, a separate commitment, or the most recent 2030 commitments). In total, 2 436 signatories committed to adaptation while about 39% submitted an adaptation plan. Because the CoM Europe reporting requirements allow extra time to provide adaptation actions, data shown in the table include some plans that provide the required RVA but might not have included adaptation actions at submission (about 14%).

Table 15. Adaptation signatories and action plans by region.

Region	Signatories committed to adaptation	Population (n. inhabitants)	Submission of partial adaptation action plans (RVA only)	Submission of full adaptation action plans (RVA+actions)	Monitoring reports (adaptation)
European Union (EU-27)	2 004	50 490 274	815	702	67
Eastern Partnership (CoM-East)	277	11 226 829	107	91	0
Europe - Non EU-27	52	7 963 121	22	19	0
Southern Mediterranean (CoM-South)	80	6 682 624	2	1	0
Rest of the world	23	18 709 385	7	6	0
Total	**2 436**	**95 072 233**	**953**	**819**	**67**

Source: JRC elaboration based on GCoM data

Figure 31 shows CoM EU signatories committed to adaptation and their geographical distribution across Europe, with the percentage of population covered (NUTS2 level).

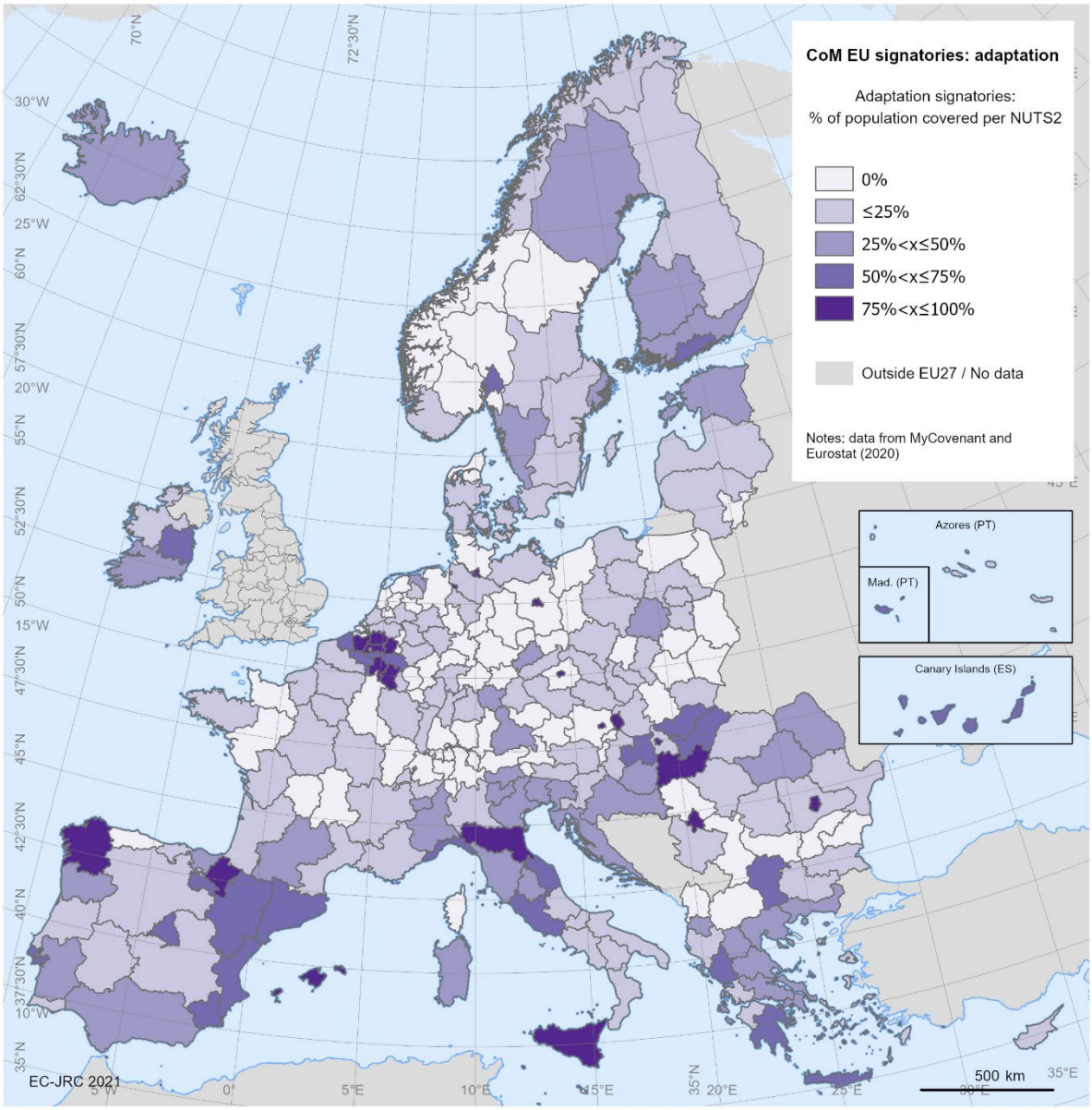
For a geographical overview of signatories committed to adaptation with a submitted action plan covering adaptation, see Figure 4(b) in section 2, which already included a map on adaptation.

[28] The major steps in data cleaning and quality scrutiny included the following criteria:
- Action plans without a valid RVA (at least one hazard reported) were discarded;
- Adaptation goals with an invalid text or a text not connected to adaptation (i.e., emission reduction target) were discarded;
- Invalid info from RVA (i.e., open field for "other climate hazards") and other text fields (i.e., "progress toward target" were discarded;
- Invalid info other text fields (i.e., "progress toward target" were discarded.

A systematic cleaning on all action titles, in order to remove actions accidentally marked as adaptation by signatories (while being mitigation only) was not conducted at this stage.

[29] For CoM East, Russian is also accepted as a reporting language.

Figure 31. CoM EU signatories committed to adaptation: population covered per NUTS2.



Source: JRC elaboration based on GCoM data

6 Results on adaptation

6.1 Adaptation goals

Similarly to setting the mitigation targets (see 4.1), cities are required to define adaptation goals. According to the guidelines, adaptation goals are formulated based on the results of the RVA and include the baseline year as well as the delivery date. There is no definition of the type of goal, but signatories track progress toward the achievement of the goal, ideally by formulating key performance indicators (KPIs) (monitored in monitoring templates).

Among the submitted 956 adaptation action plans, 57% (544) identify at least one adaptation goal. In fact, the requirement of defining at least one adaptation goal was introduced in January 2020. Therefore, signatories that submitted an action plan prior to that date and no monitoring report by the time of data extraction (May 2021) do not include such information.

While only one goal is the minimum reporting requirement, signatories averagely provide 3 goals, and the datasets include more than 1 500 goals. However, because the definition of adaptation goal lacks a specific global reference with defined quantitative targets (unlike mitigation, for which the CO_2 emission reduction is a commonly used indicator), data include different levels of information:

- About 11% (164) of the submitted goals refer to broad statements of increasing resiliency and committing to adaptation (lacking indicators of KPI to track progress over time);
- About 15% (229) of the submitted goals are aimed at reducing the overall risk of an identified climate hazard[30];
    - The most targeted climate hazards in the submitted goals are: floods & sea level rise (38%), extreme heat (24%), wildfires (21%), and droughts & water scarcity (18%);
- About 28% (423) of the submitted goals are aimed at reducing the vulnerability of specific vulnerable sectors[31] and/or specific vulnerable population groups[32];
    - The most addressed sectors in the submitted goals are water (69%) and agriculture & forestry (24%);
- About 10% (152) of the submitted goals can be linked to increasing adaptive capacity (e.g., awareness);
- About 32% (486) of the submitted goals relate to the development of detailed actions;
- A number of goals (172) are connected to mitigation (e.g., emission reduction target, energy efficiency) with indirect potential benefits on adaptation and were excluded for further analyses in this report.

Regarding adaptation, the definition of adaptation goals is still a challenging component of the action plans. Data from submitted templates show unclear goal descriptions, and only 15% of the more than 1 500 goals are linked to reducing the risk of climate hazards. Additionally, the quantitative component of the goal is often incorrectly filled in, not allowing the monitoring of the "progress toward target". This challenging aspect can be partially linked to the lack of generally accepted definitions of "adaptation goals" from international initiatives and also the lack of specific guidelines or illustrative goal examples for CoM signatories. A clarification of this aspect could be highly beneficial for improving the quality of adaptation plans and their monitoring. Additionally, the current version of the template on adaptation goals generates some confusion among signatories; further improvement of its quantitative data collection could be beneficial for action plans in setting goals and monitoring their "progress toward target" over time.

Another challenge affecting the analysis of adaptation goals and other adaptation data provided in text form was the submission of information provided in national/local language, despite English being the required

[30] Under the CoM reporting guidelines, hazards can be reported as 1st and 2nd level hazards. First level hazards are: extreme heat, extreme cold, heavy precipitation, floods & sea level rise, droughts & water scarcity, storms, wild fires, mass movement, chemical change, biological hazard, other.

[31] Under the CoM reporting guidelines, vulnerable sectors are: buildings, transport, energy, water, waste, land use planning, agriculture & forestry, environment & biodiversity, health, civil protection & emergency, tourism, education, ict (information & communication technologies).

[32] Under the CoM reporting guidelines, vulnerable population groups are: women and girls, children, youth, elderly, marginalized groups, persons with disabilities, persons with chronic diseases, low-income households, unemployed persons, persons living in sub-standard housing, migrants and displaced people, other.

language as per reporting guidelines. Future guidelines to signatories or further developments of the platform could be beneficial for analyses of the adaptation data.

6.2 Risk and Vulnerability Assessments (RVAs)

6.2.1 Climate hazards

Climate hazards are defined as "the potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources" (IPCC, 2014a, p. 1 766).

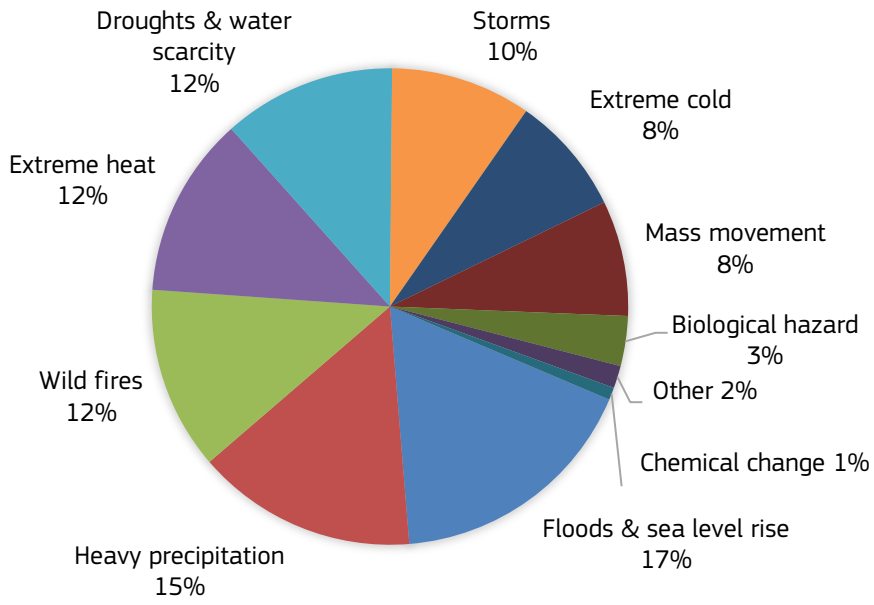
Because identifying climate hazards in the RVA is a mandatory step, all SECAPs include hazards.

