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EVALUATION OF MAIN DRIVERS AND BARRIERS OF LOCAL CLIMATE ACTION IN EUROPE

CITIES TAKING ACTION FOR THE SUSTAINABLE DEVELOPMENT GOALS

Silvia Rivas Calvete

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DOCTORAL DISSERTATION

Evaluation of main drivers and barriers of local climate action in Europe

Cities taking action for the Sustainable Development Goals

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November 2022

"A Rubén , esta tesis es tan tuya como mía.

A Julián, por materializarla

A Paolo, por supervisarla

Y por supuesto, a mi incondicional club de fans: Lola, Luis, María, Hugo y Kaui "

COMPENDIO DE PUBLICACIONES

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- Rivas S, Urraca R, Bertoldi P, 2022. Covenant of Mayors 2020 achievements: a two-speed climate action process. Sustainability, 14:15081.10.3390/su142215081
- Rivas S, Urraca R, Bertoldi P, Thiel C, 2021. Towards the EU Green Deal: Local key factors to achieve ambitious 2030 climate targets. Journal of Climate Production 320:128878. 10.1016/j.jclepro.2021.128878
- Rivas S, Hernandez Y, Urraca R, Barbosa P, 2021. A comparative analysis to depict underlying attributes that might determine successful implementation of local adaptation plans. Environmental Science & Policy 117:25-33. 10.1016/j.envsci.2020.12.002

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TESIA ARGITALPENEN BILDUMAREN MODALITATEAN AURKEZTEKO ESKAERA

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This is to **certify** that the work presented by Ms Silvia Rivas *Calvete " Evaluation of main barriers and drivers of local climate action in Europe; cities taking action for the Sustainable Development goals " meet all the scientific and formal requierements needed to be presented as a Doctoral Thesis for the purpose of obtaining the PhD degree.*

In Ispra, November 14th 2022

Paolo Bertoldi

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A esa gente pequeña , que desde lugares pequeños, haciendo cosas pequeñas, cambiará el mundo

(Eduardo Galenao)

ABSTRACT

There is no " Planet B". Natural but mainly anthropogenic factors make it impossible to maintain in the long term the current earth system. Climate change is a demonstrated fact that urges governments of all kinds as well as civil society to take action; because the climatic threat is not only damaging the environment and the natural resources, is directly threatening society's equilibrium, and security.

International governmental panels agree on the need of putting local climate action at the core of the efforts towards mitigating and adapting to climate change. This Thesis develops a deep evaluation of the local climate actions in Europe. In the frame of the European mainstream movement on the topic, and analyzing the first and unique monitoring harmonized database, it evaluates quantitatively and qualitatively the main factors and barriers explaining the effectiveness and the efficiency of the local actions developed in the period 2008-2020.

The first of the four publications developed and published during my doctorate years, and that frames this Thesis, analyzes the drivers and barriers explaining the effectiveness of the implementation of concrete climate change mitigation actions by local authorities (LAs) in Europe for that period.

After having identified the factors enabling or preventing LAs under the local climate initiative to implement and monitor the local climate actions developed, the second publication of this Thesis quantifies the real mitigation achievements in terms of Greenhouse gasses (GHG) reduction in their territories-i.e., the efficiency of the climate action.

Once the effectiveness and efficiency of the local climate action of LAs in Europe were analyzed, the objective was to evaluate the relevance, sustainability and impact of the initiative conducted. That for, in the first place the level of ambition in terms of the GHG reduction target for 2030 established by the LAs was evaluated and the achieved results were described in the third publication of this thesis.

Finally the fourth publication moves from mitigation action to adaptation to climate change, evaluating and extracting the main factors describing the local climate action in Europe in the matter.

As described in the following sections, these four publications give, for the first time, a comprehensive understanding of the major European local climate action initiative, the only one monitored in a harmonized manner. This thesis analyzes and describe the main attributes leading European LAs to the success or failure of their climate plans and would be of extreme interest for the local climate action in the next period toward 2030 objectives.

RESUMEN

No existe un "Planeta B". Hace décadas que diversos factores tanto naturales como antropogénicos hacen inviable la persistencia del sistema tierra a largo plazo tal y como lo conocemos. El calentamiento global y sus efectos , lo que conocemos como cambio climático, es un hecho demostrado que urge a las naciones, los gobiernos de todo tipo y a la sociedad civil a tomar medidas. Porque la amenaza climática no solo pone en peligro el medio ambiente y los recursos naturales, es una amenaza que afecta directamente a las sociedades, su equilibrio y seguridad.

Los paneles intergubernamentales de expertos concuerdan que la acción local climática es fundamental en los esfuerzos globales para mitigar y adaptarse a los efectos del cambio climático. Esta Tesis evalúa en profundidad la acción local climática en materia de mitigación y adaptación en Europa. Así, dentro del marco de una de las iniciativas mas importante en la materia, y en base a los únicos y primeros datos de monitorización existentes, se evalúan de manera cuantitativa así como cualitativa los factores que han determinado la eficiencia y eficacia de las acciones destinadas a mitigar y adaptarse a los efectos del cambio climático.

Así, el primero de los cuatro artículos desarrollados y publicados durante mis años de doctorado que conforman esta Tesis analiza los factores que han determinado la eficiencia en el seguimiento de la implementación de medidas de mitigación del cambio climático en ciudades de Europa.

Una vez identificados los factores que han facilitado o impedido a las ciudades adheridas a la iniciativa el implementar y monitorizar las medidas locales de acción climática proyectadas, el segundo articulo cuantifica los resultados reales obtenidos por las ciudades en sus territorios.

Una vez evaluadas la eficiencia y eficacia de la acción local climática en Europa en el periodo 2008-2020, se ha procedido a estudiar la relevancia, sostenibilidad e impacto de estas acciones, estudiando primero el nivel de ambición de las ciudades europeas para el siguiente periodo de actuación climática local (2020-2030) , cuyos resultados viene descritos en el tercer articulo de esta Tesis.

Por ultimo y dado que en 2015 se incluyo en la iniciativa el pilar de adaptación contra el cambio climático, el cuarto articulo evalúa los principales factores y características de los planes de acción en la materia .

Como se describe a continuación, veremos que estos 4 artículos dan un enfoque global o análisis ex post de la primera experiencia en materia de acción climática monitorizada de manera armonizada en Europa, evaluando los principales factores que han determinado el éxito o fracaso de los resultados e indicando el camino a tomar en la lucha local frente al cambio climático en el siguiente periodo de actuación con objetivos para el 2030.

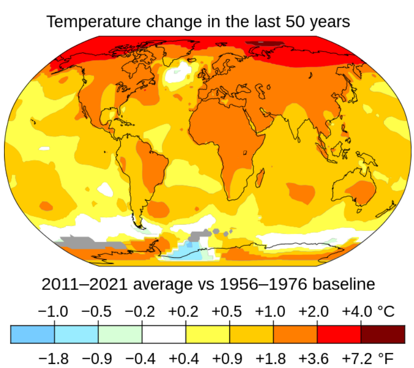
1 INTRODUCTION

1.1 General introduction

1.1.1 Climate Change as a global crisis

Every year billions of tons of CO_2 are released into the atmosphere mainly as a result of fossil fuels burning. Anthropogenic activity is producing greenhouse gas emissions (GHG) at record levels, with no signs of slowing down. This is the main cause of climate change, understood as a long-term shift in temperatures and weather patterns affecting every corner of our planet.

Figure 1 Global temperature change



Source : NASA. data.giss.nasa.gov/gistemp/maps

Rising temperatures are directly causing: (World Metereological Organisation 2019)

- Environmental degradation. Almost 60% of the world's cities with a population of more than five million inhabitants are located in areas where there is a risk of sea level rise. Almost 40% of the world's population lives less than 100 km from the coast.

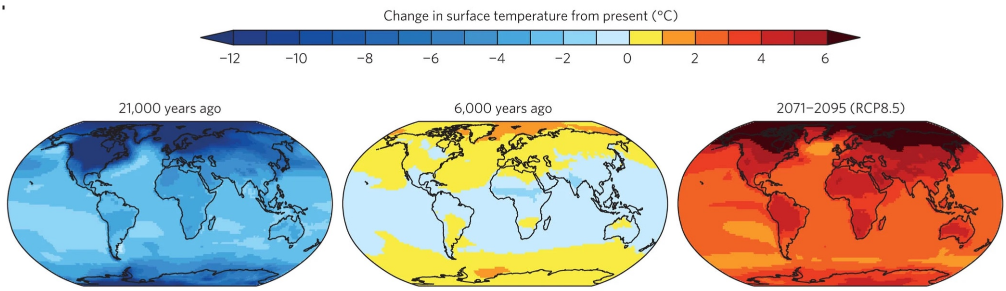
- Natural disasters and extreme weather conditions. There have always been climate-related disasters and extreme weather events on the planet, but they are becoming more frequent and intense as global temperatures rise.

- Food and water insecurity. Climate change limits the availability and quality of water for human consumption and agriculture. In many regions, crops that have thrived for centuries are barely surviving, making food security more precarious; in such cases, the main victims are often the poor and vulnerable.(Food and Agriculture Organization of the United Nations (FAO) 2015).

- Economic disruption. 90% of disasters are classified as weather and climate-related, costing the global economy $520 billion a year, and 26 million people are pushed into poverty as a result.

- Conflicts and terrorism. Climate change poses a major threat to international peace and security. The effects of climate change intensify competition for resources such as land, food and water, exacerbating socio-economic tensions and, increasingly, causing massive displacement. The World Bank estimates that if no action is taken, more than 140 million people in sub-Saharan Africa, Latin America and South Asia will be forced to migrate within their regions by 2050.

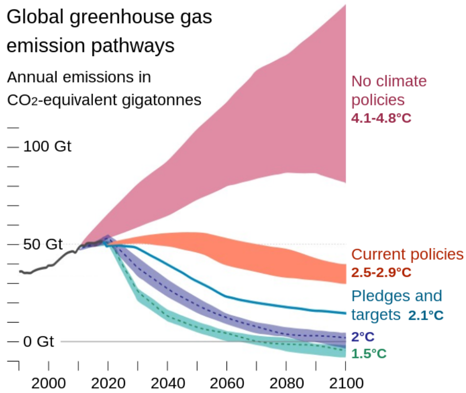
Figure 2 Model simulated global temperatures



Source: Climate Change Knowledge portal. The World Bank

According to a 2021 World Meteorological Organization (WMO) report,(World Meteorological Organization 2021) we are at least one degree Celsius above pre-industrial levels and close to what scientists warn would be "an unacceptable risk". The 2015 Paris Agreement on climate change (UNFCCC 2015) requires that ultimate warming be kept "well below" 2 degrees Celsius, and that efforts continue to further limit the increase to 1.5 degrees (IPCC 2014). But if we don't cut global emissions, temperatures could rise by up to three degrees Celsius by 2100, causing irreversible damage to our ecosystems,

Figure 3 Global greenhouse emission pathways



Source: Hannah Ritchie and Max Roser (2017) - "CO_2 and Greenhouse Gas Emissions".OurWorldInData.org

As the infinite cost of climate change reaches irreversible levels, the time has come for collective action. While new and efficient technologies (technological solutions are already available to abate more than 70% of today's emissions) is already helping us reducing net emissions and create a cleaner world, fundamental transformations will be required in all aspects of society; But, we still have a chance.

1.1.2 Climate Action

Governments worldwide join forces towards the goals adopted by the UN General Assembly in 2015 within its Agenda for 2030: Sustainable Development Goals,(United Nations. General Assembly.A/RES/70/1 2015)(see Figure 4). These objectives, constitute an action plan in favor of people, the planet and prosperity, which also intend to strengthen universal peace and access to justice.

Figure 4 Sustainable Development Goals

Source : ONU 2015

"Take urgent action to combat climate change and its impactshttps://en.wikipedia.org/wiki/Sustainable_Development_Goal_13 - cite_note-:172-1" is the official mission statement of the Sustainable Development Goal number 13. This goal has five targets that are to be achieved by 2030. They cover a wide range of issues surrounding climate action. Along with each target, there are "indicators" that provide a method to review the overall progress of each target, along with SDG 13 as a whole.

The first three targets are "output targets":

1. strengthen resilience and adaptative capacity to climate-related disasters;
2. integrate climate change measures into policies and planning;
3. build knowledge and capacity to meet climate change.

The remaining two targets established the path for reaching targets:

4. To promote mechanisms to raise capacity for planning and management
5. To implement the UN Framework Convention on Climate Change (primary international, intergovernmental forum for negotiating the global response to climate change). The 1997 Kyoto Protocol and 2015 Paris Agreement build on the Convention with the aim of achieving a stabilization of the concentration of greenhouse gases in the atmosphere at a level that prevents dangerous anthropogenic interference in the climate system.

The 196 parties (nations) that adopted the Paris Agreement are requested to communicate their post 2020 climate actions, known as their Nationally Determined Contribution (NDCs). They embody efforts by each country to reduce national emissions and adapt to the impacts of climate change. Parties shall pursue domestic mitigation measures, with the aim of achieving the objectives of such contributions. NDCs are submitted every five years to the UNFCCC secretariat. In order to enhance the ambition over time, the Paris Agreement provide that successive NDCs will represent a progression compared to the previous NDCs and reflect their highest possible ambition. It is understood that the peaking of emissions will take longer for developing country Parties, and that emission reductions are undertaken on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty, which are critical development priorities for many developing countries

Starting in 2023 and then every five years, governments will take stock of the implementation of the Agreement to assess the collective progress towards achieving the purpose of the Agreement and its long-term goals. The outcome of the global stocktake (GST) will inform the preparation of subsequent NDCs, in order to allow for increased ambition and climate action to achieve the purpose of the Paris Agreement and its long-term goals.

1.1.3 Local Climate Action

For decades, the main actors in the fight against climate change have been national and supranational entities and governments. However more than 85% of greenhouse gas emissions come from local authorities (LAs) (IPCC 2021). Likewise, more than 70% of the population lives in cities and this figure is expected to increase to 85% in 2030 (The World Bank 2020).

Several are the SGDs which specifically tackle LAs as crucial players in the path towards sustainability. SDG11 refers to "Sustainable cities and communities" and SDG 17 to “Alliances to achieve the objectives” or SDG 7 “Access to affordable and non-polluting energy. This last goal is becoming fundamental to achieve SGD13 , since the leading sources of the greenhouse gas savings that governments need to focus on, in order to realize their commitments under the Paris Agreement, are switching fuels to renewable energy and enhancing end-use energy efficiency (Boehm et al. 2022).

Therefore, LAs need to play an exemplary role since cities are the main contributors to the exacerbated climate change effects (Hoornweg et al. 2010) and can play a critical role engaging their communities and boosting cobenefits in other areas of their interest. Aware of this pivotal role that cities play in the green and just transition, governments and entities worldwide are putting cities in the core of climate developments.(EEA 2021).Cities are living labs, experimentation and innovation hubs that could enable achieving the global climate goals.

1.2 Specific introduction

1.2.1 Local Climate Action in Europe: The Covenant of Mayors initiative as a case of study

Several are the initiatives that started in Europe over the last decades to boost an effective climate action by LAs towards 2020 Energy and Climate objectives (EC 2008) such as Smartcities or Greencities. Relevant, as well, is the work conducted by cities associations (Climaet Alliance, EuroCities, C40, ICLEI.) that contribute together with the European Commission to the development and implementation of the first pan European initiative for cites of all kind towards climate action in their territories.

The Covenant of Mayors (CoM2020) initiative was launched in 2008 to support and mobilize LAs in reducing their GHG emissions. Covenant of Mayors signatories voluntarily committed to reducing their emissions by at least 20% by 2020 from their baseline year. For that, they developed and implemented local Climate Action Plans (CAP)[1] composed of (i) a strategy, (ii) an assessment (baseline emission inventory), and (iii) an action plan (concrete actions to achieve

[1] Note that for the first phase of the initiative, the European CoM2020, the CAP was called "Sustainable Energy Action Plan" (SEAP). For the second phase, the CoM2030, in Europe the CAP was called " Sustainable Energy and Climate Action Plan " (SECAP)

their target).The Covenant of Mayors initiative evolved in 2015 into the Covenant of Mayors 2030 (CoM 2030) (Bertoldi. P (ed) 2018a), extending the target year to 2030, increasing the minimum reduction target to 40% by 2030, and including the adaptation to climate change pillar. One year later, the Covenant of Mayors merged with the Compact of Mayors into the Global Covenant of Mayors (GCoM) (Global Covenant of Mayors for Climate & Energy 2018), extending the coverage of the initiative worldwide.

LAs adhered to CoM had to submit their SEAPs within two years following the adhesion date. Once the SEAP was ready, LAs uploaded all the information to a specific reporting system, the "MyCovenant" reporting platform (Neves et al. 2016). The harmonized data was stored in a relational database. Municipalities also uploaded a digital copy of the SEAP document approved by the city council. SEAPs were evaluated by the European Commission's Joint Research Centre (JRC), which provided every signatory with full feedback, highlighting the main strengths and weaknesses and giving recommendations for potential improvements.

The Covenant of Mayors imposes two types of monitoring exercises: (i) an action reporting every two years after the SEAP submission, and (ii) a full reporting every four years after the SEAP submission, including an update of the emission inventory. No specific reporting was requested at the end of the initiative in 2020 neither reporting actual data from 2020.

Nowadays, with more than 12,600 signatory cities and local governments in 139 countries on 6 continents, the initiative represents more than 1bn people, that is, 12% of the world's population. If fully implemented, the climate action plans of these cities and local governments together have the potential to reduce 2.3 billion tons of greenhouse gases per year by 2030. That is, they could potentially reverse the current trend of rising emissions and could contribute more to its reduction than the global efforts of all the nations of the world.

2 SCOPE, OBJECTIVES AND CONTRIBUTION

2.1 Problem statement/scope

As stated previously, local climate action is a key element in the global effort against climate change (Mi et al. 2019). While several are the studies conducted in the last years focusing on the commitments acquired by the LAs, (Diana Reckien et al. 2015; D Reckien et al. 2018; Croci, Lucchitta, and Molteni 2021) few are the studies that actually give an insight on the actual results achieved by the LAs (Hsu et al. 2016). This can be explained by two main reasons :

(i) most of local climate initiatives lack a concrete monitoring system. The main limitation of all these studies is that their findings are based on a series of commitments that may or may not be achieved (Palermo et al. 2020). Assessing the monitoring exercises was therefore crucial to verify the actual achievements and impacts of the designed action plans and the commitments made by the LAs.

(ii) the final and real progress of the achievements can only be evaluated after the due date of the initiatives, ergo after 2020. The few studies that have assessed the EU CoM achievements, used specific CoM sub-populations, and omit the implications of the low number of CoM 2020 monitoring reports received (32.5% of LAs with an approved SEAP) on the representativeness of their datasets partly again due to the limited access to the CoM database and due to the recent availability of monitoring data. (Kona et al. 2018) extrapolated the emissions reductions of the first 533 monitoring reports to the whole CoM population, trying to predict the theoretical reductions that would be obtained by 2050 if the same reduction rate was kept. (Hsu et al. 2020) evaluated the emissions reductions of 1066 CoM municipalities and estimated their progress by interpolating linearly their planned reductions to the year of the last monitoring report. Extrapolating emissions reductions in time and to other municipalities, could lead to unrealistic results due to the high non-linearity of local emissions reduction patterns

Therefore, the main goal of this Thesis is to make a step forward and to develop the first achievements analysis or ex-post evaluation of the local climate action in Europe for the period 2008-2020, in terms of efficiency, effectiveness, impact, relevance and sustainability. The study is based, for the first time, on the complete monitoring exercise of the main initiative for local climate action in Europe, the Covenant of Mayors (CoM2020), the only initiative providing a harmonized monitoring and reporting system.

This study, aware of the intrinsic limitations of the database described above, will extract and evaluate as well the main drivers and barriers LAs faced in their path towards sustainability, in order to stablish good practices and recommendations for LAs to improve their local action towards 2030 energy and climate goals (EC 2015) in line with the (SDG), specially number 11 " Sustainable cities and communities" and 13 "Climate Action".

