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Covenant of Mayors: 2022 assessment

Climate change mitigation and adaptation at local level

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Abstract

Cities and local authorities are key players in addressing climate change. Since 2008, the European Commission (EC) 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. 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 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.

The key findings on mitigation show that the overall commitment to reducing GHG emissions by 1 251 signatories is 43.9 % by 2030 compared to baseline emissions. Looking only at 412 action plans accompanied by at least one monitoring report, a 30.9 % reduction by 2030 is forecasted, while the targeted mean reduction is 44.6 %. This insight suggests that greater effort is necessary for signatories to advance in the implementation of their action plans and achieve the emission reduction targets they have set.

On adaptation, the report shows that several vulnerable population groups including the elderly, persons 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 extreme heat, droughts & water scarcity, heavy precipitation and floods & sea level rise) that affect 33.3 million people.

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We also thank the Covenant of Mayors Office for taking care of relations with signatories, and in particular the IT team for managing the MyCovenant reporting platform and cooperating with the Joint Research Centre (JRC) in order to continuously improve the data collection process.

Special thanks go to Massimo Clemente from JRC for his continuous support in managing the Covenant of Mayors dataset.

Finally, we are grateful to colleagues from the Covenant of Mayors Europe Office and the JRC Editorial Review Board for their useful and constructive comments on the report.

Executive summary

The Global Covenant of Mayors for Climate and Energy counts more than 10 800 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 7 000 action plans and first results based on monitoring reports.

Policy context

Cities and local authorities are crucial actors in the fight against climate change. This was acknowledged by the European Commission back in 2008, when the Covenant of Mayors (EU CoM) was launched with a main focus on abating energy-related emissions and targeting cities and local authorities from the EU. Since then, the EU 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 CoM and the GCoM 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 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 increased 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 in line with the EU goal to achieve climate neutrality by 2050 and strengthened the energy poverty dimension. In 2022, the reporting template on energy poverty was also launched.

Thanks to their proximity to citizens – including the most vulnerable ones – and to local stakeholders, cities and local authorities are recognised by the EC as key partners to engage with to fight climate change locally and ensure a just transition. More recently, in the REPowerEU Plan Communication, the EC has also stressed the leading role of cities in developing energy saving measures tailored to their local context in order to contribute addressing the current energy crisis.

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 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.

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 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.

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 2030. In terms of emission reduction achievements, for EU-27 signatories with a 2030 mitigation commitment and at least one monitoring report, a delivery gap is forecasted compared to their collective emission reduction target by 2030.

In terms of adaptation, we observe that Covenant signatories are developing a thorough understanding of their climate risks and vulnerabilities. However, they are facing challenges in setting measurable goals

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

prioritizing the hazards and impacted sectors to address. Consequently, the large number of planned actions 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 may be necessary to help signatories implement their mitigation and adaptation actions, and report regularly on their action plans.

Main findings

The vast majority of Covenant signatories (59.2 %, covering 43.8 % of the signatories' population) remains committed only to the 2020 mitigation targets, while only 39.9 % (representing about half of the CoM population) committed to a 2030 or 2050 mitigation target combined with adaptation. The remaining 1 % has a commitment to adaptation only or to adaptation combined with a 2020 mitigation target.

Looking at the pillar addressed, 81.7 % of the submitted action plans cover only mitigation and just 18 % address both mitigation and adaptation, however the number of action plans with a commitment to a 2030 or 2050 mitigation target and to adaptation is constantly growing.

Looking at the 1 292 plans with a 2030 time horizon, we can see that 61 % 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 9 % of the signatories set a target lower than 40 %, which is allowed to CoM signatories outside the EU.

The overall committed GHG emission reduction is 43.9 % by 2030 (compared to a baseline level of 321.6 $MtCO_2$-eq). Looking only at signatories from EU-27, the overall committed reduction is 46.2 % by 2030 (compared to a baseline level of 249.4 $MtCO_2$-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.

Analysing the 412 action plans accompanied by at least one monitoring emission inventory, a 30.9 % reduction by 2030 is forecasted, while the targeted mean reduction is 44.6 %. This insight suggests that greater effort is necessary for signatories to advance in the implementation of their action plans and achieve the emission reduction targets they have set.

Looking at the adaptation information coming from 1 133 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 extreme heat, droughts & water scarcity, wild fires, and heavy precipitation – that affect 33.3 million people. The following sectors are the most reported by signatories in their action plans as vulnerable to the identified climate hazards: agriculture & forestry, environment & biodiversity, civil protection & emergency, and health.

However, adaptation action is growing: there are more than 15 200 reported actions so far and figures are increasing. While there is still a gap between identified risks & vulnerabilities and action taken, 57 % 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 in order to track the overall progress of the initiative based on action plans and monitoring reports transmitted by Global Covenant cities to the European Commission through the MyCovenant reporting platform (Cerutti et al., 2013), (A. Kona et al., 2016), (A. Kona et al., 2017), (P. Bertoldi et al., 2020), (Melica, et al., 2022), (Franco, et al., 2022), or through offline reporting tools (Palermo, et al., 2022).

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); impacts of mitigation actions on air quality (Monforti-Ferrario et al, 2018; Peduzzi et al., 2020) and 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 end of March 2022. 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

Cities and local authorities are key actors in the fight against climate change. The Sixth Assessment Report (AR6) from the Intergovernmental Panel on Climate Change (IPCC) highlights the increasing diversity of actors in the global effort against climate change, with non-state and sub-national actors (including cities) playing a growing role. On the one hand, the report acknowledges that the global share of emissions that can be attributed to urban areas is increasing (from about 62% in 2015 to about 67–72% in 2020); on the other, it highlights that urban areas can create opportunities to increase resource efficiency and mitigate greenhouse gas (GHG) emissions through the systemic transition of infrastructure and urban form towards net-zero emissions (IPCC, 2022).

The European Union (EU) has committed to becoming the world's first climate-neutral continent by 2050[2]. To this end, in 2021 the European Commission (EC) has adopted a package of proposals to make the EU policies in various domains fit for achieving an interim 55% emission reduction by 2030, compared to 1990 levels. The energy crisis that followed Russia's invasion of Ukraine has shown the need for a further acceleration of the clean energy transition, to reduce Europe's dependency on unreliable suppliers and volatile fossil fuels.

Acknowledging that the impacts of climate change are already occurring today, the EU strategy on adaptation to climate change[3] 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[4].

In this context, local involvement and public participation are key points of attention for the EU: Member States are required 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. The importance of transnational networks of cities and local authorities to stimulate the development of renewable energy and energy efficiency is acknowledged at EU level.

Being the level of governance closest to citizens, cities and local authorities may influence and take action on several sectors: through local energy and climate plans, they can contribute to the implementation of EU energy and climate policies. For example, they can get involved in renewable energy communities or accelerate permitting procedures for renewable energy installations, they can improve the efficiency of their own buildings and raise citizens' awareness of building energy renovation options, they can promote sustainable mobility options and create more liveable cities. To increase the resilience of their territories, they can implement nature-based solutions in their own buildings and public infrastructure, as well as embed high-performance resiliency standards in city planning and building codes; additionally, they can promote climate awareness and disaster risk preparedness within their employees as well as with citizens and businesses.

The EU Covenant of Mayors (EU CoM) and the Global Covenant of Mayors (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. The energy poverty dimension is also gaining increasing importance, in order to achieve a just transition that leaves no one behind.

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

The EU CoM 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 all over the

[2] 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')

[3] COM(2021) 82 final

[4] 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.

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[5], 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 reporting framework for EU signatories has recently been launched[6]. 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, at least one adaptation goal and a set of actions (including at least three key actions) to increase the resilience of the local authority sectors and vulnerable groups.

As far as energy poverty is concerned, cities are required to carry out an assessment based on a proposed list of indicators, to set a goal and to plan relevant actions. Given that the reporting requirements on energy poverty are more recent, until the end of 2024 a transition period applies, during which there are no mandatory data reporting requirements for signatories.

In January 2020, the SECAP template and related reporting guidelines were updated according to the Common Reporting Framework (CRF)[7] defined in the context of the GCoM.

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

6 https://eumayors.eu/index.php?option=com_attachments&task=download&id=1358

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

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[8]
- CDP-ICLEI Track[9]

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[10], with the Global Covenant of Mayors' Secretariat[11] as well as with other offices managing regional Covenants[12,13,14] 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[15], 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[16].

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

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

of Mayors status (Cerutti et al., 2013), (Kona et al., 2016), (Kona et al., 2017), (Bertoldi et al., 2020), (Melica et al., 2022), (Franco et al., 2022), (Palermo et al., 2022) 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.

In the context of the GCoM, the JRC collaborates with partners and other research institutions for aggregation reports[17] 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)[18] (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); impacts of mitigation actions on air quality (Monforti-Ferrario et al, 2018; Peduzzi et al., 2020) and key factors enabling higher climate ambition (Rivas, Urraca, Bertoldi, & Thiel, 2021).

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

[18] 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[19]. Signatories reporting to the CDP Track[20] or through offline reporting tools are not part of the dataset and, therefore, not analysed in this report.

All the 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), also gathering the planned actions by sectors along with all GHG emission reduction targets (for years 2020, 2030 and for mid-term and 2050), as well as risk and vulnerability information on hazards and goals.

Assuring a good level of data quality has always been a challenging task: indeed, under the CoM framework, local governments 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 (see Drivers and barriers Rivas et al. 2021). From all the 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' commitments, action plans and emissions inventories. In consequence, after the JRC-harnessing process, a structured collection of action plans and monitoring reports from MyCovenant reporting platform is available at the JRC Data Catalogue[21].

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 Section 3.2, takes more in-depth analysis, screening and cleaning the data from unexplainable-outlier observations.

2.1 MyCovenant data management

For the present report, all the data is extracted from a 'frozen' version of the MyCovenant PostgreSQL database as of March 2022. The signatories and the action plans are 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: 135 profiles) or 'under evaluation' (i.e., not yet formally confirmed as signatories: 60 profiles). Besides, action plans with submission status 'under completion' (i.e., not submitted) were also excluded (3 369 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, considering 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[22].

The overall procedure was carried out in different stages. On a first stage, the raw data extraction was performed. Then, on a second stage, the available data was integrated into structured tables, adding extra information such as the GCoM identification codes for each organisation-signatory in the GCoM platform, as

[19] https://mycovenant.eumayors.eu/

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

[21] https://data.jrc.ec.europa.eu/collection/id-00354

[22] 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.

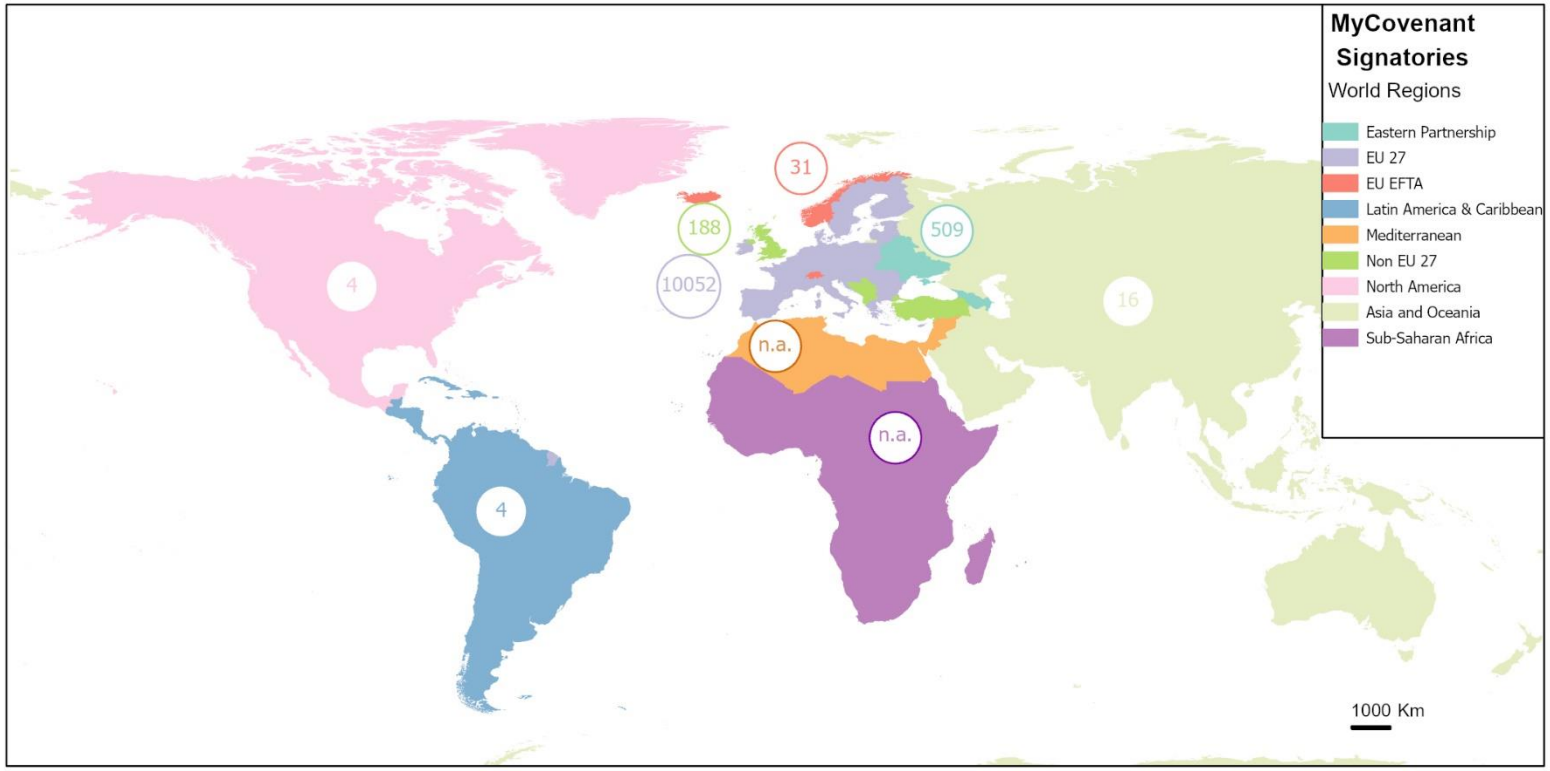
well as the NUTS3 codes (Nomenclature of Territorial Units for Statistics, level 3) for signatories belonging to EU and UK. On a third stage, the main information quality-harnessing procedure was performed, as it will be explained in the Mitigation (3.2.1) and Adaptation (5.2) Chapters. Finally, the new cleaned and structured tables were submitted for publication (Franco et al., 2022a), aiming at fulfilling the FAIR (Findability, Accessibility, Interoperability, and Reusability) 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 (end of March 2022), there was a total of 10 804 cities and local governments registered as CoM signatories through MyCovenant, covering a total population of 345.8 million inhabitants, as shown in Table 1. An overview of signatories from different world regions is presented in Figure 1.[23]. 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 10 804 signatories is 9 787.

[23] Signatories from Mediterranean cities (CoM-South) use since 2021 an adapted version of the MyCovenant reporting platform, feeding a separate database, while signatories from Sub-Saharan Africa (CoM-SSA) use an offline reporting tool, tailor-made to the regional priorities. Therefore, signatories from CoM-South and CoM-SSA are not included in the analysis underpinning this report.

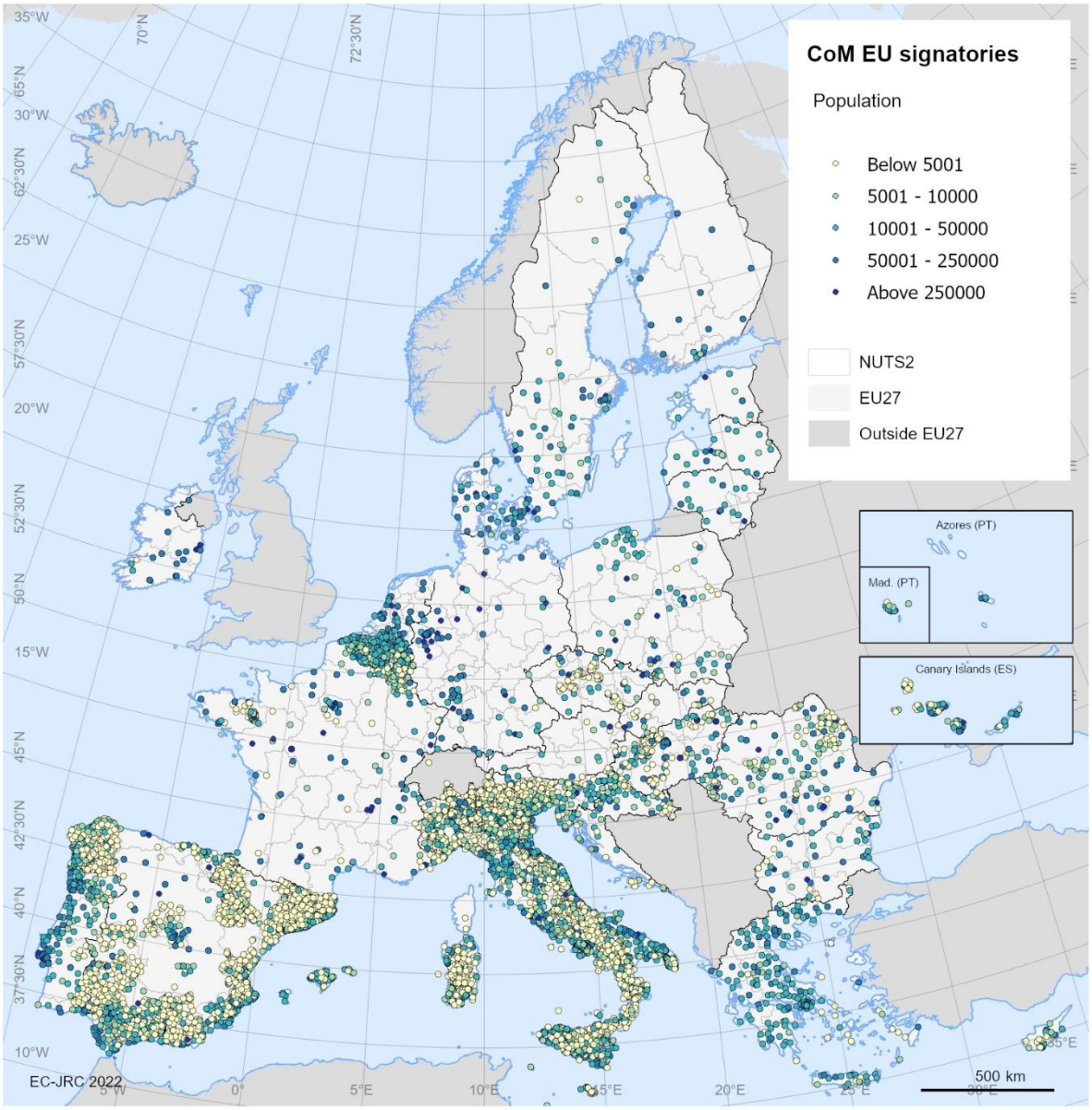
Figure 1. Overview of signatories registered through the MyCovenant reporting platform



Source: JRC elaboration based on GCoM data

As shown in Table 1, most of the signatories (10 052) come from the EU-27, covering 237.0 million inhabitants, followed by the Eastern Partnership countries (509 signatories, 33.1 million inhabitants), Europe – non-EU (219 signatories, 67.3 million inhabitants). A smaller number of signatories come from other countries (24 signatories, 8.4 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	10 052	9 035	237 017 216
Eastern Partnership (CoM-East)	509	509	33 131 458
Europe - Non EU	219	219	67 322 482
Rest of the world	24	24	8 361 235
Total	**10 804**	**9 787**	**345 832 391**

Source: JRC elaboration based on GCoM data

As described in 1.1, the Covenant initiative has evolved over time in line with the progress in EU energy and climate policy. Signatories have therefore undertaken different commitments according to the moment of adhesion. Table 2 and Table 3 show the number of signatories and the population covered by region, based on the commitment they signed up to:

- CoM 2020 refers to signatories of the Covenant of Mayors up to October 2015, commiting only to mitigation with a minimum 20% emission reduction target by 2020;
- Mayors Adapt refers to Mayors Adapt signatories up to October 2015, committing only to climate change adaptation;
- CoM 2030 refers to signatories of the Covenant of Mayors for Climate and Energy, with a commitment to adaptation combined with a 40% mitigation target by 2030[24];
- CoM 2050 refers to signatories of the new Covenant of Mayors for Climate and Energy, with a commitment to adaptation combined with climate neutrality by 2050 with an interim 55% emission reduction target by 2030.

Table 2. CoM signatories by region and by commitment.

Region	CoM 2020	CoM 2030	Mayors adapt	CoM 2050
European Union	7 889	3 638	178	331
Eastern Partnership (CoM-East)	202	378	1	17
Europe - Non EU	123	101	10	22
Rest of the world	19	5		
Total	**8233**	**4122**	**189**	**370**

Source: JRC elaboration based on GCoM data

Table 3. Population covered by region and by commitment.

Region	CoM 2020	CoM 2030	Mayors adapt	CoM 2050
European Union	198 297 617	111 600 767	24 242 081	17 887 474
Eastern Partnership (CoM-East)	21 327 765	18 640 244	98 953	949 472
Europe - Non EU	38 827 412	28 741 927	5 553 381	14 376 789
Rest of the world	6 245 574	2 115 661		
Total	**264 698 368**	**161 098 599**	**29 894 415**	**33 213 735**

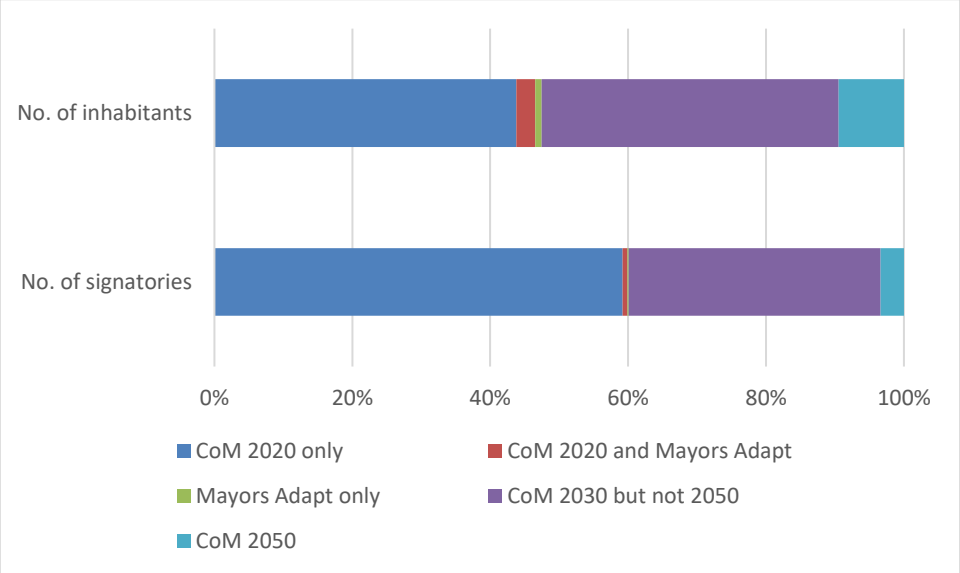
Source: JRC elaboration based on GCoM data

[24] For CoM-East signatories, the 2030 target was originally set to 30% by 2030.

A more detailed analysis on the number of signatories and population covered by country is presented in Annex 2.

Despite the high number of signatories, almost 60% of them has not yet renewed their commitment by joining CoM 2030 or 2050.

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 action plans retained in the dataset is 7 068, coming from 6 927 signatories covering almost 243 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.

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

Region	Total	Mitigation	*Mitigation 2020*	*Mitigation 2030*	*Mitigation 2050*	Adaptation
European Union (EU-27)	**6 711**	6 687	*5 770*	*1 133*	*7*	1 138
Eastern Partnership (CoM-East)	**241**	241	*125*	*121*	-	116
Europe - Non EU-27	**111**	110	*83*	*36*	-	38
Rest of the world	**5**	4	*2*	*2*	-	3
Total	**7 068**	**7 042**	***5 980***	***1 292***	***7***	**1 295**

Source: JRC elaboration based on GCoM data

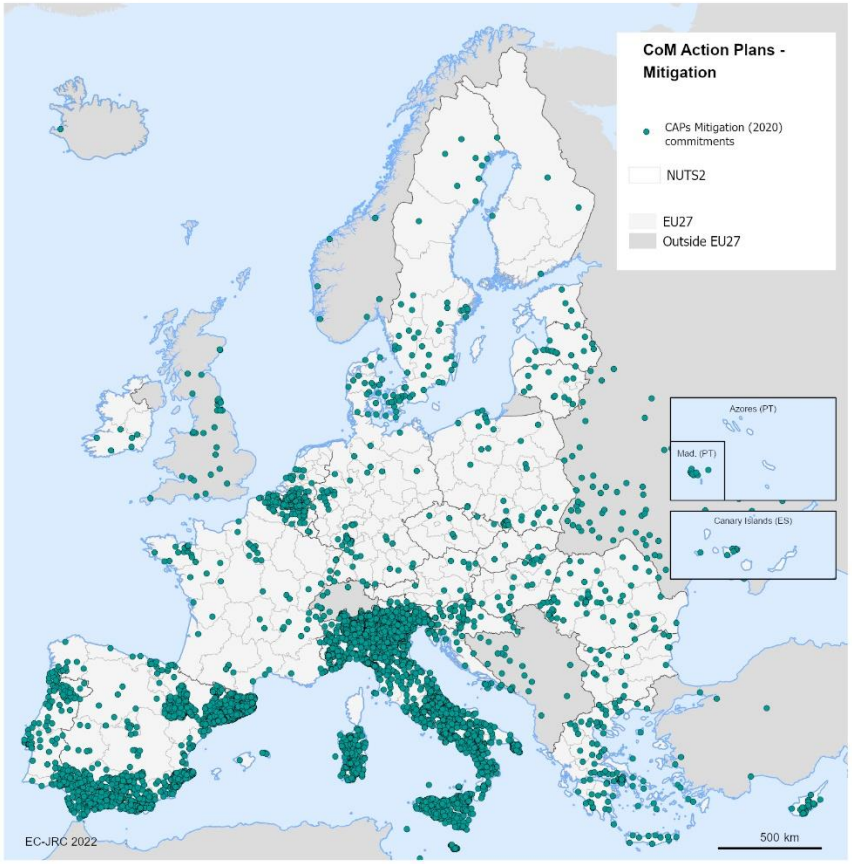
Table 5. No. of inhabitants in cities with submitted action plans.