While only one hazard is the minimum reporting requirement, signatories averagely identify 8 hazards, and the dataset includes more than 7 500 hazards. Each hazard has the following data associated:

- Level 1 hazard or level 2 sub-hazard
- Current hazard probability
- Current hazard impact
- Expected change in hazard intensity
- Expected change in hazard frequency
- Timeframe: short-term (20-30 years from now), mid-term (after 2050), long-term (close to 2100), not known (not possible to define).

The most reported climate hazards in signatories' RVAs (see Figure 32) are "Floods & Sea level rise" (17%), "Heavy precipitation" (15%), "Wild fires" (12%), "Extreme heat" (12%) and "Droughts & Water scarcity" (12%).

Figure 32. Most reported climate hazards.



Source: JRC elaboration based on GCoM data

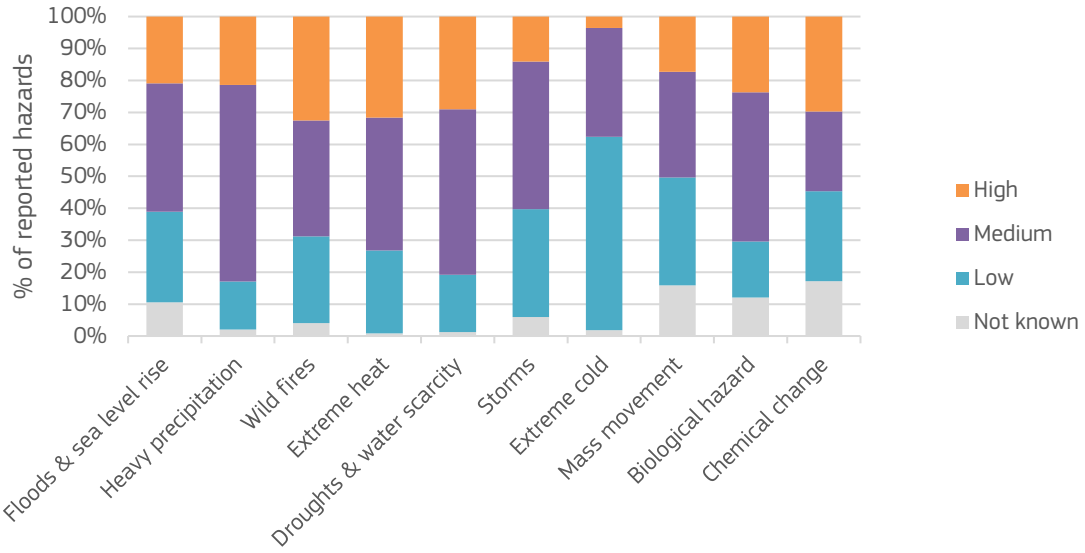
Signatories can also voluntarily report sub-hazards, which are classified under level 1 umbrella hazards (see Figure 33). For instance, "sea level rise" can be reported separately under the level 1 category "Floods & sea level rise". The most reported sub-hazards are "Extreme heat" (889 records), "Droughts & water scarcity" (882), and Heavy precipitation" (868).

Figure 33. Most reported climate hazards (inner circle) and sub-hazards (outer circle).

Source: JRC elaboration based on GCoM data

The two following figures (Figure 34 and Figure 35) include the level of probability and impact reported by signatories in their RVAs. The climate hazard "Extreme cold" is reported with the current lowest probability and impact, while all the other climate hazards are showing predominantly high/medium probability and impact.

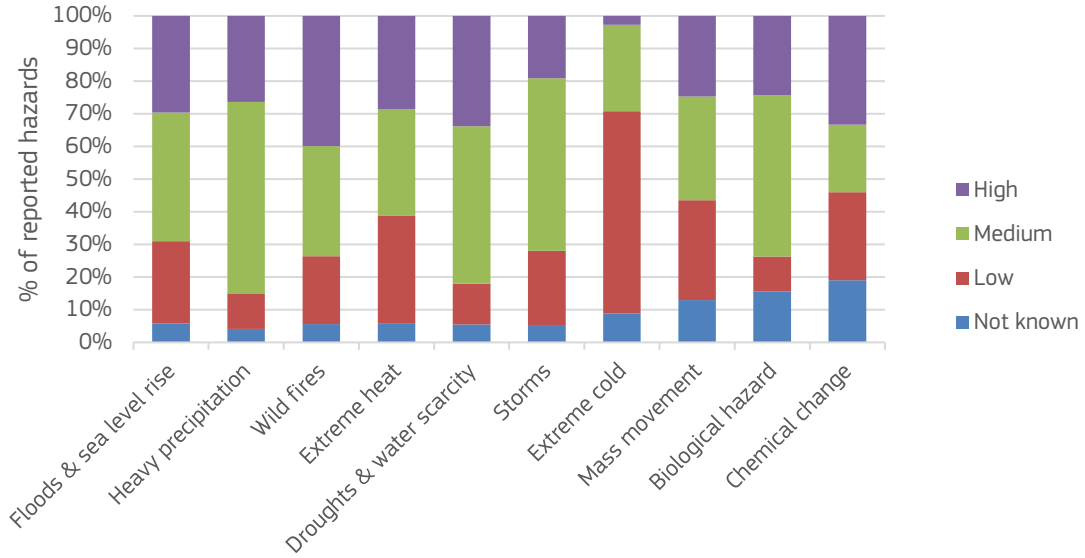
Figure 34. Level of the probability of occurrence of the climate hazard in the present.



High = extremely likely that the hazard occurs (e.g., greater than 1 in 20 chance of occurrence).
Moderate = likely that the hazard occurs (e.g., between 1 in 20 and 1 in 200 chance of occurrence).
Low = unlikely that the hazard occurs (e.g., between 1 in 200 and 1 in 2 000 chance of occurrence).
Not known = city has not experienced or observed climate hazards in the past or has no way of accurately reporting this information based on evidence or data.

Source: JRC elaboration based on GCoM data

Figure 35. Level of impact of the climate hazard in the present.

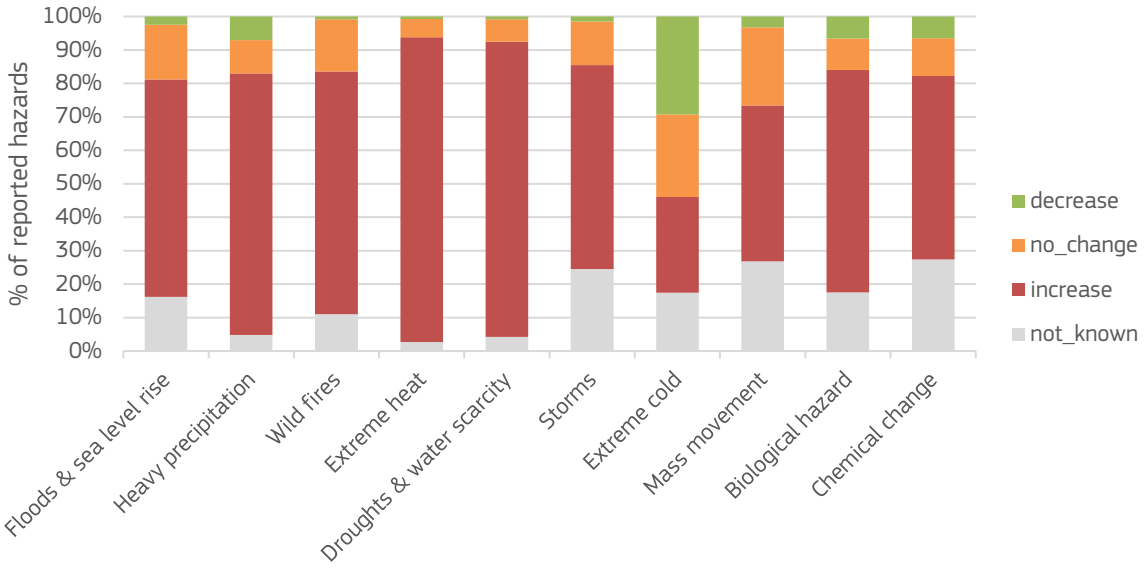


High = the hazard represents a high (or the highest) level of potential concern for your jurisdiction; when it occurs, the hazard results in (extremely) serious impacts to the jurisdiction and (catastrophic) interruptions to day-to-day life.
Moderate = the hazard represents a moderate level of potential concern for your jurisdiction; when it occurs, the hazard results in impacts to your jurisdiction, but these are only moderately significant to day-to-day life.
Low = the hazard represents a lower (the lowest) level of potential concern for your jurisdiction; when it occurs, the hazard results in impacts to your jurisdiction, but these are deemed less significant (or insignificant) to day-to-day life.
Not known = city has not experienced or observed climate hazards in the past or has no way of accurately reporting this information based on evidence or data.

Source: JRC elaboration based on GCoM data

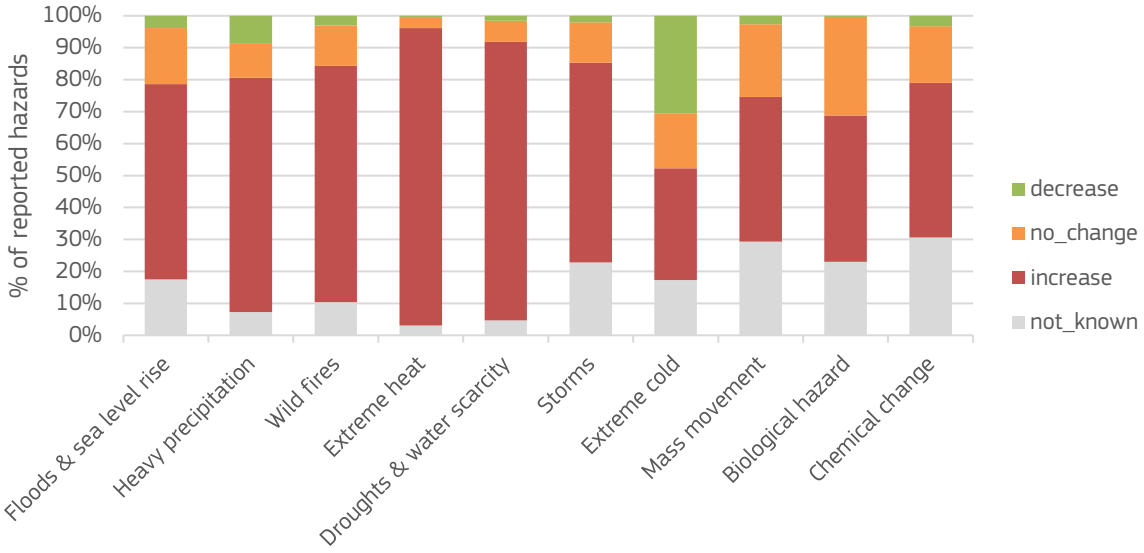
The two following figures (Figure 36 and Figure 37) include the future expected change in hazard intensity and frequency as reported by signatories in their RVAs. The climate hazard "Extreme cold" is expected not to change or decrease in intensity and frequency, while all the other climate hazards are expected to increase in both intensity and frequency.