2.2 Objectives

In order to achieve the main goal established in this Thesis, the work has been divided into four specific objectives. Each objective has been the scope of a peer-reviewed paper published in JCR journals during the doctorate years.

Objective 1 *To analyze the local climate action developed by European LAS in the period 2008-2020 evaluating the specific factors facilitating the actual implementation and monitoring of concrete energy, climate and sustainability actions in their territories.*

Since it is not possible to evaluate what is not measured, to evaluate the real effects or impact of the specific measures put in place by the LAs in Europe for that period, the first step is the gathering of the actual monitoring data reported by the cities regarding their local climate action efforts. The first question to be answered was: were the LAs joining the initiative able, following the methodological guidance published (Bertoldi et al. 2010; Neves et al. 2016), to actually make and submit a monitoring exercise? And, has this monitoring exercise the quality level needed to perform robust analyses? This gave us an index of the effectiveness of the initiative implementation. As shown before, this would be one of the main limitations of the evaluations conducted on local climate initiatives like the Covenant of Mayors.

But, further than the quantitative and qualitative analysis of the monitoring's conducted, this first objective includes the evaluation of the main attributes leading LAs to the completion of the monitoring process, as well as the main barriers faced. The lessons learnt on this exercise will help cities worldwide improving the effectiveness of their implementation of concrete actions towards a low-carbon future.

Section 3 (Material and Methods) describe all the attributes and factors considered, from the intrinsic to the LA ones (population, nation) to the methodologic (stakeholders management, the internal organization of the municipality, the existence of supports and which kind..) and economic ones. Section 3 describes, as well, all the statistical analyses conducted in order to infer the weight and significance of the elements above.

All the work conducted was included in the first paper of this Thesis (*Rivas S, Urraca R, Palermo V, Bertoldi P, 2021. Covenant of Mayors 2020: Drivers and barriers for monitoring climate action plans. Journal of Cleaner Production 332:130029. 10.1016/j.jclepro.2021.130029)* that already shown relevant conclusions on the most determinant attributes for LAs climate action: despite technical and financial barriers, factors such as the direct involvement of local staff and stakeholders in participatory processes from an early stage, an accurate budget allocation, or the development of the plan and deployment of actions as soon as possible, enabled LAs to track and monitor their progress towards their climate targets.

Objective 2 *To quantify the real impact of the local mitigation climate action in the European context in the period 2008-2020; How much did the LAs actually reduce in terms of GHG in their territories?*

To achieve this second objective, we conducted an in-depth analysis of the GHG total reduction achieved by the LAs that performed at least one monitoring exercise, in terms of total reduction, per capita reduction and reduction per sector of activity. We analyzed as well the % of reduction achieved with regards to the reduction commitment established by the LA, as an index of the efficiency of the local climate action plan designed and implemented. This work could be considered the core of this Thesis, since it gives a real insight into the actual GHG reduction the LAs achieved in the period of study. These results are the first one of its kind, since the database used for the evaluations is the first complete monitoring harmonized database available in Europe. The data and methodologies applied are explained in the next section 3.

One of the first insights extracted during this work, included in the second paper of this Thesis (*Rivas S, Urraca R, Bertoldi P, 2022. Covenant of Mayors 2020 achievements: a two-speed climate action process. Sustainability 14:15081.*10.3390/su142215081), and explained in the Conclusions section is that the inner LA characteristics, the size, makes a huge difference on the implementation and efficiency of climate action at the local level.

In parallel, we investigated the impact of the actions undertaken by sector of activity, understanding which are the sectors presenting the greatest changes, and analyzing the attributes and factors leading to these results. The study reveals that a factor to be considered key for successful climate action planning is the joint partnership between several government levels. National actors have a great contribution to the results achieved at the local level.

Objective 3 *To evaluate the relevance and sustainability of the local climate action in Europe by analyzing the level of ambition (in terms of GHG reduction goals) of the LAs for the new action period 2020-2030 towards the 2030 objectives.*

The European Green Deal (European Commission 2019), a priority of the current EU agenda, established, by the adoption of the 2030 GHG reduction targets, that local climate action in Europe is not only relevant but a clear priority that will be reinforced at least for the next decade. LAs will play a crucial role in achieving a neutral carbon future and therefore evaluating the strategies and drivers of their actions could benefit other LAs and accelerate the final result.

Therefore, we analyzed the first data available regarding the commitments made by LAs joining the most important European local climate action imitative for the period 2020-2030, focusing on the most ambitious LAs, in order to understand the key enabling factors for higher ambition.(The data and methodologies applied are explained in the next section 3). This work was presented in the third published paper of the Thesis (*Rivas S, Urraca R, Bertoldi P, Thiel C, 2021. Towards the EU Green Deal: Local key factors to achieve ambitious 2030 climate targets. Journal of Climate Production 320:128878. 10.1016/j.jclepro.2021.128878*)

Objective 4 *To investigate the main attributes that could potentially benefit the local adaptation to climate change planning in cities across Europe.*

In 2015, the described initiative (Covenant of Mayors) included as mandatory the adaptation to Climate Change pillar and developed a specific reporting system for LAs willing to join and follow the recommendations for planning concrete actions on adaptation in their territories.

Our objective was to analyze if, as in the case of the mitigation pillar, we can statistically identify key factors determining the quality and success of the local climate action plans in adaptation. The data and methodologies applied are explained in the next section 3. The results of the study are included in the fourth paper of the Thesis (*Rivas S, Hernandez Y, Urraca R, Barbosa P, 2021. A comparative analysis to depict underlying attributes that might determine successful implementation of local adaptation plans. Environmental Science & Policy 117:25-33. 10.1016/j.envsci.2020.12.002)* and shows, in line with previous results, that engagement of multiple stakeholders and citizens, particularly at the local level, might significantly facilitate reaching the minimum requirements for a good action plan in adaptation to climate change.

2.3 Contribution

This Thesis is the result of 9 years of work as scientific officer at the Joint Research Center of the European Commission of the doctoral student, devoted to local climate action support worldwide. The four papers that constitute this Thesis are the result of the main goal of the author : to make a comprehensive evaluation of the real effect of the local climate action in Europe after the mainstream movement on the topic: the Covenant of Mayors for Energy and Climate initiative. The doctoral student has been the lead of all the investigations conducted in charge of the conceptualization , investigation, methodology, formal analysis and writing and preparing the original draft. The second author in all the papers included int his thesis, R. Urraca, was in charge of the data curation and visualization and contributed to the methodology and writing and reviewing of the papers. P. Bertoldi, as well co-author of all the papers and director of this Thesis was in charge of the project administration and revision/supervision of the papers. The rest of the authors included in the papers, V. Palermo, Hernández and P.Barbosa contributed to the writing revision and editing of them.

3 MATERIALS AND METHODS

3.1 Data

The Covenant of Mayor's initiative (CoM), was the first and unique European initiative that provides harmonized data regarding the commitments as well as the monitoring exercises conducted by LAs all over Europe (and beyond) in their path towards sustainability. This is the reason why, for the purposes of this Thesis, we selected the Covenant of Mayor's dataset.

Signatories of the initiative were requested to submit via a web-based platform, "MyCovenant "a series of harmonized data/attributes according to the three main cycle steps of the local climate action, as shown in Table 1 and following the specific reporting guidelines(Neves et al. 2016):

1. Initiation: in this phase, the LA starts developing its global strategy for the short and long term regarding the desirable reduction of GHG in their territories, as well as the resilient goals. The mobilization of all the actors and engagement of relevant stakeholders is a basic component of this phase.
2. Assessment: Once the adhesion was confirmed, the LA had to develop an assessment of their current status in terms of GHG emissions, so-called Baseline Emission Inventory (BEI), and an evaluation of their risks and vulnerabilities regarding climate change, the Risk and Vulnerabilities Assessment (RVAs). These serve as a basis to first select feasible reduction targets and resilient goals, and then as the initial level to compare the potential results and achievements.
3. Planning: Based on the assessments, which will as well show the main sectors of activity and/or the main vulnerable sectors and risks in the area, the LA would need to develop, approve and implement a concrete local action plan, based on feasible, measurable and achievable concrete actions in their territories. The crucial information about these actions needs to be

reported, as well as a complete version of the local action plan approved by the council.

4. Monitoring: The initiative foresees two types of monitoring exercises: (i) an action reporting every two years after the CAP (SEAP for CoM2020, SECAP for CoM2030) submission, and (ii) a full reporting every four years after the CAP submission, including an update of the emission inventory, so called Monitoring Emissions Inventory (MEI). As stated before, unfortunately, the initiative did not require a final reporting exercise.

Table 1 CoM data submission phases

Phase	Type of data	Timeline
Adhesion	General data from the LA and the action plan	At the moment of the adhesion
	Strategy data	
Assessment	Baseline emission inventory (BEI)	Within 2 years from the adhesion
	Risk and Vulnerability assessment(RVAs)	
Planning	Set of concrete actions	Within 2 years from the adhesion
Monitoring	Action reporting	Every 4 years from the adhesion
	Full reporting	Every 6 years from the adhesion

As shown in table 2 below, at the end of the first phase of the initiative (CoM2020), end of 2020, a total number of 6620 LAs, representing 36% of the European (EU27) population adhered to the initiative. Out of those, 6437 signatories developed a local climate action plan (SEAP), 5636 had the plan accepted by the JRC and 1696 implemented and monitor it.

Table 2 EU27 LAs committed to Covenant of Mayors2020-end 2020

	Total	Total [million inhabitants]	EU-27 coverage [%]
Adhered	6620	160.0	36.0
SEAP submitted	6437	155.8	35.0
SEAP accepted	5636	135.7	30.5
Complete Monitoring	1696	85.5	19.2

As shown in table 3, as of 1st July 2020, the number of municipalities committed to the CoM 2030 initiative amounted to 2420, representing 23% of the EU-27 population, of which 647 had already submitted their SECAP and 344 had been approved by the JRC. The 334 approved municipalities represent 10.3 million inhabitants (around 2.3% of the EU-27 population).

Table 3 EU27 LAs committed to Covenant of Mayors 2030- mid 2020

	Total	Total [million inhabitants]	EU-27 coverage [%]
Adhered	2420	100.3	23.0
SECAP submitted	647	19.3	4.3
SECAP accepted	344	10.3	2.3
Complete Monitoring	-	-	-

We include now (tables 4 and 5) the specific attributes regarding climate change mitigation and adaptation to climate change as in the official reporting platform for CoM "MyCovenant". Note that only plans having passed the evaluation of the Joint Research Center have been included in this work. Note as well that from 2017 and in the frame of the GCoM two are the official platforms to report, the My Covenant (used in Europe) and the CDP platform, used abroad and therefore without relevant data for the objectives and purposes of this Thesis

3.1.1 Climate Change Mitigation data

Table 4 CoM Mitigation reporting system attributes

<table>
<tr><th colspan="3">Attributes</th><th>Type</th><th>Description/Notes</th></tr>
<tr><td>Administ. attributes</td><td colspan="2">Population</td><td>num</td><td>Attribute not analysed directly as predictor variable but used to split the dataset into two groups (small and large LAs) in the achievements study.</td></tr>
<tr><td rowspan="4">CAP general</td><td colspan="2">SEAP submission year</td><td>num</td><td>Year of submission of the action plan.</td></tr>
<tr><td colspan="2">SEAP start year</td><td>num</td><td>Year of implementation of first action. Some of the actions proposed in the SEAP, and even the whole plan, could be already ongoing when submitted to CoM 2020.</td></tr>
<tr><td colspan="2">Approved via CTC grouped evaluation</td><td>cat</td><td>-</td></tr>
<tr><td colspan="2">Signatories committed to both 2020 & 2030 initiatives</td><td>cat</td><td>Also known as ‘overlappers’.</td></tr>
<tr><td rowspan="12">CAP strategy</td><td colspan="2">2020 GHG reduction target</td><td>cat</td><td>The target is set based on the foreseen reduction in each sector for the different actions proposed.</td></tr>
<tr><td rowspan="5">Staff allocated</td><td>Local authority</td><td>cat</td><td rowspan="5">Type of staff allocated in the preparation of the SEAP. Multiple selection was available in the reporting platform.
*CoM (national) coordinators: national public bodies such as ministries or national energy agencies. Results show that this support is not correlated to greater reductions achieved in any kind of LAs.
*CoM supporters: associations of local and regional authorities, networks, thematic local and regional agencies, European federations, and not-for-profit organisations with the capacity to promote the Covenant of Mayors and to mobilise and support their members</td></tr>
<tr><td>CoM coordinator</td><td>cat</td></tr>
<tr><td>CoM supporter</td><td>cat</td></tr>
<tr><td>External consultant</td><td>cat</td></tr>
<tr><td>Other</td><td>cat</td></tr>
<tr><td rowspan="3">Stakeholders’ engagement</td><td>Local authority’s staff</td><td>cat</td><td rowspan="3">Type of stakeholders engaged in the development of the SEAP. Multiple selection was available. Note that the level of engagement is a qualitative description selected by the municipality from the three possibilities given on the reporting platforms: high, medium, and low, as part of their own progress assessment.</td></tr>
<tr><td>External stakeholder at local level</td><td>cat</td></tr>
<tr><td>Stakeholders at other levels of governance</td><td>cat</td></tr>
<tr><td rowspan="2">Financial resources</td><td>Local authority’s own resources</td><td>cat</td><td rowspan="2">Type of financing resources used to meet the budget. Multiple selection was available.</td></tr>
<tr><td>External: Public</td><td>cat</td></tr>
</table>

		External: Private	cat	
		Other	cat	
CAP assessment	BEI	Total GHG initial emissions	num	-
		Baseline Year	num	1990 or the closest subsequent year for which sufficiently comprehensive and reliable data are available. The alternative year shall not be later than 2005.
CAP planning	Mitigation Actions	Sector/Area of intervention	cat	Sector of activity of the action
		Origin of the action	cat	Whether the action has been initiated from one of the following: the local authority; a Covenant coordinator or supporter; national entity; regional entity; mixed origin; other.
		Responsible body	cat	body responsible for the action, e.g. a specific department in the municipality; name of Covenant coordinator/supporter; name of national ministry; regional agency, etc.
		Implement. timeframe	cat	Start and end date of the action
		Estimated costs	num	In euros, per action
		Estimates in 2020/2030	num	Estimation of the Energy Savings Renewable Energy production and CO_2 reduction per action by 2020/2030
CAP monitoring	MEI	Total emissions	num	
		Sector emissions	num	
		Monitoring year	num	Year of the last monitoring report submitted by the municipality
		Implementation years	num	Monitoring year – year of the first action.

3.1.2 Adaptation to Climate Change data

Table 5 CoM Adaptation reporting system attributes

Attributes			Type	Description/Notes
Administ. attributes		Population	num	
		Population density	num	
CAP general		SEAP submission year	num	Year of submission of the action plan.
		SEAP start year	num	Year of implementation of first action. Some of the actions proposed in the SEAP, and even the whole plan, could be already ongoing when submitted to CoM 2020.
CAP strategy		2030 Adaptation goal	Num	Quantitative and/or qualitative resilience goal towards 2030
	Staff allocated	Local authority	cat	Type of staff allocated in the preparation of the SEAP. Multiple selection was available in the reporting platform. **CoM (national) coordinators:* national public bodies such as ministries or national energy agencies. Results show that this support is not correlated to greater reductions achieved in any kind of LAs. **CoM supporters:* associations of local and regional authorities, networks, thematic local and regional agencies, European federations, and not-for-profit organisations with the capacity to promote the Covenant of Mayors and to mobilise and support their members
		CoM coordinator	cat	
		CoM supporter	cat	
		External consultant	cat	
		Other	cat	
	Stakeholders' engagement	Local authority's staff	cat	Type of stakeholders engaged in the development of the SEAP. Multiple selection was available. Note that the level of engagement is a qualitative description selected by the municipality from the three possibilities given on the reporting platforms: high, medium, and low, as part of their own progress assessment.
		External stakeholder at local level	cat	
		Stakeholders at other levels of governance	cat	
	Financial resources	Local authority's own resources	cat	Type of financing resources used to meet the budget. Multiple selection was available.
		External: Public	cat	
		External: Private	cat	
		Other	cat	

CAP assessment	RVAs	High-level hazards	cat	Droughts, Extreme heat, Floods, Forest Fires, Sea level rise, Landslides, Storms, Extreme cold
CAP planning	Adaptation Actions	Climate hazard(s) addressed	cat	Climate hazards addressed by the action. The list of climate hazards is identical to the climate hazards in the RVA.
		Sector	cat	Sector(s) addressed by the action (multiple selections possible). The list of sectors is identical to the sectors in the RVA.
		Outcome	cat	Main outcome(s) of the action (reached or expected).it must include an indicator for the most significant outcome, including its value, and associated unit
		Vulnerable population group(s) targeted	cat	Vulnerable population group(s) targeted through this action
		Avoided costs	num	Approximate (expected) avoided damage costs or the accrued benefits following the implementation of the adaptation action, in Euro.
		Life expectancy	num	Number of years over which the action helps to avoid costs.
		Return of investments	num	Ratio of money gained or lost on the investment relative to the amount invested, as a percentage. Expected discounted financial savings minus discounted investment/divided by discounted investment *100.
		Jobs created	num	Number of direct new jobs created, in full-time equivalent.

CAP monitoring	RVAs	High-level hazards	cat	Updtae on the status of all the hazards defined
	Adaption actions	Uopdated status of every action attribute		

3.2 Methods

3.2.1 Publication I

Data cleaning and quality control of EU-27 CoM database

For the purpose of the first publication of this Thesis, *"Covenant of Mayors 2020: Drivers and barriers for monitoring climate action plans"* we evaluated all the CoM2020 plans (SEAPS) submitted by signatories to the "My Covenant" platform, identifying those signatories having performed at least one mitigation monitoring. After a first cleaning of the submissions (incomplete or duplicated submissions, monitor exercises submitted before the starting date of the planning ...) we ended up with a population of 1643 LAs, representing 32,5% of the signatories (63% in terms of population) and 19.2% of the EU-27 population, as shown in table 2.

This population was then quality controlled in three steps: individual emissions, total emissions, and coherence between baseline and monitoring emissions. This process identified 55 monitoring exercises with erroneous data that could not be corrected. Therefore, the final number of LAs included in the study was 1580.

Statistical analysis of potential monitoring drivers

We performed statistical analyses to identify potential drivers and barriers to the submission of monitoring inventories by CoM signatories. For that, the LAs were divided into two groups: signatories with at least one MEI (1643) and signatories without any MEI (3429). Signatories flagged in the QC procedure for erroneous MEIs were kept for this comparison because they completed all the stages of the monitoring process, and they were only removed from the comparison of attributes related to emissions data.

Since the population distribution of CoM signatories is highly positively skewed (Cui et al. 2019) we applied non-parametric comparison techniques to compare the mitigation attributes submitted (see table 4) by the two groups.

Categorical attributes were analyzed with Fisher's exact test. The null hypothesis H_0 was that there is no difference between the distributions of the two groups. Therefore, if H_0 is rejected, a statistical difference in the evaluated attribute exists between both groups. Numerical attributes were compared with the Mann-Whitney U test. According to the null hypothesis $H_{0,}$ the observations of both groups are drawn from the same population, i.e., they have the same median. The alternate hypothesis H_1 stipulates that data from the two groups differ. Additionally, since the distribution of groups has the same shape, we can state that the medians of both groups are not equal. A significance level of 0.05 was used, rejecting the null hypotheses if *p-value* < 0.05.

To overcome the issue of categorizing the results into two rigid groups (significant and no-significant) (Amrhein, Greenland, and McShane 2019), we calculated two different effect size estimators(Tomczak and Tomczak 2014) the odds ratio (OR) for Fisher's exact test, and Cliff's delta (*d*) for the Mann-Whitney test.

Note that the results of the statistical tests do not necessarily imply that one variable has any causal effect on the other. It allows us to conclude that some link between the attributes and the likelihood to develop and submit a monitoring emission inventory exists.

3.2.2 Publication II

Data cleaning and quality control of the EU-27 CoM database

For the second publication of the Thesis (*Covenant of Mayors 2020 achievements: a two-speed climate action process),* we followed the same data cleaning and quality control processes described above. Since now the objective was to analyze the actual GHG emission reductions, the coherence between baseline and monitoring inventories was of even greater importance, therefore, inventories flagged as suspicious in this step were manually inspected.