Region	Total	Mitigation	*Mitigation 2020*	*Mitigation 2030*	*Mitigation 2050*	Adaptation
European Union (EU-27)	**178 196 807**	177 719 960	*155 167 280*	*49 399 772*	*1 711 799*	52 684 596
Eastern Partnership (CoM-East)	**20 896 046**	20 896 046	*15 105 532*	*5 998 227*		5 824 946
Europe - Non EU-27	**41 996 159**	41 934 739	*33 234 221*	*15 381 670*		15 793 090
Rest of the world	**1 448 349**	1 448 349	*377 486*	*1 070 863*		1 070 863
Total	**242 537 361**	**241 999 094**	***203 884 519***	***71 850 532***	***1 711 799***	**75 373 495**

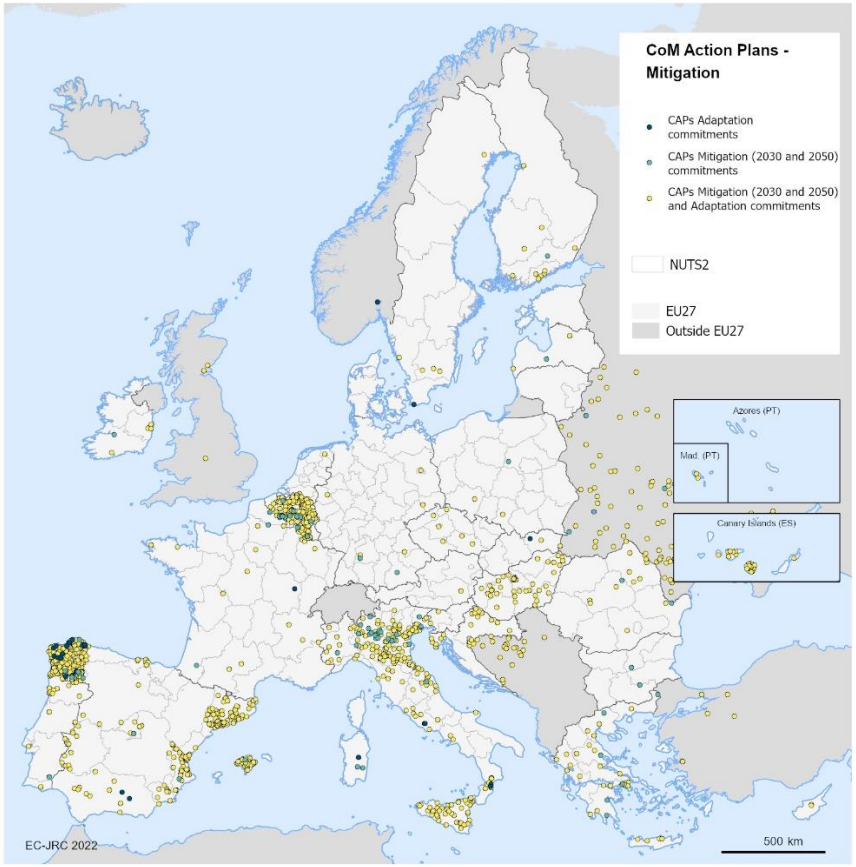
Source: JRC elaboration based on GCoM data

An overview of the signatories with a submitted action plan is provided in 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 or 2050 and adaptation (b).



(a)

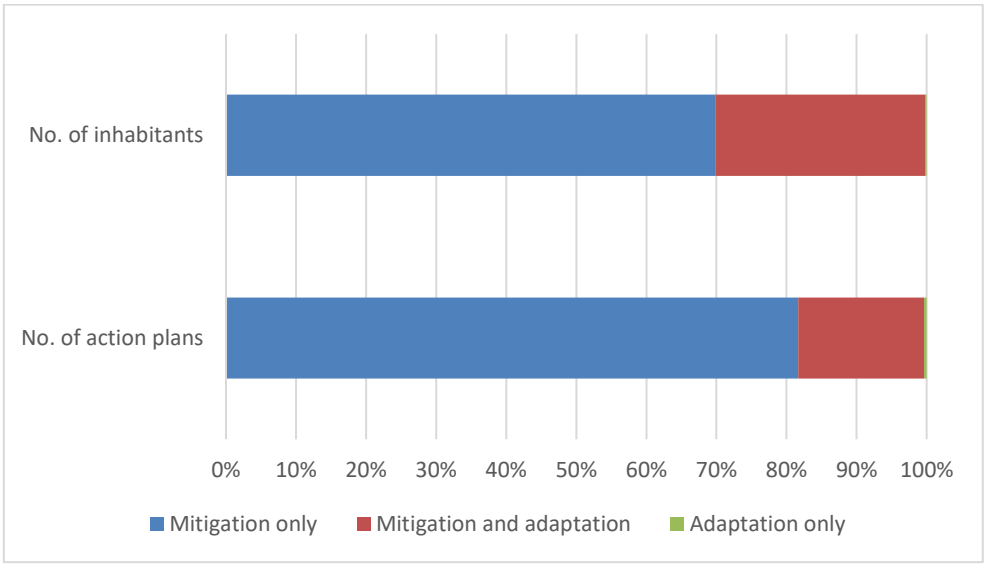


(b)

Source: JRC elaboration based on GCoM data

Looking at the action plans by pillar (Figure 5.), we note that 81.7 % of the action plans (covering 69.9 % of the population) only address the mitigation pillar and that just 18 % of the actions plans (29.9 % of the population) address simultaneously mitigation and adaptation. Less than 0.5 % of action plans and population address the adaptation pillar alone.

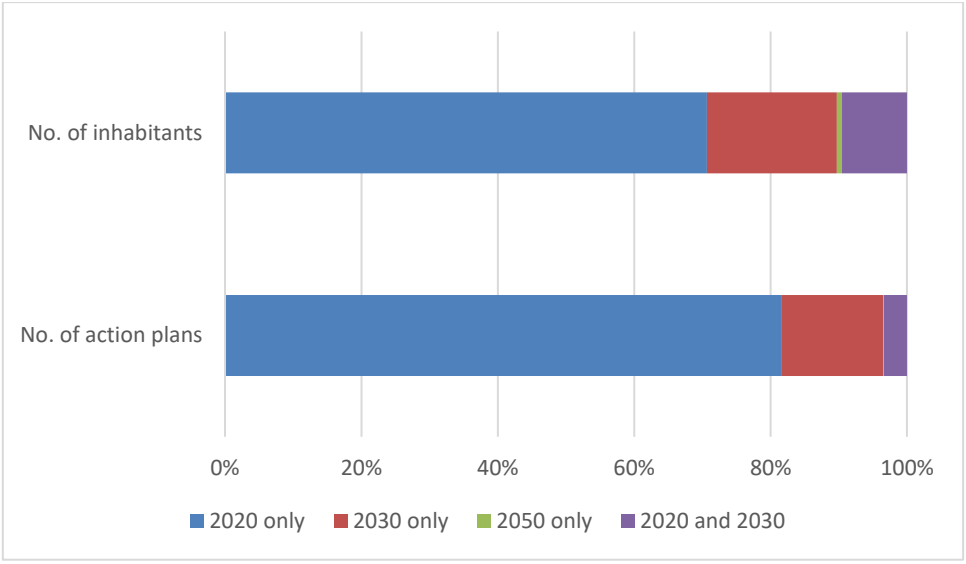
Figure 5. No. of action plans and population covered as a function of the pillar addressed.



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 81.6% of the mitigation plans (covering 70.7% of the population) has a 2020 target only, with the remaining 18.4% of the mitigation plans having a 2030 target, either combined with a 2020 target (3.4% of the plans, 9.6% of the population) or not (15% of the action plans, 19.1% 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 2 713, covering 114.8 million inhabitants. That represents 39 % of the signatories with an

action plan and 48 % 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 2 713 signatories with a monitoring report, 1 438 (covering nearly 76 million inhabitants) submitted a monitoring report flagged as "complete", i.e., including at least one monitoring emission inventory. That corresponds to 21% of the signatories with an action plan and 31% of the action plans population. The other 1 275 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)	2 628	40%	1 402	21 %
Eastern Partnership (CoM-East)	64	27%	21	9 %
Europe - Non EU-27	21	19%	15	14 %
Total	**2 713**	**39%**	**1 438**	**21 %**

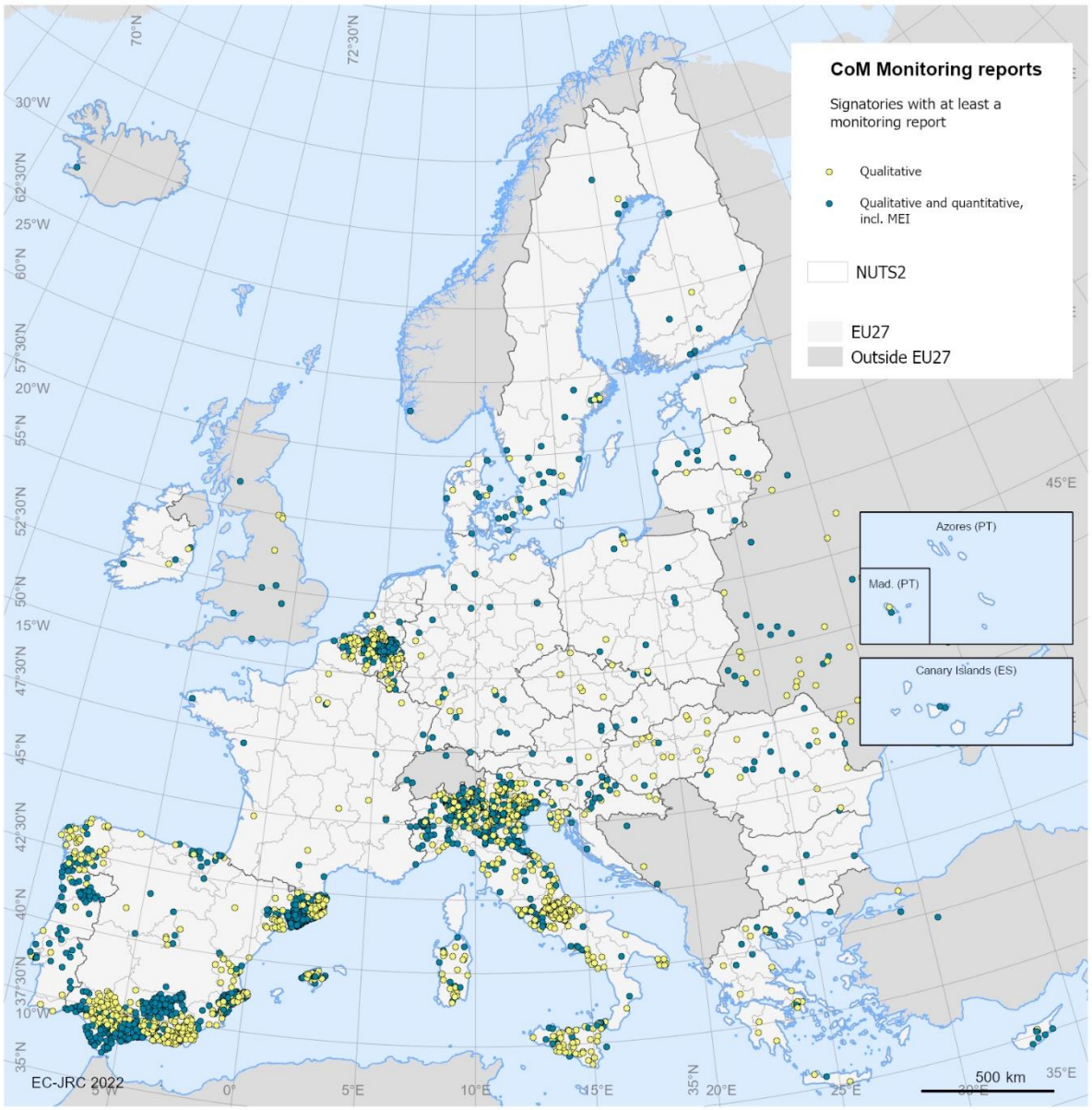
Source: JRC elaboration based on GCoM data

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)	99 134 257	56%	68 451 144	38 %
Eastern Partnership (CoM-East)	9 146 844	44%	2 947 945	14 %
Europe - Non EU-27	6 562 802	16%	4 529 331	11 %
Total	**114 843 903**	**48%**	**75 928 420**	**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[25], the Life-Cycle Assessment (LCA) approach[26] 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 consider 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 [27]. 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.

[25] https://www.ipcc-nggip.iges.or.jp/EFDB/main.php
[26] For the LCA approach many datasets are available on the market.
[27] 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 emissions inventories, and on the declared actions set out to fulfil the signatories' 2020, 2030, mid-term and 2050 commitments[28]. 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, the reported city energy activity was compared 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 (MWh/year per capita).

In order to compute the maximum threshold for each group (by electricity and thermal carriers), countries are clustered together according to their median per capita national energy consumption (following the *k-medoids* technique). 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 three clusters with maximum thresholds of 2.6, 3.3 and 7.3 (MWh/year per capita), for electricity, and with maximum thresholds of 14, 18.7 and 25 (MWh/year per capita), 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 be rare but plausible, and if an evident error is detected, it can be corrected. For example, if the city reports in kWh instead of MWh, or in activity per capita instead of absolute activity. Only if the reported values appear to be incomplete or to make no proper sense, then the inventory is removed, and cities are contacted to revise their reported information. In total, 8 signatories, along with their action plans, and 46 individual emission inventories, were removed.

Once the energy activity data 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 missing or are too different from the carrier-specific reference, then such a reference is taken in its place. In total, 37 % of all signatories were missing some information regarding their associated emission factors, and 6 % of all signatories presented emission factors that had to be revised.

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 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.

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

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 (SEAPs/SECAPs), 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 limits for acceptable emission factors were based on Lo Vullo et al., 2020; Koffi et al., 2017).

Finally, regarding the actions' details, the 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

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

In order to develop the analysis of the signatories' achievements, emissions must be converted into the same units (IPCC, tonnes of CO_2 equivalent). Given the 'GCoM – MyCovenant, 2022' dataset (Franco et al., 2022a), 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).

Concerning the analysis of the signatories' accomplishments for 2020 and 2030 commitments, it is important to acknowledge a couple of issues inherent to the available data. One concerns the direct association between any given MEI and the different BEIs that a signatory may have submitted together with its action plan. There is no explicit link between one MEI and its BEI of reference, and thus, a direct relation is assumed between all BEIs and MEIs taking part of the same action plan. Secondly, it is plausible that signatories are not completely consistent or coherent in reporting their relevant emissions for the same sectors that they include in their BEIs and MEIs. For this reason, the analysis concerning the signatories' achievements focuses only on the emissions allocated to *coherent sectors*. That is, by taking only the emissions assigned to sectors which are present in the BEIs and all associated MEIs (see Annex 1 for a comparison between all sectors and only the *coherent* ones).

Section 4.3.2 presents the analysis and results for the EU-27 signatories' (expected) accomplishments. Such an analysis focuses only on action plans holding at least one monitoring report. For 2020 commitments, there are 1851 action plans (corresponding with the same number of signatories), while for 2030 commitments, there are 412 action plans (corresponding with 406 signatories).

Following the statistical methodology presented in (Franco, et al., 2022b), the emissions inventories are estimated for a common baseline year of 2005, and then predicted for the target years of 2020 and 2030. Therefore, emissions are forecasted by adjusting a statistical model on their reported data, after minimising the prediction error for the last known value. The summary of the complete methodology and the results are shown in Tables A1-A2 (see Annex 1).

Lastly, the analysis on 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 is reported by the cities along with their per capita targets.

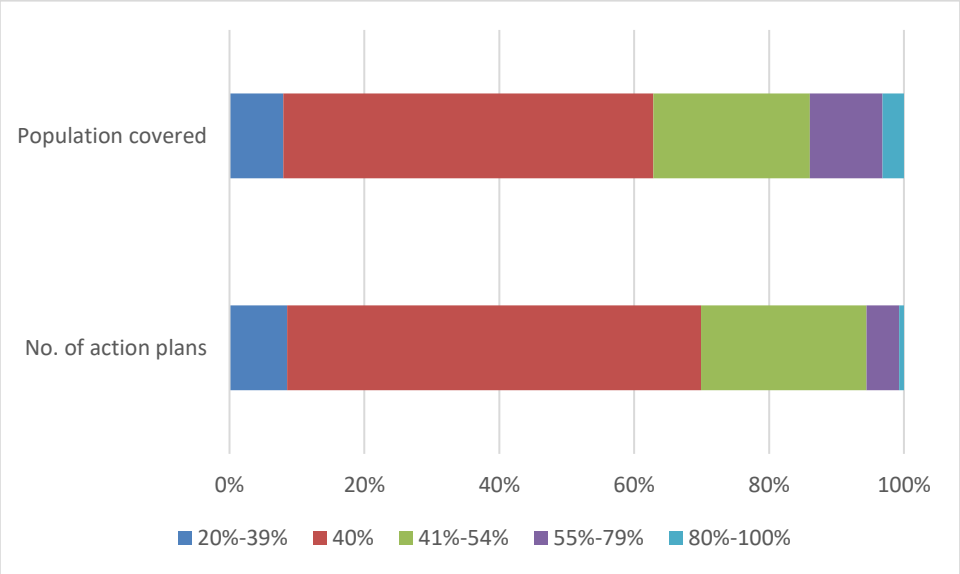
4 Results on mitigation

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 Action Plans.

Looking at the SECAPs with a 2030 time horizon (Figure 8), we can see that 61% 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 9% of the signatories set a target lower than 40%, which is allowed to CoM signatories outside the EU. Only 6% of the action plans set a target of at least 55% emission reduction. High-population signatories showed a distinct proclivity to either high targets (above 54%).

Figure 8. 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 and on the results of baseline emissions inventories reported by 1 251 cities and local authorities with data considered valid according to the procedure described in Section 3.2.1, the overall commitment by 2030 (Table 9) has been calculated. It appears that, overall, EU-27 signatories have made a more ambitious commitment compared to the minimum 40% emission reduction target by 2030. Annex 2 presents the same analysis at country level.

Table 9. 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)	249 431 599	134 295 360	46.2%
Eastern Partnership (CoM-East)	19 067 693	12 925 724	32.2%
Europe - Non EU-27	52 537 027	32 899 764	37.4%
Rest of the world	523 588	408 399	22.0%
Total	**321 559 906**	**180 529 248**	**43.9%**

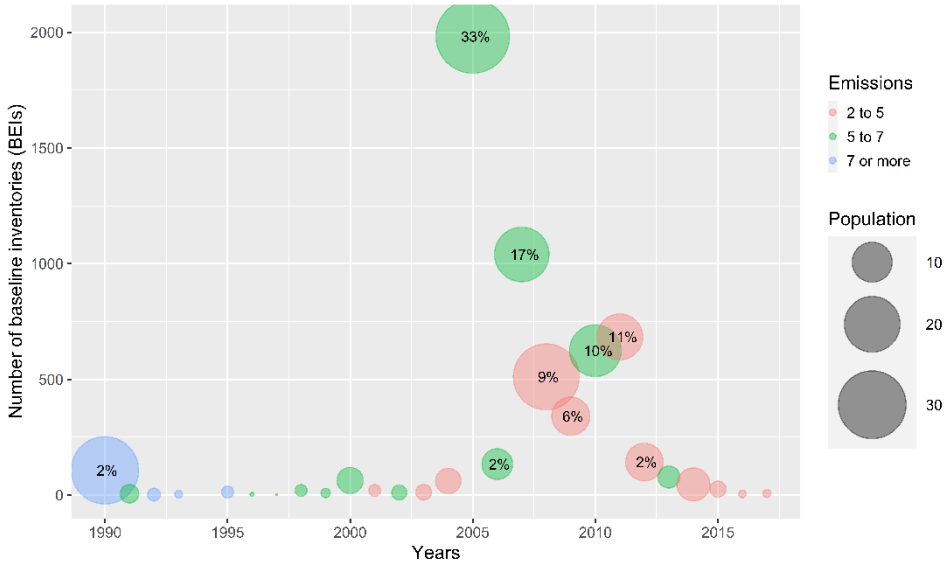
Source: JRC elaboration based on GCoM data

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 9 and Figure 10 for 2020 and 2030 commitments, respectively. In total, for all the GCoM signatories with a 2020 commitment, there are 5 950 signatories holding a BEI (from which 1930 have reported at least one MEI). Most of them have chosen 2005 as their base year, representing 33 % of all the BEIs (see Figure 9). This 33 % represents a population of 35.5 million inhabitants, generating 5.2 tonnes CO_2-eq per capita. Other frequently used base years are 2007, 2010 and 2011, including 17 %, 10 %, 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 28.3 million citizens, generating 4.45 tonnes CO_2-eq per capita. The highest level of emissions per capita is associated with 1990 baseline inventories, holding 2 % of all BEIs, generating 8.04 tonnes CO_2-eq per capita.

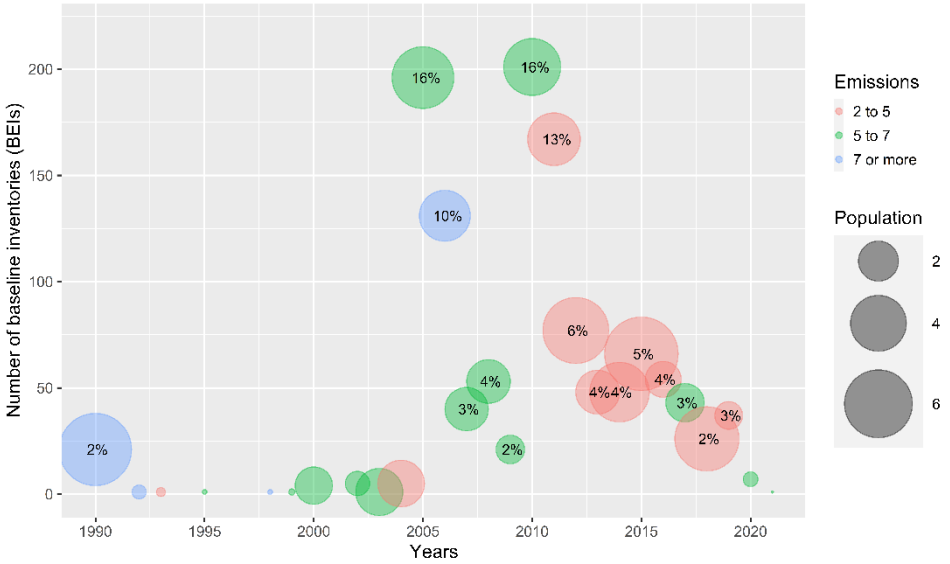
Figure 9. Frequency of BEIs for the different base years regarding 2020 commitments, along with the population (in millions) and emissions per capita (tonnes CO_2-eq) for every year.



Source: JRC elaboration based on GCoM data

Concerning 2030 commitments, in total there are 1 247 GCoM signatories with a BEI (from which 428 have also reported at least one MEI), where 16 % of them select 2005 and another 16 % choose 2010 as their base year (see Figure 10). The 2005 BEIs hold a population of 4.9 million inhabitants with 5.8 tonnes CO_2-eq per capita, against the 2010 BEIs representing a population of 4.1 million inhabitants with 4.95 tonnes CO_2-eq per capita. Other frequently used base years are 2006 (with 6.88 tonnes CO_2-eq per capita) and 2011 (with 4.5 tonnes CO_2-eq per capita), corresponding to 10 % and 13 % of all the BEIs, respectively. Besides, the year with the greatest proportion of population represented in the BEIs corresponds to 2015, containing 5% of all the BEIs with 7.07 million inhabitants and 3.8 tonnes CO_2-eq per capita.

Figure 10. 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 10 and Table 12) from those focusing on 2030 (Table 11 and Table 13) for both EU-27 and non-EU signatories.

The largest part of emissions is reported by EU-27 signatories, namely 80% for 2020 commitments and 78% for 2030 commitments. For comparison, the overall amount of emissions declared by EU-27 SEAPs with 2020 horizon (Table 10) and with 2030 horizon (Table 10) corresponds to about 29% and 9% respectively of the overall EU-27 CO_2 emissions as estimated for 2021 by EDGAR ((Crippa, et al., 2022)), 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 57% of reported SEAPs 2020 emissions (55% for 2030 SECAPs), while electricity is the second carrier with 35% of reported SEAPs 2020 and SECAPs 2030 emissions.

District heating follows with 6% of reported emissions (both for SEAPs 2020 and SECAPs 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 (47% of emissions) while non-energy related emissions become more significant (7% of emissions).

Table 10. 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
Municipal buildings equipment/facilities	11 600 238	2 578 770	5 254 117	92 119		19 525 244
Residential buildings	84 261 183	22 996 011	106 440 693	5 069 965		218 767 852
Tertiary (non municipal) buildings equipment/facilities	88 331 649	8 535 494	43 889 045	306 511		141 062 699
Industry Non-ETS	60 863 826	4 946 729	48 881 139	546 834		115 238 529
Industry-ETS	803 096	125	2 699 610	786		3 503 617
Buildings equipment/facilities non allocated	26 560 205	12 419 000	35 974 287	1 671 787		76 625 280
Agriculture Forestry Fisheries	1 724 599	307 782	4 679 223	1 665		6 713 269
Other non allocated	164 899	50 655	84 298			299 852
Municipal fleet	417 928		1 224 845	3 256		1 646 029
Public transport	2 977 912		4 263 985	40 947		7 282 844
Private and commercial transport	380 407		164 539 276	241 444		165 161 127
Transport non allocated	901 034		50 996 582	57 998		51 955 613
Waste management					2 710 630	2 710 630
Wastewater treatment and discharge					370 390	370 390
Total	**278 986 976**	**51 834 568**	**468 927 101**	**8 033 312**	**3 081 020**	**810 862 976**

Source: JRC elaboration based on GCoM data

Table 11. GHG emissions reported in BEIs related to 2030 commitments – EU-27 (units tonnes CO_2eq/year).