Figure 36. Future expected change in hazard intensity.



Source: JRC elaboration based on GCoM data

Figure 37. Future expected change in hazard frequency



Source: JRC elaboration based on GCoM data

The reported timeframes that refer to the expected changes for climate hazards in RVA are[33]:

- 44% (3 379 climate hazard) reported as "Short-term" (= 20-30 years from now)
- 30% (2 281) climate hazards) reported as "Mid-term" (= after 2050)
- 24% (1 824 climate hazards) reported as "Long-term" (= close to 2100)
- 13% (971 climate hazards) reported as "Not known" (= not possible to define)

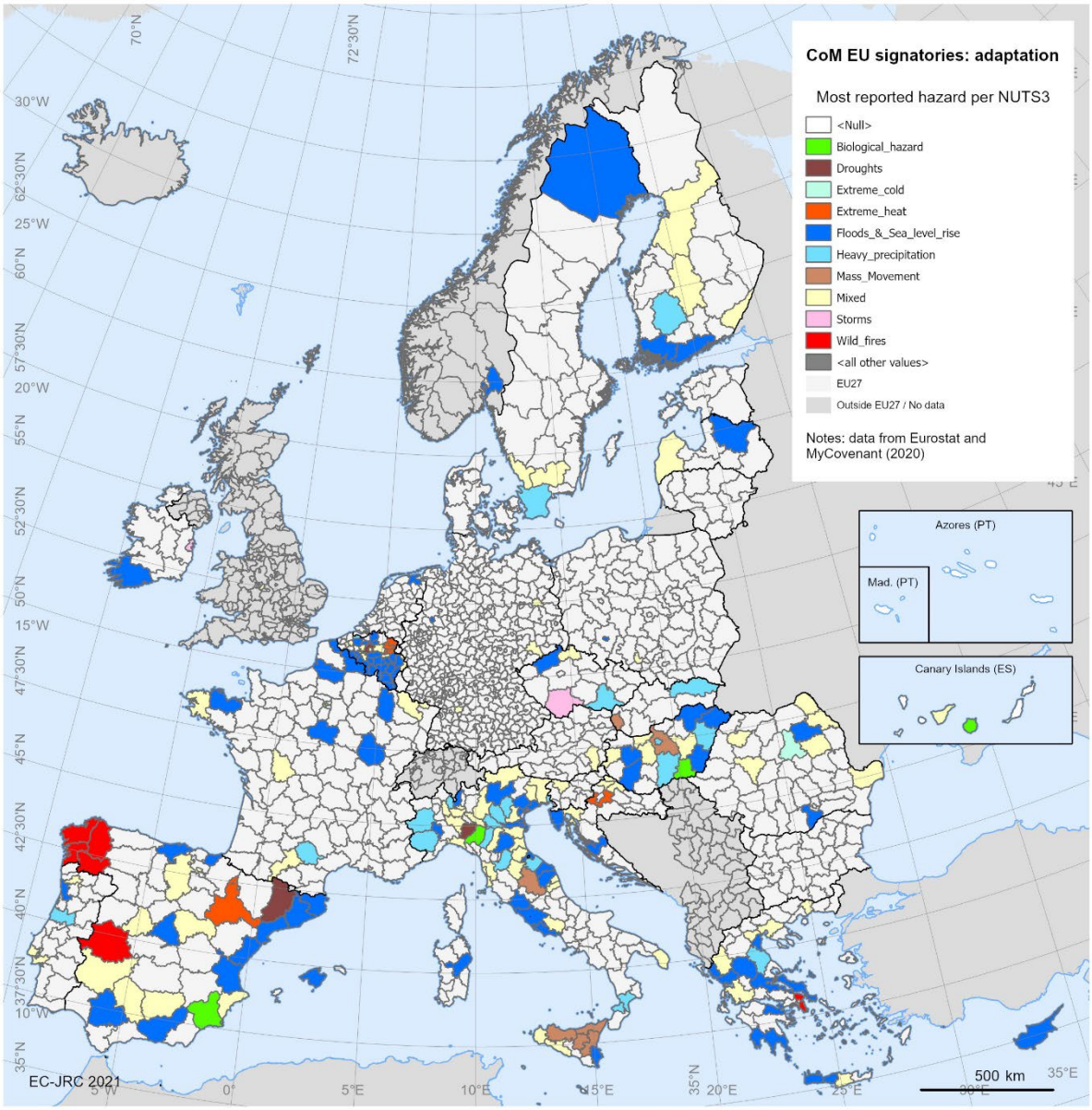
The map below (Figure 38) shows the geographical distribution of the RVA (reported hazards), highlighting the most frequently reported hazard within each NUTS3[34]:

- Floods & sea level rise, and Heavy precipitation are most reported in coastal areas and islands across all Europe, as well as some continental areas;
- Wildfires are most reported in certain NUTS3 regions in Spain (Galicia and Extremadura) and Greece;
- Mass movement (e.g., landslides) is most reported in certain NUTS3 regions in Southern Italy (e.g., Sicily);
- Droughts & water scarcity is most reported in certain NUTS3 regions in Spain (e.g., Catalonia).

[33] Multiple options can be selected by signatories for each climate hazard reported in RVA.

[34] The most frequently reported climate hazard within NUTS3. It includes all the reported hazards (level 1) within the NUTS3, regardless of their characteristics (probability, impact, expected change in intensity and frequency, timeframe).

Figure 38. Most reported climate hazard per NUTS3.



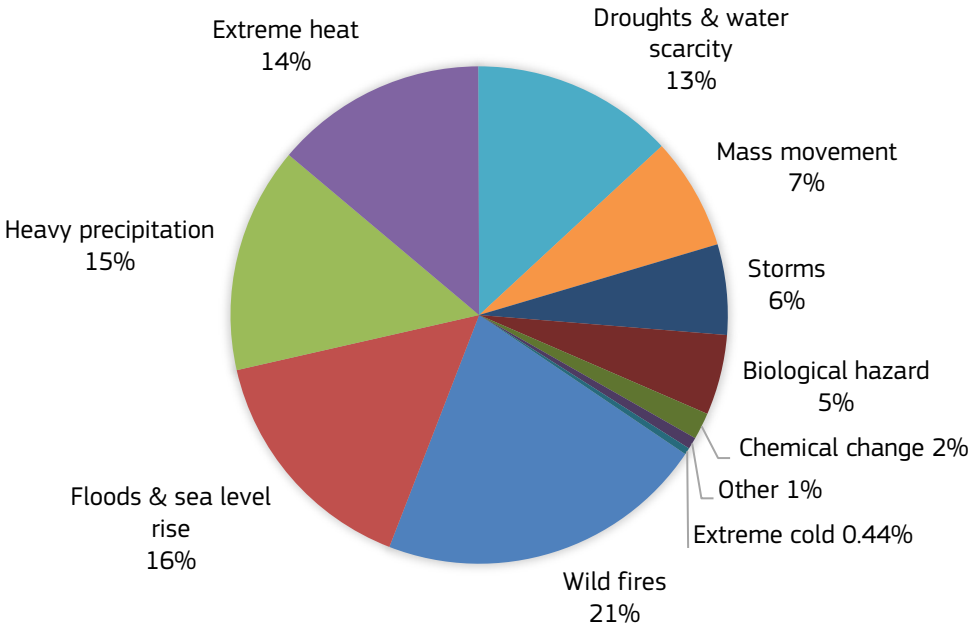
Source: JRC elaboration based on GCoM data

6.2.1.1 High-Risk Climate Hazards

Only 12% (919) of the reported climate hazards can be classified as "high-risk climate hazards", defining them as hazards with both high probability level and high impact level.

Considering only the high-risk hazards, the top climate hazards are also the most reported ones (as shown in Figure 33), but in a different order (see Figure 39): "Wildfires" is the most reported high-risk hazard, followed by "Floods & sea level rise", "Heavy precipitation", "Extreme heat", and "Droughts & water scarcity".

Figure 39. Most reported high risk climate hazards.



Source: JRC elaboration based on GCoM data

The difference is most likely rooted in the different (real or perceived) impact that fires and floods may have, compared to more probable but less destructive hazards like extreme heat or heavy precipitation that can equally reach high-impact, life-threatening levels but whose phenomenology is typically less catastrophic. Also, as adaptation is a relatively recent pillar, it reflects the sensitivity to natural hazards stimulated by most recent events, with wildfire events at the forefront.

In terms of future expectations of the reported high-risk climate hazards, signatories reported them as:

- 5% of high-risk hazards are reported with a future expected increase in hazard intensity
- 86% of high-risk hazards are reported with a future expected increase in hazard frequency.

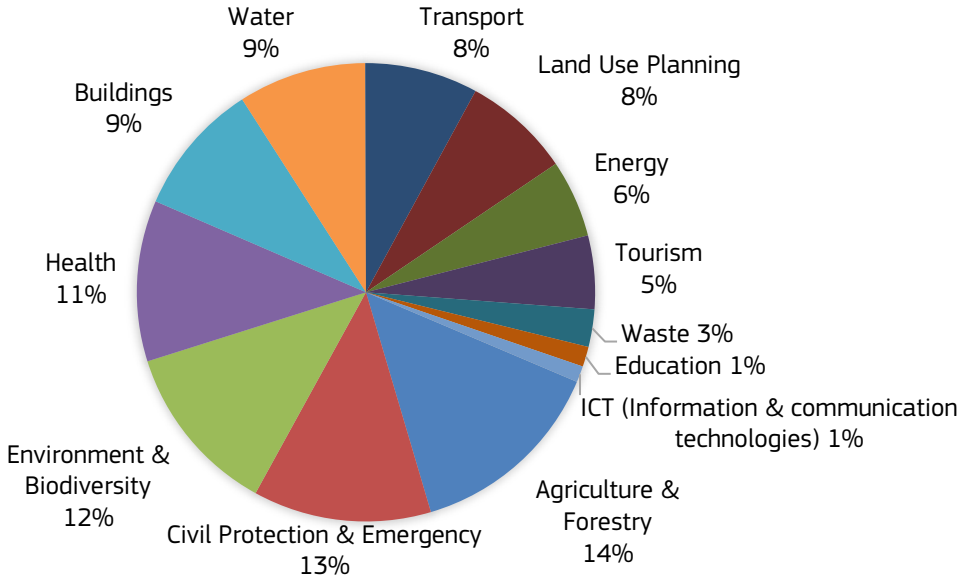
The expected change for high-risk climate hazards is reported as:

- 65%: short-term
- 40%: medium-term
- 24%: long-term
- 5%: not known.

6.2.2 Vulnerable sectors

More than 13 000 local vulnerabilities are reported by signatories for specific vulnerable sectors. As shown in Figure 40, the most reported vulnerable sectors are: "Agriculture & Forestry" (14%), "Civil protection & Emergency" (13%), "Environment & Biodiversity" (12%), "Health" (11%).