Note that after the harmonization and quality control, the main limitations remaining in the CoM emissions dataset are, the low number of monitoring exercises as well as the heterogeneity of both baseline and monitoring years. The issues are deeply explained in a dedicated section in the published article.

Analysis of CoM 2020 GHG emissions reduction

The total GHG emissions reduction achieved during the CoM 2020 initiative by each LA was analyzed on the total GHG emissions reduction in tCO_2e/cap (Eq. 1) and in percent (Eq. 2). The progress of each LA towards its target is as well evaluated as shown in Equation 3.

Equation 1 Total emissions reduction in tCo_2 reduction

$$Total\ emissions\ reduction\ [tCO_2e/cap] = total\ baseline\ emissions - total\ monitoring\ emissions$$

Equation 2 Total emissions reduction in percent

$$Total\ emissions\ reduction\ [\%] = 100 \cdot \frac{total\ emission\ reduction\ [tCO_2e/cap]}{total\ baseline\ emissions\ [tCO_2e/cap]}$$

Equation 3 Progress of each LA towards its target

$$SEAP\ progress\ [\%] = 100 \cdot \frac{total\ emissions\ reduction\ [\%]}{reduction\ target\ [\%]}$$

The GHG emissions reduction by sector was calculated in tCO2e/cap and in percent, where the % shows the sector reduction reagrding the total baseline emissions, as shown in Eq. 4. Finally, the GHG emissions reduction share of each sector was also calculated following Eq.5

Equation 4 GHG emissions reduction by sector

$$sector\ emissions\ reduction\ [\%] = 100 \cdot \frac{sector\ emissions\ reduction\ [tCO_2e]}{total\ baseline\ emissions\ [tCO_2e]}$$

Equation 5 Reduction share by sector

$$Sector\ reduction\ share\ [\%] = 100\,\frac{sector\ emissions\ reduction\ [tCO_2e]}{total\ emissions\ reduction\ [tCO_2e]}$$

Based on the different patterns observed in the previous paper between small and large LAS, the analysis of total and sector emissions reduction was made separately for small and large LAs, using a threshold of 50,000 inhabitants. LAs above 50,000 inhabitants are considered by the OECD as urban areas (OECD 2014), whereas LAs below 50,000 inhabitants correspond to small towns and rural areas. This also allows us to eliminate the potential confounding effect of population size in other predictors

Statistical analysis of potential drivers of GHG emissions reduction

Non-parametric techniques were applied between the two groups of LAs (small and large) in order to identify drivers among the mitigation attributes included in the LAs submission (see table 4) explaining the different levels of GHG reduction observed.

The association between categorical variables and the total emissions reduction was analyzed with the Mann-Whitney test. All categorical attributes were binary (True or False). The null hypothesis H_0 states that observations of both groups are drawn from the same population. H_1 stipulates that data from the two groups differ. A significance level of 0.05 was used, rejecting the null hypotheses if the p-value < 0.05. The effect size was estimated with Cliff's delta, including its 95% confidence interval

The association between numerical attributes and the total emissions reduction was analyzed with scatter density plots and the Spearman's rank correlation coefficient. The statistical significance of Spearman's correlation was evaluated with the p-value derived with an asymptotic t approximation.

Regression analysis

The impact of each predictor variable on the local GHG emissions reduction was evaluated with a linear regression model. Compared to the statistical analysis, the model considers the combined effects of all features and allows ranking them according to their importance.

The correlation between predictors (attributes in table 4) was evaluated to detect multi-collinearity effects that may inflate the model coefficients. The correlation matrix was derived using Spearman's rank correlation, for numeric-

numeric relationships, point-biserial correlation, for numeric-binary relationships, and Phi coefficient, for binary-binary relationships.

All groups of predictors with correlations above 0.35 were analyzed, discussing the most likely cause of the correlation. After this process, the 11 selected independent features were used to train a ridge regression model, a linear model with a regularization term allows to deal with the remaining multi-collinearity effects. The lambda parameter of the ridge regression model was tuned using cross-validation (10 folds). All features were standardized (mean = 0, standard deviation = 1) to obtain model coefficients of comparable magnitude. The impact of each feature on the total GHG reduction was evaluated based on the scaled model coefficients and their 95% confidence intervals.

The presence of non-linear effects was evaluated using the non-parametric Generalized Additive Model (GAM), which can cope with non-linear effects through different types of non-linear functions. GAM was able to reduce the prediction error (MAE) only by 1%, so non-linear effects were neglected.

3.2.3 Publication III

Subset description: CoM2030 submitted and accepted plans

With the aim of identifying potential drivers leading the LAs in committing to ambitious GHG reduction targets (*Towards the EU Green Deal: local key factor to achieve ambitious 2030 climate targets*), we used the CoM2030 dataset described in table 3. As of July 2020, a total number of 2420 LAs representing 23% of the EU-27 population, of which 647 had already submitted their SECAP and 344 had been approved by the JRC. Our study focuses only on the approved local action plans since the evaluation of the plans guarantees the coherence between the reduction target proposed and the actions planned to achieve those reductions. Note that out of these 344, we encountered several plans presented by grouped municipalities. To avoid potential duplications, we selected for the study only the individual plans, which accounted for 248.

CoM2030 signatories pledge to reduce their emissions by at least 40% by 2030. The European Green Deal proposed raising this target to at least 50% and towards 55% by 2030. Therefore, we used the new EGD target to classify CoM cities according to their objectives in two groups: ambitious (22 out of 248) and regular cities (226 out of 248). We considered as ambitious those CoM signatories with targets greater than the new EGD target ($target_{2030} \geq 50\%$), while regular cities are those CoM signatories committing regular targets ($40\% \leq target_{2030} < 50\%$).

Statistical analysis of potential drivers of GHG ambition

As in previous works, a statistical analysis was conducted to evaluate the detailed differences between regular and ambitious municipalities regarding mitigation attributes included in table 4. The analysis was performed using nonparametric tests due to the small sample size and the non-normality of most attributes.

The tests applied for categorical and numerical attributes were the same as explained in publication 1, Fisher exact test and the Mann-Whitney U test respectively. Similarly, a significance level of 0.05 was used, rejecting the null hypothesis if *p-value* < 0.05 and to overcome the well-known dependence of *p-value* on sample size, effect sizes were also calculated: the odds ratio for Fisher's exact test, and Cliff's delta (*d*) for Mann-Whitney test

3.2.4 Publication IV

Subset description: Adaptation plans

From the launch of the Covenant of Mayors for Energy and Climate (CoM2030) and the publication of the updated guidance and reporting materials at the beginning of 2016, LAs in Europe were able to commit to adaptation goals and develop a harmonized adaptation to climate change plan and submit into the official reporting platform for its approval by JRC. During the first years of this phase of the initiative, the mitigation and adaptation reporting timeframes were decoupled, and each part of the plan (SECAP) was analyzed separately. LAs had two years to complete their adaptation plans.

Therefore, at the end of 2018, we conducted the first analysis on the first set of Adaptation plans submitted and evaluated so far (*A comparative analysis to depict underlying attributes that might determine successful implementation of local adaptation plans*). A total of 51 European local authorities completed the submission of their Risk and Vulnerabilities Assessment (RVAs) as well as the set of actions to adapt to the expected risks, the so-called "adaptation plan" and were ready for the JRC analysis.

The JRC evaluation is based on a set of evaluation criteria proposed by Barbosa et al. (2018) that contributes to guaranteeing the credibility and reliability of the whole CoM initiative (see table 6). The purpose of the evaluation is to ensure that the city is fully compliant with the mandatory criteria of the initiative and therefore is accepted (compliant) or non-accepted (non-compliant). Secondly, recommendations for potential improvements are formulated for the city.

Table 6 JRC Adaptation evaluation criteria

Criteria	Key elements
Compliance with the reporting timeframe	RVAs and adaptation action plan
Completeness	Adaptation goals
Internal coherence	Alignment of goals, risks and actions
Quantification	RVAs and adaptation actions
Progress	Adaptation actions

The JRC adaptation team evaluated the 51 adaptation plans based on the previous evaluation criteria. As a result, the local action plans were classified in terms of performance within the initiative. Out of the 51 cities, 21 were classified as compliant with the CoM evaluation criteria, while 30 cities were classified as non-compliant.

Statistical analysis of adaptation attributes

A statistical comparative analysis of adaptation attributes (table 5) between compliant and non-compliant cities was conducted. We hypothesized that if an attribute shows a statistical difference between both groups, the attribute may be a potential driver in the acceptance of adaptation plans. The statistical analysis was performed using nonparametric tests due to the small sample size and the non-normality of most of the attributes.

Most of the attributes were categorical values with a binary response, resulting in 2x2 contingency tables when comparing the two groups of cities. These attributes were evaluated with Fisher's exact test, as described in previous publications.

The only two quantitative attributes, population size, and density, were evaluated with the two-sample Kolmogorov-Smirnov (KS) test. The KS is a nonparametric test that does not assume any distribution of the data. It evaluates whether two samples come from the same distribution by comparing their cumulative distribution functions (CDFs). The *p-value* is calculated based on the maximum distance between both CDFs. The null hypothesis H_0 is that both groups were drawn from the same distribution. Therefore, if H_0 is rejected, we can state that the distribution of the evaluated attribute is significantly different between the two groups. A significance level of 0.05 was used, rejecting the null hypothesis if the *p-value* < 0.05.

4 PUBLICATIONS

4.1 Publication I

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Covenant of Mayors 2020: Drivers and barriers for monitoring climate action plans

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ABSTRACT

How to ensure success for climate change mitigation policies? For the past decades, local climate action has been amongst the main global priorities. The Covenant of Mayors initiative is a major example of bottom-up climate initiative gathering municipalities of all sizes towards GHG reduction under a harmonised framework. Now, after the end of the first phase of the initiative in 2020, would be the time to assess the impact and effectiveness of the planed actions, based on the results of the monitoring exercise. However, the level and quality of monitoring reported by participating municipalities was not as expected and required an initial deep analysis. This study investigates the reasons behind this low number by comparing statistically the action plans of the 1643 CoM municipalities monitoring their emissions against the 3411 municipalities not doing it. The paper describes how, despite technical and financial barriers, key factors such as the direct involvement of local staff, stakeholders in participatory processes from an early stage, accurate budget allocation, or the development of the plan and deployment of actions as soon as possible, enabling municipalities to track and monitor their progress towards their climate target.

1. Introduction

The pressing challenge of climate change have been shaping the global political and policy context at different levels of governance. The European Union (EU) has been playing a leading role in the international context by setting ambitious and progressing targets in energy efficiency, renewables and carbon emissions reduction, from the 20% reduction by 2020 (2020 climate & energy package) to the 55% reduction by 2030 (2030 climate & energy framework), both compared to 1990 levels, and to the carbon neutrality by 2050 (the European Green Deal) (European Commission, 2019). In order to be successful the EU targets need to shared and reflected also at subnational levels, where, in particular, municipalities cab contribute to climate change mitigation by implementing sustainable energy and climate actions within their territories (Castán Broto, 2017). The will to contribute, to learn from examples and to exchange with peers internationally, has set the basis for the increase and diffusion of climate related initiatives (Schreurs, 2008).

The Covenant of Mayors for 2020 (CoM 2020) represented the first pan-European framework aiming at facilitating climate action of municipalities of all sizes (Gesing, 2017; Jänicke and Quitzow, 2017; Reckien et al., 2018). Launched in 2008, it pioneered a voluntary (Khan and Sovacool, 2016), bottom-up (Domorenok, 2019; Rosenzweig et al., 2010; Schreurs, 2008) multi-level governance model seeking to improve citizen's lives by reducing their total GHG emissions through a harmonised methodology and reporting system. By 2020 over 35% of the European (EU-27) population was covered by the initiative. Municipalities joining the initiative were asked to develop Sustainable Energy Action Plan (SEAPs) (Nuss-Girona et al., 2016) including an assessment of the baseline condition and concrete measures addressing activity sectors in their area of influence in order to decrease by at least 20% their GHG emissions by 2020 from their baseline year (see Section 2) (Bertoldi et al., 2010).

The European Commission's Joint Research Centre (JRC) has the mandate of evaluating the SEAPs developed by the cities, tracking local action progress towards their targets, and assessing their final achievements. The monitoring system foresees a complete monitoring exercise by the municipalities every four years (Bertoldi. P (ed), 2018a, 2018b) that includes an update of the emission inventory, the so-called monitoring emission inventory (MEI). CoM does not foresee a final monitoring report at the end of the initiative (31st December 2020 for CoM 2020).

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In addition to the commitment and planning, monitoring represents a crucial moment in the CoM methodology, to assure transparency and accountability, as no assessment is possible without the implementation of a monitoring system (Bertoldi et al., 2018; Hsu et al., 2016). Through monitoring, signatories can track the implementation of the SEAP policies and measures and emissions reduction towards the target and identify any potential shortcoming that may hinder the possibility to keep the pace with the forecasted target. The monitoring phase of the CoM has recently become of interest in literature as it allows assess real achievements in comparison to planned commitments. Some studies analysed the achieved carbon reduction as reported in the monitoring reports (Lucchitta et al., 2021), others delaborated methodologies and tools to understand the level of implementation of the CoM initiative and foster the MEI development (Cinocca et al., 2018; Di Battista et al., 2021; Messori et al., 2020). Many studies have been focusing on the drivers influencing the emissions target setting and policies' selection and implementation both in the planning (Croci et al., 2017; Nuss-Girona et al., 2016; Rivas et al., 2021a; Salvia et al., 2021) and in the monitoring phase (Hsu et al., 2020; Palermo et al., 2020).

However, the monitoring system in place in the CoM presents two important limitations that are sometimes overlooked in some of the previous studies. First, there is a shortage of monitoring reports. Only the 32.5% of accepted signatories (1643 out of 5054 municipalities) have updated their emission inventory. Second, while the CoM flexible framework is one of its key assets to facilitate municipalities in joining climate action (Bertoldi. P (ed), 2018a; Covenant of Mayors Office - Europe, 2020; Neves et al., 2016; Rivas et al., 2015), it introduces a large heterogeneity in the data reported. Among other things, municipalities have different baseline years (base year closer to 1990 and no later than 2005), start their actions at different years, and since no final monitoring is foreseen, the last update on their progress is that of their last monitoring report. All these issues should be accounted when analysing the progress of CoM signatories. This heterogeneity also leads to the use of harmonization techniques to analyse the emission data, such as the linear projection of emission reductions used by Hsu et al. (2020). However, these techniques should be used with caution because both local emissions and local action plans rarely follow a linear timeline.

The ultimate goal of this research is to assess the progress of European CoM 2020 cities towards their specific GHG reduction targets. However, due to the low number of municipalities that have monitored their emissions at least once, the present study focuses on the reasons behind this low number, besides the obvious one of a lack of final monitoring report. Understanding this is a priority because no assessment is possible without monitoring. Moreover, understanding the characteristics of municipalities conducting monitoring, and of those not doing it, is the first step before assessing the monitoring emission inventories received. To do so, this study analyses the drivers and barriers in submitting monitoring reports by comparing statistically the characteristics and action plans of "compliant" municipalities (those with at least one complete and coherent full progress report) against those non-compliant. This is the first study of this kind after the end of the CoM 2020 initiative, and to the authorś knowledge, this is also the first statistical analysis on monitoring practices with a large dataset that includes more than 5000 European municipalities out of which more than 1600 were compliant with the CoM monitoring system foreseen.

As the initiative has evolved towards 2030 and increased its geographic outreach with the so-called Global Covenant of Mayors (GCoM), this study intends to improve the structure of future monitoring systems, and more importantly to support municipalities worldwide in developing and implementing effective tracking systems. A better monitoring system would allow them to better quantify their achievements, to track the progresses towards the NDCs, to identify signatories in need of support, to bridge the identified gaps and potentially to foster a better general performance.

2. The Covenant of Mayors, the CTC approach, and the monitoring phase

The Covenant of Mayors (CoM 2020) was launched in 2008 by the European Commission in collaboration with city networks to help municipalities achieving sustainable energy goals. European municipalities voluntarily committed to reduce by at least 20% of their emissions by 2020, i.e., the same target of the EU (but with different baseline) until 2016. To reach this target, they developed and implemented Sustainable Energy Action Plans (SEAPs) (Bertoldi et al., 2010). In 2015, the Covenant of Mayors evolved into the Covenant of Mayors 2030 (CoM 2030), increasing up to 40% the minimum mitigation target by 2030, and including two new pillars: adaptation to climate change and secure, sustainable and affordable access to energy. One year later, the initiative was merged with the Compact of Mayors into the Global Covenant of Mayors for Energy & Climate (GCoM), The two initiatives, CoM 2020 and CoM 2030, coexisted for 5 years and CoM 2020 signatories were able to submit their SEAPs until 2019.

Municipalities generally developed their SEAPs individually or with the support of a Covenant Territorial Coordinator (CTC), supra-municipal entities like provinces or regions that offer technical or financial support (Melica et al., 2018).

The European Commission's Joint Research Centre (JRC) evaluates the local action plans and provides every signatory with complete feedback, highlighting the main strengths and weaknesses and giving recommendations for improvement. In the case of plans submitted via a CTC, a special evaluation group approach is applied: instead of evaluating every single plan, the JRC evaluates the methodology followed by the CTC in developing their plans, as well as 3 representative cases in terms of population covered. In case of compliance of the methodology and of the representative plans, every plan developed under the CTC and that follows the evaluated methodology will be automatically accepted. While JRC is in charge of evaluation the plans, the evaluation of monitoring is not foreseen except for the purpose of the current study. Once the plan has been accepted, signatories have to submit two types of monitoring, one on the implementation of the actions (every two years after the SEAP submission) and one on the emissions (every four years after the SEAP submission). In this study, monitoring always refer to the latter, since only the latest emission inventory allows to quantify the real achievements of CoM signatories. The submission of a final report was not foreseen by the initiative, so the last monitoring on the emissions is the last snapshot available on the progress of the action plan. The year of this last monitoring on emissions vary between signatories, and theoretically should be 4 or 8 years after their SEAP submission.

3. Materials and methods

3.1. Dataset: EU-27 accepted signatories

All the emission inventories uploaded by the signatories to MyCovenant (Covenant of Mayors Office, 2020) were retrieved to identify those signatories that had performed at least one monitoring on emissions. The inventories are internally labelled as 'Baseline emission inventories' (BEI) and 'Monitoring emission inventories' (MEI), with each signatory only allowed to define one BEI entry. Emission inventories were pre-processed as follows. First, incomplete MEIs and duplicated MEIs (same year) were removed, resulting in 1805 signatories with at least one MEI. Secondly, MEIs that had not actually monitored the progress of the action plan were also removed. Several signatories submitted inventories that had been conducted prior to the start of the plan (between the BEI year and the SEAP start year). These inventories were internally labelled as MEI but they were removed from the present study. This resulted in 1643 signatories with at least one MEI, which represents 32.5% of the accepted signatories (63% in terms of population) and 19.2% of the EU-27 population. Note that the CoM initiative allows signatories to submit plans that have already started, explaining the presence of some MEIs submitted before the SEAP submission.