Emissions in BEI - 2030 SECAPs - EU-27 only

Sector	Electricity	District heating and cooling	Fossil fuels	Renewable fuels	Non-energy related emissions	Total
Municipal buildings equipment/facilities	4 237 316	558 541	1 381 322	4 722		6 181 902
Residential buildings	27 594 954	7 933 622	38 368 999	2 129 281		76 026 856
Tertiary (non municipal) buildings equipment/facilities	30 051 503	4 022 607	17 802 664	173 719		52 050 494
Industry Non-ETS	18 189 065	1 302 512	11 837 819	112 056		31 441 452
Industry-ETS	389 103		2 140 568	1 195		2 530 865
Buildings equipment/facilities non allocated	3 876 934	11 411	915 405	44 855		4 848 605
Agriculture Forestry Fisheries	534 062	155 425	1 306 589	1 774		1 997 849
Other non allocated	171 772	148 966	76 091	117		396 947
Municipal fleet	27		742 915	4 625		747 567
Public transport	1 842 939		2 453 184	40 870		4 336 993
Private and commercial transport	129 026		59 471 899	285 283		59 886 208
Transport non allocated	37 393		6 539 444	6 419		6 583 256
Waste management					2 176 078	2 176 078
Wastewater treatment and discharge					226 527	226 527
Total	**87 054 095**	**14 133 084**	**143 036 898**	**2 804 917**	**2 402 605**	**249 431 599**

Source: JRCelaboration based on GCoM data

Table 12. 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
Municipal buildings equipment/facilities	2 750 885	1 289 167	1 475 754	5 732		5 521 537
Residential buildings	28 201 120	8 972 190	34 119 985	1 221 787		72 515 082
Tertiary (non municipal) buildings equipment/facilities	13 239 840	1 292 247	5 916 304	153 543		20 601 934
Industry Non-ETS	14 489 761	141 789	31 502 077	39 130		46 172 758
Industry-ETS	-	1 412	29 610			31 022
Buildings equipment/facilities non allocated	15 350 064	108 849	7 187 884	130 598		22 777 394
Agriculture Forestry Fisheries	23 612	31	56 167	10 217		90 026
Other non allocated	1 366					1 366
Municipal fleet	11 640		234 799	2 271		248 711
Public transport	1 428 013		2 415 996	1 492		3 845 501
Private and commercial transport	6 865		25 000 865	7 836		25 015 566
Transport non allocated			4 378 247	1 564		4 379 811
Waste management					1 843 834	1 843 834
Wastewater treatment and discharge					343 395	343 395
Total	**75 503 165**	**11 805 685**	**112 317 688**	**1 574 170**	**2 187 229**	**203 387 937**

Source: JRC elaboration based on GCoM data

Table 13. GHG emissions reported in BEIs related to 2030 commitments – Non-EU (units tonnes CO_2eq/year).

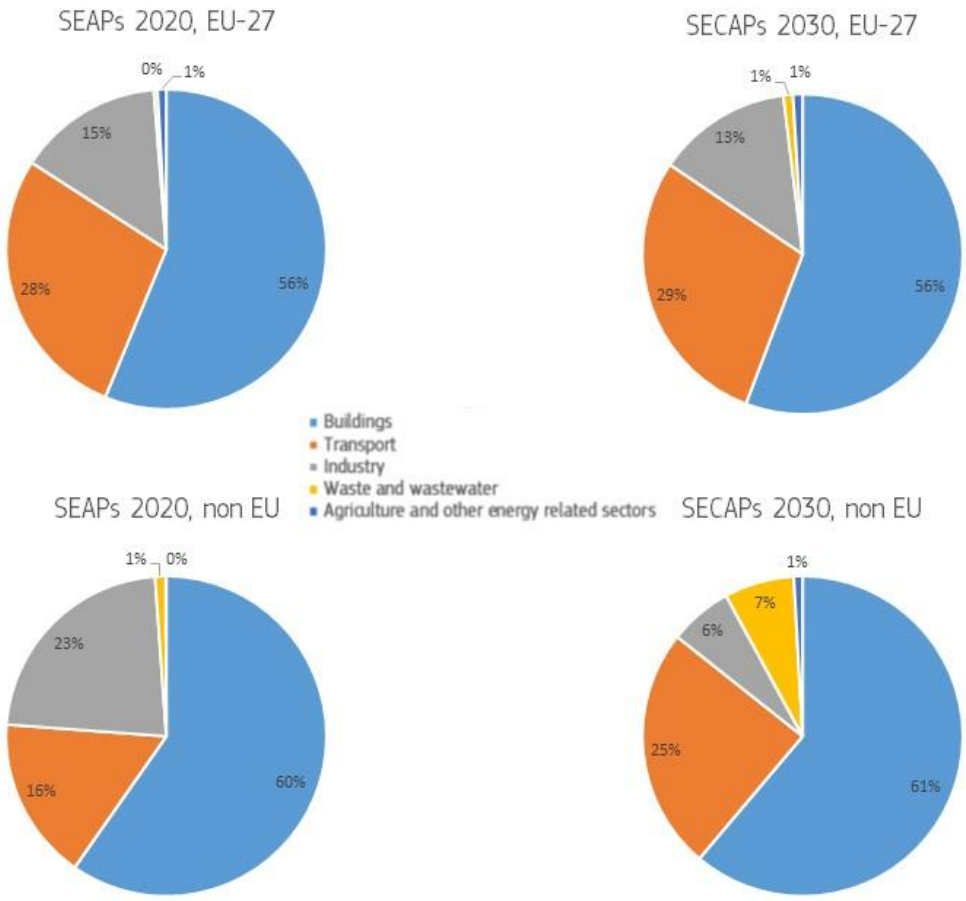
Emissions in BEI - 2030 SECAPs - Non-EU

Sector	Electricity	District heating and cooling	Fossil fuels	Renewable fuels	Non-energy related emissions	Total
Municipal buildings equipment/facilities	2 560 580	973 477	498 016	104 839		4 136 911
Residential buildings	13 978 751	3 792 718	11 125 972	461 571		29 359 011
Tertiary (non municipal) buildings equipment/facilities	7 445 575	268 479	2 422 990	20 476		10 157 519
Industry Non-ETS	1 133 590	52 552	2 132 540	27 463		3 346 145
Industry-ETS	1 201 797		63 882	1 747		1 267 426
Buildings equipment/facilities non allocated	16 968		440 338			457 306
Agriculture Forestry Fisheries	244 194	12 733	262 037	113 368		632 332
Other non allocated	1 366					1 366
Municipal fleet	10		174 127	2 228		176 365
Public transport	343 894		859 767	445		1 204 106
Private and commercial transport	241		16 271 219	32 892		16 304 352
Transport non allocated			259			259
Waste management					4 519 014	4 519 014
Wastewater treatment and discharge					566 196	566 196
Total	**26 926 965**	**5 099 958**	**34 251 145**	**765 030**	**5 085 210**	**72 128 307**

Source: JRC elaboration based on GCoM data

Figure 11 shows the distribution of emissions taking into consideration a smaller number of more aggregated macro-sectors. Buildings, transport and industry account for almost 98% of emissions except in SECAPs 2030 from non-EU signatories, where they account for about 92%. A more detailed view of these sectors is provided in the following paragraphs.

Figure 11. Distribution of emissions in BEIs by macro-sectors.



Source: JRC elaboration based on GCoM data

4.2.2.1 Buildings

Buildings account for almost two-thirds of the total emissions in BEIs. Residential buildings account for more than half of sectoral emissions for both 2020 and 2030 action plans, 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. It can be noted that in non-EU action plans the share of emissions from residential buildings increases to about 60%, while the share of tertiary buildings decreases to roughly 20%.

Regarding energy carriers, the picture is very similar for both 2020 and 2030 action plans, with electricity accounting for 47-49% of sectoral emissions, fossil fuels accounting for 40%-42%, district heating around 10% and renewable fuels associated with less than 2% of emissions.

4.2.2.2 Industry

Industry emissions reported in both 2020 and 2030 action plans are largely dominated by the non-ETS sector. In fact, the CoM approach recommends excluding from GHG accounting the emissions associated with

industries involved in the ETS (see also Table 8). There are significant differences between 2020 and 2030 action plans: in 2020 action plans, non-ETS represents 98% of industrial emissions, while in 2030 action plans its share decreases to 90%; also, major differences can be observed between 2030 EU action plans (non ETS accounting for 93% of sectoral emissions) and 2030 non-EU action plans (non ETS accounting for 75% of reported industrial emissions).

From the energy carrier perspective, electricity and fossil fuels together result in about 96% of emissions in all cases, with small variations for different time horizons and geographical areas. In general, electricity is more relevant for SEAPs 2030 (54% of the industrial emissions) than for SEAPs 2020 (46%), 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 4% and 12%. A relevant share of non-allocated transport is reported, notably for 2020 action plans, in some cases up to 23%. Fossil fuels overwhelmingly dominate the sector, constantly above 95%, with the rest of emissions mostly associated with electricity, being renewable fuels below 0.5%.

4.2.2.4 Waste (non-energy related emissions)

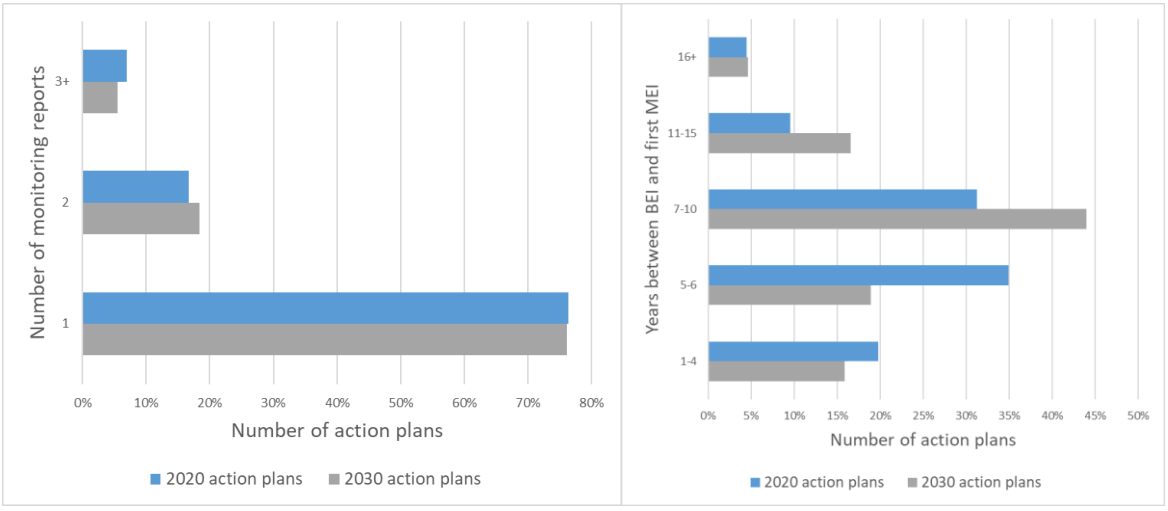
The waste sector produces non-energy related emissions, divided between actual waste management, accounting for between 84% and 90% of the emissions, and wastewater treatment producing the remaining emissions.

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 the first MEI in the following four years after the submission of the BEI (see the frequency of reporting in the CoM Reporting Guidelines), most of them require more time. Figure 12(a) shows the frequency of MEIs, observing that over 70% of all action plans have one MEI, while less than 20% have two MEIs and an even lower percentage, less than 10%, have more than three MEIs. Meanwhile, as shown in Figure 12(b), for 2020 commitments, the majority (35%) requires from 5 to 6 years to submit their first MEI, against the 44% of 2030 commitments, requiring between 7 and 10 years to do so. These insights confirm the findings presented in Rivas et al. 2022, about the barriers and difficulties that local governments face for undertaking the monitoring of emissions.

Figure 12. For all action plans, (a) the frequency of monitoring reports and (b) the number of years elapsed between the BEI and the signatories' first MEI.

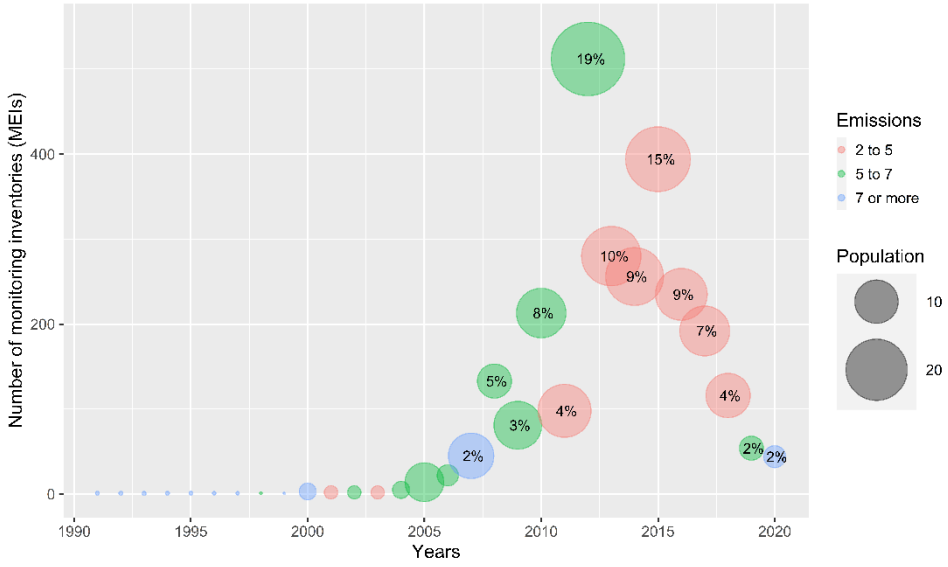


(a) (b)

Source: JRC elaboration based on GCoM data

Concerning 2020 commitments (see Figure 13), most signatories choose 2012 as the monitoring year, representing 19% of all MEIs. Those signatories represent a population of 28.9 million inhabitants, holding 4.86 tonnes CO_2-eq per capita. Other frequently used monitoring years go from 2013 to 2015, having 10%, 9% and 15% of all MEIs, respectively.

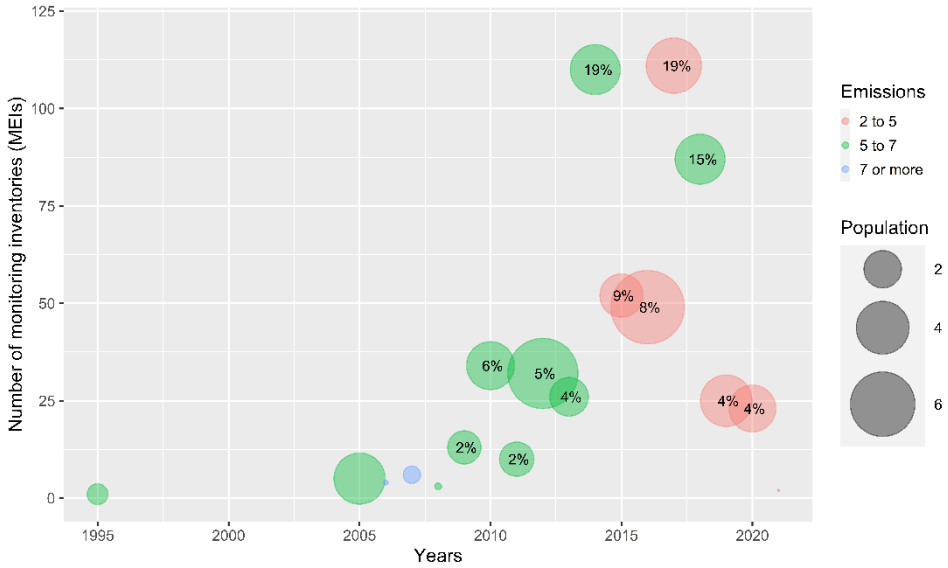
Figure 13. Frequency of MEIs for the different monitoring years regarding 2020 commitments, along with the population (in millions) and emissions per capita (tonnes CO_2-eq) for every year.



Source: JRC elaboration based on GCoM data

As for 2030 commitments (see Figure 14), most signatories have a MEI either on 2014 (19%) or in 2017 (19%). For 2014, there are 3.57 million inhabitants with 4.67 tonnes CO_2-eq per capita, while for 2017, there are 4.14 million inhabitants with 4.32 tonnes CO_2-eq per capita. Other frequently used monitoring years for 2030 commitments are 2015, 2016 and 2018, representing 9%, 8% and 15% of all MEIs, respectively.

Figure 14. 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.

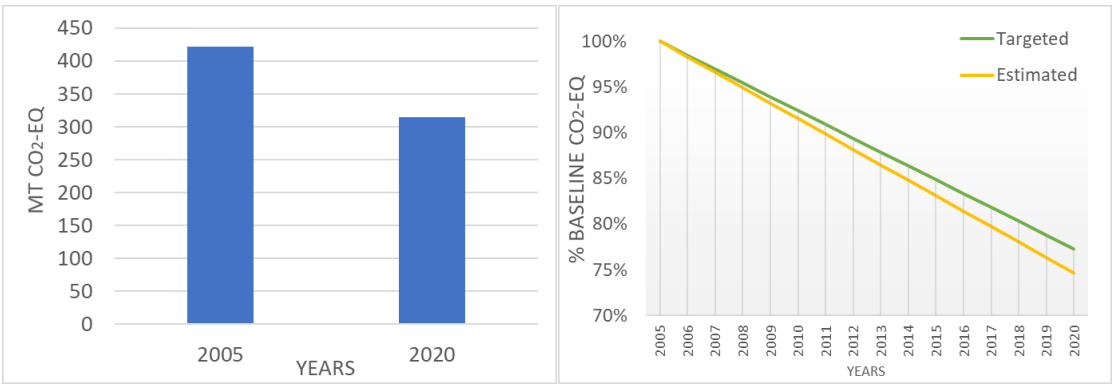


Source: JRC elaboration based on GCoM data

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 1 851 action plans in EU--27 with a commitment for 2020, with a BEI and at least one MEI. For this subset of action plans, and focusing only on the emissions consistently reported for the same sectors throughout the different inventory years (named *coherent sectors*), it is observed that an estimated 25.3 % mean reduction was achieved from 2005 to 2020[29], amounting to an absolute reduction of 106.79 Mt-CO_2 (see Figure 15(a)). As a result, from 2005 to 2020, the signatories positively exceeded their targeted mean reduction of 22.7 %, by 2.6 %, as shown in Figure 15(b).

Figure 15. (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 EU27 action plans.

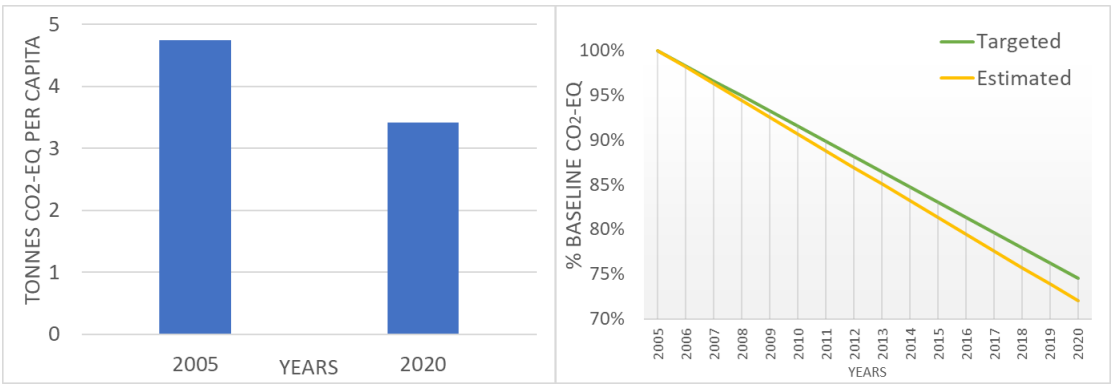


(a) (b)

Source: JRC elaboration based on GCoM data

Extending the previous analysis to a *per capita* frame, EU-27 signatories with a 2020 commitment achieved an estimated 28 % reduction in the volume of their per capita emissions inventories. The total GHG emissions reduction sums up to 1.33 tonnes-CO_2 per capita (as shown Figure 16(a)), positively exceeding by 3 % the targeted mean reduction of 25 % (for the period between 2005 and 2020), as shown in Figure 16(b).

Figure 16. (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.



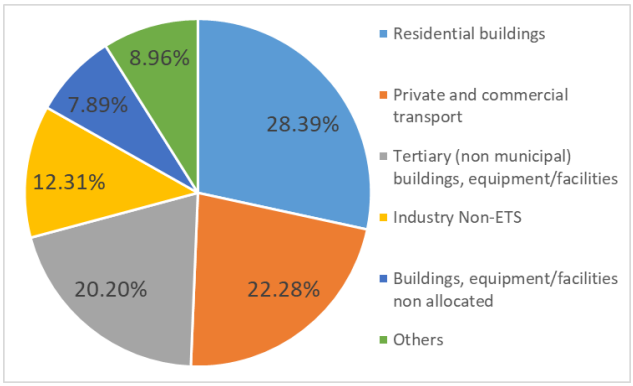
(a) (b)

Source: JRC elaboration based on GCoM data

[29] 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.

The total estimates (shown in Figure 15), can be decomposed by sub-sectors after taking the reported emissions in the latest available MEIs that signatories have submitted. The shares are presented in Figure 17 for the different sub-sectors, continuing the general trend found in their respective BEIs (see Figure 11). Hence, the residential buildings subsector has the highest importance (28.4 %), followed by private and commercial transport (22.3 %), tertiary (non-municipal) buildings (20.2 %), and Industry (12.3 %).

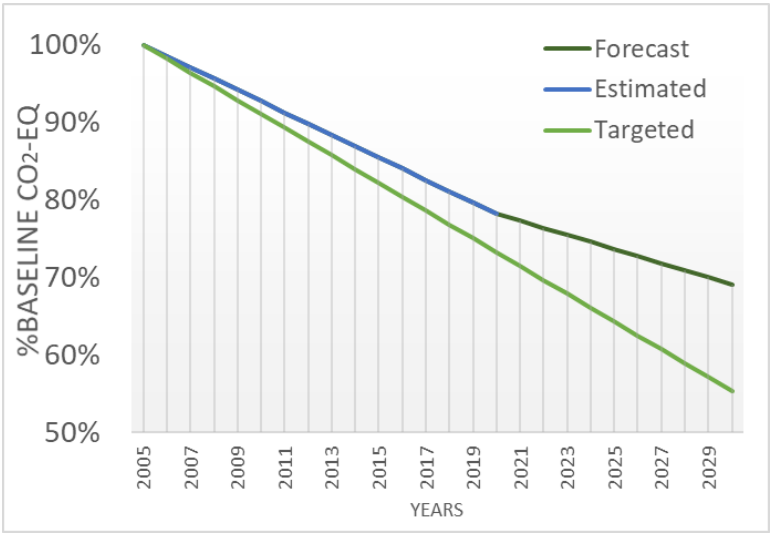
Figure 17. Emissions shares by sub-sector according to the latest MEIs reported in EU-27 signatories' SEAPs with 2020 commitments.



Source: JRC elaboration based on GCoM data

On the other hand, for EU-27 signatories with 2030 commitments, there are 412 action plans having a BEI and at least one MEI. After setting the base year to 2005, and considering only the coherent sectors, this subset signatories have the ambition of reducing their emissions, on average, by 44.6 %, but their predicted achievements fall 13.7 % short from such an ambition. In this way, the forecasted emissions in 2030 are in line with achieving a 30.9 % reduction (see Figure 18), entailing an absolute GHG emissions reduction of 34.05 Mt-CO_2. This insight suggests that more time and effort is necessary for signatories to advance in the implementation of their complete action plans and obtain more encouraging results.

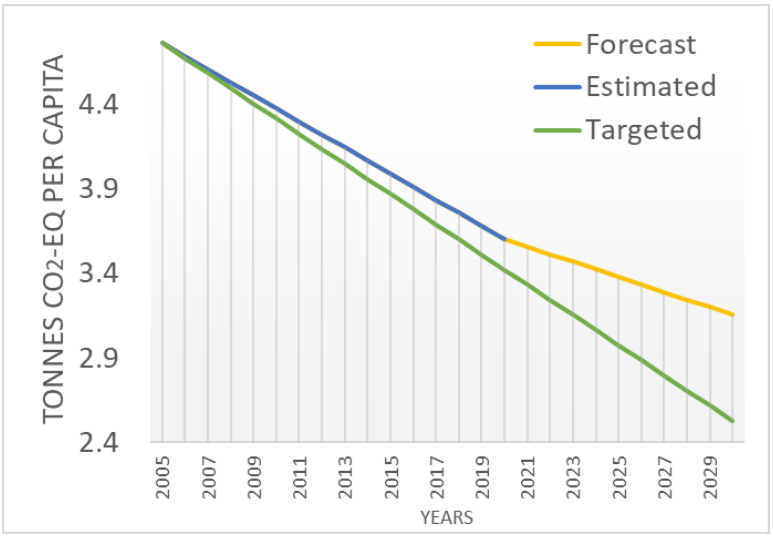
Figure 18. Trajectories of forecasted emissions and 2030 targets in EU-27 action plans.



Source: JRC elaboration based on GCoM data

As for per capita figures, EU-27 signatories with 2030 commitments are predicted to accomplish a 33.7 % reduction in tonnes-CO_2 per capita, hence achieving a total reduction of 1.6 tonnes-CO_2 per capita. The results fall short when compared to their declared ambitions, aiming at a 46.9 % reduction between 2005 and 2030. The trajectory of the signatories' emissions against their proposed target is shown in Figure 19.

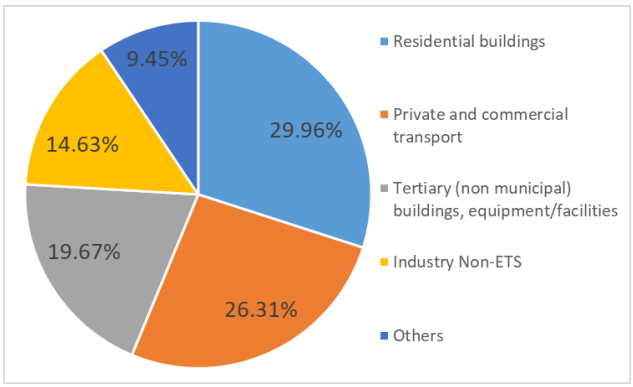
Figure 19. Trajectories of forecasted emissions per capita and 2030 targets in EU-27 action plans.