Figure 40. Most reported vulnerable sectors

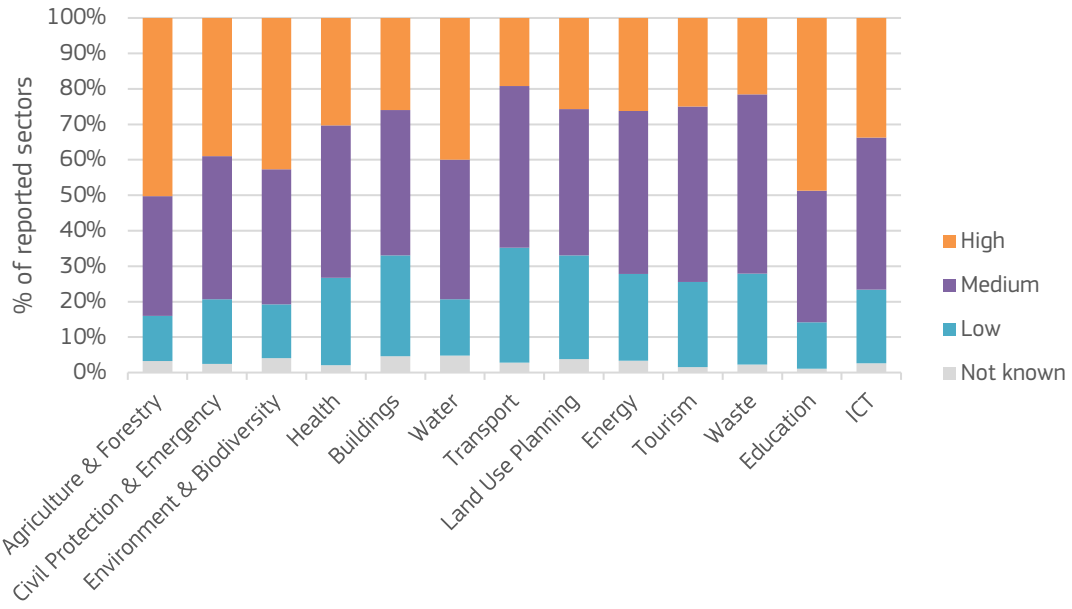


Source: JRC elaboration based on GCoM data

Considering the reported level of vulnerability for each sector (Figure 41) all the sectors are showing predominantly high/medium levels of vulnerability:

- "Agriculture & Forestry" and "Education" are reported with the highest level of vulnerability
- "Buildings" and "Transport" are reported with the lowest level of vulnerability.

Figure 41. Current level of vulnerability of the vulnerable sector.



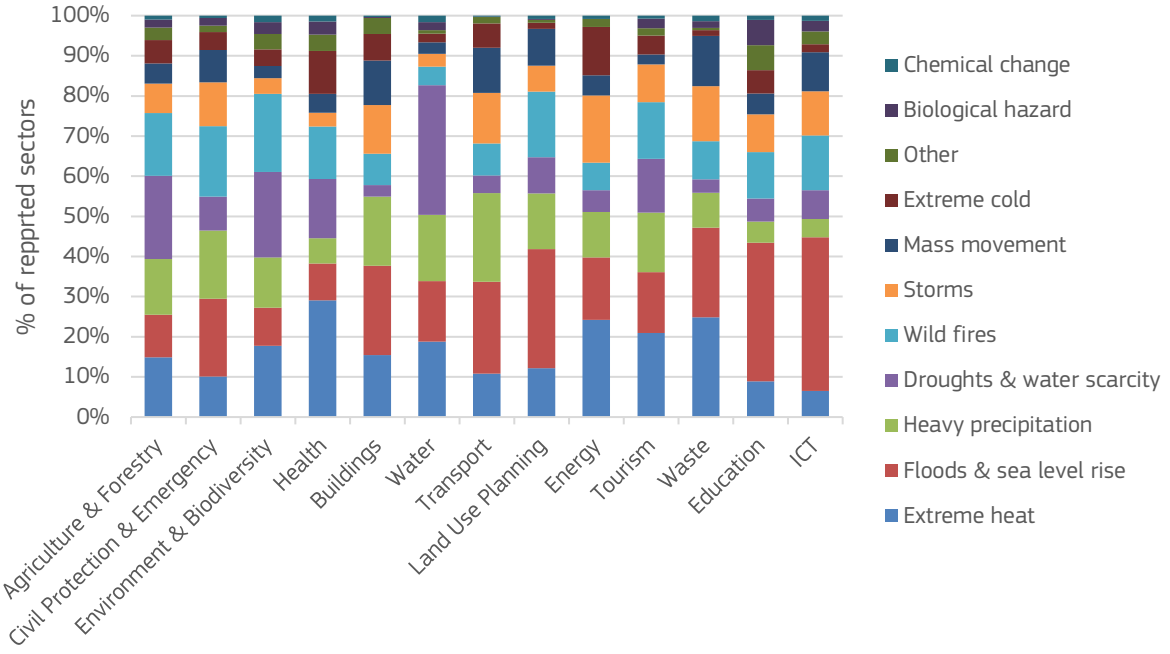
High = sector is very likely to be affected by the climate hazard.
Moderate = sector is expected to be occasionally affected by the climate hazard / Low = sector is unlikely to be affected by the climate hazard.
Not known = not possible to define.

Source: JRC elaboration based on GCoM data

Because each sector is reported as vulnerable to a specific climate hazard, it is possible to analyse to most reported hazards per sector. Figure 42 shows that:

- "Agriculture & Forestry" is reported as most vulnerable to "Droughts & Water scarcity"
- "Civil protection & Emergency" is reported as most vulnerable to "Floods & Sea level rise"
- "Environment & Biodiversity" is reported as most vulnerable to "Droughts & Water scarcity"

Figure 42. Vulnerable sectors and climate hazards.



Source: JRC elaboration based on GCoM data

6.2.3 Vulnerable population groups

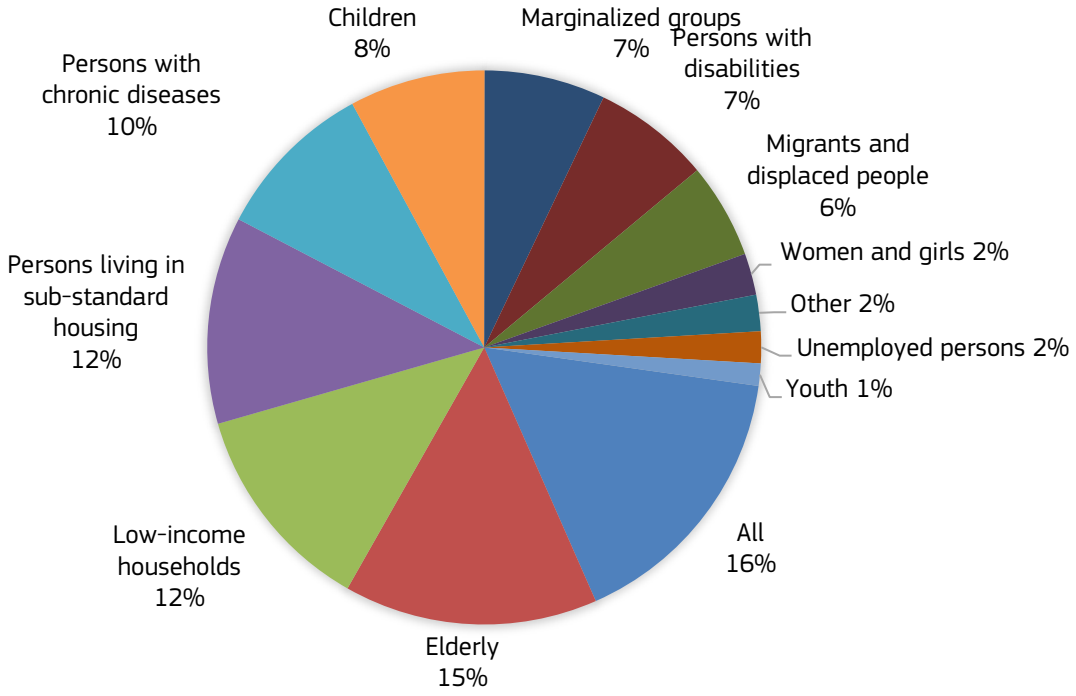
Vulnerable population groups are exposed to climate hazards, as reported by signatories in their RVA, despite the fact that this information is not mandatory.

As shown in Figure 43, the most reported vulnerable population groups are:

— All[35] (16%), Elderly (15%), Low-income households (12%), Persons living in sub-standard housing (12%)

[35] The template in MyCovenant allows selecting "All" and other categories at the same time (multi-choice option).

Figure 43. Most reported vulnerable population groups.



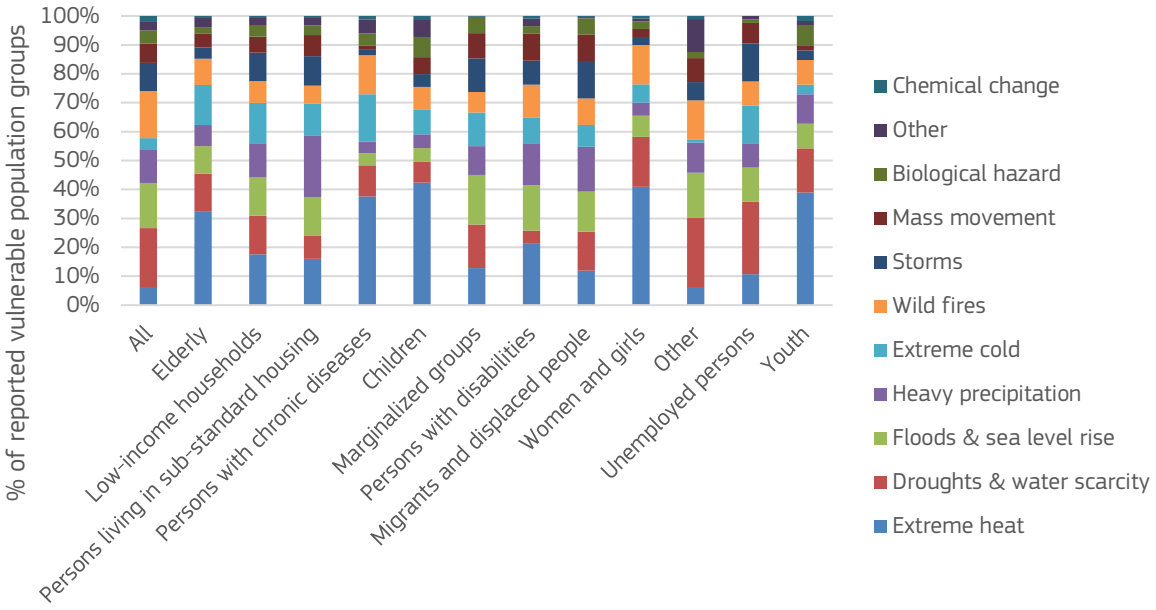
Source: JRC elaboration based on GCoM data

Because each group is reported as vulnerable to a specific climate hazard, it is possible to analyse the most reported hazards per group.

Figure 44 shows that:

- "Elderly" and "Persons living with chronic diseases" are reported as most vulnerable to "Extreme heat"
- "Low-income households" are reported as most vulnerable to "Extreme heat" and "Extreme cold"
- "Persons living in sub-standard housing" are reported as most vulnerable to "Heavy precipitation"
- When data is marked as "All", without a specific vulnerable population group, it is reported as most vulnerable to "Droughts & Water scarcity" and "Wild fires".