3.1.1. Quality control

Data inconsistencies are more likely in MEIs than in BEIs, because BEIs undergo an external validation process that analyses their coherence with the reduction target and the actions proposed. However, the quality control procedure was applied to both BEIs and MEIs as to keep a consistent dataset. The quality control procedure consisted of three steps:

1. **Individual emissions.** CoM signatories submit the individual emissions per energy carrier and activity sector, which are classified into energy and non-energy sectors. In energy sectors (residential, transport, agriculture), signatories report electricity consumptions along with an emission factor to calculate the final emissions. In non-energy sectors (wastewater and waste management) the emissions are directly reported. For more information about the carriers, sectors and subsectors, we refer to the CoM reporting guidelines (Covenant of Mayors Office - Europe, 2020).
   The main limitation of MyCovenant emissions data is that, if the emission factor is missing, the emissions of that carrier/subsector are neglected, underestimating the total emissions of the municipality. To solve this, missing emission factors in the electricity carrier were filled with the National and European Emission Factors for Electricity consumption (NEEFE) values (Koffi et al., 2017) for the corresponding country and year. Missing emission factors in non-electricity carriers were filled with the median of the factors for the other inventories of the municipality if available, otherwise with the CoM default factors (Koffi et al., 2017). Additionally, if the difference between the electricity emission factor and the NEEFE value was larger than 1, the electricity factor was replaced by the NEEFE one.
2. **Total emissions.** CoM signatories can use a flexible methodology to report their inventories (Bertoldi. P (ed), 2018a). They can either use (i) LCA or IPPCC methodology, (ii) CO_2 or CO_2eq units, or (iii) the base year closer to 1990 and no later than 2005. Inventories were harmonised as follows: LCA emissions were transformed into IPCC ones by applying a factor of 0.885, which is the average ratio between LCA and IPCC factors (Cerutti et al., 2013). CO_2 was transformed into CO_2eq by applying a factor of 1/0.85 because CO_2 is responsible for 85% of the global warming potential at European scale (Cerutti et al., 2013). Harmonised inventories were analysed in three different groups to mitigate the variations of the baseline year: [1990, 2000), [2000, 2010), [2010, 2020). Harmonised inventories were quality controlled by inspecting inventories outside the following range: [0.5, 40 tCO_2eq].
3. **Coherence.** The coherence between baseline and monitoring emissions was evaluated based on the following parameters:

$$GHG\ reduction\ [tCO_2e/cap] = GHG\ emissions_{BEI} - GHG\ emissions_{MEI} \quad (1)$$

$$GHG\ reduction\ [\%] = 100\frac{GHG\ emissions_{BEI} - GHG\ emissions_{MEI}}{GHG\ emissions_{BEI}} \quad (2)$$

$$SEAP\ progress\ [\%] = 100\frac{GHG\ reduction\ [\%]}{2020\ GHG\ reduction\ target\ [\%]} \quad (3)$$

As with the total emissions, a set of statistically possible limits was calculated for each variable based on their distributions, inspecting values outside those ranges. The ranges established were [−5, 10] for GHG reduction in tCO_2e/cap, and [−100, 100] for GHG reduction in %.

The quality control process identified 55 signatories with erroneous data that could not be corrected. Therefore, the final number of signatories with quality control monitoring emission inventories was 1580 (97% of the signatories with at least 1 MEI).

3.2. Statistical analysis

3.2.1. Potential drivers of monitoring local action plans

A statistical analysis was performed in order to identify potential drivers and barriers for the submission of monitoring inventories by CoM signatories. For that, the 5054 accepted SEAPs were divided into two groups: signatories with at least one MEI (1625) and signatories without any MEI (3429). Signatories flagged in the QC procedure for erroneous MEIs were kept for this comparison because they completed all the stages of the monitoring process, and they were only removed from the comparison of attributes related on emissions data.

The attributes analysed were classified into four main groups (Table 1). Most of the attributes were extracted from several parts of the SEAP template. The data were introduced by the signatories through the online platform MyCovenant (Covenant of Mayors Office, 2020). For more details on the template structure and definitions, we refer to the CoM reporting guidelines (Covenant of Mayors Office - Europe, 2020) and to the GCoM common reporting framework (Global Covenant of Mayors for Climate & Energy, 2018). Note that in case of attributes such as staff allocation, stakeholders' involvement, administrative structure and financial resources, signatories can select more than one level per group. Therefore, these attributes cannot be treated as a unique categorical variable, instead, they have to be analysed as individual binary attributes.

Finally, the study includes a brief description of the monitoring progress at country level (percentage of municipalities with monitoring, SEAP submission year, and population size). Nationally aggregated values are used to evaluate if a geographical or political component exists behind some of the patterns observed in the comparison at municipality level. However, note that the study is focused on municipality level, so an in-depth analysis at country level is outside the scope of the study.

3.2.2. Statistical metrics

The statistical comparison was made using non-parametric techniques due to non-normality of the attributes. This is because the population distribution of CoM signatories is highly positively skewed, with around 90% of signatories having less than 50000 inhabitants. This distribution affects all the attributes that depend on population. Additionally, even attributes normalised by population such is the case or GHG emissions per capita have non-normal distribution. In this line, several studies in literature confirm that anthropogenic GHG emissions follow lognormal distribution (Cui et al., 2019; Ott, 1990).

Categorical attributes were analysed with the Fisher's exact test. All categorical values have a binary response which results in 2x2 contingency tables when comparing the two groups. The null hypothesis H_0 is that there is no difference between the distributions of the two groups. Therefore, if H_0 is rejected, a statistical difference in the evaluated attribute exists between both groups. Numerical attributes were compared with the Mann-Whitney *U* test, a non-parametric ranked test used to evaluate the differences between two non-normal groups. According to the null hypothesis H_0, the observations of both groups are drawn from the same population, i.e., they have the same median. The alternate hypothesis H_1 stipulates that data from the two groups differ. Additionally, since the distribution of groups has the same shape, we can state that the medians of both groups are not equal.

A significance level of 0.05 was used, rejecting the null hypotheses if $p\text{-value} < 0.05$. However, categorising the results into two rigid groups, significant and non-significant, should be avoided (Amrhein et al., 2019). This is particularly evident in the present study. Due to the relatively large sample size, even small differences are likely to be significant (Altman and Krzywinski, 2017). To overcome this issue, we calculated two different effect size estimators (Tomczak and Tomczak, 2014): the odds ratio (OR) for Fisher's exact test, and Cliff's delta (*d*) for Mann-Whitney test. In both cases, 95% confidence intervals (CIs) were included. Both metrics will be the main element used for the discussion

Table 1
Attributes analysed as potential drivers or barriers for the submission of monitoring emission inventories. Data types: cat = categorical, num = numerical, spa = spatial.

Attributes			Data type	Description
City attributes	Geographical location		spa	–
	Population		num	–
	Population density		num	–
SEAP general	SEAP submission year		num	Year of submission of the action plan
	SEAP start year		num	Year of implementation of first action
	Approved via CTC grouped evaluation		cat	see Section 2.
	Signatories committed to both 2020 & 2030 initiatives		cat	Also known as 'overlappers'.
SEAP strategy	2020 GHG reduction target		cat	–
	Staff allocated	Local authority	cat	Type of staff allocated in the preparation of the SEAP
		CoM coordinator	cat	
		CoM supporter	cat	
		External consultant	cat	
		Other	cat	
	Stakeholders invovlement	Local authority's staff	cat	Type of stakeholders engaged in the development of the SEAP. Multiple selection is available. Note that the level of engagement is a qualitative description selected by the municipality from the three possibilities given on the reporting platforms: high, medium and low, as part of their own progress assessment.
		External stakeholder at local level	cat	
		Stakeholders at other levels of governance	cat	
	Annual budget		num	Overall budget for the implementation of the actions described in the SEAP
	Financial resources	Local authority's own resources	cat	Type of financing resources used to meet the budget. Multiple selection is available.
		External: Public	cat	
		External: Private	cat	
		Other	cat	
SEAP assessment	BEI	Total emissions	num	–
		Baseline Year	num	Chosen by each municipaliiy as the year closer to 1990 and no later than 2005 when they can collect emission data

of the results, and they are interpreted as follows. Given a particular attribute, OR represents the odds that the outcome will occur, in this case the submission of monitoring inventory. OR varies within [0, inf], with values between [0, 1] and [1, inf] corresponding to inverse and direct relationship, respectively. If 95% CI includes 1, the two groups analysed are statistically the same (McHugh, 2009), otherwise, the larger the OR the stronger the effect observed. Cliff's delta varies from -1 to 1, with negative and positive values representing inverse and direct relationships, respectively. Its magnitude is interpreted as follows: small effect ($0.11 < |d| < 0.28$), medium effect ($0.28 < |d| < 0.43$), large effect ($|d| > 0.43$).

Note that the results of the statistical tests do not allow to conclude anything more concrete than some link between the attributes and the likelihood to develop and submit a monitoring emission inventory exists. It does not necessarily imply that one variable has any causal effect on the other.

4. Results and discussion

4.1. Monitoring emission inventories of CoM 2020 signatories

By the end of CoM 2020 (31st December 2020), of the 6620 municipalities representing 160 million inhabitants (36% of EU-27 population) that had adhered to the initiative (Table 2), 5636 representing 135.7 million inhabitants (30.5% of EU-27 population) submitted their SEAPs and 5054 passed the JRC's evaluation system, ensuring their coherence and robustness. Thus, this group of 5054 plans is set as the base for the current study.

The 1643 accepted signatories submitted at least a full monitoring report, which includes a Monitoring Emission Inventory (MEI) as an update of the Baseline Emission Inventory (BEI) included in the initial plan. This represents 32.5% of the accepted signatories (63% in terms of population) and 19.2% of EU-27 population. The quality control of the MEIs submitted identified 55 signatories with erroneous data that could not be corrected, reducing the final number of municipalities with a valid MEI to 1599.

CoM 2020-approved plans were submitted primarily from 2011 to 2015 at a constant rate of around 900 SEAPs/year (Fig. 1a). In 2015 the steady decrease in SEAP submissions coincided exactly with the launch of the second phase of the initiative, CoM 2030. Municipalities monitoring their emissions submitted their SEAPs mostly during the first years of the initiative (2011–12). Most of them submitted just one (79,9%) or two MEIs (14.9%), which is compliant with the frequency established by the CoM reporting framework (Fig. 1b). A 5.2% of the

Table 2
Summary of CoM 2020 signatories within EU-27 member states. Population coverage refers to EU-27 member states. The differences between "total" municipalities and "SEAPs" received are due to groups of municipalities developing joint SEAPs.

Status		Municipalities		Population	
		Total	SEAPs	Total [million inhabitants]	Coverage [%]
Committed		6620	5964	160.0	36.0
SEAP submitted		6437	5812	155.8	35.0
SEAP accepted		5636	5054	135.7	30.5
Monitoring emission inventories (MEIs)	Total	1696	1643	85.5	19.2
	Quality controlled	1646	1599	83.5	18.8

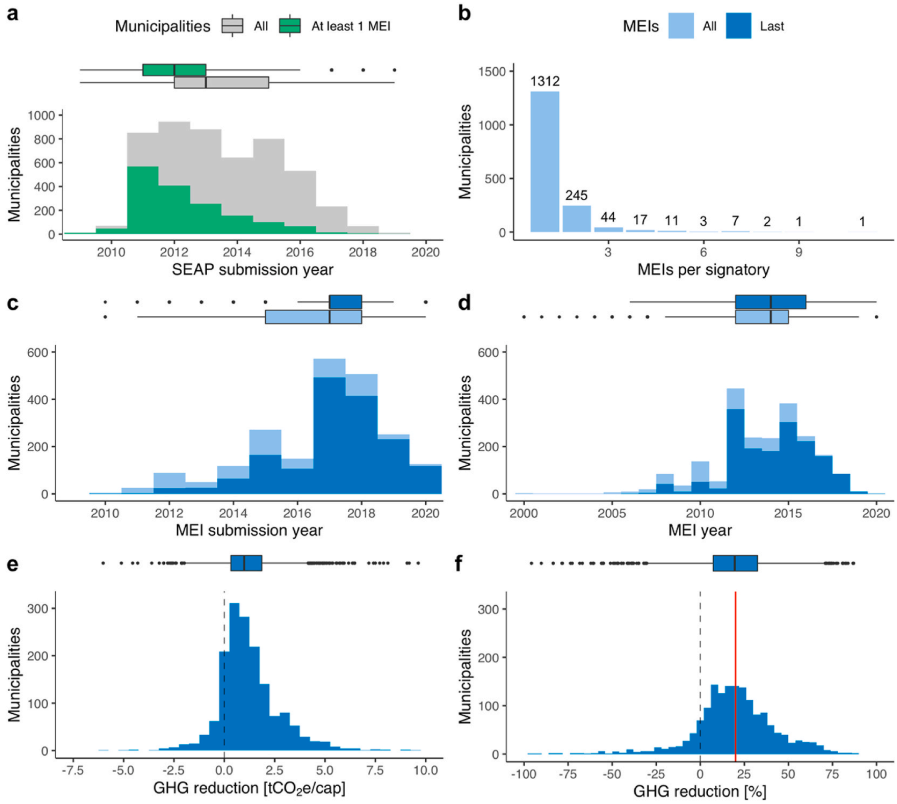

Fig. 1. Summary of the monitoring inventories submitted by CoM 2020 signatories. **(a)** submission year of the Sustainable Energy Action Plan (SEAP) of CoM 2020 municipalities with and without monitoring, **(b)** number of Monitoring Emission Inventories (MEIs) submitted per signatory, **(c)** MEI submission year, **(d)** MEI year. Results of the last monitoring inventory available: **(e)** GHG reduction per capita **(f)** GHG reduction with respect to the baseline emissions. The red line shows the CoM 2020 minimum GHG reduction target of 20%. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

signatories voluntarily monitored their emissions with a higher temporal frequency than the initiative requires. On average, the first MEI was submitted 4 years after the SEAP submission, which is exactly the timeline established by the initiative, but the data submitted were collected 3 years prior to the submission date (Fig. 1c and d). This lag is explained by the delay in publishing and gathering yearly energy data. As with SEAP submission, MEI submission steadily declined after 2017, with only 113 MEIs received in the last year of the initiative.

The year of the (last) monitoring inventory varies significantly, with 2012 and 2015 being the most frequent ones. On average, the last emissions were monitored in 2014, 6 years before the end of the initiative. Thus, the CoM monitoring exercises should be understood as the last GHG emissions snapshot available for each municipality, not as the result of the CoM 2020 initiative. This last snapshot shows that, on average, CoM 2020 signatories reduced their emissions by 0.986 tCO_2e/cap (127.7 Mt CO_2e), corresponding to 19.5% reduction on their baseline emissions (Fig. 1e and f). Most signatories are approaching their targets (average SEAP progress = 81.92%) and 40% (corresponding to 35.2% in terms of population) have already accomplished their goals (SEAP progress >100%). A 87% of the municipalities monitoring their emissions (92% in terms of population) reduced their emissions level (median = 1.18 tCO_2e/cap, 22.2%), while 13%, mostly small-sized municipalities, increased it from their baseline year (median = −0.43 tCO_2e/cap).

4.2. Drivers and barriers of action plan monitoring

A statistical analysis was performed in order to identify potential drivers and barriers affecting the submission of monitoring inventories by CoM signatories. Thus, we divided the 5054 accepted SEAPs into two groups: signatories with at least one MEI (1643) and signatories without any MEI (3411). Signatories flagged in the QC procedure as erroneous MEIs were kept for this comparison because they completed all the stages of the monitoring process, but they were removed from the comparison of attributes related to emission data.

The analysis conducted shows that the larger the municipality the more likely it is to monitor its emissions (Fig. 2a–b, d = 0.27). In this sense, 17 out of the 18 CoM cities with more than 1 million inhabitants (all but Madrid) have submitted at least one MEI (Fig. 2a), explaining why the percentage of signatories conducting monitoring is greater in terms of population (63%) than in terms of individual municipalities (32.5%). This also means that signatories without monitoring are primarily small towns. The percentage of small towns (below 10 000 inhabitants) is greater among municipalities that don't monitor their emissions (72.6% vs 54%). The monitoring submission patterns are also similar when analysed terms of population density (Fig. 2c).

Municipalities that monitor their emissions adhered to CoM 2020 earlier than the rest, submitting on average their plans two years before (2012 vs 2014, d = −0.5) (Fig. 3a). The highest percentage of signatories with MEI (67%) refer to those submitting their SEAPs at the beginning of

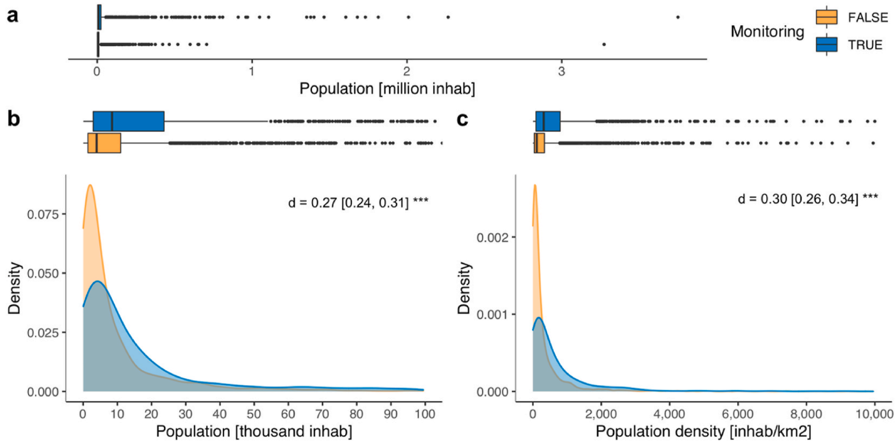

Fig. 2. Summary of the general attributes of the municipality: **(a)** population, **(b)** population of municipalities below 100000 inhabitants and **(c)** population density. *d* represents Cliff's delta with its 95% confidence interval. Asterisks denote $p < 0.05$ (*), $p < 0.01$ (**), $p < 0.001$ (***).

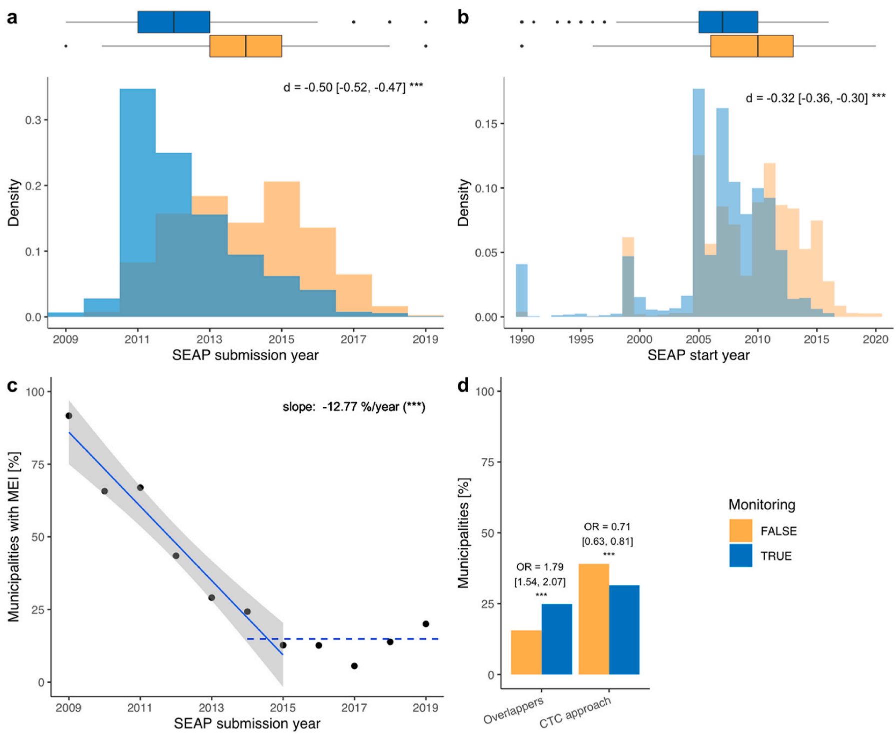

Fig. 3. Summary of the general attributes of the Sustainable Energy Action Plan (SEAP). **(a)** SEAP submission year and **(b)** SEAP start year of municipalities with and without monitoring. **(c)** Variation of the percentage of municipalities monitoring their emissions with the SEAP submission year. Grey shaded regions represent the 95% CI. **(d)** Municipalities approved via the Covenant Territorial Coordinator (CTC) grouped evaluation approach and municipalities adhered to both CoM 2020–2030 initiatives (overlappers). *OR* and *d* represents the odds ratio and Cliff's delta, respectively, with their corresponding 95% confidence intervals. Asterisks denote $p < 0.05$ (*), $p < 0.01$ (**), $p < 0.001$ (***).

the initiative (2009–2012). A negative relationship was found between the MEI submission rate and the SEAP submission year. The number of MEIs received decreased the later the SEAP was submitted by −12.77%/year until 2015, and since then, it has been oscillating around 15% among late signatories (Fig. 3c). Note that the slight increase since 2017 is just an artefact due to the low number of SEAPs submitted during those years.