Source: JRC elaboration based on GCoM data

For these subset of 2030 commitments, the total estimates (shown in Figure 19), can be decomposed by sub-sectors after taking the latest MEIs. The shares are presented in Figure 20 for the different sub-sectors, continuing the general trend found in their respective BEIs (see again Figure 11), but also, very much in line with the shares previously identified for 2020 commitments. In consequence, the residential buildings subsector has the highest importance (30 %), followed by private and commercial transport (26.3 %), tertiary (non-municipal) buildings (20 %), and Industry (14.6 %).

Figure 20. Emissions shares by sub-sector according to the latest MEIs reported in EU-27 signatories' SECAPs with 2030 commitments.



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, many local authorities prefer to report a more comprehensive list of actions, not only three; therefore, the analysed dataset contains **194 180 mitigation actions/measures** from signatories located in Europe and beyond, committed to 2020 and/or 2030 targets. That corresponds to an average of **27.6 mitigation actions/measures per action plan**.

Out of those 194 180 mitigation actions/measures, 2582 are also targeting adaptation to climate change while 989 are targeting energy poverty.

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.

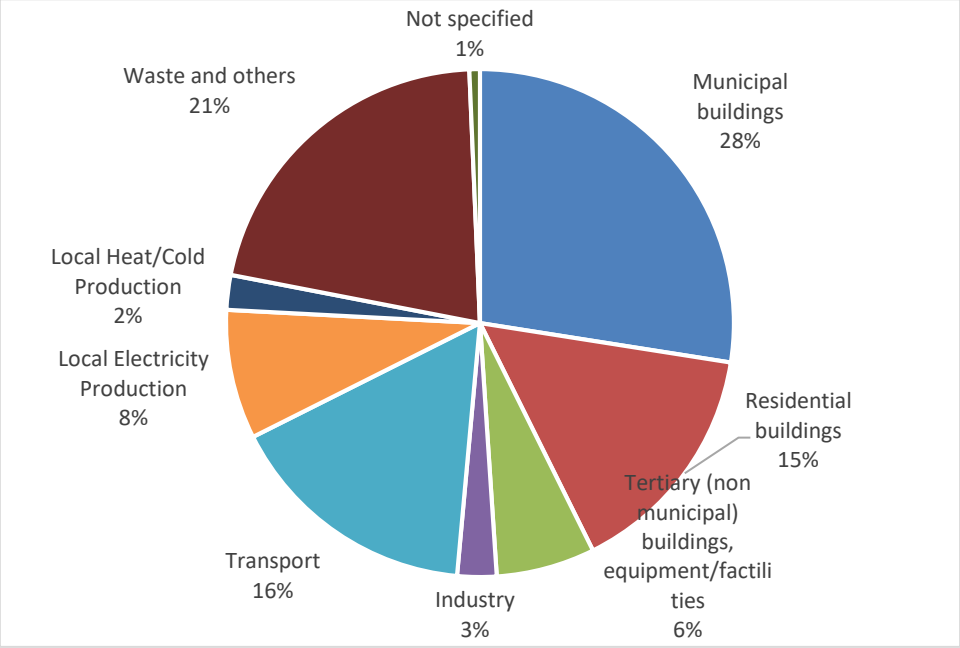
4.4.1 Actions/measures by sector

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: 99 893 actions/measures
- Transport: 31 375 actions/measures
- Local energy production: 20 276 actions/measures
- Waste and others: 41 334 actions/measures
- Not specified: 1 302

As shown in Figure 21, 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 (51%) of the actions listed in MyCovenant. The transport sector, accounts only for 16% of the planned actions/measures, despite representing 26-28% 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% 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 21. Share of mitigation actions/measures by targeted sector.



Source: JRC elaboration based on GCoM data

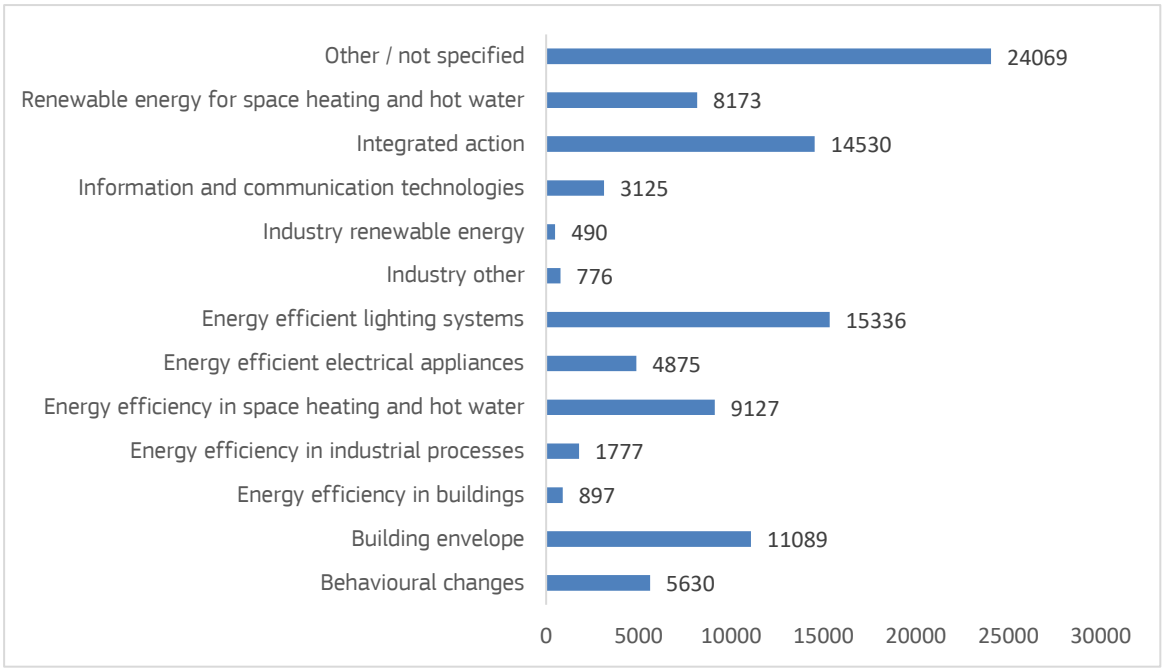
4.4.2 Actions/measures by area of intervention

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 99 893 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 22). 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.

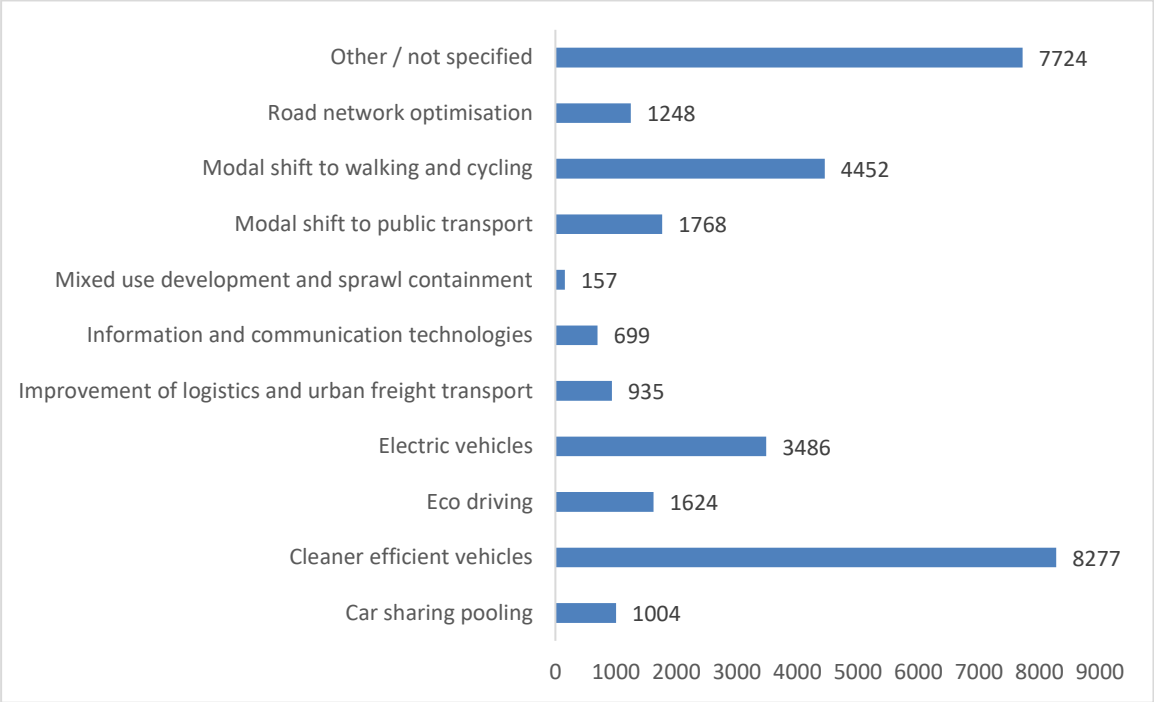
Figure 22. Stationary energy sector – Actions/measures by area of intervention.



Source: JRC elaboration basedon GCoM data

In the transport sector (Figure 23), the large majority of the 31 375 total planned actions concerns cleaner/efficient vehicles and electric vehicles (more than 11 700 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 4 400 measures classified as a modal shift to walking and cycling) or towards public transport (more than 1 700 measures) and to promote eco-driving (1 600 measures).

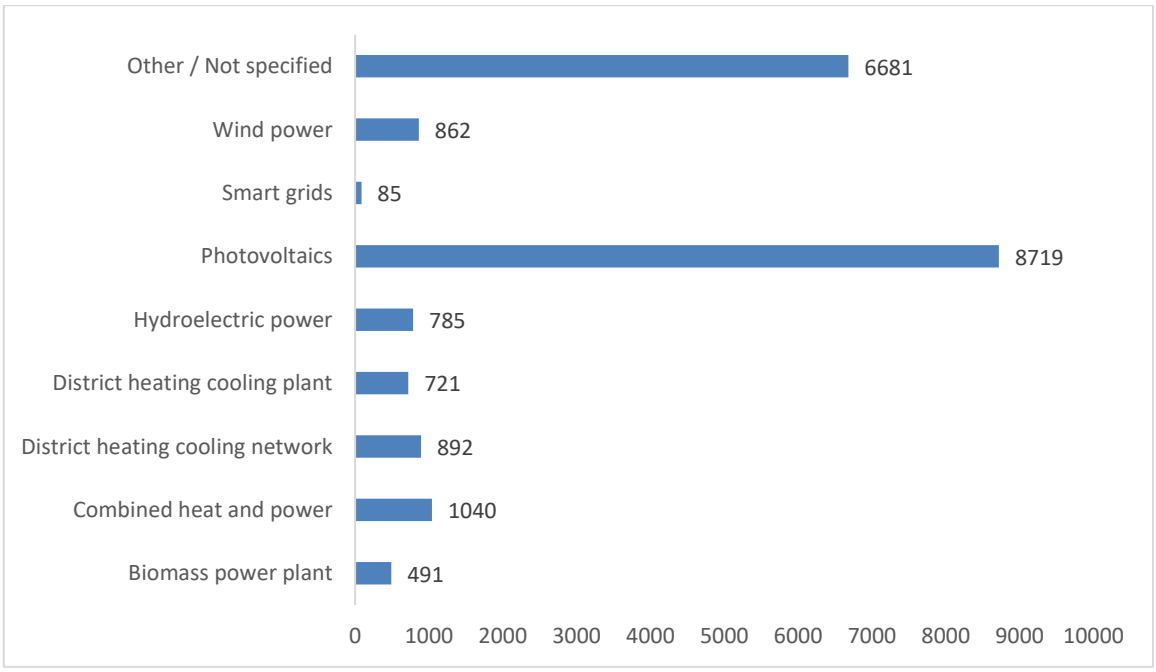
Figure 23. Transport sector - Actions/measures by area of intervention.



Source: JRC elaboration based on GCoM data

Looking at the 20 276 measures addressing the supply of energy (Figure 24), we can see a strong push towards photovoltaic (8 719 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.

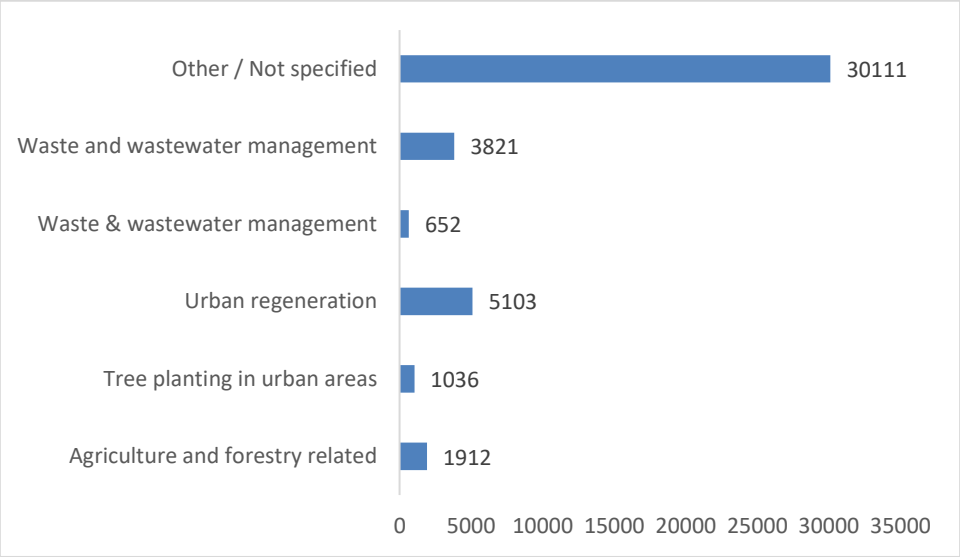
Figure 24. Energy production sector – Actions/measures by area of intervention.



Source: JRC elaboration based on GCoM data

The last sector, including waste and others (Figure 25), is more heterogeneous and comprises 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 25. Waste and other sectors - Actions/measures by area of intervention.



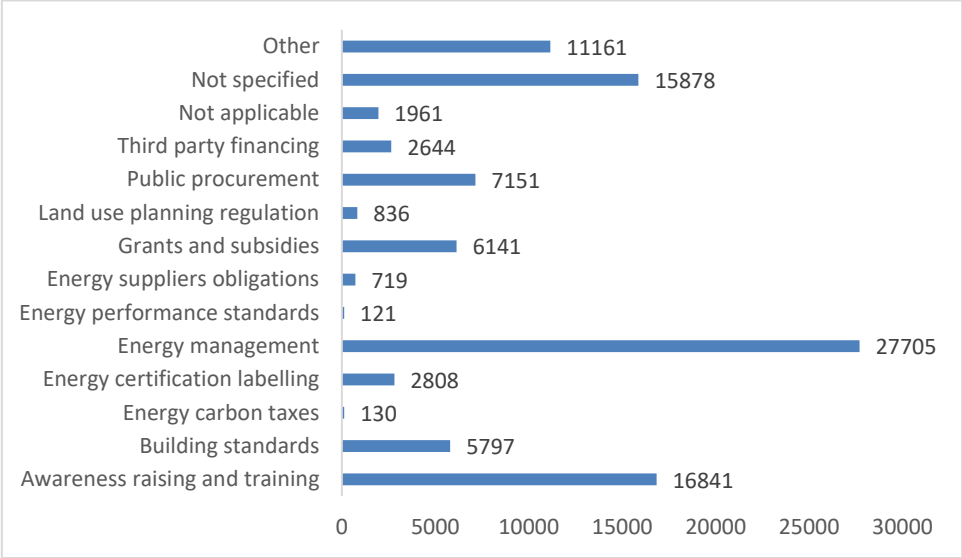
Source: JRC elaboration based on GCoM data

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 26 shows the policy instrument assigned to actions/measures targeting the stationary energy sector. The energy management policy instrument is associated with 27 705 reported actions (28 %), mainly addressing municipal buildings. The second preferred instrument is awareness-raising and training (16 841 actions), targeting, in particular, the residential buildings sector, but also municipal and tertiary buildings. Public procurement is also a quite common instrument (7 151 actions), followed by building standards (5 797), grants and subsidies (6 141) and energy certification/labelling (2 808). Other instruments seem less common in local mitigation plans.

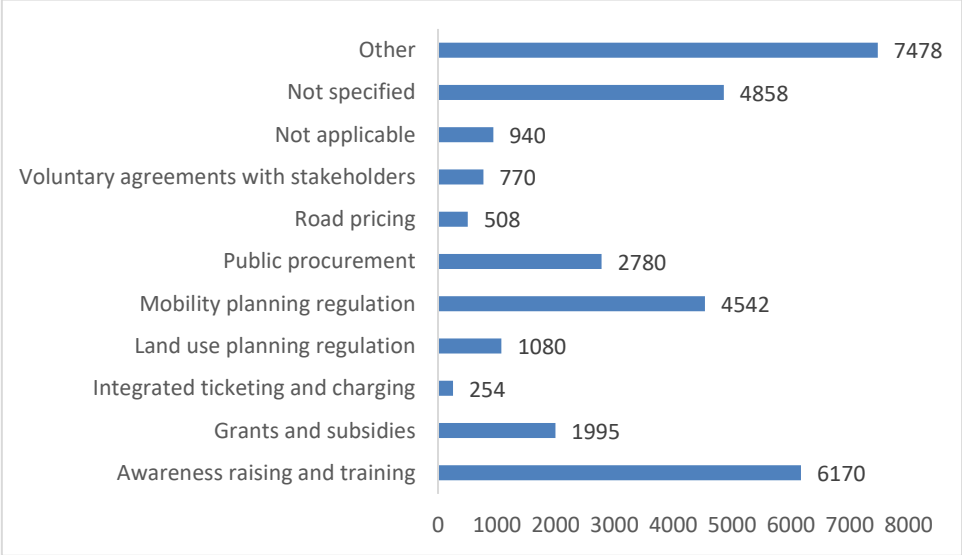
Figure 26. Stationary energy sector - Actions/measures by policy instrument.



Source: JRC elaboration based on GCoM data

In the transport sector (Figure 27), the preferred instrument is awareness-raising and training (6 170 actions out of 31 375), followed by mobility planning regulation (4 542 actions), public procurement to renew municipal fleet and vehicles used in public transport (2 780 actions), and grants and subsidies (1 995 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.

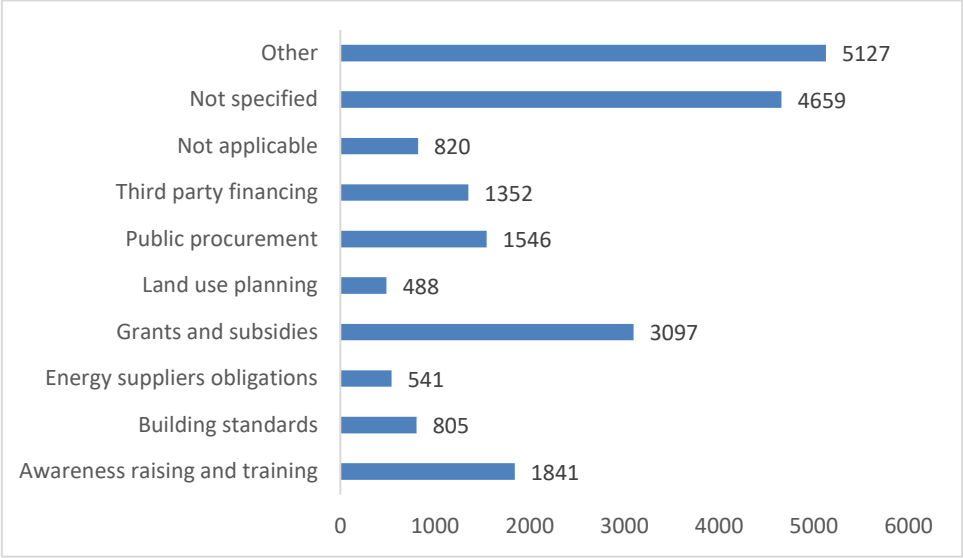
Figure 27. Transport sector - Actions/measures by policy instrument.



Source: JRC elaboration based on GCoM data

In the energy production sector (Figure 28), the most common policy instrument (when indicated) are grants and subsidies (3 097 actions out of 20 276), followed by awareness-raising and training (1 841 actions), public procurement (1 546 actions), third party financing (1 352 actions), building standards (805), energy suppliers obligations (541), and land use planning regulation (488).

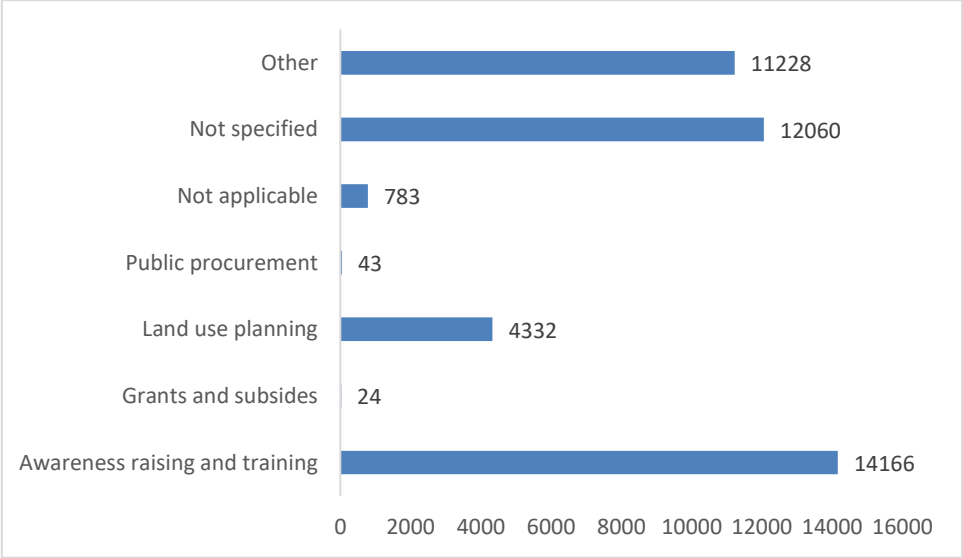
Figure 28. Energy production sector – Actions/measures by policy instrument.



Source: JRC elaboration based on GCoM data

Finally, the sector "waste and others" (Figure 29) includes two main policy instruments (when reported): awareness-raising and training (14 166 actions) and land use planning (4 332 actions).

Figure 29. Waste and other sectors - Actions/measures by policy instrument.

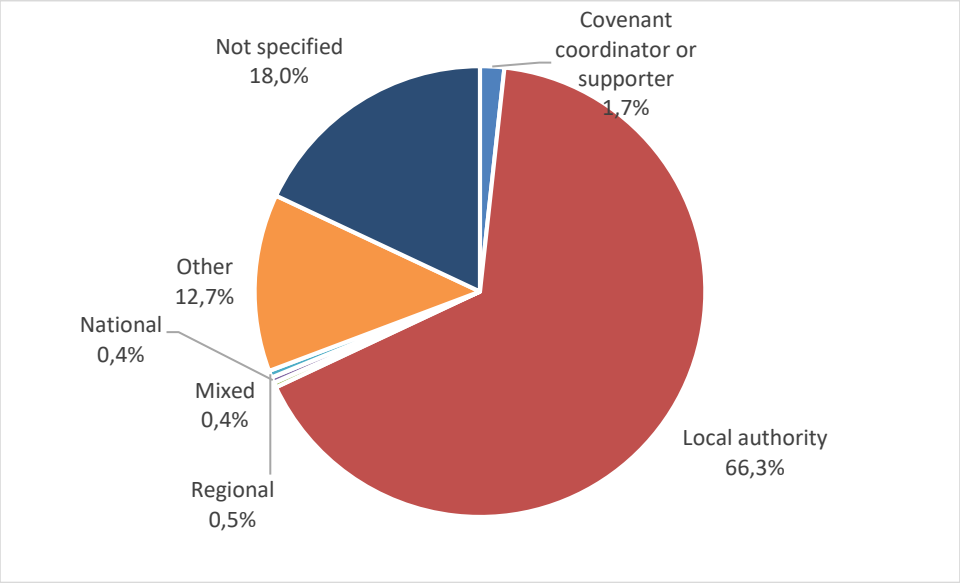


Source: JRC elaboration based on GCoM data

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. Covenant coordinators or supporters are indicated as the initiators of about 2 % of the actions/measures, while for almost one third the initiator is either "other" or not specified (Figure 30).

Figure 30. 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.

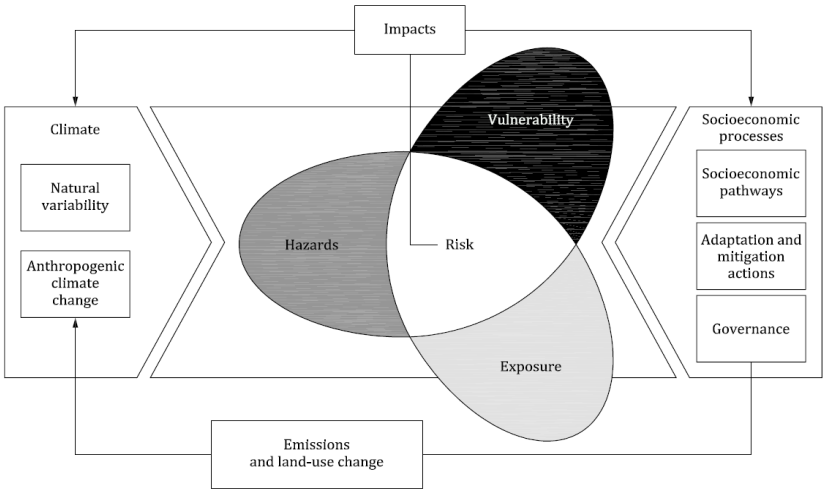
In January 2020, the reporting requirements changed, removing some mandatory information (i.e., Adaptation Scoreboard at the Registration stage) while introducing others (i.e., Adaptation goals). The reporting guidelines are in line with the Common Reporting Framework (CRF) by GCoM also for the adaptation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

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

- Committing to climate adaptation
- Conducting a Risk and Vulnerability Assessment (identifying the most relevant climate hazards and most vulnerable sectors)
- Identifying adaptation goals
- 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 31). 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 31) and socioeconomic processes, including adaptation and mitigation (right side), are drivers of hazards, exposure, and vulnerability.