Figure 44. Vulnerable population groups and climate hazards.



Source: JRC elaboration based on GCoM data

Considering only the signatories reporting high risk hazards (353), with both high level of probability and high level of impact (see 6.2.1.1), data shows an amount of population exposed of more than 18.8 million of inhabitants.

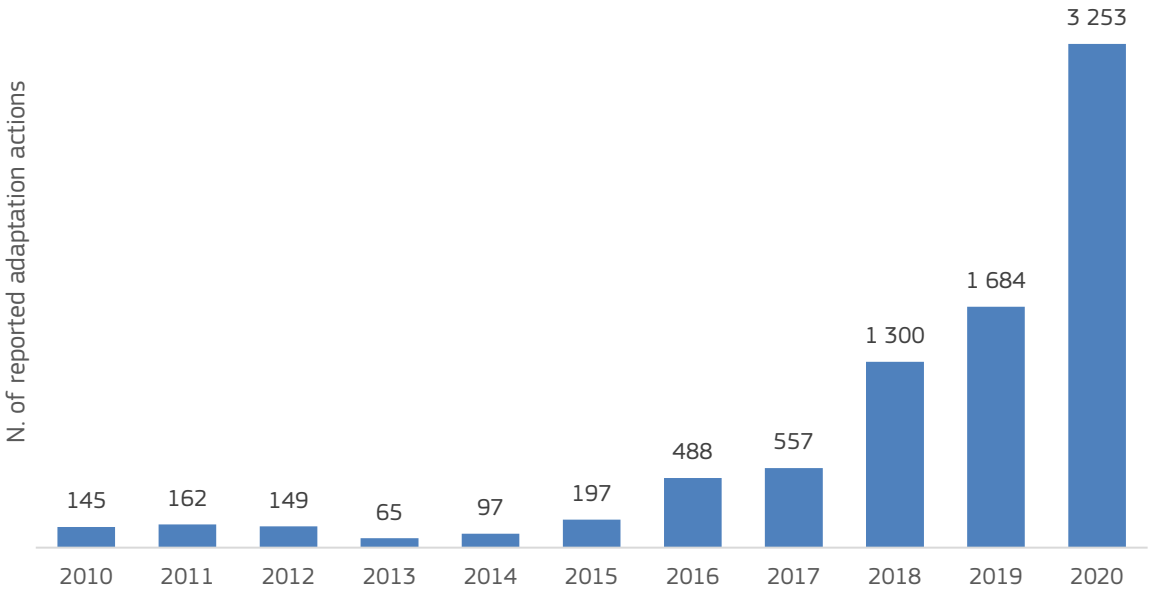
6.3 Climate adaptation actions and measures

More than 10 900 adaptation actions are reported by signatories. While only "key" actions are required according to the reporting guidelines, 81% (8 930) are marked as non-key action, and they include the minimum level of information required.

Among all the actions, 16% (1 788) are reported by signatories as both mitigation and adaptation actions.

As shown in Figure 45, since the beginning of the Mayors Adapt/Covenant of Mayors 2030 initiative in 2015 up to 2020 the number of actions implemented is growing every year at an exponential rate.

Figure 45. Adaptation actions with their reported implementation start year.



Source: JRC elaboration based on GCoM data

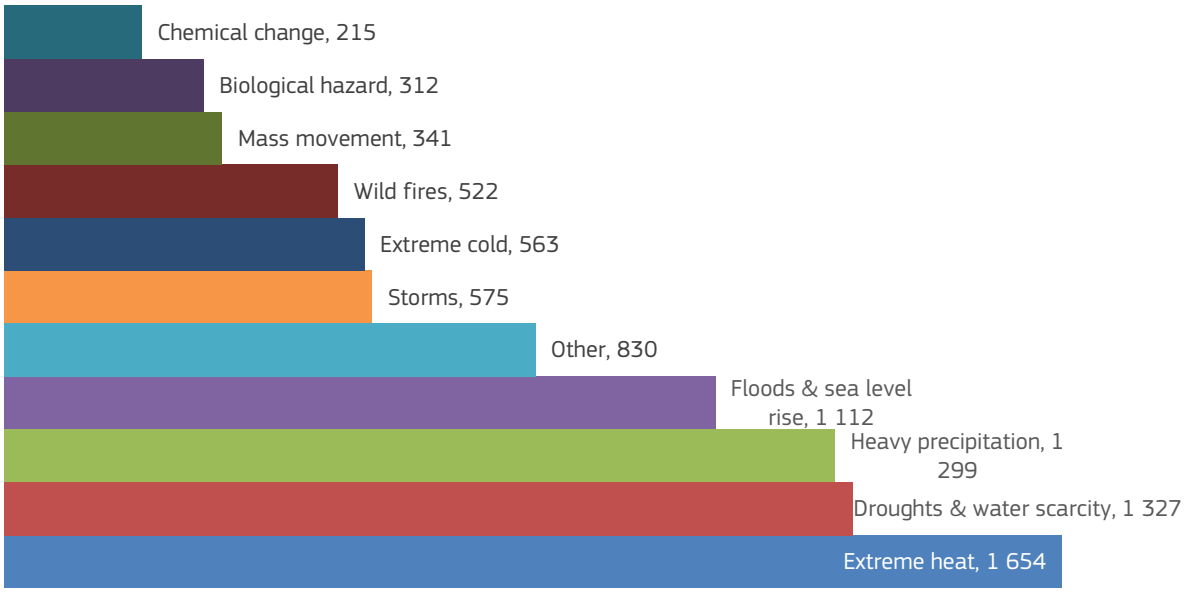
6.3.1 Actions and most addressed climate hazards

33% of adaptation actions (3 589) report which climate hazard(s) they are addressing. This information is mandatory only for key actions in the most recent version of the reporting guidelines; multiple hazards can be selected for each action.

According to the data shown in Figure 46, the most addressed hazards are: “Extreme heat”, “Droughts & Water scarcity”, and “Heavy precipitation”.

That slightly differs from the most reported hazards in the RVA (see also 6.3.4).

Figure 46. Adaptation actions and most addressed climate hazards.



Source: JRC elaboration based on GCoM data

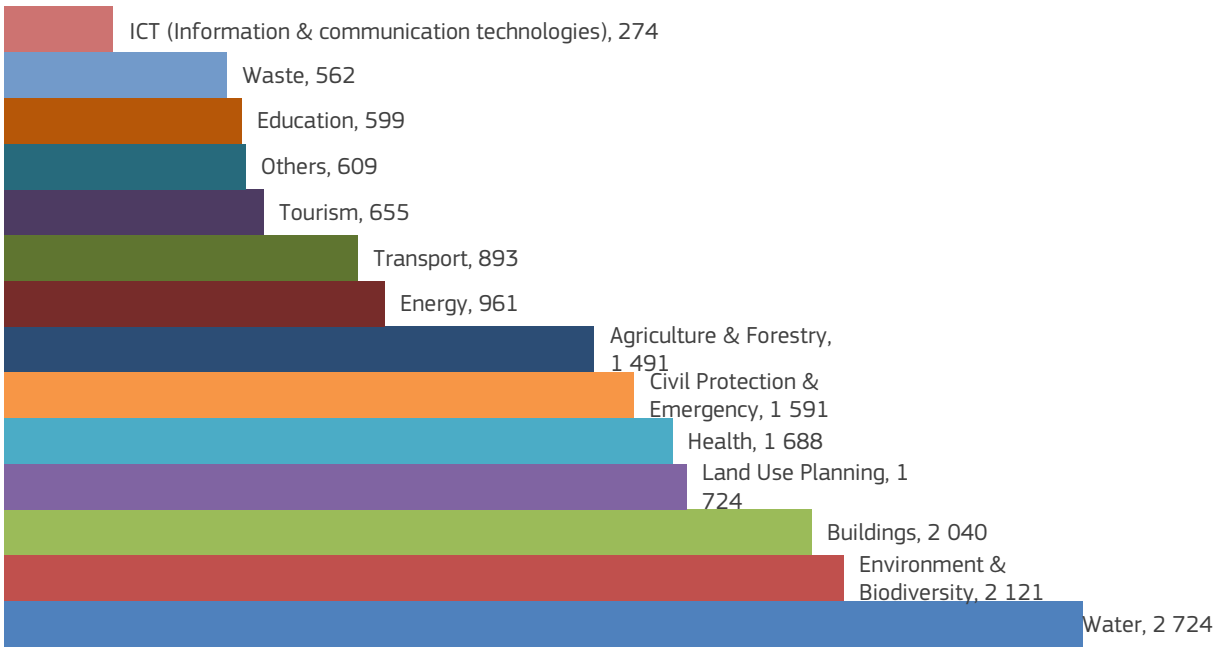
6.3.2 Actions and most targeted vulnerable sectors

99% of adaptation actions (10 922) report which sector they are targeting. This information is mandatory for all actions in the recent version of the reporting guidelines.

According to the data shown in Figure 47, the most targeted sectors are: "Water", "Environment & Biodiversity", and "Buildings".

That slightly differs from the most reported sectors in the RVA (see also 6.3.4).

Figure 47. Adaptation actions and most targeted vulnerable sectors



Source: JRC elaboration based on GCoM data

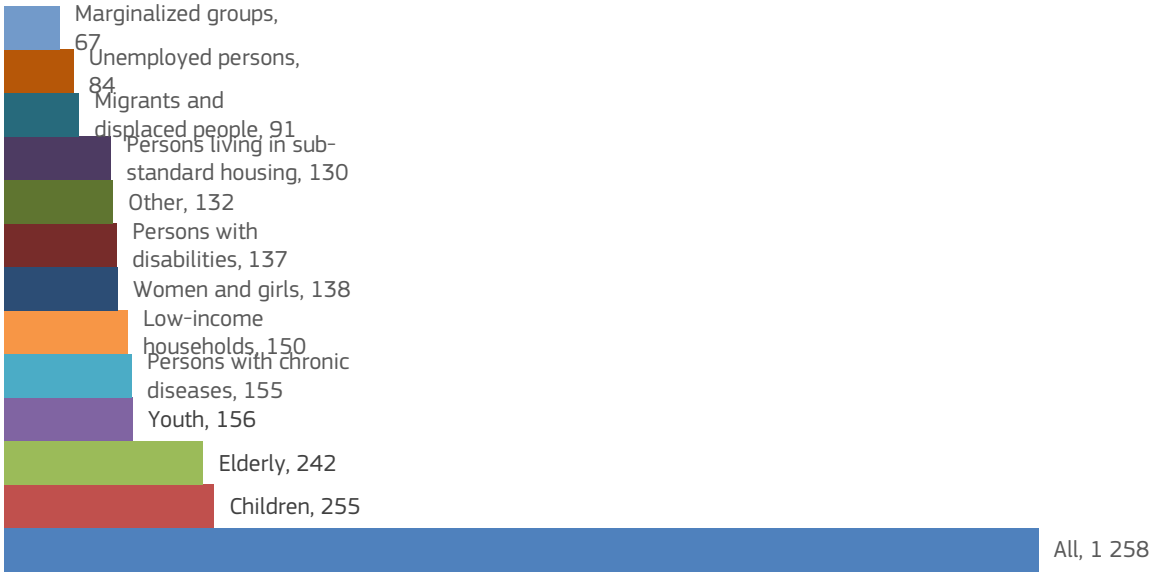
6.3.3 Actions and most targeted vulnerable population groups

16% of adaptation actions (1 760) report which vulnerable population group they are targeting. This information is optional in the most recent version of the reporting guidelines.