Municipalities that monitor their emissions also implemented their plans earlier (2007 vs 2010, d = −0.32) (Fig. 3b). The SEAP start year, i.e., the implementation year of the first action, appears as a good indicator of the municipal experience on climate action planning. The percentage of plans starting before 2010 is greater in cities monitoring their results (71% started before 2010) than in those that don't monitor (44% started before 2010). Local climate action plans starting before 2010 usually correspond to frontrunners municipalities with long experience in climate action whose plans were implemented before joining the CoM (Hanover, Barcelona, Sonderborg, Munich) (Rivas et al., 2015), contrary to municipalities with and without monitoring (3.7% and 25.2% respectively) whose plans started after 2012. This second group normally corresponds to municipalities taking their first steps into climate action planning.

Climate action experience also relates to the percentage of overlappers (Bertoldi. P (ed), 2018a) (municipalities that extended their efforts from CoM 2020 to CoM 2030), which was greater among signatories monitoring their emissions (23% vs. 15%). The percentage of overlappers is relatively low potentially because CoM 2030 initiative is still in its initial phase. However, preliminary results show that overlappers are 1.79 times more likely to monitor their emissions. Overlappers may not only have more climate experience, but they may also update their emission inventory while preparing the new action plan for CoM 2030. Else, the odds of monitoring emissions are 1.41 times lower for municipalities approved under the Covenant Territorial Coordinators (CTC) grouped approach (36% of approved signatories). Only 28% of these municipalities submitted a MEI, compared to 34% which did not use the CTC evaluation approach. CTCs are supra-municipal entities such as regions or provinces that provide technical or financial support to municipalities (usually small municipalities with little previous experience in climate planning) in developing their plans (Bertoldi. P (ed), 2018a). CTCs have been very useful in helping small towns develop their first climate plan (Melica et al., 2018), however the results suggest the need to increase support on the monitoring phase of the plans.

Municipalities that develop their plans in-house are more likely to monitor their emissions than those outsourcing them to external consultants (van Staden, 2017) (Fig. 4a). Indeed, the odds of monitoring a plan decrease by 1.39 when external consultants are involved. Signatories monitoring their emissions are also more likely to engage all types of stakeholders (Fig. 4b), and on average, the odds of submitting a MEI are 3.1–3.7 times higher with local or external stakeholders and the public participation (Boehnke et al., 2019; Melica et al., 2018; Rivas et al., 2021a). Most municipalities used local authority funds to develop and implement their plans, even those that did not monitor their emissions. However, the odds of monitoring emissions are 2.24 times higher when the local authority provides financial support to the development and implementation of the plan. For the few municipalities lacking local authority's funds, the probability of monitoring their emissions more than halves (from 32.8 to 11.1%). Additionally, municipalities that initially do not allocate their financing sources are 1.85 times less likely to submit a MEI (Fig. 4c). This could be related to lack of experience and/or difficulties in distributing unallocated funds. Remarkably, municipalities that monitor their emissions rely on lower budgets that those that do not conduct any monitoring (39.25 vs 60.25 EUR/year/cap) (Fig. 4d). This supports the idea that the budget allocation level is not the main driver for monitoring, and that an in house plan could lead to monitoring exercises in local administrations.

Municipalities that monitor emissions are slightly less ambitious

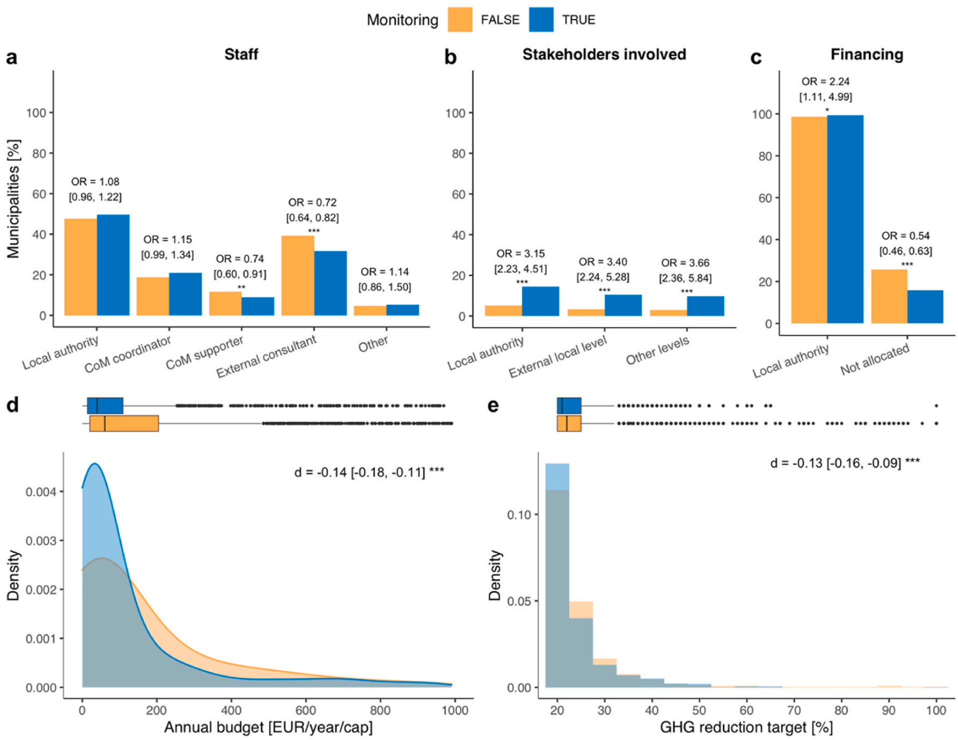

Fig. 4. Statistical analysis of the sustainable energy action plan (SEAP) strategy. **(a)** Staff allocated, **(b)** stakeholders engaged, **(c)** financing sources, and **(d)** annual budget for the development of the plan. **(e)** GHG reduction target for 2020. *OR* and *d* represents the odds ratio and Cliff's delta, respectively, with their corresponding 95% confidence intervals. Asterisks denote $p < 0.05$ (*), $p < 0.01$ (**), $p < 0.001$ (***).

(target = 21%) than their counterpart (target = 22%) (Hsu et al., 2020) (Fig. 4e). Municipalities with monitoring commit to the minimum target of 20% by 2020 in a higher percentage (41%) that those municipalities without monitoring, that commit to that minimum target on a 28%. By contrast, 46 out of the 47 most ambitious municipalities (target >65%) did not perform monitoring. Within the previous, 36 developed their plans with the support of a CTC who outsourced the development of the plans to external consultants supervised by the municipalities. This agrees with the analysis of the staff allocated for the development of the plan. External contracts work typically ends after the development of the plan and does not include the implementation and/or monitoring phase. This not only confirms that in-house plans controlled by local staff are more likely to be monitored but it also suggests that some of the targets proposed by external entities are less realistic, maybe because of their disengagement from the monitoring phase.

Municipalities that monitor emissions had greater per capita emissions in their baseline year (5.2 vs 4.35 tCO_2e/cap) (Fig. 5a) (Croci et al., 2017). This is partly due to their slightly older baseline years (Fig. 5b) (Rivas et al., 2021b), which is in line with the results from the analysis of the SEAP submission and SEAP start years. These municipalities have more climate experience, in fact they adhered to the CoM and implemented their plans at an earlier stage and therefore compiled their baseline inventory with older data. However, the analysis of baseline emissions in three different intervals of the baseline year reveals that, regardless the baseline year, municipalities that monitor their emissions emit more (Fig. 5c). This could also be related to their climate experience and ability of to compile more precise inventories, either because of the availability of more accurate data or because of the wider sector activities under their supervision. Another hypothesis could be linked to their earlier engagement in climate action to counteract their high emission levels. Due to the population differences between both groups, this is even more evident when looking at the absolute emissions. The total baseline emissions of municipalities monitoring their emissions (504 $MtCO_2e$) double those of municipalities without monitoring (223 Mt CO_2e), which might explain why they joined climate action before and why they are more experienced.

Overall, the statical comparison showed that strategic attributes like previous experience in climate action, early participation in the initiative, engagement of local staff and stakeholders, avoidance of external consultants, and accurate budget allocation led the signatories to completing the monitoring process. The shortage of monitoring reports over the years can be related to the attribute of voluntariness of the CoM, and the consequential low priorities of municipalities in monitoring climate action due to the workload required, often couple with the lack of technical expertise and funding for this task (Adami et al., 2019; Christoforidis et al., 2013; De Pascali and Bagaini, 2019; Messori et al., 2020). Additionally, the lack of a final monitoring exercise in the CoM initiative by the end of the first phase (31st December 2020), due to the extension to 2030 and to avoid too frequent report not only contributed to the low number of monitoring reports received but also increased the heterogeneity of the last monitoring emission inventories available. Despite all of this, results show that 40% of signatories has already reached their target 6 years before the end of the initiative and more than 80% of municipalities have reduced their emissions.

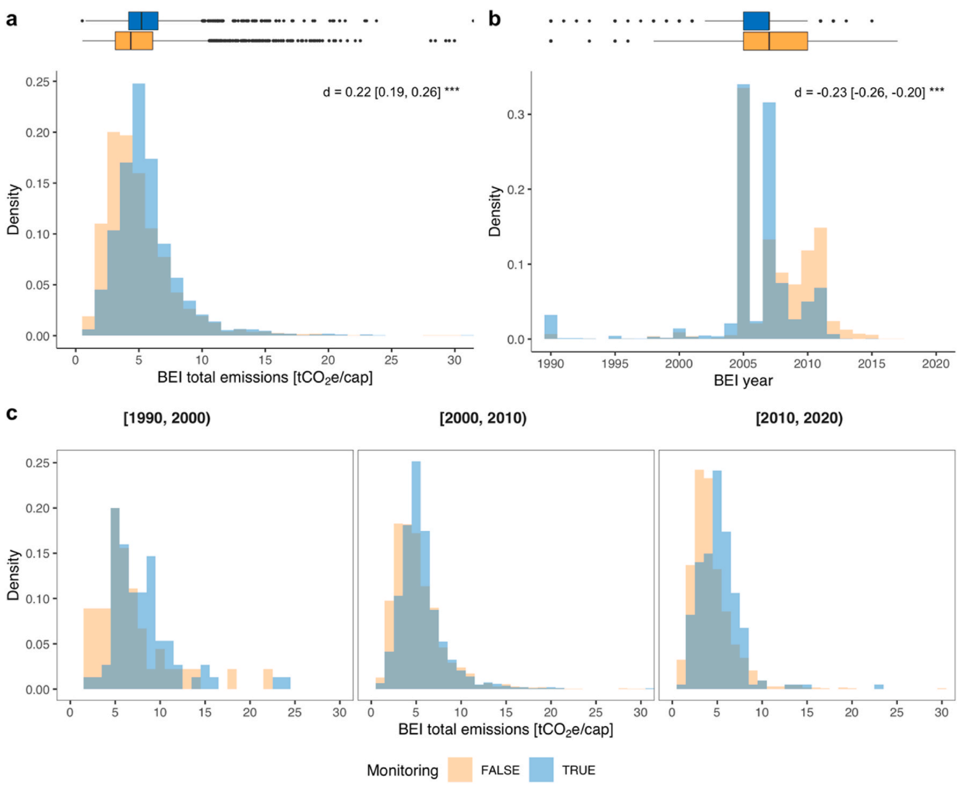

Fig. 5. Statistical analysis of the sustainable energy action plan (SEAP) emission inventories: **(a)** total GHG baseline emissions, **(b)** baseline year, and **(c)** total GHG baseline emissions per baseline year. *d* represents Cliff's delta with its 95% confidence interval. Asterisks denote $p < 0.05$ (*), $p < 0.01$ (**), $p < 0.001$ (***).

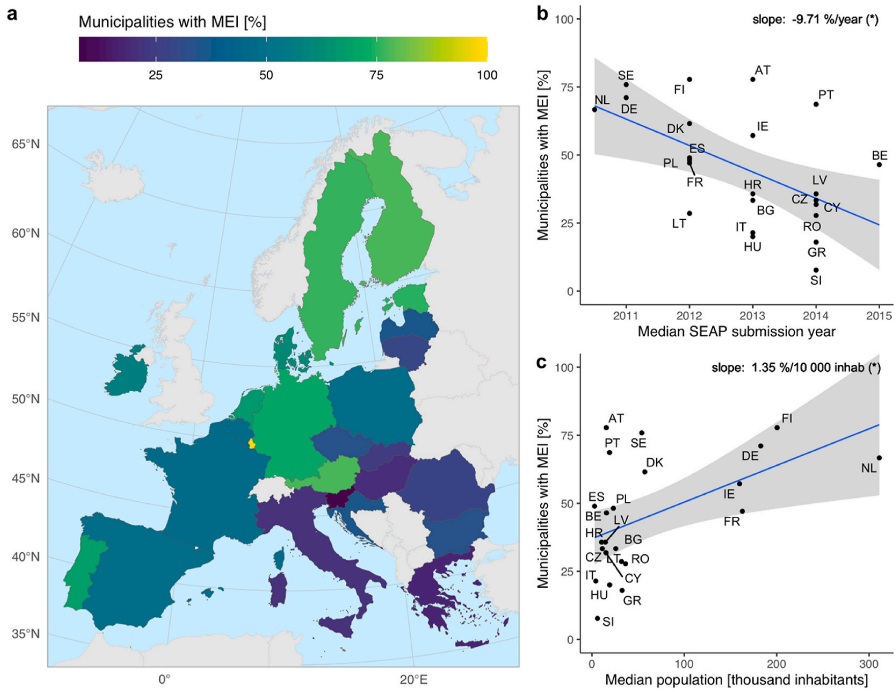

Fig. 6. **(a)** Percentage of municipalities submitting a Monitoring Emission Inventory (MEI) per country. Variation of the number of MEIs with **(b)** the median Sustainable Energy Action Plan (SEAP) submission year and **(c)** median population per country (countries with at least 5 signatories). Grey shaded regions represent the 95% confidence interval. Asterisks denote $p < 0.05$ (*), $p < 0.01$ (**), $p < 0.001$ (***). Countries are named following ISO 3166-1 alpha-2 codes.

4.3. National trends

Preliminary results on national monitoring trends (see Fig. 6), that will be included in an upcoming research focusing on CoM achievements per member state (MS), shows that municipalities in Northern Europe (Finland - FI, Sweden - SE, Estonia - EE) and Central Europe (Germany - DE, Denmark - DK, Austria - AT) submit more monitoring inventories, with 70–80% of their signatories having presented at least one MEI. On the contrary, municipalities of Southern and Eastern Europe perform less monitoring (<25% of signatories with MEI). The patterns at country level are linked to two of the attributes analysed for individual municipalities, SEAP submission year and population, which at the same time are internally correlated: larger cities typically implement and submit their plans before smaller ones because they have more climate experience and thus are more likely to monitor them.

The average values per country showed a MEI submission decreased of −9.71%/year with an increasing SEAP submission year, which is in line with the results obtained from the analysis of the individual municipalities (−12.77%/year). The exceptions are Belgium (BE), Portugal (PT) and Austria (AT), which all managed to obtain high MEI submissions despite being late signatories The reason behind these outcomes could be the significant supporting role by energy agencies (i.e., in Portugal) or an already embedded GHG emission monitoring system at super-municipal level in Belgium. In parallel, regional laws including the provisions of funds and incentives to municipalities only for the preparation of their local action plans, neglecting the monitoring phase could explain, albeit partially, the low number of MEI submitted by Italian signatories in comparison to the high number of MEIs. Concerning population, the percentage of MEI submissions increased by +1.35% per each 10 000 inhabitants (Reckien et al., 2015, 2018). All countries where the signatories were primarily large municipalities (average population >100 000 inhabitants) scored above 45% on MEI submissions, while the percentage of MEIs submitted in countries composed by small municipalities vary considerably. All countries with a monitoring percentage below 40% belong to this group. In some cases, such as Italy, this could be explained by the large presence of CTCs that outsource the plan development to external consultants, excluding the monitoring phase from the contracts. Nevertheless, countries such as AT or PT still managed to obtain a monitoring percentage above 60% despite their small-sized signatories.

5. Conclusions

The Covenant 2020 initiative guided more than 5200 municipalities of all sizes in their climate action, offering a harmonised methodology based on a partnership learning. The benefits of a common action on climate change are clear, and now is the moment of estimating the real impact of this bottom-up initiative. However, this is not a straightforward exercise due to (i) the lack of the requirement of a final monitoring report at year 2020, (ii) low number of intermediate monitoring reports submitted (32.5% of accepted signatories), and (iii) heterogeneity of both baseline and monitoring years. The criticism that voluntary bottom up initiative will not deliver on GHG mitigation, is counterbalanced by the CoM planning, monitoring and reporting framework. However this is valid only if a large majority of participants monitor and report regularly, which for the CoM 2020 was not the case. Moreover, the monitoring phase maximises the efficiency of the measures implemented and provides an understanding of the feasibility and real impact of such measures, which can also be readjusted according to needs.

As shown in previous studies (Reckien et al., 2018; Rivas et al., 2021b), a key element for climate action success is to ensure the inclusion of the monitoring process in the planning phase. Previous local experience in climate change and early participation to and submission of the SEAP in the CoM initiative is usually linked to larger municipalities (frontrunners). Frontrunners have access to older and more accurate baseline emissions inventories and can develop, implement and submit plans sooner, enabling a potentially easier respond to plan adjustment, which is usually carried out in-house. On the contrary, small municipalities showed less experience in their approach to climate action, resulting in late enrolment to the initiative, reliance on very recent data and the need for CTC or external consultants support, with consequent difficulties in preparing plan monitoring.

While municipalities cannot acquire climate experience overnight, the study reveals many other enabling factors for a successful local action plan monitoring: (i) direct and long-lasting involvement of local staff, (ii) avoidance of external consultants, whose contribution may be limited to the development of the plan, (iii) stakeholders engagement and the organisation of participatory processes, (iv) accurate budget allocation at the start of plan, (v) early development of the plan and deployment of the actions. In contrast, neither an increase in total planned budget nor higher ambitions can be considered determining factors for the successful finalisation and monitoring of the plan.

From the initiative perspective, particularly for CoM 2030 and GCoM, the need to ensure the correct implementation of a monitoring exercise is of paramount importance.

It would be critical for small cities to receive technical support to enable them to report and to improve the support they receive by CTCs. This support needs to complement a correct elaboration of the plan with a tailor-made support in the implementation and monitoring phase of the plan. For larger cities, the Covenant community acts as a unique forum for peer sharing and building climate knowledge.

All that said, the preliminary results of the initiative are more than promising. The last monitoring snapshot (average data from 2014) showed that 40% of the signatories monitoring their plans already accomplished their target, and more than 80% have reduced their emission. On average by 2020 municipalities are achieving reductions of 1 tCO2e/cap and are on a good path towards achieving their targets.

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CRediT authorship contribution statement

Silvia Rivas: Conceptualization, Methodology, Investigation, Writing – original draft. **Ruben Urraca:** Investigation, Data curation, Formal analysis, Visualization, Writing – original draft. **Valentina Palermo:** Writing – review & editing. **Paolo Bertoldi:** Writing – review & editing, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2021.130029.

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4.2 Publication II

Rivas S, Urraca R, Bertoldi P, 2022. Covenant of Mayors 2020 achievements: a two-speed climate action process. Sustainability, 14:15081.10.3390/su142215081

sustainability

Article

Covenant of Mayors 2020 Achievements: A Two-Speed Climate Action Process

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Abstract: Assessing the world's collective progress towards the Paris Agreement's long-term goals is a global priority. Local authorities (LAs), in particular, play an important role in a just transition. This paper evaluates the real achievements of local climate action plans developed in Europe from 2008 to 2020 under the Covenant of Mayors initiative. On average, 85.6% of the GHG reduction targets were achieved way before the year 2020; however, our assessment shows different reduction patterns, with several leading LAs exceeding by 2–4 times their targets and 12% of LAs increasing their baseline emissions. This paper weighs the factors which have a determinant impact on these patterns, investigating the key drivers and barriers towards a clean energy transition under a new population-driven approach. While, for large LAs, the climate experience and the engagement of stakeholders is an asset for increasing their achievements, small LAs are much more conditioned by the political mandate and support from regional governments or external actors. The key factor for climate action planning appears to be the joint partnership between several government levels from a national perspective.