Figure 31. Illustration of the core concept of risk (AR5), based on IPPC AR5[30].



Source: IPPC AR5

[30] 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[31]. 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[32]. The language barrier, therefore, affected the quality scrutiny process and data analysis for adaptation.

Table 14 shows the number of signatories committed to adaptation (either from the previous Mayors Adapt initiative, a separate commitment, or the most recent 2030 and 2050 commitments). In total, 4 560 signatories committed to adaptation with a total of 1 133 submitted a complete adaptation plan. Because the CoM Europe reporting requirements allow extra time to provide adaptation actions, data shown in the table include plans that provide the required RVA but might not have included adaptation actions at submission (about 12%).

Table 14. Adaptation signatories and action plans by region.

Region	Signatories committed to adaptation	Population (n. inhabitants)	Submission of partial adaptation action plans (RVA)	Submission of full adaptation action plans (RVA+ actions)	Monitoring reports (adaptation)
European Union (EU-27)	4 044	18 779 978	1 133	996	54
Eastern Partnership (CoM-East)	384	42 348 633	115	101	0
Europe - Non EU-27	127	137 975 742	38	33	0
Rest of the world	5	2 115 661	3	3	0
Total	**4 560**	**201 220 014**	**1 289**	**1 133**	**54**

Source: JRC elaboration based on GCoM data

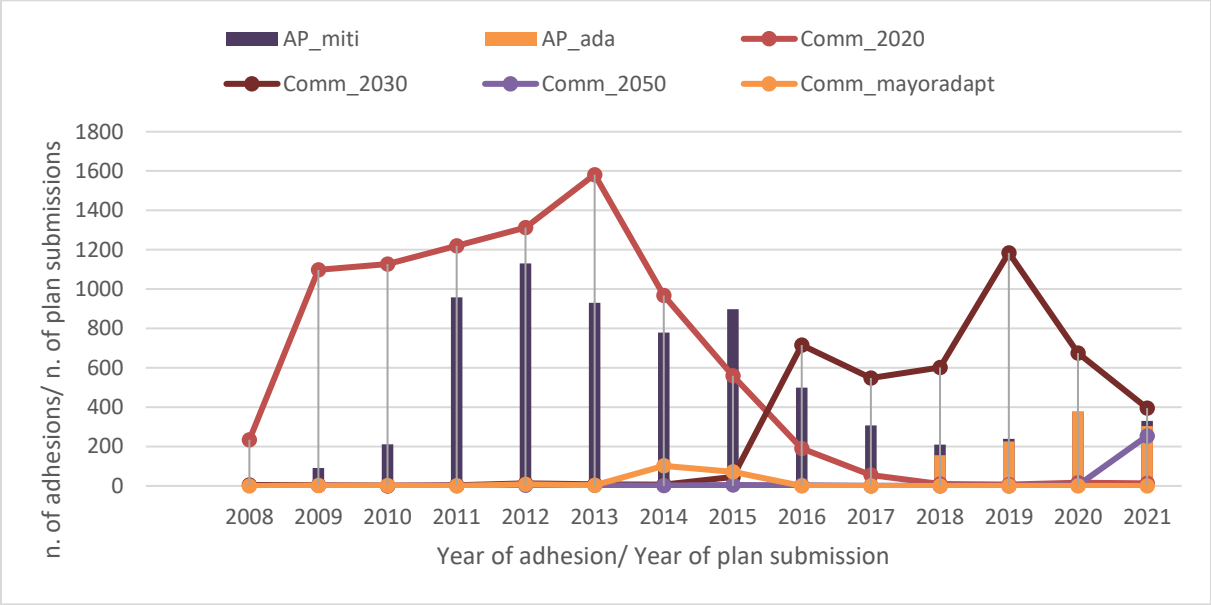
Figure 32 shows the evolution of adaptation in the Covenant initiative: adaptation commitments started with Mayors Adapt then merged into the CoM 2030, which represents the second "wave" of commitments; the new CoM 2050 commitment also includes the adaptation pillar (see also Section 2). Adaptation action plans started to be submitted after the Mayors Adapt, increasing their number in 2018, 2019, and peaking in 2020, with a minor decrease in 2021.

[31] 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") were discarded;
- Invalid info in 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.

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

Figure 32. GCoM signatories' commitments (Comm) and action plans submissions (AP) over time



Source: JRC elaboration based on GCoM data

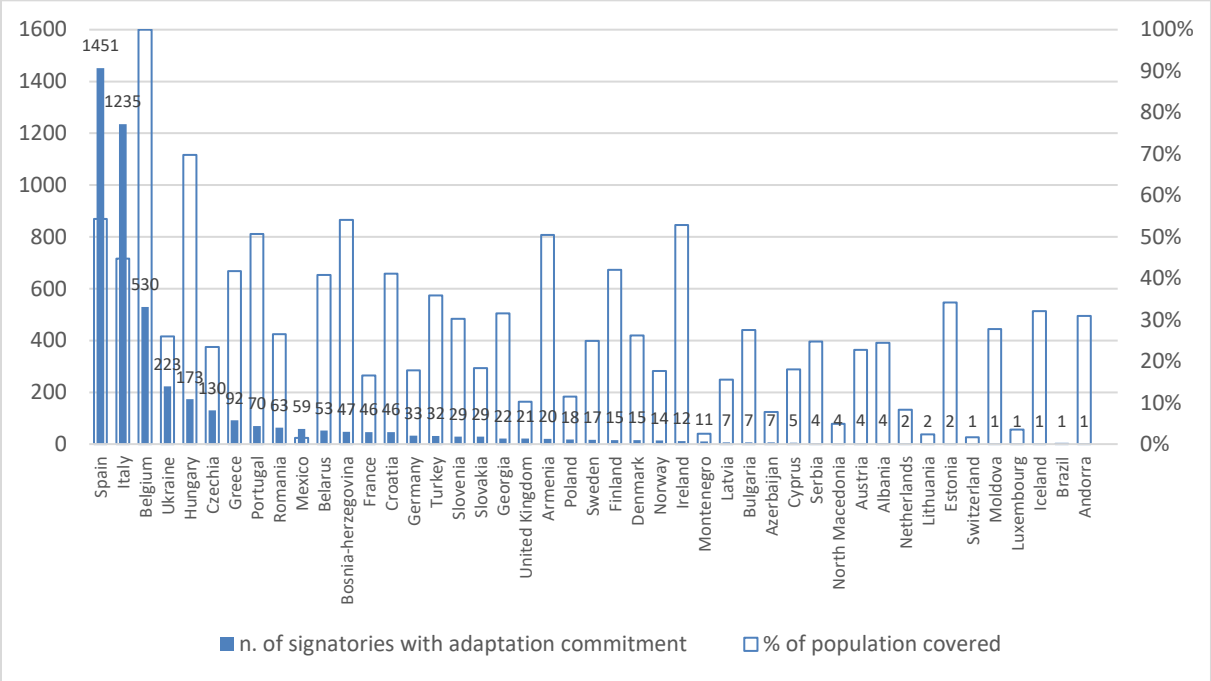
See Figure 33 for a geographical overview of signatories committed to adaptation. Spain, Italy and Belgium include the highest numbers of signatories. There is a well balanced territorial coverage (i.e. NUTS2, NUTS3 covered) within the countries with some concentrations in certain regions (e.g. Galicia in Spain, or Sicily in Italy).

In terms of individual country and population covered, Figure 34 shows that while Spain, Italy and Belgium have highest number of signatories, the share of population covered is higher for Belgium, close to 100 %. Some countries with less signatories have a high share of population covered due to the adhesion of the capital city or dense population areas (i.e. Budapest districts for Hungary).

Figure 33. GCoM signatories with adaptation commitment

Source: JRC elaboration based on GCoM data

Figure 34. GCoM signatories with adaptation commitment by country and % of population covered



Source: JRC elaboration based on GCoM data

6 Results on adaptation

6.1 Adaptation goals

Similarly to setting the mitigation targets (see Section 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 1 289 RVA, only 58 % (744) identify at least one adaptation goal. In fact, the requirement of defining at least one adaptation goal was only introduced in January 2020..

While only one goal is the minimum reporting requirement, signatories averagely provide 2-3 goals, and the datasets include more than 1 800 goals. However, because "adaptation goal" lacks a specific 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:

— 195 goals come as an empty or invalid text and are thus excluded from the dataset;

— 284 goals are connected to mitigation (e.g., emission reduction target, energy efficiency) with indirect potential benefits on adaptation;

— 40 goals refer to broad statements of increasing resiliency and committing to adaptation (lacking indicators of KPI to track progress over time);

The definition of adaptation goals is still a challenging component of the action plans. Data from submitted templates show unclear goal descriptions, and only a minor number is linked to reducing the risk of climate hazards through reduction of exposure and/or vulnerabilities. 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. However, the current version of the template on adaptation goals allows signatories to report base year values and target year values, thus improving the collection of quantitative data, enabling a better monitoring of "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 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 10 400 hazards. Each hazard has the following data associated:

— Level 1 (L1) hazard and level 2 (L2) 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).

In order for a signatory to report an L2 hazard (i.e. "River flood") the platform requires to add an L1 hazard (i.e. "Floods & sea level rise"); therefore care must be taken to avoid a potential double counting of climate hazards in the dataset. A total of 10 477 records are reported for climate hazards: 8 334 L1 climate hazards and 2 143 L2 climate hazards (see **Table 15**).

Table 15. Climate hazards reported: level 1 hazards and level 2 sub-hazards.

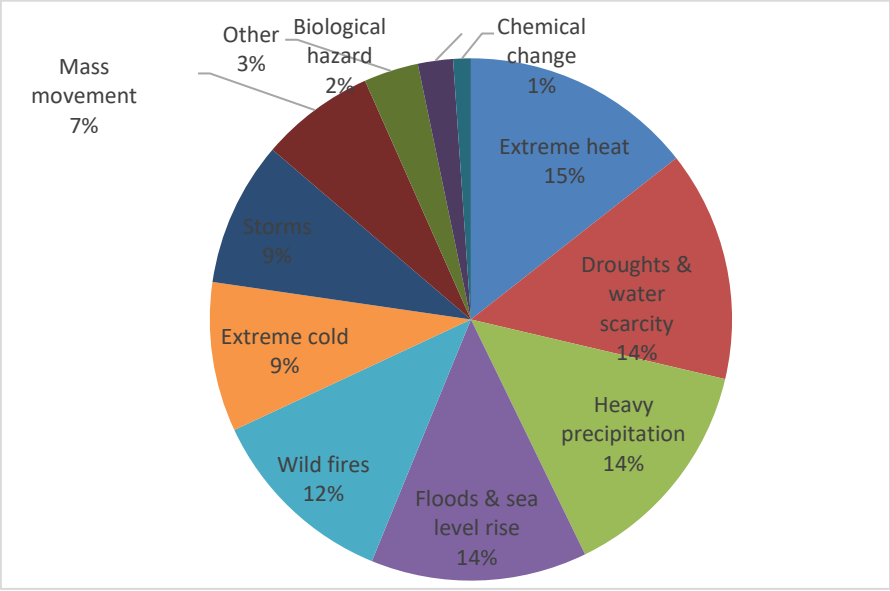
Climate hazard	L1	L2	Total
Floods & sea level rise	**1 116**	**650**	**1 766**
Floods & sea level rise	1 116		1 116
Sea level rise		241	241
River flood		186	186
Flash / surface flood		137	137
Coastal flood		64	64
Groundwater flood		16	16
Permanent inundation		6	6
Heavy precipitation	**1 178**	**424**	**1 602**
Heavy precipitation	1 178		1 178
Heavy rainfall		287	287
Hail		65	65
Heavy snowfall		48	48
Fog		24	24
Wild fires	**988**	**311**	**1 299**
Wild fires	988		988
Forest fire		266	266
Land fire		45	45
Extreme heat	**1 200**		**1 200**
Extreme heat	1200		1200
Droughts & water scarcity	**1 189**		**1 189**
Droughts & water scarcity	1 189		1 189
Storms	**747**	**266**	**1 013**
Storms	747		747
Severe wind		163	163
Lighting / thunderstorm		47	47
Trophical storm		25	25
Tornado		11	11
Storm surge		11	11
Extratrophical storm		6	6
Cyclone (hurricane / typhoon)		3	3
Mass movement	**591**	**203**	**794**
Mass movement	591		591
Landslide		138	138
Subsidence		28	28
Rockfall		26	26
Avalanche		11	11
Extreme cold	**771**		**771**

Climate hazard	L1	L2	Total
Extreme cold	771		771
Biological hazard	**181**	**238**	**419**
Biological hazard	181		181
Insect infestation		91	91
Vector-borne disease		60	60
Water-borne disease		47	47
Airborne disease		40	40
Other	**282**		**282**
Other	282		282
Chemical change	**91**	**51**	**142**
Chemical change	91		91
Atmospheric CO_2 concentration		30	30
Saltwater intrusion		17	17
Ocean acidification		4	4
Total	**8334**	**2 143**	**10 477**

Source: JRC elaboration based on GCoM data

The most reported L1 climate hazards in signatories' RVAs (see Figure 35) are "Extreme heat" (15 %), Droughts & Water scarcity" (14 %), "Heavy precipitation" (14 %), "Floods & Sea level rise" (14 %).

Figure 35. Most reported climate hazards.



Source: JRC elaboration based on GCoM data

Signatories can also voluntarily report sub-hazards (see Figure 36).

The most reported sub-hazards are "Extreme heat" (1200 records), "Droughts & water scarcity" (1189 records), "Heavy precipitation" (1178), under which "Heavy rainfall" is the most reported sub-hazard (287).

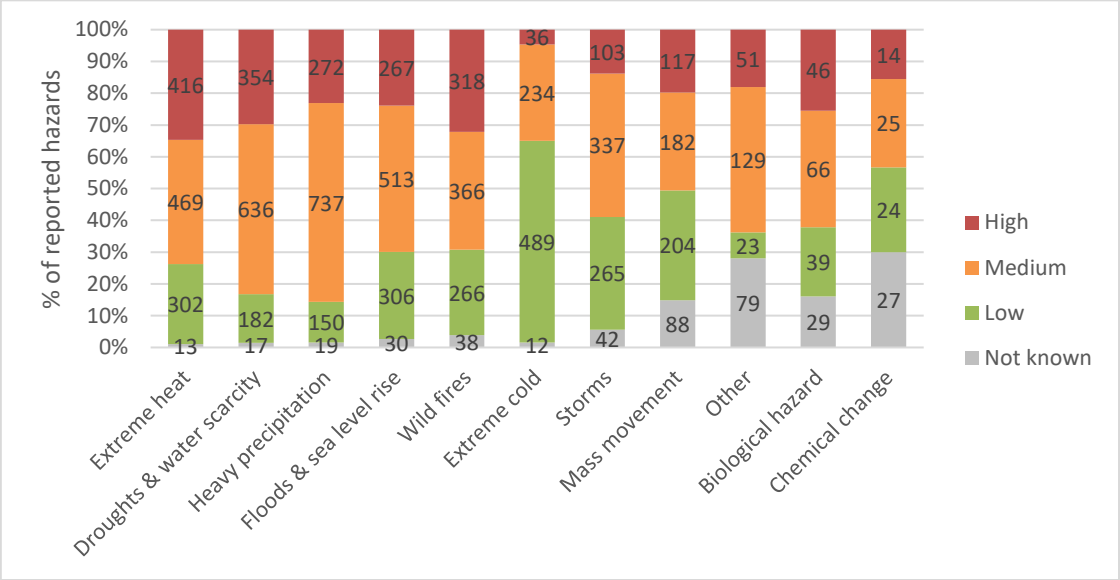
Figure 36. Most reported climate hazards (inner circle) and sub-hazards (outer circle).

Source: JRC elaboration based on GCoM data

The two following figures (Figure 37 and Figure 38)[33] include the probability and impact reported by signatories in their RVAs. The climate hazard "Extreme heat" comes with the highest occurrence of high probability and impact. "Extreme cold" is reported with the current lowest probability and impact, "Chemical change" is reported with the highest "Not known" probability, while all the other climate hazards are showing predominantly high/medium probability and impact.

[33] The shares are based on percentage cover proportionally within the same category; absolute values are reported in the charts.

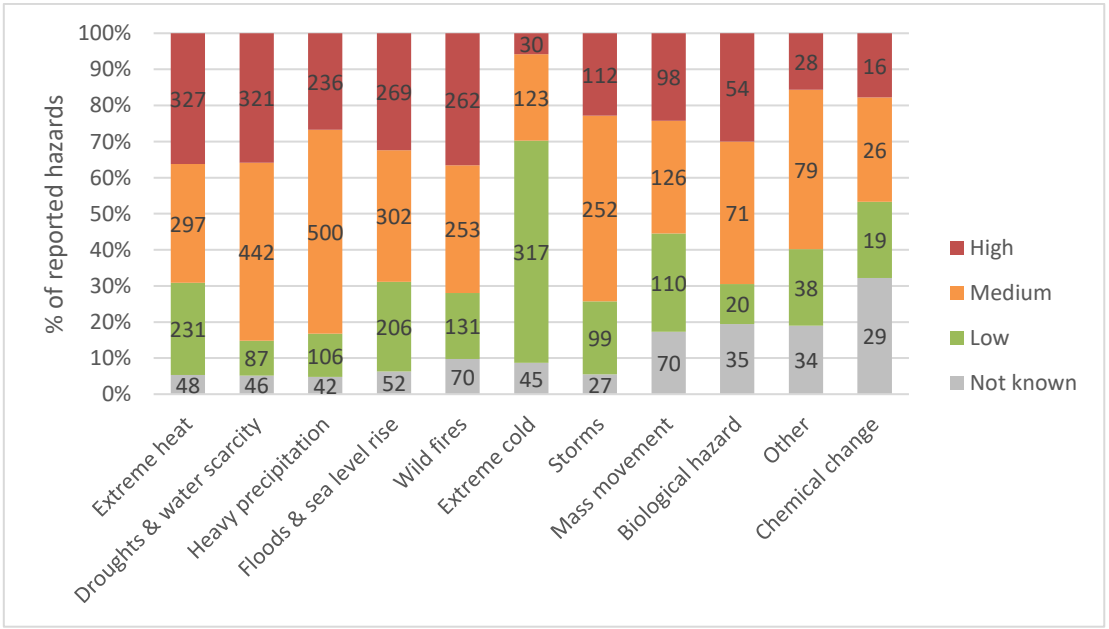
Figure 37. Level of the probability of occurrence of the climate hazard in the present.



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 38. Level of impact of the climate hazard in the present.

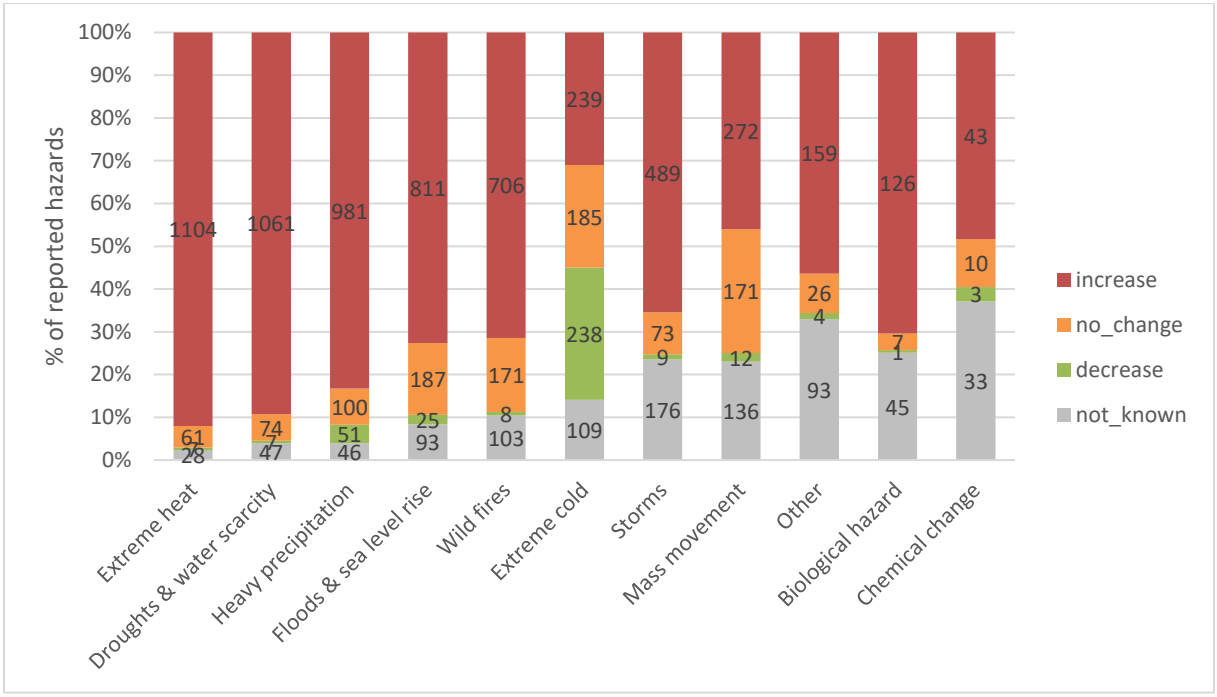


High = the hazard represents a high (or the highest) level of potential concern for your jurisdiction; when it occurs, the hazard results in (extremely) serious impacts to the jurisdiction and (catastrophic) interruptions to day-to-day life.
Moderate = the hazard represents a moderate level of potential 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

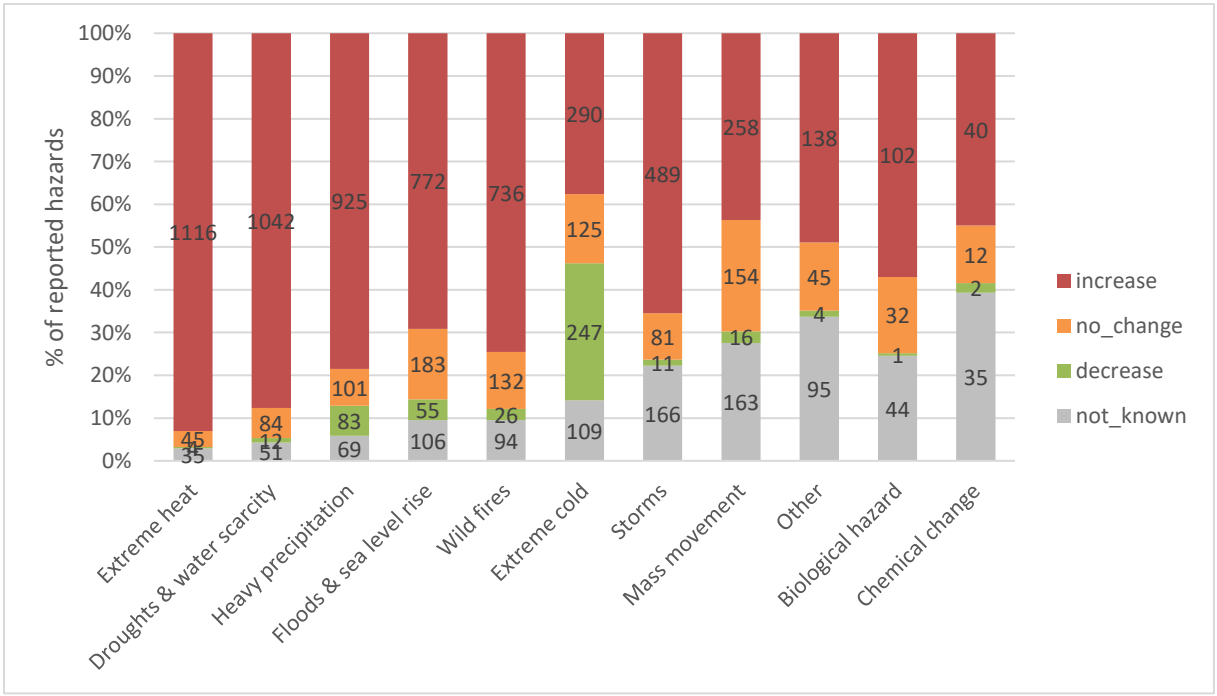
The two following figures (Figure 39 and Figure 40) include the future expected change in hazard intensity and frequency as reported by signatories in their RVAs. The climate hazard "Extreme cold" is expected not to change or decrease in intensity and frequency, while all the other climate hazards are expected to increase in both intensity and frequency.

Figure 39. Future expected change in hazard intensity.