According to the data shown in Figure 48, the most targeted population groups are: “All”, “Children”, “Elderly”.

That slightly differs from the most reported sectors in the RVA (see also 6.3.4).

Figure 48. Adaptation actions and most targeted vulnerable population groups



Source: JRC elaboration based on GCoM data

6.3.4 Adaptation "gap" and potential incoherence among goals, RVA and actions

As noted in the previous sections, there is a slight incoherence among hazards and sectors reported in SECAPs (goals, RVA, and actions). The major differences are among the hazards and sectors reported in RVA and in the actions:

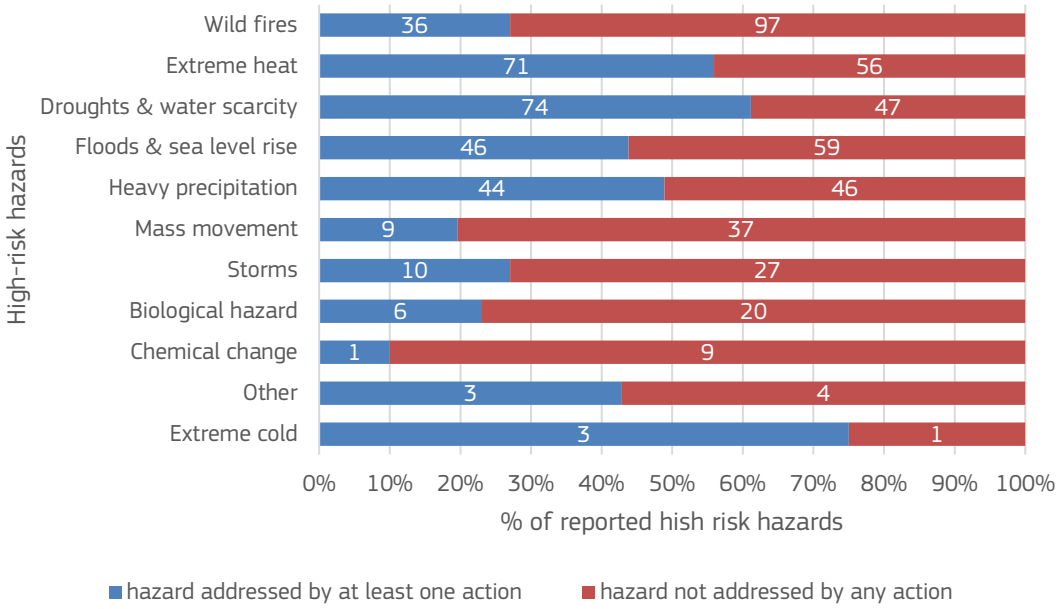
- While "Wildfires" is among the most reported hazards in goals and RVA, is it not among the most addressed hazards in the action plans
- While "Agriculture & Forestry" is among the most reported vulnerable sectors in goals and RVA, is it not among the most addressed sector in the action plans.

This can be linked to difficulties in some signatories in developing actions in sectors in which they have limited jurisdictional competence. For example, in some EU signatories, Agriculture and Forestry are managed and regulated at the regional or national level, leaving little room for actions to local authorities. On the contrary, building codes, land use planning and education with public awareness campaigns are often the sectors where local authorities can exercise more influence and plan actions.

Considering only the "high-risk hazards" (as defined in 6.2.1.1), it is possible to analyse how many of them are targeted by planned actions. The following Figure 49 shows the proportion of signatories reporting a "high-risk hazard" also reporting at least a matching action: the chart shows the number of reported high-risk hazards by signatories: the ones that are covered in the action plan are shown in blue, while the ones reported in RVA but not mentioned in the action plans are in red:

- "Wildfires", despite being the most reported "high risk" hazard (in 133 RVAs), if covered by at least one adaptation action in only 27% of the signatories
- More than half of the "Extreme heat" and "Droughts & Water scarcity" RVA high-risk hazards are addressed by at least one action (56% and 61% respectively)
- 44% of "Flood & Sea level rise" and 49% of "Heavy precipitation" are covered in submitted action plans.

Figure 49. Proportion of signatories reporting a "high risk" hazard also reporting at least a matching action.



In blue: number of reported high-risk hazards covered in action plans.
In red: number of reported high-risk hazards not yet addressed in submitted action plans. Hazards are ordered by the number of signatories reporting them as high risk in their RVAs.

Source: JRC elaboration based on GCoM data

Considering the overall number of signatories reporting high-risk hazards (353):

— 53% of signatories reporting at least one high-risk hazard are also reporting at least one matching action to address it.

6.3.5 Monitoring and implementation

Only 67 monitoring reports include valid information on adaptation: "progress toward target" (monitoring of the adaptation goal) and the "implementation status" of the planned adaptation actions.

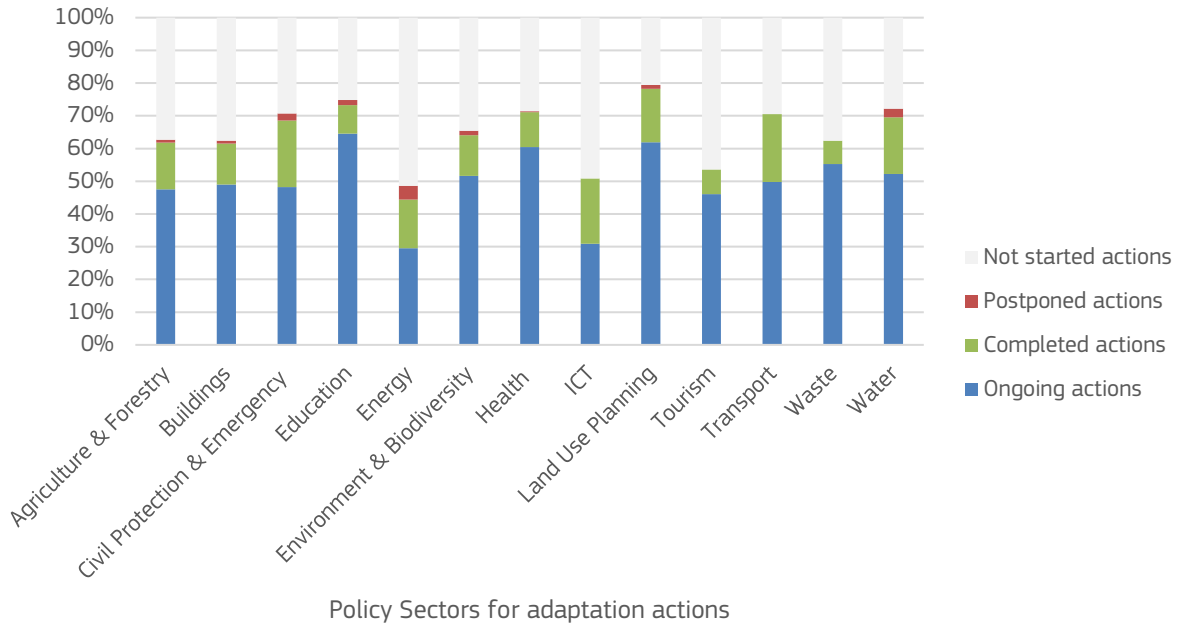
As mentioned in 6.1, current adaptation goals are not defined by signatories in a way to allow quantitative monitoring of their progress. This aspect should be further developed in future iterations of the template and guidelines.

The implementation status of the actions in the monitoring reports shows that 51% (5 535) of adaptation actions are reported as "completed" or "ongoing" (Figure 50).

The implementation status of the ongoing or completed 51% share shows progress in comparison to the overall implementations status of adaptation planning of signatories, as filed at the registration phase in the "Scoreboard". While the scoreboard is not updatable in monitoring reports, it provides an overall picture of the 768 signatories that filled the info.

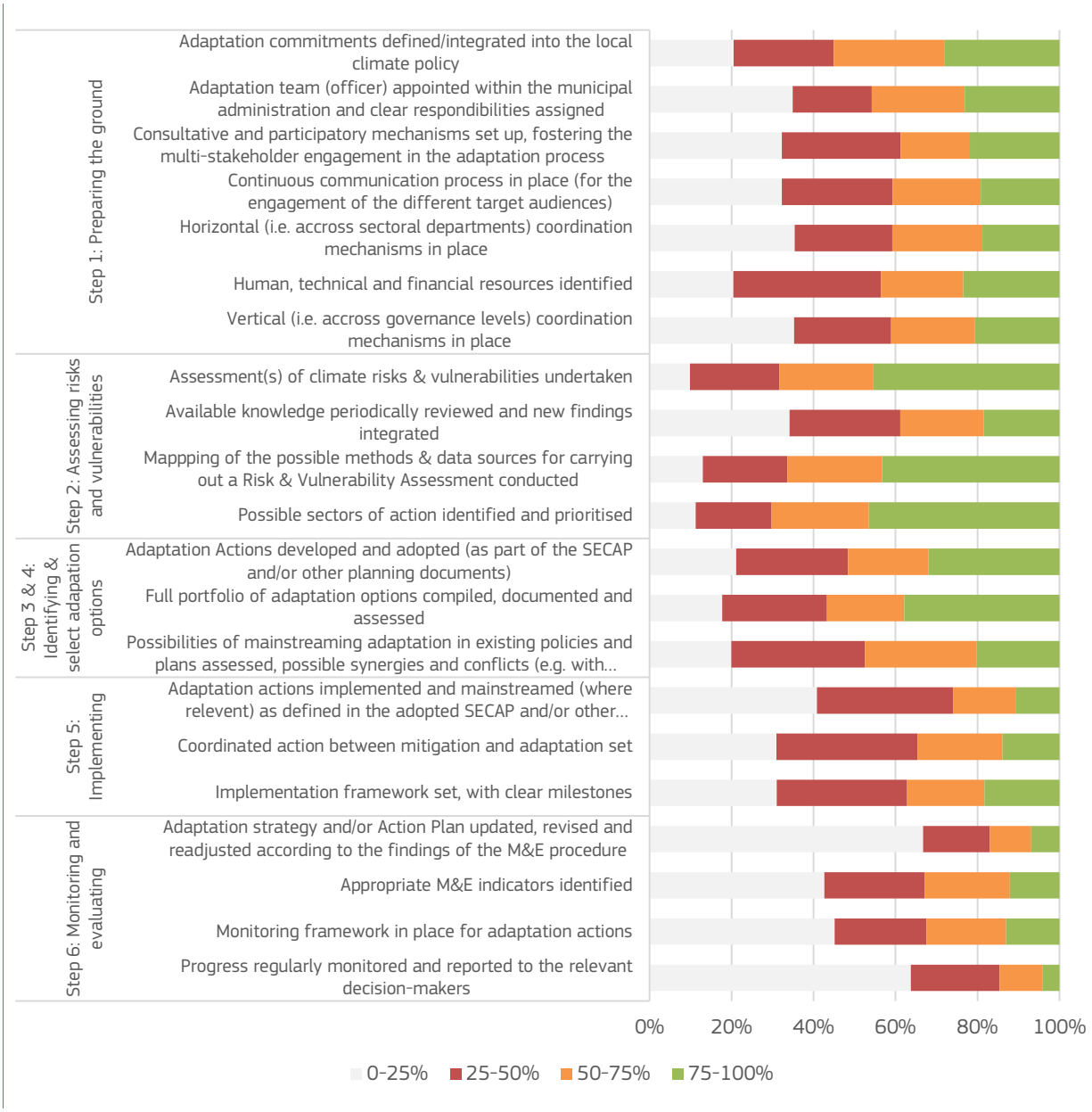
"Assessing climate risks and vulnerabilities" (RVA) is among the steps reported with the most complete status (75-100%), while planning and implementing actions are among the steps with a partially complete status (25-50%). Under Monitoring, the step about "updating the action plan" is reported with the most incomplete status (0-25%). See Figure 51.