Keywords: climate change; mitigation; Covenant of Mayors; Green Deal; environmental justice; local climate action

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1. Introduction

The climate emergency not only damages the environment; it weakens our political, economic, and social systems [1,2]. Countries and communities need to address the specific risks the climate crisis poses in pursuit of people's equality and dignity [3]. Particularly, local authorities (LAs) play an exemplary role since cities are the main contributors to the exacerbated climate change effects [4–8], and can play a critical role in engaging their communities because action on climate change brings many co-benefits addressing other areas of public concern such as public health. Several initiatives have started in Europe over the last decades to boost effective climate action by LAs towards the 2020 Energy and Climate objectives [9] (e.g., Smartcities, Greencities). Relevant as well was the work conducted by cities associations (e.g., Climate Alliance, EuroCities, C40, ICLEI). However, the Covenant of Mayors 2020 (CoM 2020) was the first harmonized framework guiding local authorities of all sizes towards a decarbonized, resilient future, including a complete reporting, evaluation, and monitoring system. This is the first initiative of its kind to provide real achievement data to evaluate, being launched by the European Commission in 2008 and aiming at guiding LAs all over Europe towards reducing their total GHG emissions by 2020 through the development and implementation of the so-called Sustainable and Energy Action Plans (SEAPs).

Despite the lack of final monitoring of the implementation of concrete actions towards GHG reduction, the low number of monitoring reports followed by the LAs [10], and methodological issues regarding the reporting system and database management (see Discussion section), several studies tried to extract relevant information from this first exercise in order to improve or guide local action planning worldwide [11–14]. In fact, the evaluation and assessment of the real achievements and impacts of such a bottom-up [15,16] multilevel experience [7,17,18] could leverage climate ambition towards a Green Deal and a just clean energy revolution, and so, is the objective of this paper.

So far, most Covenant of Mayors studies have focused on the action plans, investigating aspects such as why LAs engage in local climate action (i.e., political influence, cities network support) [8,19], what drives their ambition levels (i.e., climate experience, technical and financial resources) [20,21], what are their expected reductions by sector [12], and what type of actions do they propose [22]. Based, also, on analyzing SEAPs, some studies have assessed different aspects of the CoM methodology [23,24]. Most of the previous studies use specific CoM subpopulations that, in some cases, reduce to a specific country [25–27], region [28], or LA [29,30]. This is mainly due to the limited access to the CoM database and the existing issues for post-processing the data. In any case, studies usually do not distinguish between climate action plans developed under the first phase of the initiative (CoM 2020) and the second (CoM 2030), though each initiative has different objectives, methodologies and even reporting systems. Moreover, most of the studies do not differentiate between plans that have been validated by official European Commission approval and those that never received a positive evaluation [31]. Despite all of this, the main limitation of all these studies is that their findings are based on a series of commitments that may or may not be achieved. Assessing the monitoring reports is, therefore, crucial to verify the true achievements and impact of action plans designed and commitments made by the LAs.

Fewer studies have assessed the EU CoM achievements—partly, again, due to the limited access to the CoM database and due to the recent availability of monitoring data. Kona et al. [32] extrapolated the emission reductions of the first 533 monitoring reports to the whole CoM population, trying to predict the theoretical reductions that would be obtained by 2050 if the same reduction rate was kept. Hsu et al. [33] evaluated the emission reductions of 1066 CoM municipalities and estimated their progress by interpolating linearly their planned reductions to the year of the last monitoring report. Again, both studies, which present similar positive trends, use specific CoM sub-populations, and omit the implications of the low number of CoM 2020 monitoring reports received (32.5% of LAs with an approved SEAP) on the representativeness of their datasets. However, the main limitation to track CoM emission reductions arises from its flexible methodology [31]. Both baseline and monitoring years vary between LAs, so their reduction targets, baseline emissions, emission reductions, and SEAP progress are not directly comparable. The previous studies tackled this issue by using linear interpolation techniques, either to extrapolate the emissions [32] or to interpolate the expected reductions [33]. However, both approaches—particularly extrapolating emission reductions in time and to other municipalities—could lead to unrealistic results due to the high non-linearity of local emission reduction patterns (see Methods section).

Therefore, while there are several studies conducted in the past years focusing on the commitments acquired by the LAs, rare are the studies that give an insight into the actual results achieved by the LAs due mostly to (i) the lack of a concrete monitoring exercise and (ii) the final and real progress of the achievements only being evaluated after the due date of the initiatives; ergo, after 2020. This paper presents the first comprehensive and complete evaluation of the achievements of European LAs after the end of CoM 2020 initiative (December 2020). For the first time, it has been possible to access the full monitoring exercise after the due date of the first phase of the CoM initiative. For that, we analyze all European LAs that have submitted at least one monitoring report: 1643 LAs representing 19.2% of the EU-27 population. We tackle the heterogeneity of baseline and monitoring years by measuring the sensitivity of our results against the variations of these parameters. We also acknowledge the low representativeness of CoM LAs conducting monitoring (see Section 5). Indeed, this exercise was initiated in a previous publication [10] that analyzed the reasons behind the reduced number of monitoring reports received, including aspects such as the city size and the influence of the climate experience. This paper goes one step forward by evaluating the achievements of the 1643 LAs monitoring their plans.

Beyond showing the progress of the initiative, where 39.9% of the signatories have already achieved their targets 6 years before the due date, this paper focuses on explaining how and why. The study evaluates the drivers and most important actions leading LAs to greater emission reductions and the barriers faced by signatories that increased their emissions during the implementation of the local action plan (13% of them). The study is conducted separately for small (<50,000 inhabitants) and large (>50,000 inhabitants) LAs, showing how their reduction patterns are different and which factors are of greater influence in their achievements.

2. Covenant of Mayors Initiative

The Covenant of Mayors initiative (CoM 2020) was launched in 2008 by the European Commission to support and mobilize LAs in reducing their GHG emissions. Covenant of Mayors signatories voluntarily committed to reducing their emissions by at least 20% by 2020 from their baseline year. For that, they developed and implemented a Sustainable Energy Action Plan (SEAP) composed of (i) a strategy, (ii) an assessment (baseline emission inventory), and (iii) an action plan (concrete actions to achieve their target) [31]. The Covenant of Mayors Initiative evolved in 2015 into the Covenant of Mayors 2030 (CoM 2030), extending the target year to 2030, increasing the minimum reduction target to 40% by 2030, and including the adaptation to climate change pillar. One year later, the Covenant of Mayors merged with the Compact of Mayors into the Global Covenant of Mayors (GCoM) [34,35], extending the coverage of the initiative worldwide [35]. In this study, we analyze the final achievements of CoM 2020 initiative, which ended in December 2020.

CoM 2020 LAs had to submit their SEAPs within two years following the adhesion date. Once the SEAP was ready, LAs uploaded all the information to the MyCovenant reporting platform. The harmonized data was stored in a relational database. Municipalities also uploaded a digital copy of the SEAP document approved by the city council. SEAPs were evaluated by the European Commission's Joint Research Centre (JRC), which provided every signatory with full feedback, highlighted the main strengths and weaknesses, and gave recommendations for potential improvements. SEAPs could be accepted directly or accepted after the LAs implemented the corrections proposed by JRC. Several LAs developed their plans with the support of a Covenant Territorial Coordinator (CTC), a supra-municipal entity that provides technical and financial support to provinces and regions [23]. In this case, instead of evaluating each plan individually, the JRC evaluated the CTC methodology and representative cases of the province/region so every plan that followed the same methodology could be automatically accepted.

The Covenant of Mayors imposes two types of monitoring exercises: (i) an action report every two years after the SEAP submission, and (ii) a full report every four years after the SEAP submission, including an update of the emission inventory.. No specific reporting was requested at the end of the initiative in 2020, neither the update of the 2020 emission inventory.

3. Materials and Methods

3.1. Dataset: CoM 2020 LAs with at Least One Monitoring Emission Inventory

At the end of the CoM 2020 initiative (31 December 2020), 6620 European (EU-27) LAs had adhered to the initiative, 5636 had a local action plan approved by the JRC, and 1696 had submitted at least one monitoring emission inventory (Table 1). The total number of SEAPs submitted, accepted, and monitored was 1643 since, out of the 1696 LAs presenting a monitored accepted plan, 53 did it following the "Joint SEAP approach", presenting a common SEAP for several LAs [36]. Only 27.5% of CoM 2020 signatories (53.4% in terms of the total population) submitted a monitoring report. LAs with at least one monitoring report still represent 19.2% of the EU-27 population. This group is the population under analysis in this study.

LAs uploaded all their emission inventories into MyCovenant reporting platform. The baseline emission inventory was labelled as BEI, and all other inventories submitted were labelled as monitoring emission inventories (MEI). However, not all MEIs uploaded into MyCovenant monitor SEAP implementation. For instance, LAs could submit emission inventories compiled between their baseline year and the start of the action plan. All these inventories were discarded. In addition, 331 LAs submitted more than one monitoring report. In these cases, only the latest report was included in the current analysis.

Table 1. Status at the end of the initiative of EU-27 LAs committed to Covenant of Mayors 2020.

		Number of LAs	Number of SEAPs	Total [Million Inhabitants]	EU-27 Coverage [%]
Committed		6620	5964	160.0	36.0
SEAP submitted		6437	5812	155.8	35.0
SEAP accepted		5636	5054	135.7	30.5
MEI submitted	Total	1696	1643	85.5	19.2
	Quality controlled	1646	1599	83.5	18.8

GHG emission inventories were quality controlled with the procedure described in Rivas et al. [10]. The same procedure was applied to both baseline and monitoring emission inventories. The QC procedure consists of three steps:

1. Quality control of individual emissions. LAs reported their emissions for each activity sector and energy carrier. CoM inventories include direct energy and non-energy emissions that occur in the local territory, but also indirect emissions due to grid-supplied energy that is consumed within the local territory. In energy sectors (residential, transport, and agriculture), an emission factor (EF) was applied to electricity consumption values. In non-energy sectors (wastewater and waste management), emissions were directly reported. The complete description of energy carriers as well as activity sectors and subsectors is available in the CoM reporting guidelines [37]. Note that, despite emissions being self-reported by LAs, LAs cannot choose what to report as CoM reporting guidelines establish a set of minimum mandatory sectors. For some energy carriers, activity data was reported but the EF was missing. MyCovenant treated missing EFs as zero, underestimating the emissions of that energy carrier. Electricity EFs were filled with National and European Emission Factors for Electricity consumption (NEEFE) values [38] for the corresponding country and year. Non-electricity EFs were filled either with the median EF for that energy carrier in the other inventories of the municipality or with the CoM default EFs [38].
2. Quality control of total emissions. The total emissions were obtained by adding the individual emissions of all energy carriers and activity sectors. The Covenant of Mayors allows LAs to implement a flexible approach: (i) using either LCA or IPCC methodologies and (ii) reporting either in CO_2 or CO_2e units. The different approaches were harmonized as follows. LCA emissions were transformed into IPCC emissions by applying a factor of 0.885, which is the average ratio between LCA and IPCC factors [39]. CO_2 was transformed into CO_2e by applying a factor of 1/0.85, because CO_2 is responsible for 85% of the global warming potential at a European scale [39]. Harmonized inventories were normalized per capita. Finally, inventories with total GHG emissions outside [0.5, 40 tCO_2e/cap] were flagged as potential outliers.
3. Coherence between baseline and monitoring inventories. The coherence between baseline and monitoring inventories was evaluated based on the total GHG emissions reduction in tCO_2e/cap (Equation (1)) and percent (Equation (2)). Inventories with total emissions reduction outside [−5, 10 tCO_2e/cap] or [−100, 100%] were also flagged as suspicious.

$$\textit{Total emission reduction } [\text{tCO}_2\text{e/cap}] = \textit{total baseline emissions} - \textit{total monitoring emissions} \quad (1)$$

$$\textit{Total emission reduction } [\%] = 100 \times \frac{\textit{total emission reduction } [\text{tCO}_2\text{e/cap}]}{\textit{total baseline emissions } [\text{tCO}_2\text{e/cap}]} \quad (2)$$

Inventories flagged in steps (2) and (3) were manually inspected. Most of the errors occur when LAs upload their emissions data into the MyCovenant reporting platform. Therefore, suspicious inventories were cross-checked with the emissions reported by the LAs in their original SEAP document submitted to the platform. If possible, the data was corrected; otherwise, the inventory was removed (55 inventories).

After harmonization and quality control, the main limitation remaining in the CoM emissions dataset is the heterogeneity of both baseline and monitoring years:

- The baseline year is 1990 or the closest subsequent year for which sufficiently comprehensive and reliable data are available. The alternative year shall not be later than 2005. In practice, most CoM signatories used 2005-07 (55% of accepted plans), although baseline years vary from 1990 to 2015.
- The monitoring year corresponds to the last monitoring report submitted by each signatory. It varies from 2012 to 2018 (median = 2014). Only 7.07% of LAs submitted a monitoring report in 2020. Overall, there is a low number of LAs monitoring their plans (27.5% of CoM signatories), and the few who perform monitoring typically just submit one report (80% of LAs conducting monitoring) 4–5 years after the SEAP submission. No final report was foreseen by 2020.

This results in two problems. First, it is not possible to evaluate the results of the CoM 2020 initiative due to the lack of monitoring reports for 2020. The best we can do is to analyze the municipality's status at the time of its last monitoring. Second, emission inventories, emission reductions, and emission targets are not comparable between LAs. Theoretically, the older the baseline year and the more recent the monitoring year, the easier it should be to obtain larger reductions because LAs had more years to implement their actions, and because older inventories should be larger and thus easier to reduce, as the average European emissions have been steadily declining since 1990, and particularly since 2008 [40].

As abovementioned, previous assessments of CoM achievements harmonized the inventories assuming a constant emissions reduction from year to year. Hsu et al. [33] interpolated linearly city targets between the baseline and target year to estimate their progress in the monitoring year. However, only 40% of SEAPs started at their baseline year, so using the baseline year as year zero gives unrealistic predictions. Moreover, emissions reductions of many LAs are far from linear (Figure S1) [6]. Extrapolations such as those made by Kona et al. [32] introduce even larger errors since the emissions reduction speeds differ significantly between LAs. A total of 48% of LAs were able to reach (and even surpass) their targets 5 years before the end of the initiative, while 12% of LAs had increased their emissions in their last monitoring. These harmonization approaches may lead to a more unrealistic scenario than analyzing the raw heterogeneous data and accounting for its limitations. Therefore, we opted for the second approach. We compare GHG emissions reductions obtained in different baseline and monitoring years, including both the baseline and monitoring years in our analysis to evaluate the sensitivity of our results to the variations in these parameters.

3.2. Analysis of CoM 2020 GHG Emissions Reduction

The total GHG emissions reduction achieved during the CoM 2020 initiative by each LA was analyzed based on Equations (1) [tCO_2e/cap] and (2) [%]. The progress of each LA towards its target was evaluated as:

$$\textit{SEAP progress } [\%] = 100 \times \frac{\textit{total emission reduction } [\%]}{\textit{reduction target } [\%]} \quad (3)$$

GHG emissions reductions were also analyzed by activity sector. For that, activity subsectors reported in the MyCovenant platform were aggregated as follows:

- Residential and tertiary buildings: residential buildings, tertiary buildings, and buildings not allocated.
- Municipal buildings equipment and facilities (exemplary sector).
- Industry, excluding emissions from plans included in the EU Emissions Trading System (ETS).
- Transport: including municipal fleet, public transport, private transport, and transport not allocated.
- Others: water management, waste management, agriculture forestry fisheries, non-energy sectors, other.

The GHG emissions reduction by sector was calculated in tCO_2e/cap and in percent, where the % shows the sector reduction with respect to the total baseline emissions:

$$sector\ emission\ reduction\ [\%] = 100 \times \frac{sector\ emission\ reduction\ [tCO_2e]}{total\ baseline\ emissions\ [tCO_2e]} \quad (4)$$

The GHG emissions reduction share of each sector was also calculated as:

$$sector\ reduction\ share\ [\%] = 100 \times \frac{sector\ emission\ reduction\ [tCO_2e]}{total\ emission\ reduction\ [tCO_2e]} \quad (5)$$

The analysis of total and sector emissions reduction was made separately for small and large LAs, using a threshold of 50,000 inhabitants. LAs above 50,000 inhabitants are considered by the OECD as urban areas [41], whereas LAs below 50,000 inhabitants correspond to small towns and rural areas. The split was made based on the differences observed between small and large LAs in a previous analysis of the whole CoM population (including LAs without monitoring): large LAs are more likely to submit monitoring information and have older baseline inventories, more ambitious targets, longer-term plans, and specific departments dedicated to climate action. On the contrary, for small LAs, CoM was the first approach to climate action and they needed more external support, either from CTCs or from external consultants. Moreover, the uncertainty of the emissions reduction and SEAP progress in small LAs is larger. Despite working with normalized quantities (tCO_2eq/cap or %), any small, unexpected change in the total GHG emissions—or any mistake during the data reporting—will have a greater impact on small LAs due to their smaller total emissions in absolute units.

Based on this, our hypothesis is that small and large LAs have different reduction patterns, so they need to be analyzed separately. This also allows us to eliminate the potential confounding effect of population size on other predictors.

3.3. Statistical Drivers of GHG Emissions Reduction

Statistical analysis was conducted to look for drivers that explain the different GHG emission reductions observed between types of LAs. Several predictor variables potentially associated with total GHG emissions reduction were identified from the data uploaded by LAs into the MyCovenant reporting platform (Table 2). The target variable used was the total GHG emissions reduction in %. The statistical analysis was made separately for small and large LAs. In both cases, most of the variables follow a non-normal distribution, so non-parametric techniques were used.

The association between categorical variables and the total emissions reduction was analyzed with the Mann–Whitney test, a non-parametric ranked test used to evaluate the differences between two non-normal groups. All categorical attributes were binary (True or False). The null hypothesis H0 states that observations of both groups are drawn from the same population, i.e., they have the same median. H1 stipulates that data from the two groups differ. If both groups have distributions of the same shape, we can state that the medians of both groups are not equal. A significance level of 0.05 was used, rejecting the null hypotheses if *p*-value < 0.05. Throughout the paper, asterisks indicate $p < 0.05$ (*), $p < 0.01$ (**), and $p < 0.001$ (***). The effect size was estimated with Cliff's delta (d), including its 95% confidence interval. Negative and positive values of d, varying from −1 to 1, represent inverse and direct relationships, respectively. Its magnitude is interpreted as follows: small effect ($0.11 < |d| < 0.28$), medium effect ($0.28 < |d| < 0.43$), and large effect ($|d| > 0.43$).

Table 2. List of predictor variables extracted from MyCovenant reporting platform as potentially linked with the total GHG emissions reduction. Data types: cat = categorical, num = numerical.