Source: JRC elaboration based on GCoM data

Figure 40. Future expected change in hazard frequency



Source: JRC elaboration based on GCoM data

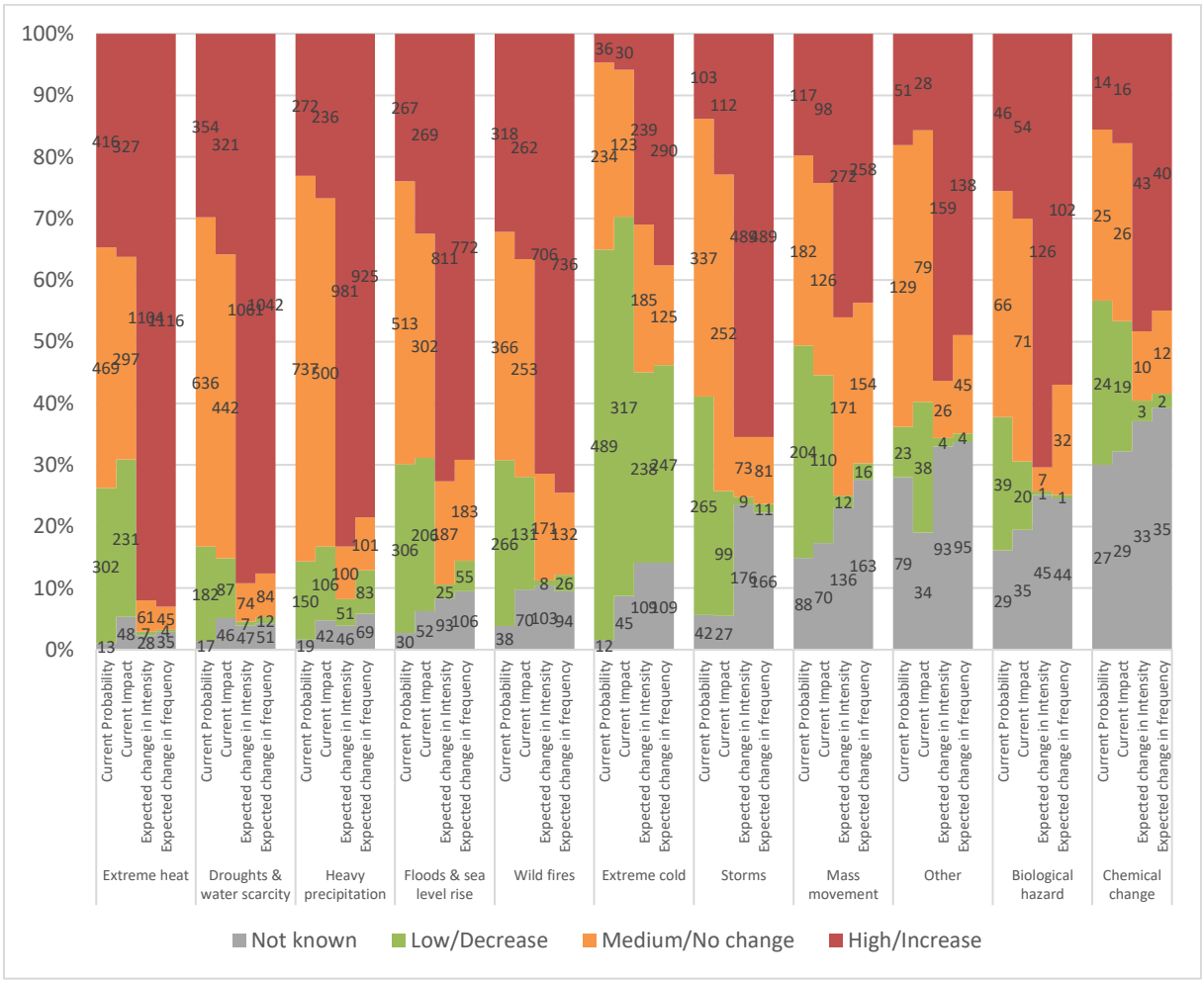
The reported timeframes that refer to the expected changes for climate hazards in RVA are[34]:

- 46 % (3 861 climate hazards) "Short-term" (= 20-30 years from now)
- 30 % (2 513) climate hazards) "Mid-term" (= after 2050)
- 23 % (1 927 climate hazards) "Long-term" (= close to 2100)
- 11 % (910 climate hazards) "Not known" (= not possible to define)

Figure 41 shows all climate hazards and their characteristics for comparison:

- considering the green bars, "Extreme cold" is reported with the current lowest impact/probability, and is also expected to have the highest decrease in intensity/frequency; all the other climate hazards are showing predominantly high/medium impact and with expected increase in intensity/frequency
- looking at the shift from current to future (first two bars vs last two bars), "Extreme heat", "Droughts & water scarcity" and "Heavy precipitation" show the most reported expected increase in intensity/frequency
- considering the grey bars (not known), it can be noted that it is harder for some hazards to estimate the future conditions, in particular for "Chemical change", "Biological hazard", "Mass movement", and "storms".

Figure 41. Hazards and their attributes as reported in MyCovenant



Source: JRC elaboration based on GCoM data

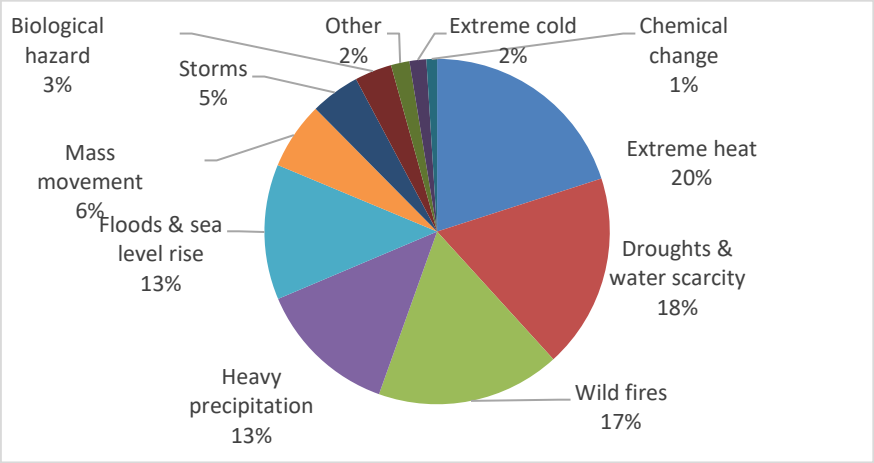
[34] Multiple options can be selected by signatories for each climate hazard reported in RVA.

6.2.1.1 High-Risk Climate Hazards

Only 14 % (1 208) of the reported climate hazards can be classified as "high-risk climate hazards", namely hazards with both high probability level and high impact level. However, 44% of action plan RVAs (57) include at least one high risk hazard.

Considering only the high-risk ones (Figure 42), the most reported climate hazards are: "Extreme heat" (20 %), "Droughts & water scarcity" (18 %), and "Wildfires" (17 %). The top 3 reported climate hazards are therefore slightly different compared the overall most reported ones (as shown in Figure 36). In particular, "Wild fire" was the fifth most reported hazard but it is ranked as third when considering only high-risk hazards.

Figure 42. 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 may have, compared to more probable but less destructive hazards like extreme heat or heavy precipitation that can equally reach high-impact, with life-threatening levels but whose phenomenology is typically less catastrophic. Also, as adaptation is a relatively recent pillar, it could reflect the sensitivity to natural hazards stimulated by most recent years events, with wildfire events at the forefront.

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

- 89 % of the high-risk hazards with a future expected increase in hazard intensity
- 88 % of the high-risk hazards with a future expected increase in hazard frequency.

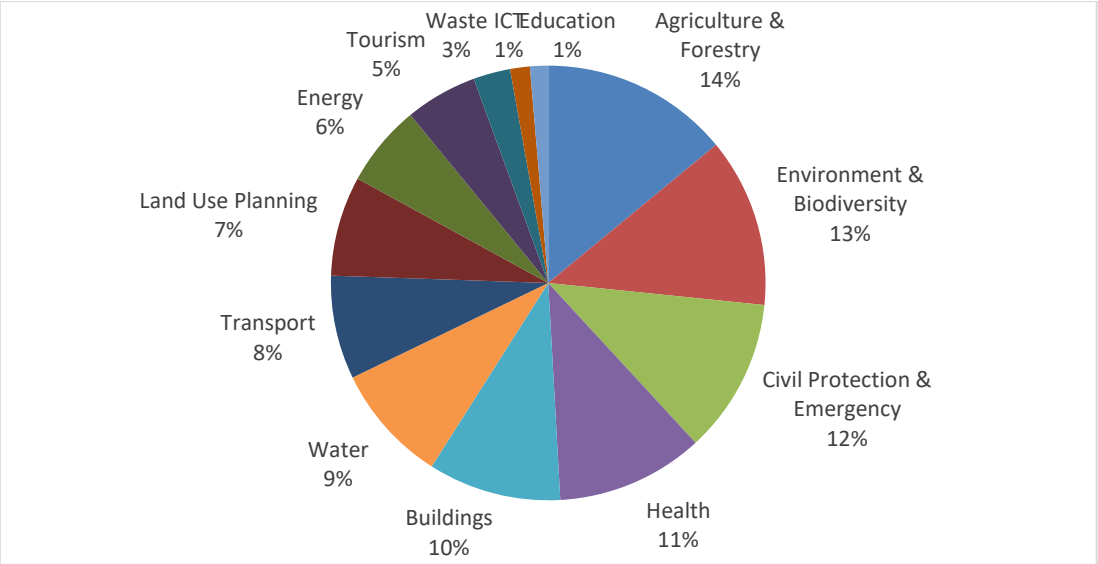
The expected change for high-risk climate hazards is reported as:

- 66 %: short-term
- 37 %: medium-term
- 19 %: long-term
- 6 %: not known.

6.2.2 Vulnerable sectors

More than 23 500 local vulnerabilities are reported by signatories for specific vulnerable sectors. As shown in Figure 43, the most reported vulnerable sectors are: "Agriculture & Forestry" (14 %), "Environment & Biodiversity" (13 %), "Civil protection & Emergency" (12 %), "Health" (11 %), and "Buildings" (10 %).

Figure 43. Most reported vulnerable sectors

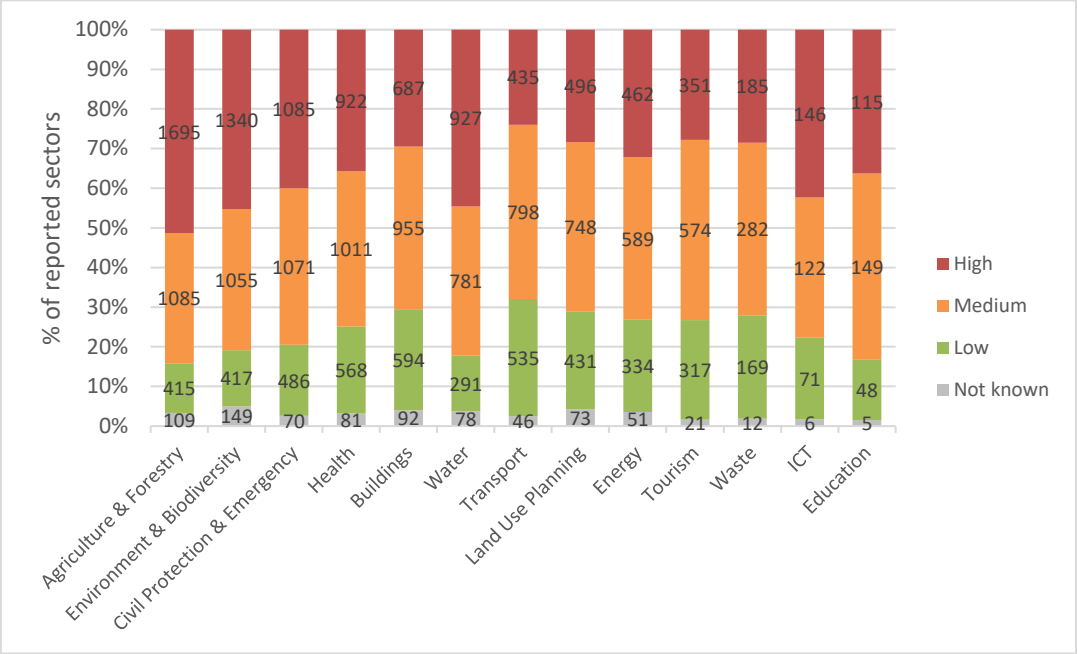


Source: JRC elaboration based on GCoM data

Considering the reported level of vulnerability for each sector (Figure 44), all the sectors are showing predominantly high/medium levels of vulnerability, notably:

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

Figure 44. Current level of vulnerability of the vulnerable sectors.



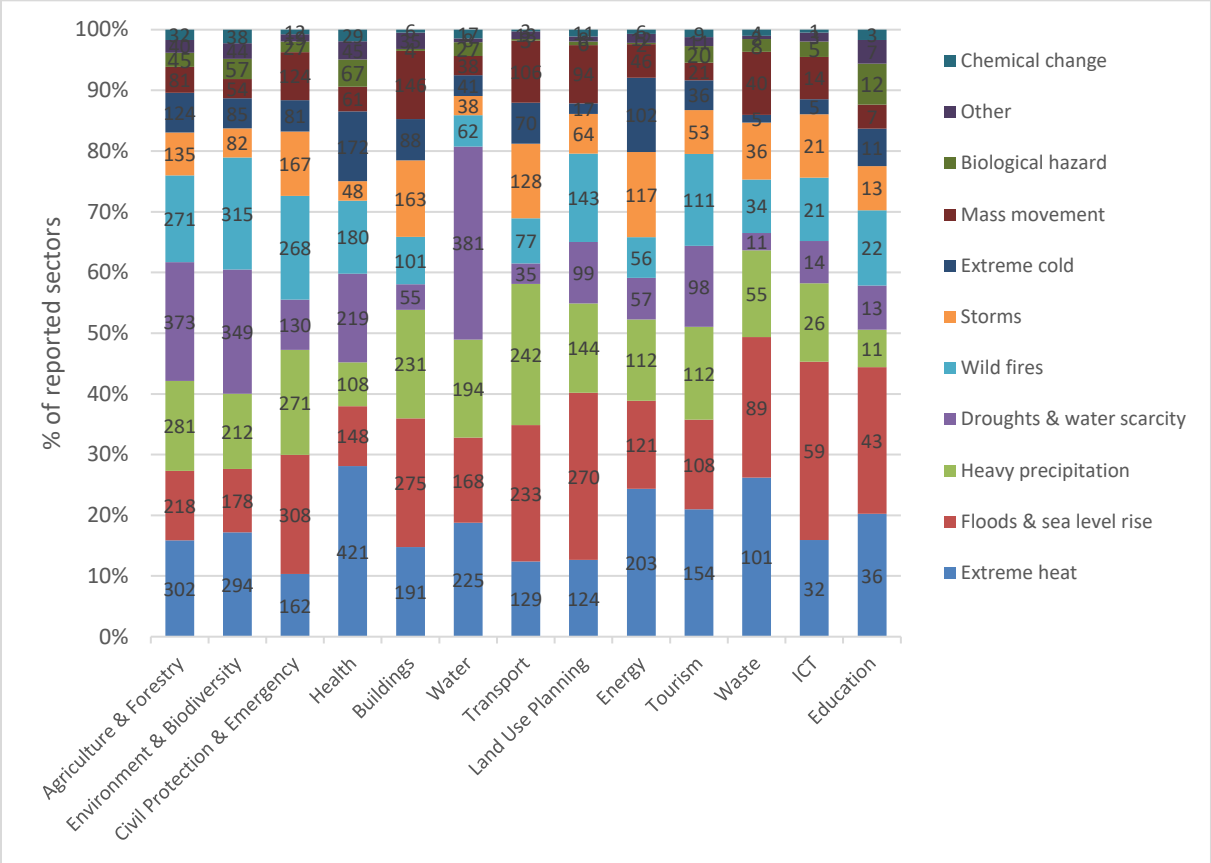
High = sector is very likely to be affected by the climate hazard.
Moderate = sector is expected to be occasionally affected by the climate hazard / Low = sector is unlikely to be affected by the climate hazard.
Not known = not possible to define.

Source: JRC elaboration based on GCoM data

Because each sector is reported as vulnerable to a specific climate hazard, it is possible to analyse the most reported hazards per sector. Figure 45 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"
- "Health" is reported as most vulnerable to "Extreme heat"
- "Building" sector is reported as most vulnerable to "Floods & Sea level rise" and "Heavy precipitation"
- "Water" is reported as most vulnerable to "Droughts & Water scarcity".

Figure 45. Vulnerable sectors and climate hazards.



Source: JRC elaboration based on GCoM data

6.2.3 Vulnerable population groups

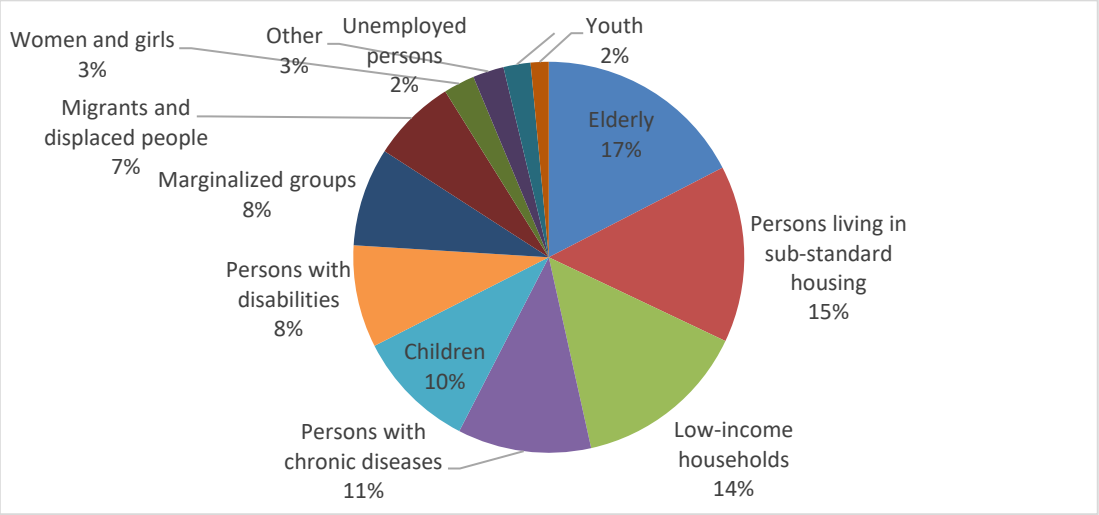
41 % of the action plans (531) report information on Vulnerable population groups in their RVA, despite the fact that this information is not mandatory.

As shown in Figure 46, the most reported vulnerable population groups are[35]:

— "Elderly" (17 %), "Persons living in sub-standard housing" (15 %), "Low-income households" (14 %), and "Persons with chronic diseases" (11 %)

[35] The template in MyCovenant allows selecting "All" and other categories at the same time (multi-choice option). 1 334 records are reported as "All" in the vulnerable population groups section of the RVA template, but they have been discarded for purpose of this analysis.

Figure 46. Most reported vulnerable population groups.

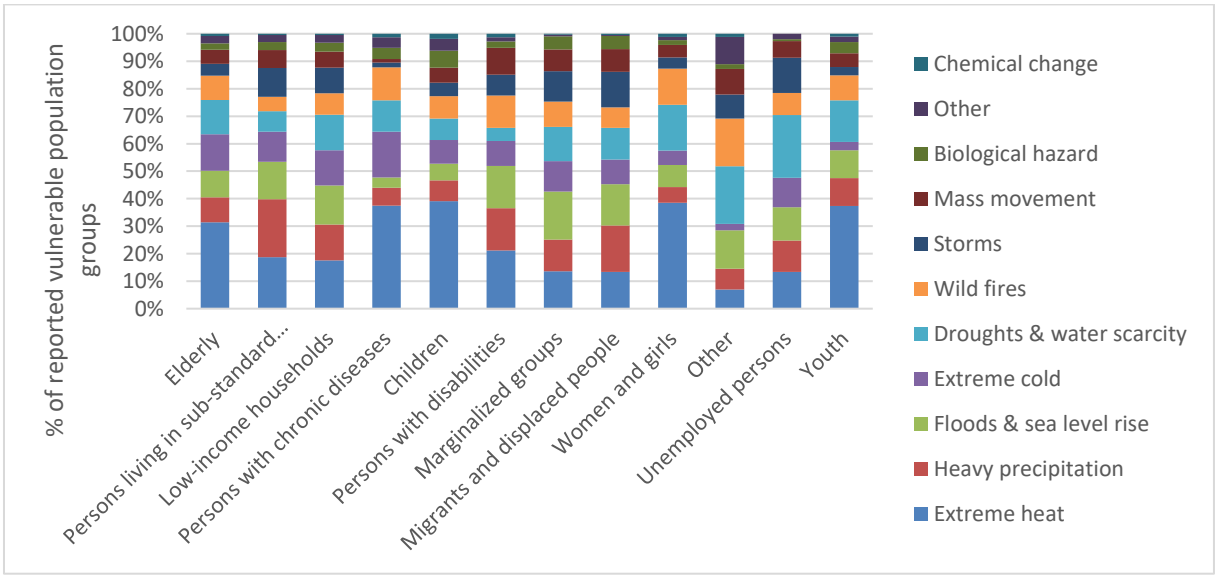


Source: JRC elaboration based on GCoM data

More than 6 600 vulnerable population groups are reported as exposed to climate hazards. Because each group is reported as vulnerable to a specific climate hazard, it is possible to analyse the most reported hazards per group. Figure 47 shows that:

- "Elderly" and "Persons living with chronic diseases", "Children", and "Youth" are reported as most vulnerable to "Extreme heat"
- "Persons living in sub-standard housing" are reported as most vulnerable to "Heavy precipitation"
- "Low-income households" are reported as most vulnerable to "Extreme heat", "Extreme cold", and "Floods & sea level rise".

Figure 47. Vulnerable population groups and climate hazards.



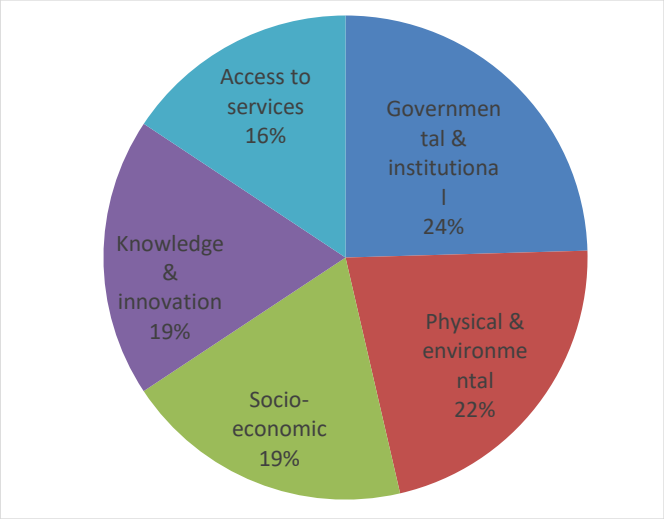
Source: JRC elaboration based on GCoM data

Considering only the signatories reporting high risk hazards (533), with both high level of probability and high level of impact (see 6.2.1.1), data shows an estimated amount of population exposed of more than 33.3 million of inhabitants.

6.2.4 Adaptive capacity

More than 7 000 adaptive capacity factors[36] are reported by signatories for specific vulnerable sectors. As shown in Figure 48, the most reported adaptive capacity factors are: "Governmental & institutional" (24 %), "Physical & environmental" (22 %), "Socio-economic" (19 %), "Knowlwdge & innovation" (19 %), and "Access to services" (16 %).

Figure 48. Most reported adaptive capacity factors



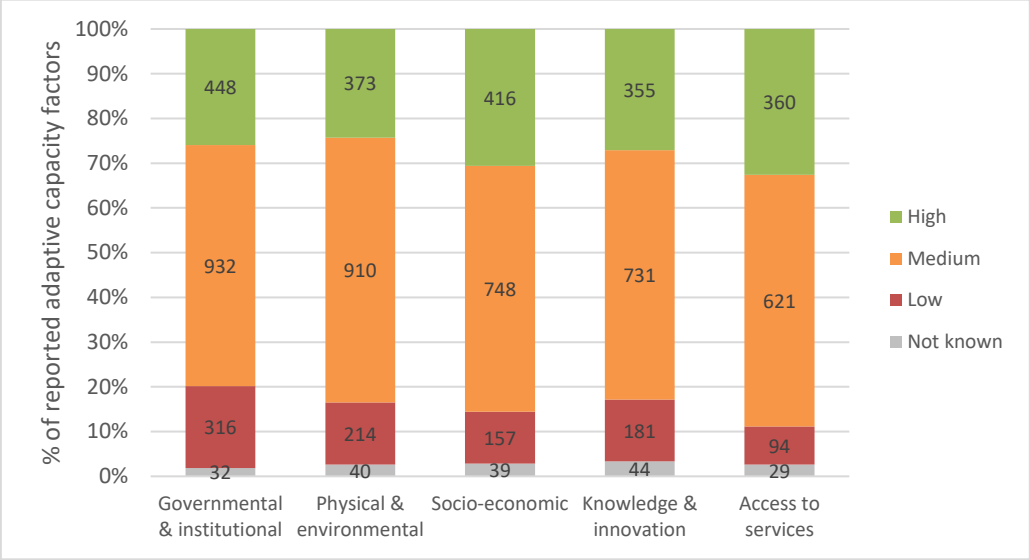
Source: JRC elaboration based on GCoM data

Considering the reported level of adaptive capacity for each sector (Figure 49), all the sectors are showing predominantly high/medium levels of adaptive capacity[37]:

- "Access to services" and "Socio-economic" factors are reported with the highest level of adaptive capacity
- "Governmental & institutional" and "Knowledge & innovation" factors are reported with the lowest level of adaptive capacity.

[36] MyCovenant platform considers the following adaptive capacity factors:
Access to services: Availability of and access to basic services (e.g. healthcare, education, etc.)
Socio-economic: Interaction between economy and society, influenced by the availability of assets (e.g. economic health, employment, poverty, immigration); level of social awareness and cohesion
Governmental & institutional: Existence of institutional environment, regulation and policies (e.g. restriction laws, preventive measures, urban development policies); local government leadership and competencies; staff capacity and existing organizational structures (e.g. knowledge and skills of staff, level of interaction between municipal departments/bodies); availability of budget for climate action
Physical & environmental: Availability of resources (e.g. water, land, environmental services) and the practices for their management; availability of physical infrastructure and conditions for its use and maintenance (e.g. green-blue infrastructure, health and educational facilities, emergency response facilities)
Knowledge & innovation: Availability of data and knowledge (e.g. methodologies, guidance, assessment and monitoring frameworks); availability of and access to technology and technical applications (e.g. meteorological systems, early warning systems, flood
[37] The shares are based on percentage cover proportionally within the same category; absolute values are reported in the charts.

Figure 49. Current level of adaptive capacity.