Figure 50. Implementation status of adaptation actions as reported in monitoring reports.



Source: JRC elaboration based on GCoM data

Figure 51. Level of progress of MyCovenant signatories in adaptation planning and implementation.



Source: JRC elaboration based on GCoM data

7 General conclusions on mitigation and adaptation

7.1 Overall considerations

Over the past 13 years, the Covenant of Mayors has contributed to the creation of a European and, later on, a global movement of cities and local authorities committed to taking action on climate change mitigation and adaptation. It has been instrumental in shaping approaches and methodologies for the development of climate plans at the local level, which can usefully complement national plans and programmes and thus contribute to the objectives of the Paris agreement and, at the EU level, of the 2050 climate neutrality target. A common but flexible approach to reporting allows assessing cities' efforts in a consistent manner and evaluating the collective level of ambition and achievements of cities of different sizes, geographies and backgrounds.

7.2 Main findings

This report is based on data collected through MyCovenant until mid-May 2021. The initiative counts 10 568 committed cities and local authorities, covering a total population of 331.2 million inhabitants.

Box 2. Signatories and commitments

Most of the signatories (9 755, covering 216.2 million inhabitants) come from the EU-27, followed by the Eastern Partnership countries (478 signatories, 32.6 million inhabitants), by Europe – non EU-27 (158 signatories, 34.3 million inhabitants) and by South Mediterranean countries (123 signatories, 12.6 million inhabitants). MyCovenant is mostly used by signatories from Europe or from countries where the EU has been supporting the initiative since 2011.

The vast majority of the signatories (63.2%, covering 46% of the inhabitants) remains committed only to the 2020 mitigation targets, while only 35.8% (representing about half of the CoM population) are committed to a 2030 mitigation target combined with adaptation. The remaining 1% has a commitment to adaptation only or adaptation combined with a 2020 mitigation target.

The first part of the analysis underpinning the results presented in this report consisted of a harnessing procedure aimed at enhancing the quality of the signatories' reported data through a statistical analysis and internal-consistency general rules. On this basis, we defined a subset of 6 752 signatories with a submitted action plan, covering 236 million inhabitants.

Subsequently, in order to assess the collective achievements of EU-27 cities, we had to perform estimations to obtain the corresponding emissions on the same base year for all of the cities.

Box 3. Action plans and commitments

Looking at the action plans by pillars, we noted that 85.8% of the action plans (covering 77% of the population) only address the mitigation pillar and that just 13.7% of the actions plans (22.4% of the population) address simultaneously mitigation and adaptation. Less than 1% of the action plans and population address the adaptation pillar alone. That is due to the fact that the adaptation pillar was introduced more recently in the initiative compared to mitigation.

86% of the mitigation plans (covering 80% of the population) have a 2020 target only, with the remaining 14% of the mitigation plans having a 2030 target, either combined with a 2020 target (3.4% of the plans, 8.3% of the population) or not (10.8% of the action plans, 11.8% of the population).

In terms of reporting on the action plan's implementation, 2 592 signatories, covering 106.8 million inhabitants, have submitted at least one monitoring report. Out of these, 1 370 (covering nearly 73 million inhabitants) submitted a monitoring report flagged as "complete", i.e., including at least one monitoring emission inventory. The other 1 222 signatories submitted a "light" monitoring report, mainly including qualitative information on the actions' implementation status.

Regarding climate change mitigation, Covenant cities and local authorities with a submitted action plan show a collective ambition that exceeds the minimum commitments required by the Covenant Europe. The 2020 estimated results based on implementation reports seem to confirm that cities are delivering on their commitments, whereas for 2030 a delivery gap is forecasted (Box 4).

Box 4. Climate mitigation: baseline emissions, overall ambition and achievements

Based on data from 6 752 submitted action plans, the overall committed GHG emission reduction is 26% by 2020 (compared to a baseline level of 965.7 $MtCO_2$ eq) and 44.5% by 2030 (compared to a baseline level of 211.8 $MtCO_2$ eq). Looking only at signatories from EU-27, the overall committed reduction is 26.4% by 2020 (relative to base year emissions of 797.9 $MtCO_2$ eq) and 46.6% by 2030 (compared to a baseline level of 177.4 Mt CO_2 eq).

Almost the totality (>98%) of the reported emissions in baseline emission inventories are related to energy use, with waste treatment playing a minor role in the inventories. Fossil fuels cause 58% of reported SEAPs 2020 emissions (56% for 2030 SECAPs), while electricity is the second carrier with 33% of reported SEAPs 2020 emissions (34% for 2030 SECAPs).

Based on a subset of 1 825 action plans in EU-27 with a commitment to 2020 followed by at least one monitoring report, it is estimated a 26.1% mean reduction from 2005 to 2020. As a result, from 2005 to 2020, cities positively exceeded their targeted mean reduction of 25%.

Based on 326 action plans with a 2030 commitment and at least one monitoring report, the forecast on their expected achievements is not so optimistic, as their monitoring reports allow predicting a 37.8% reduction by 2030, while their targeted mean reduction is 46.6%.

Almost 183 000 mitigation actions were reported by Covenant signatories, corresponding to an average of **27 mitigation actions/measures per action plan.**

Box 5. Climate mitigation actions and measures

The stationary energy sector (including municipal, residential and tertiary buildings together with industry) accounts for more than half (52%) of the actions listed in MyCovenant. The transport sector accounts only for 16% of the planned actions/measures, despite representing 26-27% of emissions in the BEIs. About 10% of the actions aim at reducing emissions through local energy production (electricity and/or district heat/cold). Finally, 21.7% of the actions address waste and other sectors.

In the **stationary energy sector**, the majority of actions/measures aim at improving the energy efficiency of lighting systems, building envelopes, space heating and hot water systems, and of electric appliances. Many measures are also aiming at promoting renewables for space heating and hot water. A lower share of actions/measures target the industrial sector, mainly aiming at improving energy efficiency in industrial processes. Many actions are classified as "integrated action", meaning that they target in a holistic way the building system. About one-fourth of the actions/measures were reported under the category "Other" or not specified. In terms of policy instruments, energy management is associated with 27% of reported actions, mainly addressing municipal buildings. The second preferred instrument is awareness-raising and training, targeting the residential sector, in particular. Public procurement is also a quite common instrument, followed by building standards, grants and subsidies and energy certification/labelling.

In the **transport sector**, the large majority of the planned actions concern cleaner/efficient vehicles and electric vehicles, showing that local authorities rely to a great extent on the gradual improvement of the fleet of vehicles, which are bound by European standards, and might also depend on national incentives and economic performance. Local authorities then try to encourage a shift towards active mobility or towards public transport, and to promote eco-driving. As to the policy instruments adopted in the transport sector, preference seems to be given to awareness-raising and training, followed by mobility planning regulation, by public procurement (to renew municipal fleet and vehicles used in public transport) and then by grants and subsidies.

Regarding adaptation, the definition of adaptation goals is still a challenging component of the action plans. Data from submitted templates show unclear goal descriptions, and only 15% of the more than 1 500 goals are linked to reducing the risk of climate hazards. Additionally, the quantitative component of the goal is often incorrectly filled in, not allowing the monitoring of the "progress toward target". A clarification of this aspect could be highly beneficial for improving the quality of adaptation plans and their monitoring.

Despite the challenges on the definition of the adaptation goals, the definition of climate risks and vulnerabilities (RVA) has reached a fairly developed phase with more than 7 500 climate hazards reported with a good level of information. In fact, five characteristics are associated with each of them (current probability and impact, expected change in intensity and frequency, timeframe), and it is possible to analyse

the most reported climate hazard, to highlight the high-risk ones in connection with specific contexts and geographical areas.

Box 6. Overall reported climate risks and vulnerabilities

The most reported hazards among signatories are "Floods & Sea level rise" (17%), "Heavy precipitation" (15%), "Wildfires" (12%), "Extreme heat" (12%). They are all reported with predominantly high/medium impact and with an expected increase in intensity, except the extreme cold, which is reported with the current lowest impact and is expected not to change or decrease in intensity. However, there are differences according to local context and local climate. In fact, data shows that some hazards are most reported in some regions rather than others (e.g., "wildfires" most reported in certain NUTS3 region in Spain).

The most reported vulnerable sectors are: "Agriculture & Forestry", reported as most vulnerable to "Droughts & Water scarcity"; "Civil protection & Emergency", reported as most vulnerable to "Floods & Sea level rise"; "Environment & Biodiversity", reported as most vulnerable to "Droughts & Water scarcity"; and "Health", reported as most vulnerable to "Extreme heat".

The most reported vulnerable population groups are: "Elderly" and "Persons living with chronic diseases", reported as most vulnerable to "Extreme heat"; "Low-income households", reported as most vulnerable to "Extreme heat" and "Extreme cold"; "Persons living in sub-standard housing", reported as most vulnerable to "Heavy precipitation". When marked as "All", without a specific vulnerable population group, data is reported as most vulnerable to "Droughts & Water scarcity" and "Wildfires".

Despite it being optional information in the reporting requirements, signatories reported vulnerable population groups exposed to climate hazards. High-value information can be obtained from action plans if reporting information on social vulnerabilities is encouraged and perhaps required in future developments.

Considering only the signatories reporting high-risk hazards, data shows an amount of population affected of more than 18.8 million inhabitants, roughly equivalent to the population of Sweden and Austria combined.

More than 10 900 adaptation actions are reported by signatories. Since the beginning of the Mayors Adapt and the Covenant of Mayors 2030 initiative up to 2020, the number of actions implemented is growing every year at an exponential rate. Data shows potential incoherencies or "gaps" among the reported hazards and the most hazards addressed by actions. At the same time, the most reported vulnerable sectors are not the most targeted sectors by actions. However, the gap can be linked to difficulties by signatories in developing actions in sectors in which they have limited jurisdictional competence or financial capacity.

Box 7. Adaptation actions and "gaps"

While "Wildfires" is among the most reported hazards in goals and RVA, is it not among the most addressed hazards in the action plans. In fact, the most addressed hazards in the reported actions are: "Extreme heat", "Droughts & Water scarcity", "Heavy precipitation".

Additionally, while "Agriculture & Forestry" is among the most reported vulnerable sectors in goals and RVA, is it not among the most addressed sector in the action plans. On the contrary, the most targeted sectors are: "Water", "Environment & Biodiversity", "Buildings".

However, considering the overall number of signatories reporting high-risk hazards (353), 53% are also reporting at least one matching action to address it.