<table>
<tr><th colspan="3">Attributes</th><th>Type</th><th>Description/Notes</th></tr>
<tr><td colspan="3">Population</td><td>num</td><td>Attribute not analyzed directly as predictor variable but used to split the dataset into two groups (small and large LAs).</td></tr>
<tr><td rowspan="4">SEAP general</td><td colspan="2">SEAP submission year</td><td>num</td><td>Year of submission of the action plan.</td></tr>
<tr><td colspan="2">SEAP start year</td><td>num</td><td>Year of implementation of first action. Some of the actions proposed in the SEAP, and even the whole plan, could be already ongoing when submitted to CoM 2020.</td></tr>
<tr><td colspan="2">Approved via CTC grouped evaluation</td><td>cat</td><td>-</td></tr>
<tr><td colspan="2">Signatories committed to both 2020 and 2030 initiatives</td><td>cat</td><td>Also known as 'overlappers'.</td></tr>
<tr><td rowspan="13">SEAP strategy</td><td colspan="2">2020 GHG reduction target</td><td>cat</td><td>The target is set based on the foreseen reduction in each sector for the different actions proposed.</td></tr>
<tr><td rowspan="5">Staff allocated</td><td>Local authority</td><td>cat</td><td rowspan="5">Type of staff allocated in the preparation of the SEAP. Multiple selection was available in the reporting platform.
-CoM (national) coordinators: national public bodies such as ministries or national energy agencies. Results show that this support is not correlated to greater reductions achieved in any kind of LA.
-CoM supporters: associations of local and regional authorities, networks, thematic local and regional agencies, European federations, and not-for-profit organizations with the capacity to promote the Covenant of Mayors and to mobilize and support their members.</td></tr>
<tr><td>CoM coordinator</td><td>cat</td></tr>
<tr><td>CoM supporter</td><td>cat</td></tr>
<tr><td>External consultant</td><td>cat</td></tr>
<tr><td>Other</td><td>cat</td></tr>
<tr><td rowspan="3">Stakeholders' engagement</td><td>Local authority's staff</td><td>cat</td><td rowspan="3">Type of stakeholders engaged in the development of the SEAP. Multiple selection was available. Note that the level of engagement is a qualitative description selected by the municipality from the three possibilities given on the reporting platforms: high, medium, and low, as part of their own progress assessment.</td></tr>
<tr><td>External stakeholder at local level</td><td>cat</td></tr>
<tr><td>Stakeholders at other levels of governance</td><td>cat</td></tr>
<tr><td rowspan="4">Financial resources</td><td>Local authority's own resources</td><td>cat</td><td rowspan="4">Type of financing resources used to meet the budget. Multiple selection was available.</td></tr>
<tr><td>External: Public</td><td>cat</td></tr>
<tr><td>External: Private</td><td>cat</td></tr>
<tr><td>Other</td><td>cat</td></tr>
</table>

Table 2. *Cont.*

Attributes			Type	Description/Notes
SEAP assessment	BEI	Total GHG emissions	num	-
		Baseline year	num	1990 or the closest subsequent year for which sufficiently comprehensive and reliable data are available. The alternative year shall not be later than 2005.
SEAP monitoring	MEI	Total emissions	num	
		Sector emissions	num	
		Monitoring year	num	Year of the last monitoring report submitted by the municipality
		Implementation years	num	Monitoring year—year of the first action.

The association between numerical attributes and the total emissions reduction was analyzed with scatter density plots and the Spearman's rank correlation coefficient. Compared to the Pearson coefficient, Spearman's correlation evaluates the monotonic relationship based on the ranked values for each variable. The resulting coefficient is better suited for non-normal data and for ordinal variables, such as in the case of the different years included as independent attributes [42]. Its magnitude can be interpreted similarly to that of effect size. The statistical significance of Spearman's correlation was evaluated with the *p*-value derived with an asymptotic t approximation.

3.4. Regression Analysis

The impact of each predictor variable on the local GHG emissions reduction was evaluated with a linear regression model. Compared to the statistical analysis, the model considers the combined effects of all features and allows for them to be ranked according to their importance. Note that, during both the statistical and regression analyses, we can only extract conclusions from the population under study, i.e., CoM LAs that are monitoring their plans and reporting their progress. No inference can be made about the reduction patterns of LAs not reporting monitoring data.

The correlation between predictors was evaluated to detect multi-collinearity effects that may inflate the model coefficients, and to discuss the effects of potential confounding features. The correlation matrix was derived using Spearman's rank correlation for numeric–numeric relationships, point-biserial correlation for numeric–binary relationships, and Phi coefficient for binary–binary relationships. All features described in Table 2 were analyzed in the correlation matrix as potential predictors of the total GHG emission reduction. The sectorial information was included using the sector share instead of the sector reduction, as the latter is trivially related with the output. Only sectors with significant contributions were included (residential, transport, and industry). Attributes with missing values (e.g., stakeholder-related features) were analyzed in the correlation matrix but discarded as predictors in the model to keep all the instances in the regression analysis.

All groups of predictors with correlations above 0.35 were analyzed, discussing the most likely cause of the correlation. For the regression analyses, some correlated features were combined in a single predictor (e.g., binary predictors). In other cases, different sets of independent predictors were made and the one minimizing the predictor error was selected. The multi-collinearity analysis and the feature selection process are available as Supplementary Material.

After this process, the 11 selected independent features were used to train a ridge regression model, a linear model with a regularization term that allows for dealing with the remaining multi-collinearity effects. The lambda parameter of the ridge regression model was tuned using cross-validation (10 folds). All features were standardized (mean = 0, standard deviation = 1) to obtain model coefficients of comparable magnitude. The impact of each feature on the total GHG reduction was evaluated based on the scaled model coefficients ant their 95% confidence intervals.

The presence of non-linear effects was evaluated using the non-parametric Generalized Additive Model (GAM), which can cope with non-linear effects through a different type of non-linear function. GAM was able to reduce the prediction error (MAE) only by 1%, so non-linear effects were neglected.

4. Results and Discussion

4.1. Reducing GHG Emissions in the Frame of the Covenant of Mayors

At the end of CoM 2020 initiative (31 December 2020), 6620 European (EU-27) LAs had adhered to the initiative and 5636 had a local action plan approved by JRC, but only 27.5% of CoM 2020 signatories (53.4% in terms of the total population) had submitted a monitoring report. LAs with at least one monitoring report still represent 19.2% of the EU-27 population.

LAs with at least one monitoring report are on track to achieve their goals (Tables 3 and 4). They have reduced a total of 120.69 $MtCO_2e$, which corresponds to an average reduction per LA of 1.23 tCO_2e/cap or 19.6% of their baseline emissions. Comparing their reductions with their targets, these LAs have already achieved 85.85% of their initial commitments 6 years before the end of the initiative (average year of last monitoring inventory). Small LAs represent 83.9% of signatories, accounting for 16.4% in terms of the total population but only 13.9% in terms of total emissions in the baseline year (Table 3). On the other hand, large LAs, representing 16% of the signatories, account for more than 86% of the total emissions recorded in the baseline years.

Table 3. Total GHG emissions reduction achieved by the 1599 European LAs submitting at least one monitoring report. The reductions correspond to the year of the last monitoring inventory compiled by each municipality.

	Pop. < 50,000	**Pop. > 50,000**	**All**
SEAPs	1341	258	1599
Population [million inhabitants]	13.37	70.21	83.58
Baseline emissions [$MtCO_2e$]	74.09	457.88	531.97
Total emission reduction [$MtCO_2e$] ([%])	14.48 (19.54)	106.21 (23.2)	120.69 (22.69)

The density curves (Figure 1) show a similar pattern in terms of total GHG emissions reduction per capita with average values of 1.21 and 1.35 tCO_2eq/cap for small and large LAs, respectively. Some differences between small and large LAs appear when analyzing their total emissions reduction in %. While reductions achieved by large LAs are centered around the CoM 20% minimum target, small LAs present a higher variability. Particularly, the fraction of small LAs achieving reductions between 50–100% doubles that observed for large LAs. These differences increase when evaluating the SEAP progress (Figure 1c). The average progress is larger for small LAs (86.73%) than for large ones (79.56%). The spread of the SEAP progress is again larger for small LAs, which have more unexpected emissions reductions (reductions above their targets or increasing emissions). Particularly, 40.72% of small LAs have already reached their targets before the end of the initiative, compared to 35.60% of large LAs. Surprisingly, small LAs required less time to achieve it (7.1 vs. 9 years on average). On the other side of the curve, a relevant group of LAs have increased their emissions in this final snapshot. This group is also larger for small LAs (13.50% vs. 9.69%). Even if, as described before, the emission reduction progression is rarely linear, a significant increase in GHG emissions in a period of implementation of a climate action plan highlights the presence of a potential issue.

Table 4. Average baseline emissions, reduction targets, and emissions reductions of the 1599 LAs submitting at least one monitoring report. The reductions correspond to the year of the last monitoring inventory compiled by each municipality.

		Pop. < 50,000	**Pop. > 50,000**	**All**
Baseline emission year		2006	2003.9	2006
Baseline emissions [tCO2e/cap]		5.62	6.13	5.7
Submission year		2012.4	2012.1	2012.4
SEAP start year (first action)		2006.9	2005.6	2006.6
GHG reduction target [%]		23.47	25.51	23.8
Monitoring year		2013.9	2014.6	2014
Monitoring year—SEAP start year		7.1	9	7.4
Emission reduction [tCO_2e/cap] ([%])	Residential and tertiary	0.47 (8.05)	0.77 (11.27)	0.52 (8.57)
	Municipal buildings	0.04 (0.87)	0.03 (0.57)	0.04 (0.82)
	Industry	0.19 (2.24)	0.25 (3.46)	0.20 (2.43)
	Transport	0.47 (7.88)	0.27 (4.31)	0.44 (7.30)
	Others	0.03 (0.49)	0.03 (0.40)	0.03 (0.47)
	TOTAL	1.21 (19.52)	1.34 (20.01)	1.23 (19.6)
SEAP progress [%]		86.73	79.56	85.58
SEAP progress > 100% [%]		40.72	35.60	39.90
SEAP progress < 0% [%]		13.50	9.69	12.88

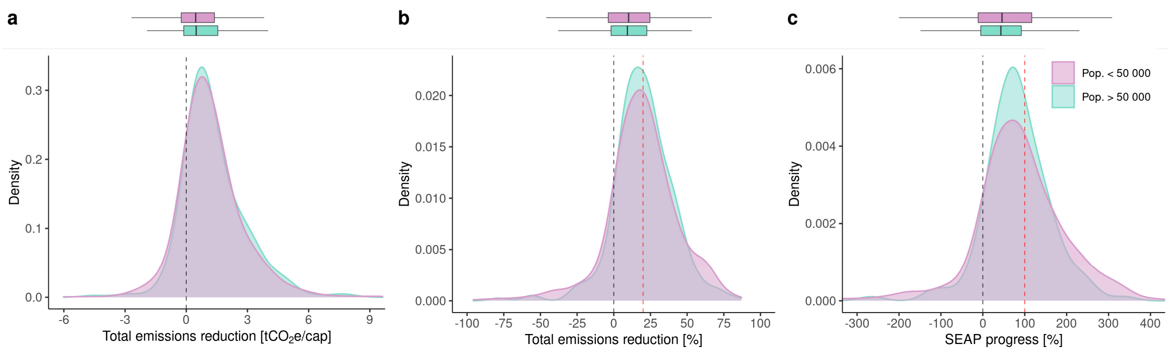

Figure 1. Summary of the GHG emissions reduction reported by CoM 2020 LAs in their last monitoring report. (**a**) Total emissions reduction [tCO_2e/cap]. (**b**) Total emissions reduction with respect to their baseline emissions [%]. The red line shows the CoM 2020 minimum reduction target of 20%. (**c**) SEAP progress [%]. The red line shows a SEAP progress of 100% (municipalities that have already reached their targets).

Overall, emissions reductions of small LAs deviate more from their planned reductions than those of large LAs. This could be related to the level of planning of the local action plan and the level of robustness when accounting for baseline emissions and planning expected reductions. A better knowledge of baseline emissions could facilitate more accurate development of reduction actions. The greater experience and resources to collect data from large LAs may explain why they were able to develop more accurate and feasible plans [10,20]. On the contrary, small LAs—in principle, with limited technical expertise and resources—could be prone to developing less-accurate emissions inventories and less-controlled mitigation actions. In addition, as explained in the Methods section, errors and unexpected reductions in the inventories (e.g., unaccounted sectors due to lack of data) have a larger impact on smaller LAs, since the total emissions would be smaller as well as maneuvering capacity.

However, the results have shown that no matter the size of the LA, a significant % of signatories reported an unforeseen and uncontrolled increase in emissions in their territories after starting the implementation of the climate action plan. This requires further studies aiming at extracting what could be the factors leading the LAs to this potential planning failure.

4.2. Emission Reductions Per Sector

A sectorial analysis (Figure 2) was conducted aiming at revealing possible drivers leading a city to more efficient reduction. The sectorial analysis (Figure 2a) shows that reductions obtained for both groups of LAs mainly come from the residential sector (41%), the transport sector (40%), and the industry sector (11.5%). Most of the signatories included in the study (over 95%) reported data in the residential, transport, and municipal sectors. This last exemplary sector, despite the high rate of reporting, always only accounts for a minimum share of reduction. While for large LAs the residential sector accounts for the largest share (56%) [11,33] followed by 20.1% in transport, both sectors have an equal contribution in small LAs (38.8% of total emissions reduction). Important as well is to note the relevant contribution of the industrial sector, especially in larger LAs. Even if the reporting level is medium (59%), when present, the reductions achieved (18.6 % of the share) are similar to those attributed to the transport sector.

The correlation analysis (Figure 2c) between per sector and total emissions reduction confirms what was mentioned above. In large LAs, the residential ($\rho = 0.63$ ***), transport ($\rho = 0.42$ ***), and industry ($\rho = 0.40$ ***) sectors are those that better explain the change in the total emissions. In small LAs, transport ($\rho = 0.68$ ***) is the sector most correlated with total emission reductions, followed by residential ($\rho = 0.57$ ***).

This poses a first big question: How do the most important reductions per sector due to local climate action come from sectors of activity with limited local competence, such as transport or industry, especially in small LAs, reaching emissions reductions above 50%? Would these sectors of activity be the uncovered main contributors to the results achieved by LAs of all sizes?

Analyzing the sector share by different intervals of total emissions reduction (Figure 2c, Table S1), we can distinguish three main patterns:

a. Average reducers: 38.52% of LAs (41,86% of large LAs, 37,88% of small LAs) achieved in their monitoring report a reduction from 0 to the minimum target of 20% at the end of CoM 2020. In this group of LAs, the reductions achieved follow a regular or expected contribution based on local competencies, i.e., greater reductions in the residential sector (63.66% for large LAs, and 56.96% for small LAs), followed by the contribution of transport (21% for both types of LAs), possibly related to a municipal fleet—and local incentives/taxes for—moving to electric, collective, or less pollutant transport. A minor industry contribution (14% for large LAs, 15.54% for small LAs) is observed due to the limited industry activities considered in the frame of the Covenant that excludes all the ETS scheme activities.
b. Super reducers: 48.03% of LAs achieved in their monitoring report a higher level of reductions (over 20% reaching even more than 90%). Most of these reductions were not foreseen in the plan, since many LAs in this group committed to the minimum target. In this group, the higher the reduction, the greater the contribution from the transport sector, especially in small LAs (reaching a share of 66.78% for total reductions between 60–80%). In large LAs, the residential sector presents the largest share (39.22) in LAs with reductions above 60%, followed by transport and industry, whose share increases up to 21% in large LAs, cutting over 60% of their emissions. Exemplary is the case of Kalamaria (Greece), reaching 83% of the total reduction, corresponding to progress of 350% from its original target. In this case, 40% of the

concrete actions implemented targeted the transport sector, from swift to biofuels, to promote alternative transport modes and replace old motor vehicles. Actions on local electricity production account, as well, for a high share of the reductions foreseen. Rus and Aguilar de Segarra are other examples of small LAs with a total reduction of around 85%, which corresponds to the progress of 400% (four times its original target). In both cases, the transport and local energy production actions implemented accounted for a high share of the total reductions. Since the sectors that explain the reductions are under the limited direct influence of the LAs, we could infer that these reductions, which were not foreseen in the action plan, are unexpected reductions that occurred in the geographical area of the LAs due to events out of local control. While nowadays in Europe local authorities have the possibility of implementing measures on transport activities (especially after the publication of the 2022 new European Urban Mobility Framework, not in place during the evaluated period), the impact of the local actions cannot explain the GHG emissions changes shown in the monitoring data because LAs do not have competencies out of their territory, and their activities mostly target only municipal fleets that represents a small share of the local emissions due to transport activities. A greater level of municipalization of facilities [20], the implementation of national policies tackling specific sectors like transport, or an unprecedented technology improvement in the area (e.g., the construction of a new Eolic power plant in 2014 on the island of El Hierro, Spain) could explain these large unplanned reductions. In a previous study [20], we showed how large LAs with competencies in the transport sector were able to set the most ambitious targets for local climate action. However, this is not a possibility for LAs under 50,000 inhabitants that usually do not have a public transport network, whereas the study shows this sector accounts for more than 50% of the reductions.

c. Increasers: 12.13% of LAs increased their emissions by the end of the initiative. In small LAs, we observe increases up to 40% of the baseline emissions, mostly due to the transport sector. This could be partially explained by a non-accurate compilation of the baseline emission inventories. Several small LAs may have reported zero baseline emissions in a specific sector due to the unavailability of data, but they may have been included in the monitoring inventory once the data was accessible. In large LAs, several sectors contribute to the emission increase: transport (52%), residential (32%), industry (20%), and others (26%). The increasing emissions in both small and large LAs also support the hypothesis of a great influence of policies and/or technological developments out of the control of the LA on the total emissions in the area.

A high percentage of both large and small LAs present non-planned large emissions reductions, as well as emission increases, explained by an important change in sector emissions not under the total influence of local authorities. For the latter case, how can the LAs counteract these side effects and ensure the most efficient achievement of their reduction goals?

4.3. Key Local Action Planning Elements for Reducing Municipal GHG Emissions

To support LAs in their efforts towards carbon neutrality, we analyzed the attributes required in the CoM2020 reporting system, aiming at identifying common factors enhancing the performance of the plan.

Figure 3 shows common patterns in the emission reduction of both types of LAs. First, there is a positive correlation between baseline emissions and the reduction achieved in the last monitoring report (ρ = +0.30 ***, +0.27 ***). This evidence supports that the larger the emissions, the easier is to develop actions to mitigate them. Even though the level of emissions is inherent to the city, it would be advisable to make an effort in accounting for as much emission sources as possible at the beginning of the planning phase to enhance the chances of reducing local emissions. There is, as well, a positive relation between the submission year of the local action plan and the emissions cut (ρ = −0.22 ***, −0.28 ***). This would mean that, in principle, having a longer period to act locally increases the chances of implementing effective measures. Therefore, it is advisable in general to encourage LAs to start their climate action as soon as possible.