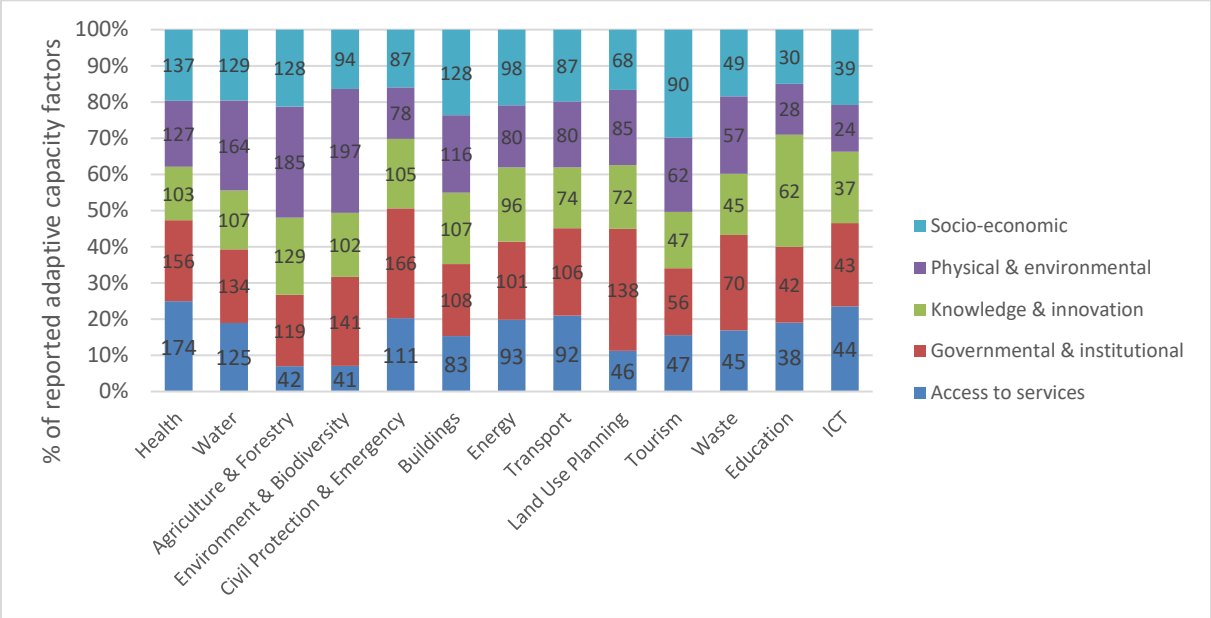
High = high ability to adjust/adapt to potential climate change impacts.
Moderate = moderate ability to adjust/adapt to potential climate change impacts.
Low = low ability to adjust/adapt to potential climate change impacts.
Not known = not possible to define.

Source: JRC elaboration based on GCoM data

Because each factor is reported as linked to a specific sector, it is possible to analyse the most reported factor per sector. Figure 50 shows that:

- "Socio-economic" adaptive capacity factors are reported as most linked to the "Tourism" sector
- "Phisical & environmental" adaptive capacity factors are reported as most linked to "Agriculture & Forestry" and "Environment & Biodiversity" sectors
- "Knowledge & innovation" adaptive capacity factors are reported as most linked to the "Education" sector
- "Governmental & institutional" adaptive capacity factors are reported as most linked to "Land use planning" and "Civil Protection & Emergency" sectors
- "Access to services" adaptive capacity factors are reported as most linked to the "Health" sector.

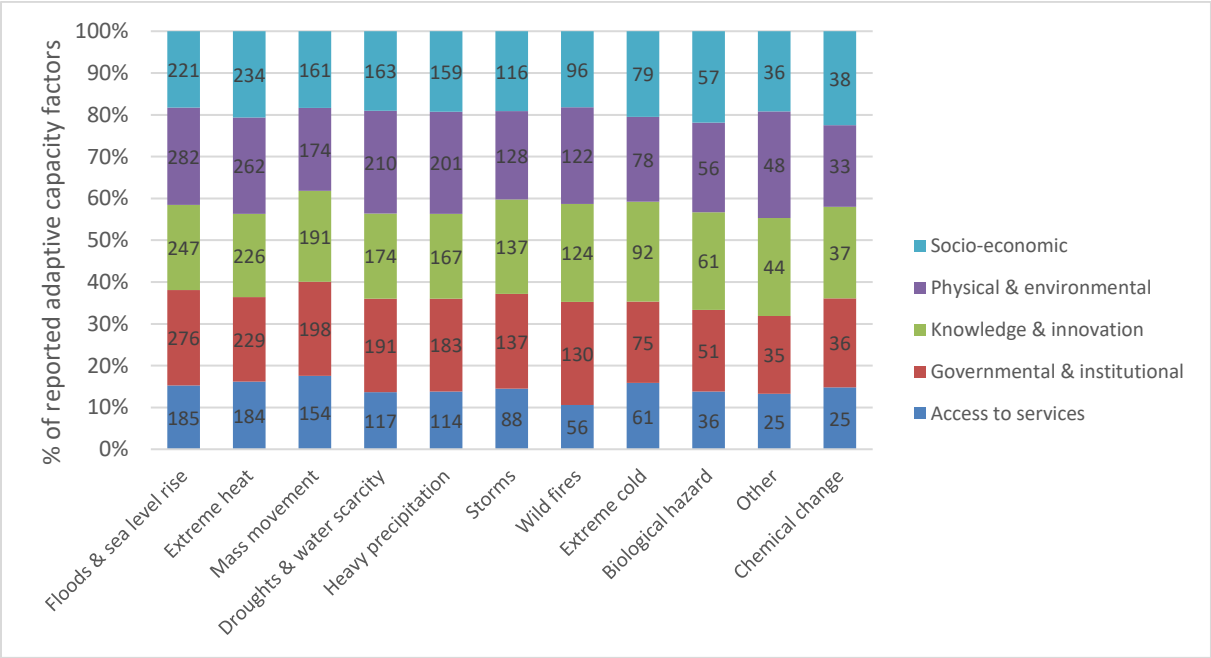
Figure 50. Adaptive capacity factors and vulnerable sectors.



Source: JRC elaboration based on GCoM data

Because each factor is reported as linked to a specific climate hazards, it is possible to analyse the most reported factor per hazard. Figure 51 shows that all climate hazards share similar proportions of adaptive capacity factors.

Figure 51. Adaptive capacity factors and climate hazards.



Source: JRC elaboration based on GCoM data

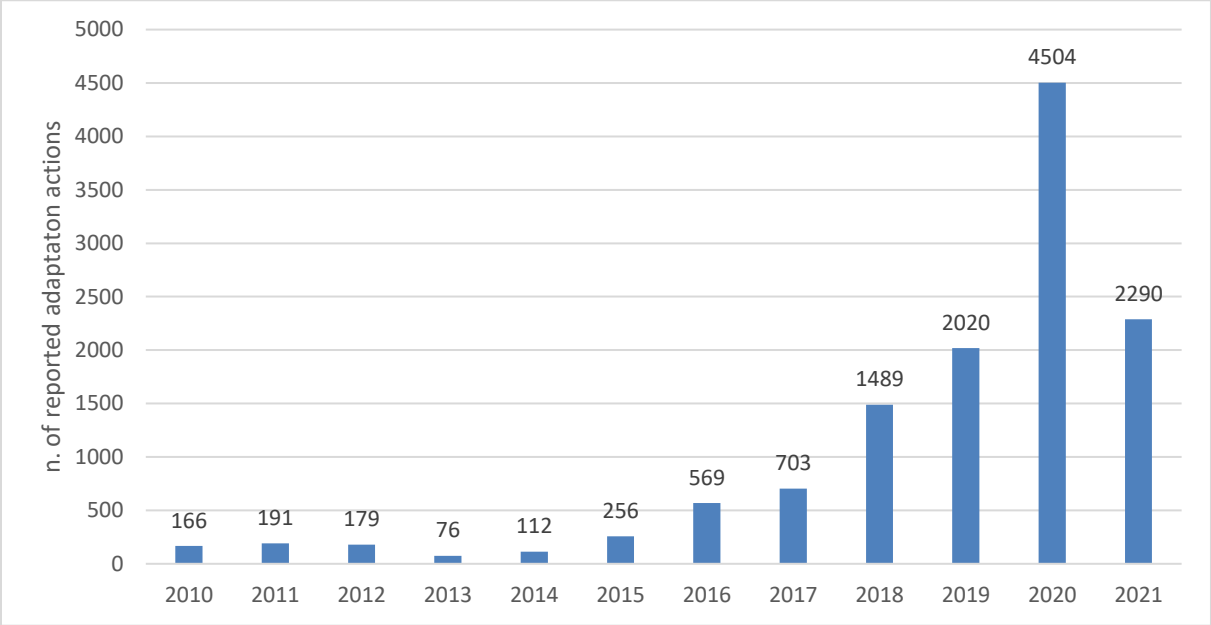
6.3 Climate adaptation actions and measures

More than 15 200 adaptation actions are reported by signatories. While only "key" actions are required according to the reporting guidelines, 80 % (12 375) are marked as non-key actions and include the minimum level of information required.

Among all the actions, 17 % (2 582) are reported by signatories as both mitigation and adaptation actions.

As shown in Figure 52, since the beginning of the Mayors Adapt/Covenant of Mayors 2030 initiative in 2015 up to 2020 the number of actions implemented has been growing every year with a peak in 2020, while a decrease in 2021 is recorded.

Figure 52. Adaptation actions with their reported implementation start year.



Source: JRC elaboration based on GCoM data

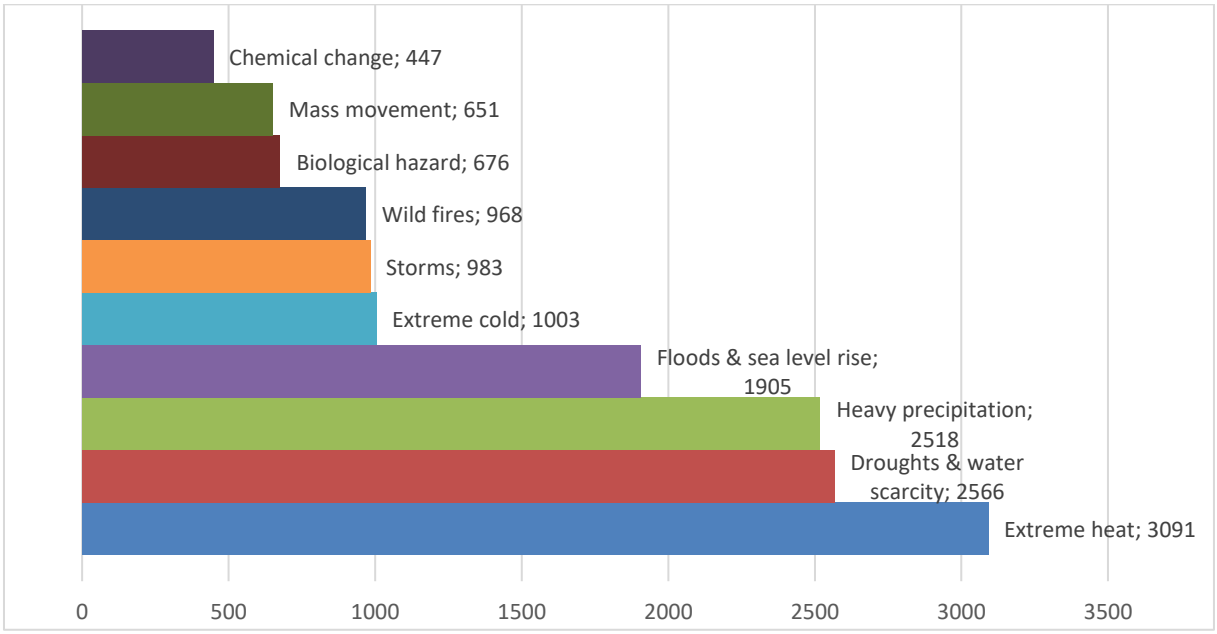
6.3.1 Actions and most addressed climate hazards

41 % of the adaptation actions (6 291) 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 53, 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 also6.4).

Figure 53. Adaptation actions and most addressed climate hazards.



Source: JRC elaboration based on GCoM data

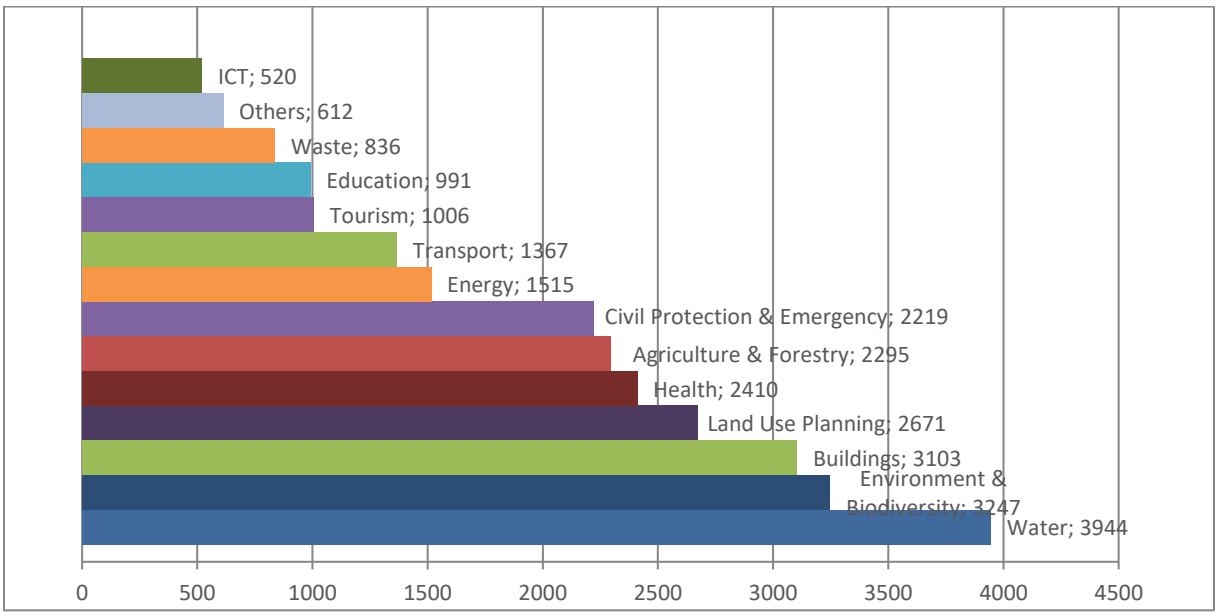
6.3.2 Actions and most targeted vulnerable sectors

98 % of adaptation actions (14 985) 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 54, the most targeted sectors are: "Water", "Environment & Biodiversity", and "Buildings".

That slightly differs from the most reported sectors in the RVA (see also6.4).

Figure 54. Adaptation actions and most targeted vulnerable sectors



Source: JRC elaboration based on GCoM data

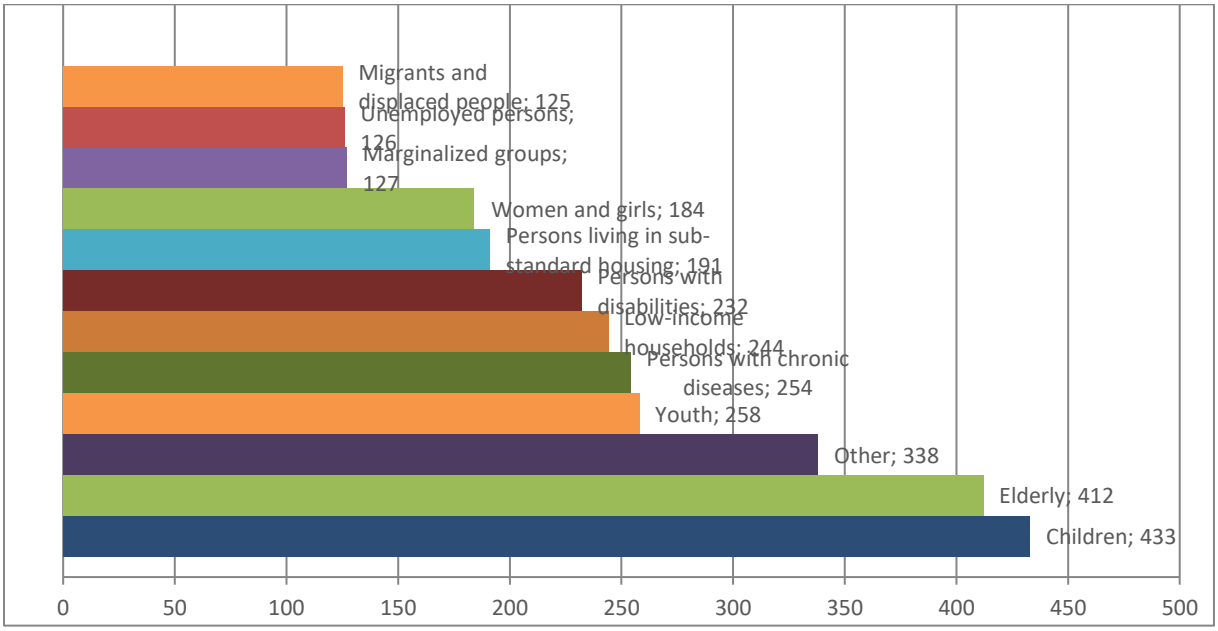
6.3.3 Actions and most targeted vulnerable population groups

32 % of the adaptation actions (3 557) report which vulnerable population group they are targeting. This information is optional in older and also in most recent version of the reporting guidelines.

According to the data shown in Figure 55, the most targeted population groups are[38]: "Children" and "Elderly".

That slightly differs from the most reported vulnerable groups in the RVA (see also6.4).

Figure 55. Adaptation actions and most targeted vulnerable population groups



Source: JRC elaboration based on GCoM data

6.4 Adaptation "gap" and potential incoherence among 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 high-risk hazards in 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 developing actions in sectors in which signatories 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.

However, 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. Figure 56 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:

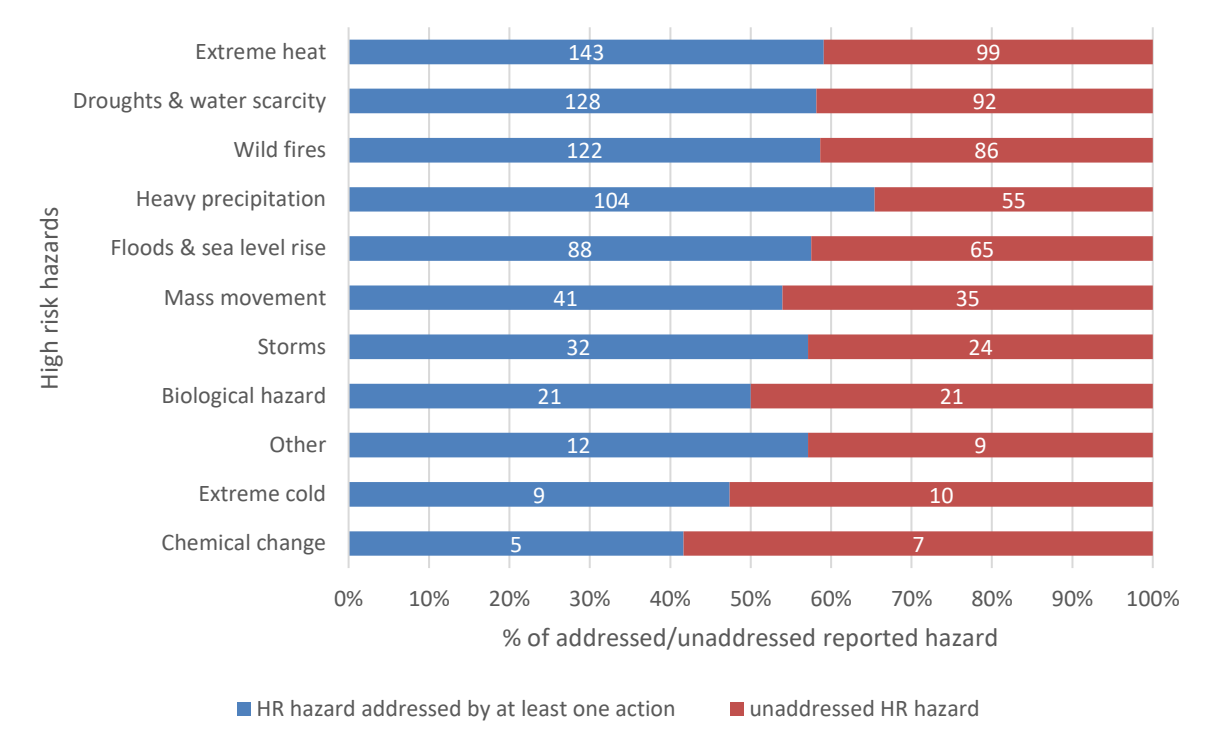
[38] The template in MyCovenant allows selecting "All" and other categories at the same time (multi-choice option). 2 646 records are reported as "All" in the vulnerable population groups section of the action template, but they have been discarded for purpose of this analysis.

— Overall, among all the high risk hazard reported in RVA by signatories (1208), 57 % of them (705) are already addressed by at least one adaptation action

— "Heavy precipitation" shows the highest share (65 %) of hazard covered by at least one adaptation action

— More than 59 % of the "Extreme heat" and "Wild fires" high-risk hazards reported in RVA are addressed by at least one action.

Figure 56. 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 (572):

— 410 (72 %) of signatories action plans that report at least one high-risk hazard are also reporting at least one matching action to address it.

While there is a gap between the overall climate hazards identified and the actions taken, it can be noted that when it comes to high risk hazards, the majority of action plans are probably well designed to address them.

Looking at the sectors reported in RVA as "high vulnerable", it is possible to analyse how many of them are targeted by planned actions. Figure 57 shows the proportion of signatories reporting a "high-vulnerable sector" also reporting at least a matching action: the chart shows the number of reported high-vulnerable sectorss by signatories: those that are covered in the action plan are shown in blue, while those reported in RVA but not mentioned in the action plans are in red:

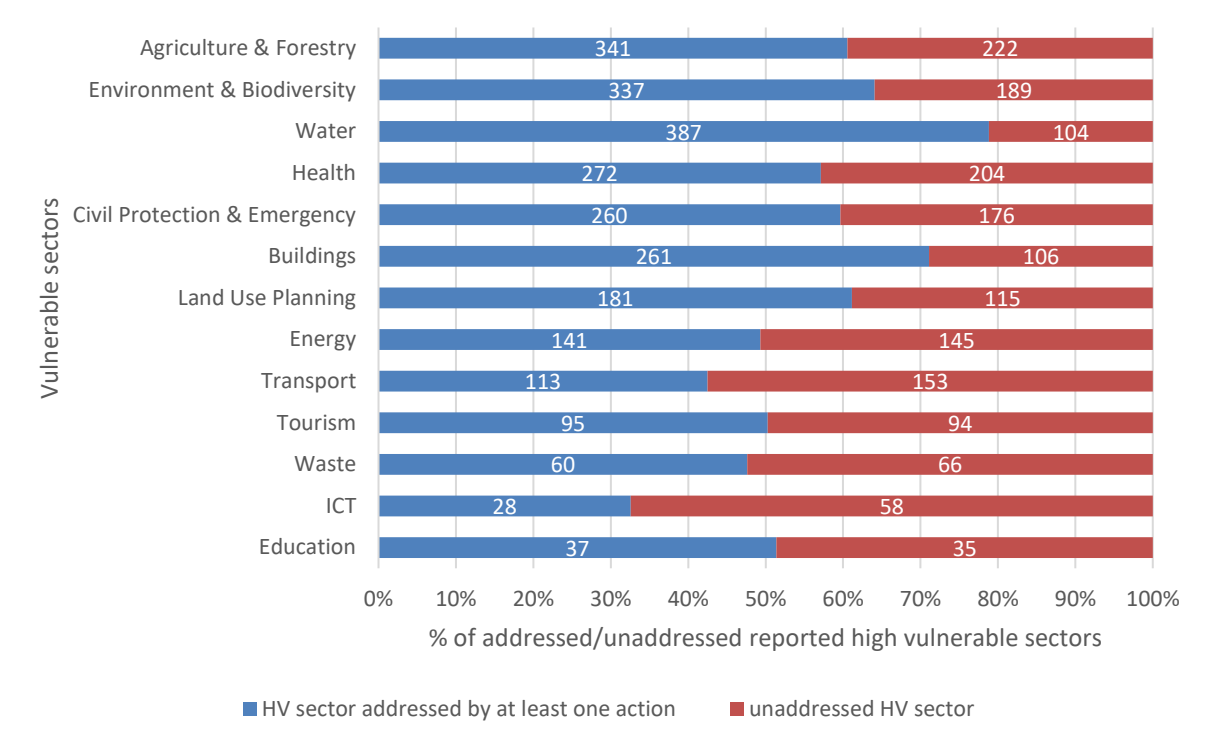
— Overall, among all the high vulnerable sectors reported in RVA by signatories (4180), 60 % of them (2513) are already addressed by at least one adaptation action

— "Water" shows the highest share (79 %) of high vulnerable sector covered by at least one adaptation action

— More than 71 % of the vulnerabilities in "Buildings" reported in RVA are addressed by at least one action.

Despite the fact "Buildings" is not among the top vulnerable sectors, when it is reported as high vulnerable it is mostly addressed by at least one action. This is probably linked to the fact that acting on "Buildings" is in the governamental domain of most local authorities signatories of the GCoM (i.e. promoting sustainable building codes, resilient retrofitting of public owned buildings, etc.).

Figure 57. Proportion of signatories reporting a "high vulnerable" sector also reporting at least a matching action.



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

Source: JRC elaboration based on GCoM data

Considering the overall number of signatories reporting high-vulnerable sectors (760):

— 647 (85 %) of signatories action plans that report at least one high-vulnerable sector are also reporting at least one matching action to address it.

While there is a gap between the overall vulnerable sectors identified and the actions taken, it can be noted that when it comes to high vulnerable sectors, the majority of action plans are probably well designed to address them.

6.5 Monitoring and implementation

Only 54 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, the recent update on adaptation goals submissions are defined in a way to allow quantitative monitoring of their progress. Next iteration of this report will be able to analyse adaptation goals and their progress toward target.

163 monitoring reports include information on the "implementation status" of the "planned adaptation actions". In total, 2308 adaptation actions are reported at the monitoring stage.