Monitoring progress on adaptation for CoM signatories is still in its infancy, given the fact that most of the action plans do not include monitoring reports at the current stage (only 69 out of 953 action plans). Additionally, the current structure of the template does not fully allow for easy monitoring and tracking progress toward the adaptation goals. Future iterations of the adaptation monitoring report could provide signatories with a dashboard of risks and vulnerabilities and the progress made in tacking them with implemented actions.

A final remark on adaptation analysis: the presence of "optional" information does not allow for a comprehensive and comparative analysis of adaptation action plans as signatories show a different level of effort in submitting information. Additionally, most of the optional information is not linked to other fields of the template, limiting its usefulness.

7.3 Final conclusions

The Covenant of Mayors has been instrumental in creating a community of over 10 500 cities and local authorities in Europe and beyond, committed to fighting climate change. It supports signatories' efforts through the provision of guidance, technical assistance, sharing of best practices and peer learning. At the same time, it helps consolidate practices to monitor and report on energy consumption and GHG emissions as well as risks and vulnerabilities at the local level, allowing decision-makers to identify priority sectors, set emission reduction targets and adaptation goals and plan relevant measures. All these are considered key strengths of the initiative.

At a closer look, the vast majority of the Covenant signatories remain committed to a 2020 mitigation target that does not include adaptation. That is also confirmed by the analysis of the action plans, a majority of which have a timeframe limited to 2020, while only a low share have a target to 2030 and address the adaptation pillar at the same time. The estimated achievements of 2020 signatories seem to be quite positive, being in line with the overall ambition of cities and local authorities. That will have to be checked and hopefully confirmed through actual data once a critical mass of signatories submits a monitoring emission inventory for the year 2020. On the other hand, the forecasts for 2030 are less optimistic, with preliminary results showing a delivery gap in comparison to the overall targeted reduction.

On adaptation, while committed signatories and adaptation action plans are less numerous than mitigation ones, figures are constantly growing. For example, considering the reported adaptation actions by year (2010-2020), the numbers are increasing at an exponential rate, and the trend is projected to continue. That is particularly significant considering that, under the current reporting guidelines, signatories are not required (and therefore not encouraged) to report actions in the first two years from registration; consequently, the real complete adaptation action plans and actions might be underrepresented in the figure submitted in MyCovenant and presented in this report.

While some challenges remain in some aspects of the adaptation pillar, such as the definition of adaptation goals, internal gaps/incoherence of action plans, and the reporting requirement of adaptation actions, much can be done in providing further guidance to signatories and further developing the template in the collection high-quality information.

This report is expected to inform further reflections on the future of the initiative, with a view to building on its key strengths in order to deliver more tangible results on the ground. Further analyses could aim at better understanding, for example through a broad consultation of Covenant cities and local authorities, the reasons that are preventing them from renewing their commitments to 2030 or 2050 targets. The reasons for the rather low share of monitoring reports could also be investigated. Gaining a better understanding of all these issues could allow the European Commission to provide more targeted support and tap into the potential of cities and local authorities to address the climate challenge.

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List of abbreviations, formulations and definitions

BEI	Baseline Emission Inventory
CH_4	Methane
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
CO_2-eq	CO_2-equivalents
CoM	Covenant of Mayors for Climate and Energy
CoM-East	Covenant of Mayors East (Eastern Partnership countries)
CoM-South	Covenant of Mayors South (Southern Mediterranean Partner countries)
CRF	Common Reporting Framework
DG ENER	European Commission's Directorate-General for Energy
DG CLIMA	European Commission's Directorate-General for Climate Action
EC	European Commission
EEA	European Environmental Agency
EFTA	European Free Trade Association
ETS	Emissions Trading System
EU	European Union
EU-27	European Union with 27 Member States
GCoM	Global Covenant of Mayors for Climate and Energy
GHG	Greenhouse Gas
IEA	International Energy Agency
ICT	Information and Communication Technologies
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
kWh	Kilowatt Hour
LAU	Local Administrative Units
LCA	Life-Cycle Assessment
MEI	Monitoring Emission Inventory
Mt	Million Tonnes
MWh	Megawatt Hour
N_2O	Nitrous Oxide
NDC	Nationally Determined Contribution
NUTS	Nomenclature of Territorial Units for Statistics
NUTS2	Level 2 regions based on the Nomenclature of territorial units for statistics
NUTS3	Level 3 regions based on the Nomenclature of territorial units for statistics
SEAP	Sustainable Energy Action Plan
SECAP	Sustainable Energy and Climate Action Plan
TWG	Technical Working Group
UNFCCC	United Nations Framework Convention on Climate Change

URS	Unified Reporting System

List of boxes

List of figures

List of tables

Annexes

Annex 1. Statistical methodology

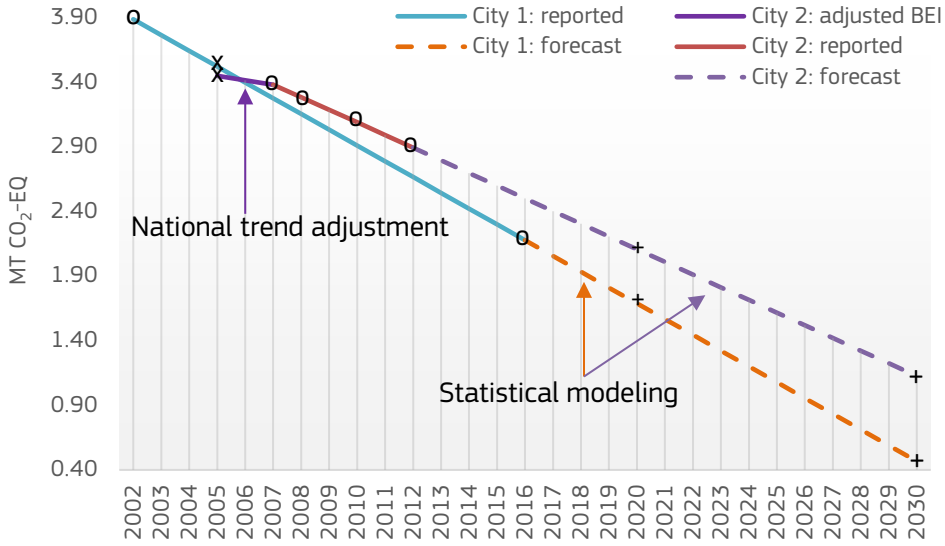
In this Annex 1, the brief explanation presented in Section 3.2.2 is extended, offering greater details on the statistical methods for the estimation and prediction of emissions for each signatory. Firstly, the base year is set to 2005, being the year serving as a reference for measuring the performance of the cities' mitigation actions. As already mentioned, the estimated emissions in 2005 for cities reporting on a base year earlier than 2005, are taken according to the linear equation between the city's reported baseline inventory and its last monitoring inventory (see Figure A1, the 2005 estimation of "city1"). Meanwhile, for cities with a base year occurring after 2005 (see Figure A1, for "city2"), their corresponding baseline emissions are adjusted according to a national per capita factor (f), which takes into account the national per capita emissions for 2005 (NE_{2005}), and for the base year (NE_{base}), as in

$$f = \frac{NE_{2005}}{NE_{base}}.$$

In total, for cities committed to 2020 targets, 11% of the cities have their base year occurring before 2005, as opposed to 54% of the cities having their base year after 2005. Meanwhile, for 2030 commitments, 8% of the cities have their base year occurring before 2005, in contrast to 62% of the cities having their base year after 2005.

The models for estimating the cities' emissions in 2020 and 2030 followed a machine learning methodology, minimizing the error over the last known value, as will be explained below. The input data for the development of the models consisted of the cities' reported emissions for their baseline and the following monitoring inventories, projecting their emissions to 2020 and 2030, as shown in Figure A1.

Figure A1. Picture of the statistical methodology for the estimation of the cities' emissions.



Cities report their emission inventories (marked with o) for a given year, and their emissions are estimated for 2005 (marked with x), and forecasted to the target years (marked with +) of 2020 and 2030.

Source: JRC

Therefore, each city had a sparse time series with a yearly frequency, being sparse because many years between the base and the last monitoring years had missing values. Hence, firstly, the imputation of data had to be performed, building the yearly time series on which the algorithms could learn the mechanism or function explaining their behaviour. That was done by continuing the linear trend between the years holding the known emission values (Figure A1). Secondly, the best model was identified for each city (i), according to the minimum error ($error_i$) for the predicted value ($\hat{y}_{it}$), computed over the last known emission value (y^*_{it}) that is, the emission value coming from the city's last monitoring report. This error was computed for each city, by

$$error_i = \frac{|\hat{y}_{it} - y^*_{it}|}{y^*_{it}}.$$

In this way, the last known value was left out for validation, and the best model was identified, which achieved the minimum prediction error. Then, the complete time series was fitted again under the same functional form of the identified model, and the corresponding prediction was taken for the cities' emissions in the target years.

Under this methodology, the time series was modelled after three different approaches. One approach consisted of a Double Exponential Smoothing (DES) (Winters, 1960; Box et al., 2016), characterizing the level and the trend of the series, according to

$$\hat{y}_{t+1} = L_t + T_t,$$

where L_t and T_t, respectively, stand for the smoothed level and trend of the time series. A second approach consisted of an Auto-Regressive Integrated Moving Average process (Box et al.; 2016), commonly known as an ARIMA(p,d,q), implementing linear filters to characterize the series, in the form of

$$\hat{y}'_t = Z_t + \sum_{j=1}^{p} \phi_j y'_{t-j} + \sum_{j=1}^{q} \theta_j Z_{t-j},$$

where y' stands for the differentiated series to the order of d, and p and q respectively stand for the number of lagged observations and the number of standard-normal innovations to include in the process. This model was used as the default option for cities with just a couple of observations in its historical series, in which case the model consisted in the mean value of both observations. These models were validated by the Ljung-Box test (Box et al., 2016), checking that no significant correlation among the residuals was left unexplained.

The third and last approach to modelling the series consisted of an auto-regressive feed-forward neural network with one hidden layer, estimating any non-linear function with a high level of complexity (Hornik et al. 1989). This architecture was examined with 3, 5, 7 or 10 hidden decision units, or neurons, in a single hidden layer, receiving input from 1 to 5 lagged observations (depending on the available data).

In general, both for 2020 and 2030 commitments, 82% of the cities were modelled after an ARIMA(p,d,q) process, followed by 15% of the cities with a neural network making use of 3 or 4 lags, 2% with a neural network making use of 1 or 2 lags, and the last 1% with a DES. The summary of the performance of this methodology (ML) is presented in Table A1, comparing its performance on the last known value with the other three more direct methods. Namely, a first method (M1) which directly takes the last known value for the prediction, a second method (M2) which continues the linear trend between the base and the last monitoring inventory; and a third method (M3) which adjusts the last known value by the national per capita linear trend. As a result, the ML methodology outperforms all other methods accomplishing a minimum mean error for prediction on the last known value, which for 2020 commitments amounts to 0.19 and for 2030 amounts to 0.14.

Table A1. The summary of the error of prediction for the last known value for the statistical (ML), last known value (M1), linear trend (M2) and national adjustment (M3) methodologies.

Error\Method	**ML**	**M1**	**M2**	**M3**
2020-Mean	0.193	0.219	0.332	0.196
2030-Mean	0.142	0.170	0.208	0.143

Source: JRC

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