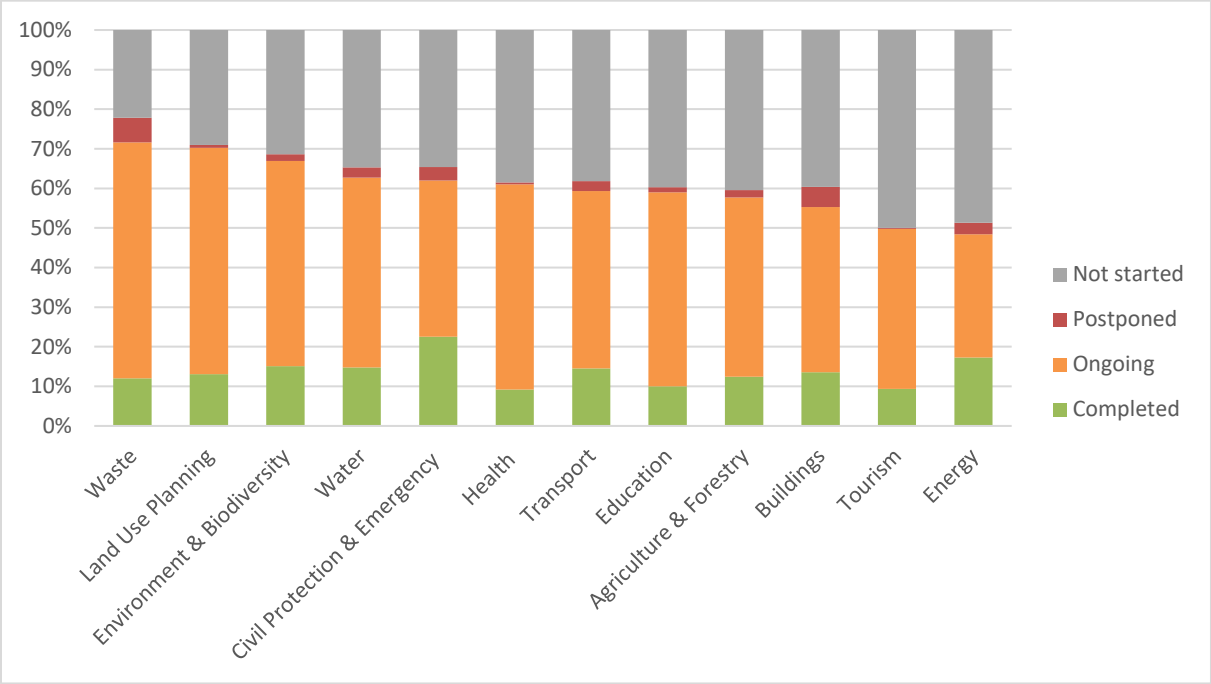
The implementation status of the actions in the monitoring reports shows that 60 % of adaptation actions are reported as "completed" (14 %) or "ongoing" (46), while 40 % are reported as "postoponed" (2 %) or "not

started" (Figure 58). Those percentages vary across sectors, with "Waste", "Land use planning", "Environment & Biodiversity" being the policy sectors with the highest shares of complete/ongoing actions, and "Buildings", "Tourism" and "Energy" the policy sectors with the higher shares of non-started/postponed actions.

The implementation status of the ongoing or completed actions shows progress of the actions, while the overall implementations status of adaptation planning of signatories, was filed at the registration phase in the "Scoreboard" section. While the scoreboard is not updatable in monitoring reports, it provides an overall picture of the signatories that filled the info.

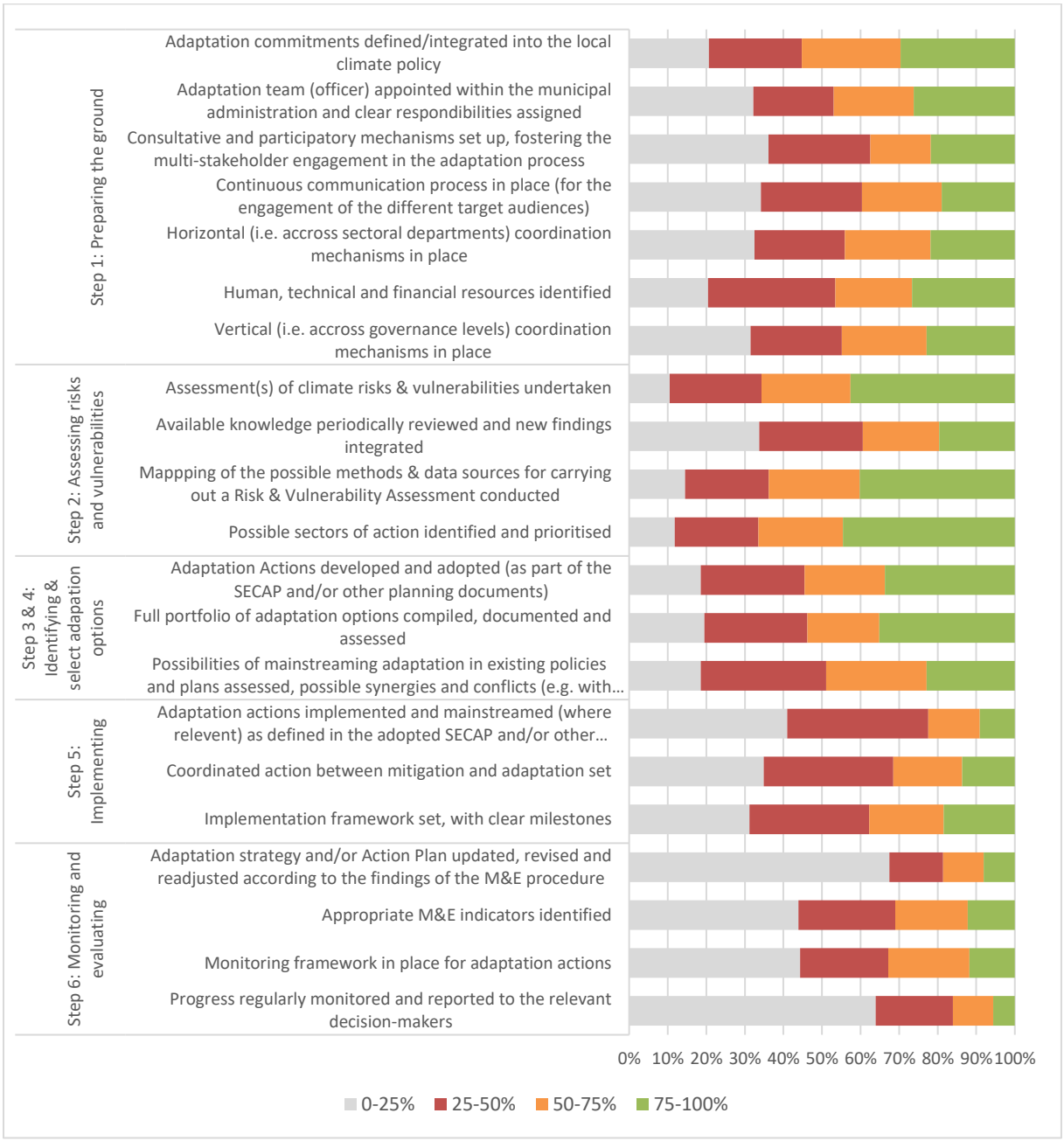
Regarding the analysis of the scoreboard (Figure 59), "Assessing climate risks and vulnerabilities" (RVA) is among the steps reported with the most complete status (75-100 %), while planning and implementing actions are among the steps with a partially complete status (25-50 %). Under Monitoring, the step about "updating the action plan" is reported with the most incomplete status (0-25 %).

Figure 58. Implementation status of adaptation actions as reported in monitoring reports.



Source: JRC elaboration based on GCoM data

Figure 59. Scoreboard 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 14 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 end of March 2022. The initiative counts 10 804 committed cities and local authorities, covering a total population of 345.8 million inhabitants.

Box 2. Signatories and commitments

Most of the signatories (10 052, covering 237 million inhabitants) come from the EU-27, followed by the Eastern Partnership countries (509 signatories, 33.1 million inhabitants) and by Europe – non EU-27 (219 signatories, 67.3 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 (almost 60 %, covering 44 % of the inhabitants) remains committed only to the 2020 mitigation targets, while 40 % (representing about half of the CoM population) are committed to a mitigation target by 2030 and/or by 2050 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 7 068 action plans, covering almost 243 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 81.7 % of the action plans (covering 69.9 % of the population) only address the mitigation pillar and that just 18 % of the actions plans (29.9 % of the population) address simultaneously mitigation and adaptation. Less than 0.5 % 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.

81.6 % of the mitigation plans (covering 70.7 % of the population) have a 2020 target only, with the remaining 18.4 % of the mitigation plans having a 2030 target, either combined with a 2020 target (3.4 % of the plans, 9.6 % of the population) or not (15 % of the action plans, 19.1 % of the population).

In terms of reporting on the action plan's implementation, 2 713 signatories, covering 114.8 million inhabitants, have submitted at least one monitoring report. Out of these, 1 438 (covering nearly 76 million inhabitants) submitted a monitoring report flagged as "complete", i.e., including at least one monitoring emission inventory. The other 1 275 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 by 2030 and achievements

Based on data from 1 292 submitted action plans with a 2030 target, the overall committed GHG emission reduction is 43.9 % by 2030 (compared to a baseline level of 321.6 $MtCO_2$ eq). Looking only at signatories from EU-27, the overall committed reduction is 46.2 % by 2030 (compared to a baseline level of 249.4 Mt CO_2 eq).

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 55 % of reported emissions, while electricity is the second carrier with 35 % of reported emissions.

Looking only at 412 action plans with at least one monitoring report, a 30.9 % reduction by 2030 is forecasted, while the targeted mean reduction is 44.6 %. This insight suggests that greater effort is necessary for signatories to advance in the implementation of their action plans and achieve the emission reduction targets they have set.

More than 194 000 mitigation actions were reported by Covenant signatories, corresponding to an average of **27.6 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 (51 %) of the actions listed in MyCovenant. The transport sector accounts only for 16 % of the planned actions/measures, despite representing 26-28 % 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 % 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 28 % 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.

The definition of adaptation goals is still a challenging component of the action plans. Data from submitted templates show unclear goal descriptions, and only a minor number is linked to reducing the risk of climate hazard risks and/or vulnerabilities. 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 10 400 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 climate hazards in signatories' RVAs are "Extreme heat" (15 %), Droughts & Water scarcity" (14 %), "Heavy precipitation" (14 %), and "Floods & Sea level rise" (14 %). 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 in sub-standard housing"; "Elderly", "Persons living with chronic diseases", "Children" and "Youth" are reported as most vulnerable to "Extreme heat"; "Persons living in sub-standard housing" are reported as most vulnerable to "Heavy precipitation"; "Low-income households" are reported as most vulnerable to "Extreme heat", "Extreme cold", and "Floods & sea level rise".

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 33.3 million inhabitants.

More than 7 000 adaptive capacity factors[39] are reported by signatories for specific vulnerable sectors. The most reported adaptive capacity factors are: "Governmental & institutional" (24 %), "Physical & environmental" (22 %), and "Socio-economic" (19 %).

More than 15 200 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 hazards most 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

The most addressed hazards are: "Extreme heat", "Droughts & Water scarcity", and "Heavy precipitation".

The most targeted sectors are: "Water", "Environment & Biodiversity", and "Buildings".

The most targeted population groups are : "Children" and "Elderly".

Considering the overall number of signatories reporting high-risk hazards (353), 57 % are also reporting at least one matching action to address it.

[39] MyCovenant platform considers the following adaptive capacity factors:

Access to services: Availability of and access to basic services (e.g. healthcare, education, etc.)

Socio-economic: Interaction between economy and society, influenced by the availability of assets (e.g. economic health, employment, poverty, immigration); level of social awareness and cohesion

Governmental & institutional: Existence of institutional environment, regulation and policies (e.g. restriction laws, preventive measures, urban development policies); local government leadership and competencies; staff capacity and existing organizational structures (e.g. knowledge and skills of staff, level of interaction between municipal departments/bodies); availability of budget for climate action

Physical & environmental: Availability of resources (e.g. water, land, environmental services) and the practices for their management; availability of physical infrastructure and conditions for its use and maintenance (e.g. green-blue infrastructure, health and educational facilities, emergency response facilities)

Knowledge & innovation: Availability of data and knowledge (e.g. methodologies, guidance, assessment and monitoring frameworks); availability of and access to technology and technical applications (e.g. meteorological systems, early warning systems, flood

7.3 Final conclusions

The Covenant of Mayors has been instrumental in creating a community of over 10 800 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 the latest 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 for mitigation, figures are constantly growing. For example, the number of reported adaptation actions has been growing every year with a peak in 2020, while a decrease in 2021 is recorded. 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 for the collection of 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)
CoM-SSA	Covenant of Mayors in Sub-Saharan Africa
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 Environment 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 Contributions
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

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Annexes

Annex 1. Statistical methodology

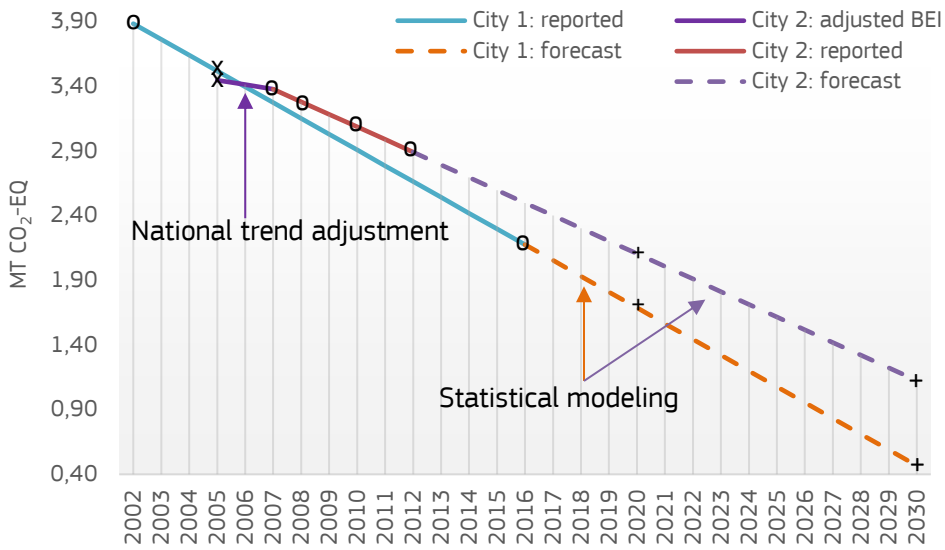
In this Annex 1, the brief explanation presented in Section 3.2.2 is extended, offering greater details on the statistical methods for the estimation and prediction of emissions for each signatory. Firstly, the base year is set to 2005, being the reference year for measuring the performance of the cities' mitigation actions. In this way, for cities reporting a base year earlier than 2005, the estimated emissions in 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 f, which considers NE_{2005} and NE_{base}, as in

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

In total, for cities committed to 2020 targets, 10 % of the cities have their base year occurring before 2005, as opposed to 52 % 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 64 % 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 it will be explained below (see also Franco et al. 2022b). The input data for the development of the models consists in 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: Own elaboration

Therefore, each city has a sparse time series with a yearly frequency, being sparse because many years in between the base and the last monitoring years have missing values. Hence, firstly, the imputation of data is performed, building the yearly time series on which the algorithms can learn the stochastic process explaining their behaviour. This is done by continuing the linear trend between the years holding the known emissions values (see again Figure A1). Secondly, the best model is identified for each city (i), according to the minimum error ($error_i$) for the predicted value ($\hat{y}_{it}$), computed over the last known emissions value (y^*_{it}). This last

known emissions value consists in the emissions value coming from the city's last MEI. This error was computed for each city, by

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

Therefore, the last known value is left out for validation, and the best model is identified that achieves the minimum prediction error. Then, the complete time series is fitted again under the same functional form of the identified model, and the corresponding prediction is taken for the cities' emissions in the target years.

Under this methodology, the time series are modelled after three different approaches. One approach consisted in a Double Exponential Smoothing (DES) (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 consists in 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 included in the process. The ARIMA(p,d,q) models are validated by the Ljung--Box test (see again Box et al., 2016), checking that no significant correlation among the residuals is left unexplained.

The third and last approach to modelling the series consists in an auto-regressive feed-forward neural network with one hidden layer, estimating non-linear functions with a fair level of complexity (Hornik et al. 1989). This architecture is examined with different number of neurons, namely 3, 5, 7 or 10 neurons in the single hidden layer, receiving as input from 1 to 5 lagged observations (depending on the available data).

The summary of the performance of this methodology (ML) is presented in Table A1, taking all reported sectors, not necessarily the coherent ones (recall that the *coherent sectors* refer only to the sectors that are included in all the emission inventories reported by the signatories throughout their reporting years). The performance for the ML method is compared on the last known value with 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 most recent emissions inventories, and a third method (M3) which adjusts the last known value by the national per capita trend. As a result, for 2020 commitments, the ML methodology outperforms all other methods, accomplishing the best mean (0.133) and maximum (3.008) error for prediction on the last known value. Concerning 2030 commitments, both ML and M3 methods are very close, with a mean error of 0.14, although the ML method achieves the lowest maximum error (3.008).

Table A1. Summary of the mean and maximum prediction error of the last known value for the statistical (ML), last known value (M1), linear trend (M2) and national adjustment (M3) methodologies, taking the emissions from all the available sectors.

Error\Method	ML	M1	M2	M3
2020-Mean	0.133	0.159	0.22	0.150
2020-Max	3.008	4.248	6.909	3.416
2030-Mean	0.147	0.176	0.227	0.146
2030-Max	3.008	3.564	3.986	3.416

Source: Own elaboration

On the other hand, the results concerning only the coherent sectors are summarised in Table A2. There for 2020 commitments, the ML methodology outperforms all other methods, accomplishing the best mean

(0.132) and maximum (1.397) error for prediction on the last known value. Comparing with the previous analysis on all sectors, the maximum error reduced by more than half. Concerning 2030 commitments, both ML and M3 methods are again very close, but this time the ML method achieves the minimum mean error (0.127), although this time, the M3 method achieves the lowest maximum error (0.778).

Based on these results (taking both the results for all the sectors and only for the coherent sectors), it can be conjectured that on the first stages of the signatories' implementation of their action plans, the national emissions per capita trend is informative for predicting the signatories' future achievements. At the same time, once the signatories report updated emissions inventories and advance in the implementation of their action plans, the ML method presents the most competitive results, which are expected only to increase their accuracy as more data from the signatories become available (see again Franco et al. 2022b).

Table A2. Mean prediction error of the last known value for the statistical (ML), last known value (M1), linear trend (M2) and national adjustment (M3) methodologies, taking only coherent sectors (emissions allocated to sectors that are consistently reported at the BEI and associated MEIs).

Error\Method	ML	M1	M2	M3
2020-Mean	0.132	0.149	0.234	0.143
2020-Max	1.397	2.785	12.982	2.050
2030-Mean	0.127	0.158	0.209	0.128
2030-Max	1.056	0.921	1.327	0.778

Source: Own elaboration

Additionally, it can be concluded that the analysis for only coherent sectors obtains, in general, better results with respect to the prediction errors. In this sense, as the predictions perform better when considering only on the coherent sectors, the analysis on the expected achievements for the signatories focuses on the most reliable data contained in the history of emissions inventories, regarding only the coherent sectors.

Annex 2. Signatories and population covered by country

Table A3. Signatories by country and commitment

Country	CoM 2020	CoM 2030	CoM 2050	Mayors Adapt
Albania	3	3	1	1
Andorra	0	0	1	0
Argentina	2	0	0	0
Armenia	13	20	0	0
Austria	27	4	1	1
Azerbaijan	1	7	1	0
Bangladesh	1	0	0	0
Belarus	14	53	0	0
Belgium	292	501	22	15
Bosnia-herzegovina	19	44	3	0
Brazil	0	1	0	0
Bulgaria	43	3	2	2
Chile	1	0	0	0
Croatia	77	41	2	3
Cyprus	25	4	1	0
Czechia	13	64	98	0
Denmark	40	7	4	4
Estonia	7	2	0	1
Finland	10	14	1	0
France	161	39	11	6
Georgia	12	21	0	0
Germany	76	21	10	11
Greece	173	76	9	14
Hungary	60	166	6	2
Iceland	1	1	0	0
Ireland	12	11	2	1
Italy	4465	1128	25	69
Kazakhstan	9	0	0	0
Kosovo	2	0	0	0
Kyrgyzstan	5	0	0	0
Latvia	21	6	0	2
Lithuania	15	2	0	0
Luxembourg	11	1	1	0
Macedonia, The Former Yugoslav Republic Of	5	0	1	1
Malta	36	0	0	0
Mexico	0	4	0	0
Moldova, Republic Of	34	56	6	0
Montenegro	5	1	0	0
Netherlands	28	8	1	2
Norway	8	12	2	0
Poland	70	16	2	1
Portugal	138	50	9	15

Country	CoM 2020	CoM 2030	CoM 2050	Mayors Adapt
Romania	145	48	19	2
Serbia	12	3	0	0
Slovakia	13	27	0	2
Slovenia	37	23	4	2
Spain	1833	1359	99	22
Sweden	61	17	1	1
Switzerland	11	1	1	0
Tajikistan	1	0	0	0
Turkey	12	24	9	2
Ukraine	128	221	10	1
United Kingdom	45	12	5	6
Total	**8233**	**4122**	**370**	**189**

Source: JRC elaboration based on GCoM data

Table A4. Population covered by country and commitment

Country	CoM 2020	CoM 2030	CoM 2050	Mayors Adapt
Albania	704 886	483 786	208 600	421 286
Andorra	-	-	24 000	-
Argentina	2 947 907	-	-	-
Armenia	1 467 999	1 495 333	-	-
Austria	2 296 101	2 031 611	11 756	1 914 743
Azerbaijan	4 000	784 325	102 861	-
Bangladesh	81 720	-	-	-
Belarus	1 084 364	3 854 979	-	-
Belgium	9 059 999	9 027 776	1 081 197	2 502 790
Bosnia-herzegovina	1 751 845	1 736 069	15 433	-
Brazil	-	152 435	-	-
Bulgaria	3 140 774	1 506 564	137 366	261 288
Chile	269 992	-	-	-
Croatia	2 044 223	1 626 412	65 689	24 998
Cyprus	526 492	154 284	7 000	-
Czechia	1 660 689	2 266 223	1 570 992	-
Denmark	3 470 444	351 963	460 768	718 120
Estonia	594 573	454 600	-	445 000
Finland	2 061 897	2 248 859	76 850	-
France	20 064 907	8 725 397	3 497 513	1 336 022
Georgia	1 889 943	1 147 043	-	-
Germany	19 356 656	10 260 943	3 464 051	4 818 546
Greece	7 035 125	3 745 486	436 918	570 989
Hungary	3 069 419	6 544 278	492 847	64 078
Iceland	118 427	118 427	-	-
Ireland	1 789 157	2 315 718	290 500	332 015
Italy	55 602 143	23 260 002	507 529	3 005 419
Kazakhstan	2 621 055	-	-	-
Kosovo	180 514	-	-	-
Kyrgyzstan	294 900	-	-	-

Country	CoM 2020	CoM 2030	CoM 2050	Mayors Adapt
Latvia	1 131 739	283 858	-	66 257
Lithuania	1 486 419	65 805	-	-
Luxembourg	275 355	22 100	22 100	-
Macedonia, The Former Yugoslav Republic Of	877 768	-	63 376	38 092
Malta	243 906	-	-	-
Mexico	-	1 963 226	-	-
Moldova, Republic Of	1 693 412	670 390	79 245	-
Montenegro	273 822	15 697	-	-
Netherlands	4 964 707	669 852	29 022	749 271
Norway	1 480 853	665 906	284 994	-
Poland	4 933 373	2 641 091	1 684 737	122 000
Portugal	8 048 612	4 030 714	525 569	1 153 861
Romania	8 873 012	4 594 056	1 021 769	69 041
Serbia	830 077	1 701 073	-	-
Slovakia	579 215	512 313	-	469 647
Slovenia	885 558	362 143	81 272	13 700
Spain	30 569 056	21 311 872	2 369 529	5 479 361
Sweden	4 534 066	2 586 847	28 500	124 935
Switzerland	909 198	146 000	146 000	-
Tajikistan	30 000	-	-	-
Turkey	10 587 778	19 274 258	12 646 266	590 204
Ukraine	15 188 047	10 688 174	767 366	98 953
United Kingdom	21 112 244	4 600 711	1 012 120	4 503 799
Total	**264 698 368**	**161 098 599**	**33 213 735**	**29 894 415**

Source: JRC elaboration based on GCoM data

Table A5. Overall commitment by 2030, based on submitted action plans per country

Country	Total emissions in BEI [$tCO_2eq/year$]	Targeted emission in 2030 [$tCO_2eq/year$]	Overall committed reduction by 2030
Armenia	18 235	12 673	31%
Austria	78 939	54 360	31%
Azerbaijan	212 087	148 461	30%
Belarus	4 319 722	3 038 737	30%
Belgium	28 608 748	16 805 508	41%
Bosnia-herzegovina	2 119 665	1 271 138	40%
Bulgaria	166 250	99 750	40%
Croatia	1 318 242	695 443	47%
Cyprus	183 520	110 112	40%
Czechia	11 780 893	6 618 092	44%
Finland	9 090 396	3 029 119	67%
France	19 761 704	10 735 908	46%
Germany	39 934 012	16 526 092	59%
Greece	9 675 873	5 801 028	40%
Hungary	15 805 597	9 197 527	42%
Ireland	11 662 361	8 324 665	29%
Italy	51 038 168	27 717 453	46%
Latvia	386 339	220 674	43%
Mexico	523 588	408 399	22%
Moldova, Republic Of	186 900	111 496	40%
Netherlands	1 039 976	311 993	70%
Poland	6 598 991	4 079 063	38%
Portugal	9 629 692	4 722 525	51%
Romania	2 009 936	1 193 599	41%
Serbia	7 528 437	4 517 062	40%
Slovakia	234 826	124 458	47%
Slovenia	1 261 106	756 664	40%
Spain	28 470 127	16 922 704	41%
Sweden	695 904	248 625	64%
Türkiye	36 665 687	25 174 171	31%
Ukraine	14 330 749	9 614 358	33%
United Kingdom	6 223 237	1 937 393	69%

Source: JRC elaboration based on GCoM data

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