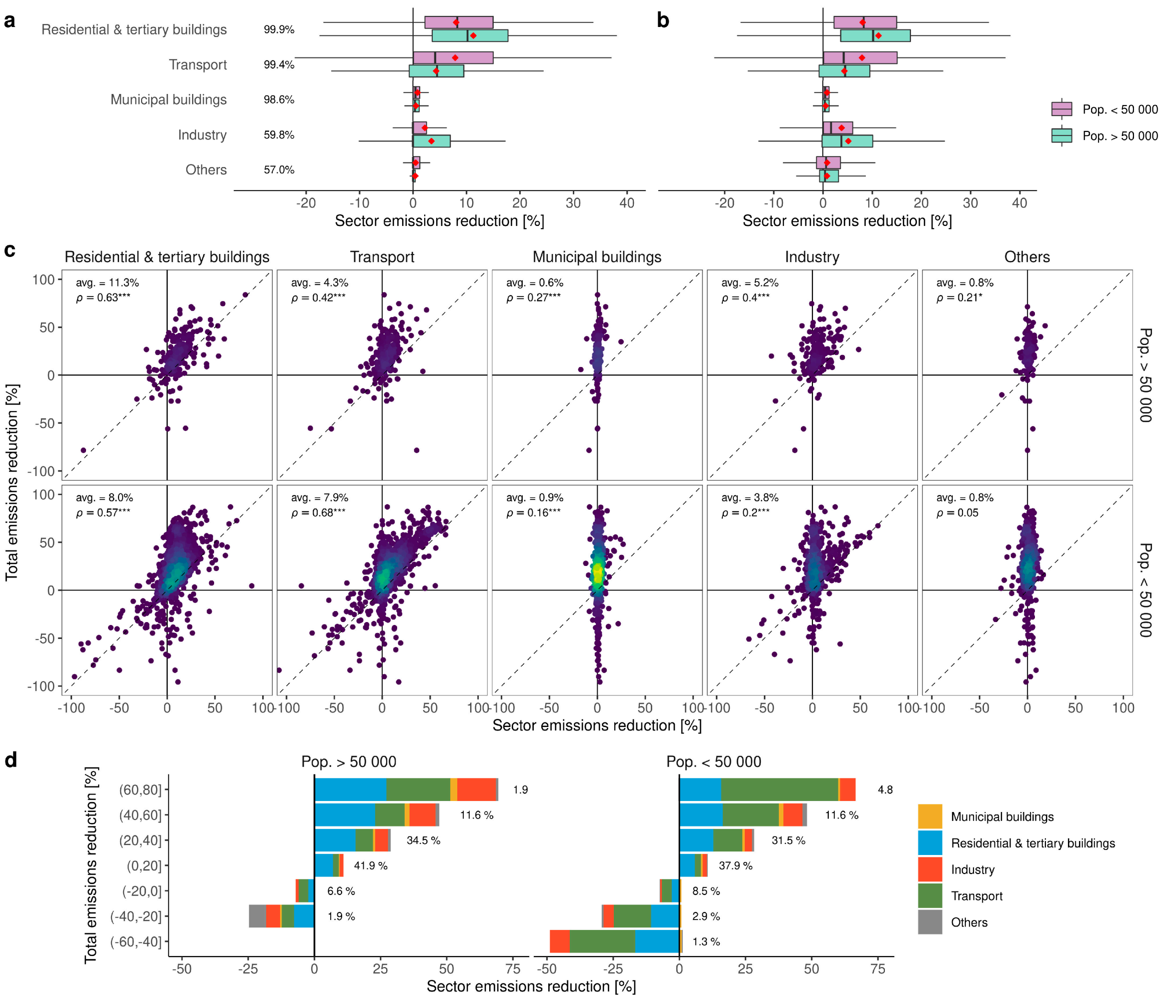

Figure 2. Summary of the GHG emissions reduction per sector. (**a**) Total reduction per sector. The label shows the percentage of LAs reporting emissions in that sector. (**b**) Same as (**a**) but excluding LAs not reporting emissions in each sector. Red diamonds show the mean. (**c**) Scatterplots of sector vs. total GHG emissions reduction for each LA. avg. shows the average emissions reduction per sector. ρ represents Spearman's rank correlation coefficient. Asterisks denote $p < 0.05$ (*), $p < 0.01$ (**), $p < 0.001$ (***). (**d**) Variation of sector share with different levels of total GHG emission reduction. The inset shows the percentage of LAs in each interval.

On the other hand, some attributes show different patterns depending on the LA size. Even if the majority of LAs, regardless of their size, were committed to the minimum target (79.86% of LAs have a target below 25%), the reduction target is only positively correlated with the reductions obtained in large LAs ($\rho = +0.20$ **). A positive correlation between these two variables indicates a good selection of the target and coherence in city planning. By contrast, the reductions obtained by small LAs are independent of their target ($\rho = -0.01$). The correlation matrix (Figure S4) provides more information about planning coherence. In large LAs, the reduction target is positively correlated with baseline emissions per capita and negatively correlated with the baseline year. This is, somehow, the expected pattern, since it should be easier to reduce earlier inventories; the total emissions are generally larger, and there is more time available to implement mitigation actions. However, small LAs do not follow this pattern. Not only is the reduction target uncorrelated with the total reduction, but also with the baseline year and baseline emissions size. This could mean that the emissions assessment at the baseline year and the feasibility of the measure to be implemented are the main factors in the selection of the target. Note that committing to the minimum target is a typical decision for newcomers to climate action, while frontrunners tend to be more ambitious [20].

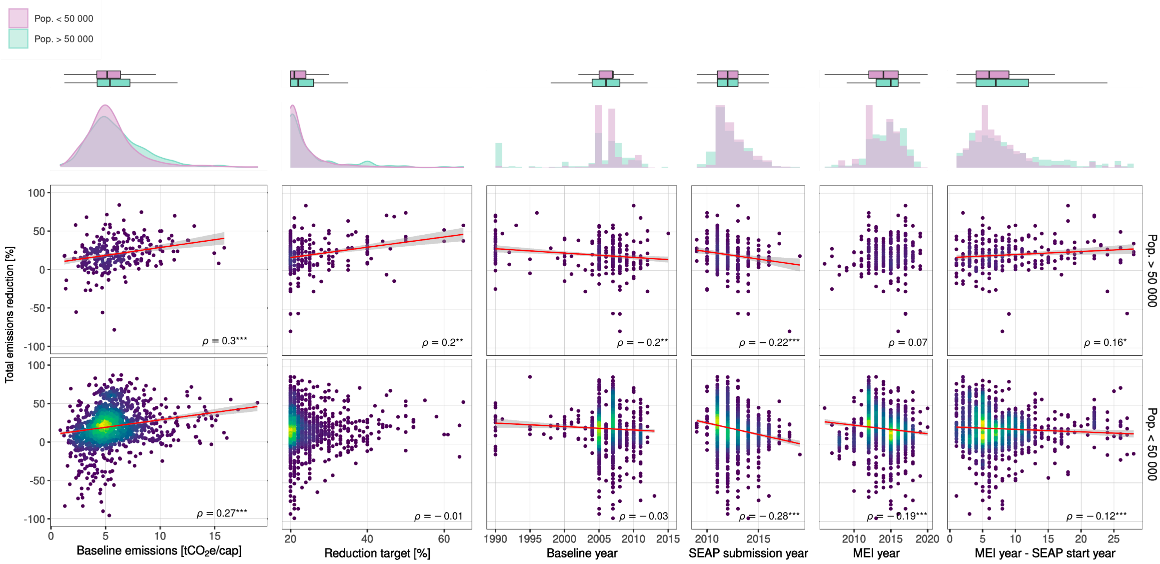

Figure 3. Statistical analysis of numerical attributes. ρ represents Spearman's rank correlation coefficient. Only statistically significant ($p < 0.05$) regression lines are plotted. Asterisks denote $p < 0.05$ (*), $p < 0.01$ (**), $p < 0.001$ (***).

Moreover, different is the emissions behavior of large and small LAs in regards to the last monitoring year submitted. Large LAs obtain larger reductions the longer the implementation phase of the plan (ρ = +0.16 *), following a more incremental increase in the reductions. By contrast, small LA's reductions are negatively correlated with both the duration of the implementation phase (ρ = −0.12 **) and the monitoring year (ρ = −0.19 ***). The greatest reductions in small LAs occurred around 4–6 years from the start of the plan and 5–8 years before the end of the initiative, going against the general principle relating longer periods of action with longer achievements. This timeline is coincidental with the political mandate in LAs in Europe (4–5 years), which makes us believe that the political component of the local action planning in this kind of LAs contributes the most. The plans are prepared to achieve their targets at the end of the political cycle and not at the end of the initiative subscribed to, i.e., the CoM 2020.

Figure 3 gives us, as well, an important fact regarding the kind of analysis that can be conducted for the CoM 2020 dataset. As above mentioned, we should theoretically expect larger reductions the older the baseline year and the later the monitoring year. However, results show that reductions are weakly correlated with both baseline and monitoring years, these correlations diverge between small and large LAs, and, in small LAs, the correlations diverge from their expected behavior. This has a two-fold implication. First, our results are not systematically biased by the heterogeneous baseline and monitoring years, due to the lack of correlations and the diverging trends between LAs. Second, this adds another line of evidence to those mentioned in the Methods section on how extremely sensitive it could be to interpolate or extrapolate local emission inventories (see Limitations section).

Figure 4 presents the analysis of categorical attributes. For large LAs, there are two factors correlated with greater reductions: (a) conducting a stakeholders engagement process, especially within the local authority, and (b) to be an overlapper LA, i.e., LAs that, after joining CoM 2020, continue their increasing mitigation ambition by signing up to the extension of the initiative to 2030. In line with other studies [10,20,43], the active engagement of stakeholders in participatory processes from the early stages of the action planning benefits the full process and, therefore, is translated into greater achievements, ergo, larger reduction of the baseline emissions. As shown in Figure 4 and Table S2, large LAs with engagement processes within the local authority reduce on average 5% more than those without them.

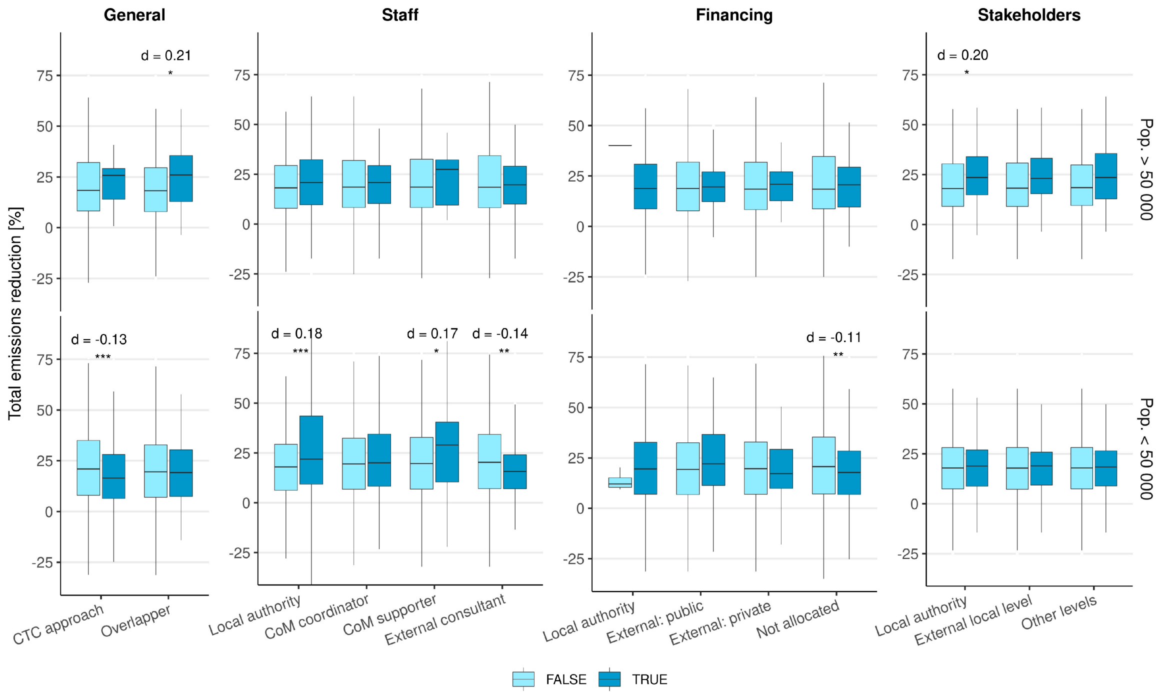

Figure 4. Statistical analysis of categorical attributes. Medians are statistically compared based on Mann–Whitney test. *d* represents Cliff's delta with its corresponding 95% confidence intervals. Asterisks denote $p < 0.05$ (*), $p < 0.01$ (**), $p < 0.001$ (***).

Covenant coordinators [23] are public authorities that are in a position of providing strategic guidance, as well as technical and financial support, to Covenant of Mayors signatories. There are three main types: CoM coordinators, CoM supporters, and Covenant Territorial Coordinators (CTCs) (see Methods Section). Results show that the involvement of CoM supporters is correlated with achieving greater reductions in the case of small LAs (4% on average). These supporters, closer to the local level, could ease technical and financial barriers that small LAs are prone to face. This could also mean that national supporters could benefit the LAs by having better information and understanding of the national policies already in place (or envisaged) to enhance the development of a more realistic and ambitious plan towards a just transition.

The involvement of local staff in every step of action planning is, as well, correlated with greater achievements. Finally, for small LAs, results show that the more detailed the allocation of funds for the development of the plan, the better results are obtained (3%). On the contrary, the study shows that LAs supported by the last type of coordinator, the "Covenant Territorial Coordinators (CTCs)", have smaller emission reductions than those without support. CTCs are decentralized authorities such as regions, provinces, or grouping of local authorities. While a positive effect or influence on gathering LAs for the initiative is demonstrated [23], the current effect on the implementation and achievement of the plan is not positive. This could be explained by the lack of personalization of the support given [20]. The same negative effect is found in small LAs with support from external consultants, which are usually hired for developing the local action plans in this type of LA. As described in previous studies [10,20,43], these companies include in their contracts only the development of the plan, excluding all the relevant phases of implementation, monitoring, and evaluation, which leads to poor implementation as well as a lack of monitoring reports and final evaluation of the impact of the actions undertaken. A deeper analysis of the different support given by the three types of coordinators could lead to an interesting best-practices extraction exercise on how to effectively support especially small LAs in local climate action.

4.4. Regression Analysis

The multi-collinearity between all the attributes was analyzed in the Supplementary document with a correlation matrix, analyzing and discussing groups of predictors with correlations above 0.35. The number of predictors was reduced from 25 to 11, selecting the set of independent features that best explain the GHG reduction variability. The ridge regression model has a Mean Absolute Error of 13.3% and 16.2% for large and small municipalities, respectively. The smaller error at large LAs could be explained by the potentially higher quality of the data reported by this kind of LA, and by the higher coherence of their plans, which makes it easier to estimate the total GHG reduction with the available group of predictors.

As shown in Figure 5, three significant predictors were found for large LAs: GHG reduction target and submission year, both with a similar influence on the output, and MEI year, with a smaller effect. The positive coefficients for the GHG reduction target and MEI year, and the negative coefficient for the submission year, are somehow expected—as described above—when the reductions are coherent with both the action plan and CoM timeline.

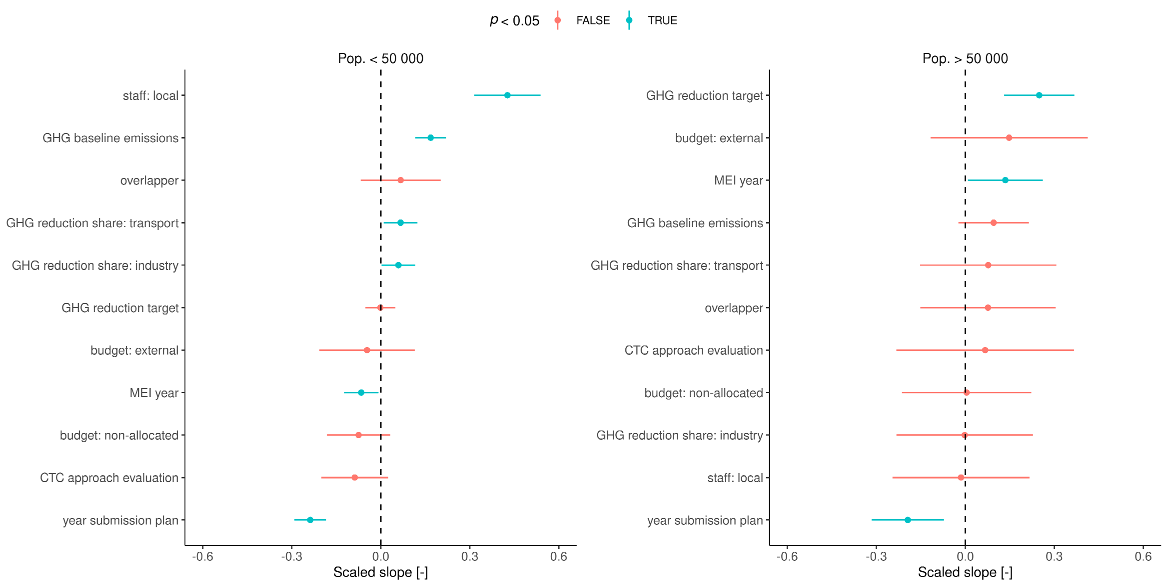

Figure 5. Ridge regression model coefficients with their 95% confidence interval for the 11 selected features.

The number of significant predictors increased up to seven for small LAs, as the larger number of small LAs narrows the confidence intervals. Using local staff in the development of the action plan was, by far, the predictor with the highest influence on the total GHG reduction for small LAs. It was followed by GHG baseline emissions and the submission year. The positive effect of the submission year in both small and large LAs could be explained, in line with previous results, by the combination of two effects. First, frontrunners tend to have more climate experience, which allows them to better develop and implement their plans. Second, they can start their plans before, and are more likely to have former baseline years.. The latter was measured in the correlation matrix. In large LAs, the submission year has a correlation of +0.41 with the baseline year and +0.17 with the SEAP start year in large LAs, while these values reduce to +0.05 and +0.00 in small LAs. This suggests that the climate experience might be even more critical for small LAs than for large ones. The three significant predictors with a smaller influence on the output were the reduction share of transport and energy sectors, and MEI year. Industry and transport reduction share both have a positive effect on the total reduction, which is in line with the sectorial analysis (Figure 2) that showed the key role of these sectors in achieving reductions above 20%. Compared to large LAs, the MEI year has a negative impact on the total GHG reduction. As discussed above, this goes against the expected reduction pattern, since larger reductions are expected close to the end of the initiative.

5. Limitations of the Study and CoM Methodology

The study is affected by different limitations, most of them originating from the CoM framework and its reporting system.

The first one is the reduced number of CoM signatories that are monitoring their progress (only 27.5% of CoM signatories). The reasons behind this low number were studied in a previous study [10]. Despite this, the number of LAs conducting monitoring is large enough to conduct statistical and regression analysis, as these LAs cover all EU-27 countries and still represent 19.2% of their total population. Note that, throughout the whole study, the population under analysis is CoM LAs monitoring their plans. We cannot infer anything from LAs outside this population, such as LAs with approved plans but not reporting monitoring information. This is the main reason for the critical importance of conducting the monitoring phase: we can only evaluate what we measure.

As stated in the methodology, another important limitation of the study is the different baseline and monitoring years of each LA. We discard the option of harmonizing the inventories to a common baseline and monitoring year, as this may introduce even higher uncertainty due to the specific reduction patterns of each LA. Instead, we analyzed the effects of this heterogeneity on our results by introducing both the baseline and monitoring year as predictor variables. We also analyzed the potential confounding effect of these variables on other predictors (e.g., submission year or GHG reduction target) in the multi-collinearity assessment. The effect of baseline and monitoring years on the total GHG reduction was higher in large LAs, due to the higher coherence of their plans, so—in this case—larger reductions are partly explained by older baseline years and later monitoring years. However, this effect was not observed in small LAs, which instead tend to have smaller reductions with later monitoring years (most likely due to the reduced experience of the LAs, and to their later adhesion).

All the data (predictors and output) has been self-reported by LAs, and may present some quality issues. To mitigate this, we only included LAs with plans officially accepted by CoM, as this guarantees that the data have undergone a series of basic quality checks and a coherence analysis. We also performed an extensive QC of the emissions reported by LAs, correcting the data when possible and discarding statistically unrealistic values. Despite this, some quality issues may remain in the dataset affecting both the predictors and the output. For instance, the large increase in GHG emissions in some sectors and LAs could be explained by the addition of new sources of information during the monitoring phase. However, this type of issue cannot be flagged with the information available.

Finally, we would like to clarify that the main goal of the study is to determine which LAs managed to obtain higher GHG emissions reductions and how they did it. We also included the GHG target as a potential predictor to check the coherence of the reductions with the action plan strategy, and we also evaluated the progress of each LA towards their target (GHG reduction/GHG target). However, readers should note that the GHG target is not a 'real' predictor, as just setting a high target does not guarantee a high GHG emissions reduction. Similarly, the GHG reduction target does not introduce any type of confounding effect, as setting a high target does not influence other predictors. Indeed, the relationship is the other way around. Attributes such as climate experience or developing plans locally have a positive effect both on setting ambitious targets and achieving those targets [20]. In any case, the study reveals the limited relationship between targets and achievements, particularly in small LAs, where high achievements are obtained with low coherent plans. The reasons behind the low coherence of these plans are outside the scope of the present study, but will be a clear objective for future analyses.

6. Conclusions

Local authorities already substantially contribute towards climate change mitigation. This initial evaluation of the first phase of the Covenant of Mayors (CoM 2020) reveals that, on average, EU LAs achieved 85.6% of their commitments already 6 years before the due date in 2020, and that 48% of them had already reached and even surpassed (super reducers) their targets before the end of the first phase of the initiative. However, large and small LAs present different reduction patterns driven by different interests and opportunities, and therefore, they have been treated independently in this research: LAs tend to focus on a long term-target and base their objectives and timelines on a coherent study of the initial emissions and the local capabilities, while small LAs are mostly driven by the political cycle. Local climate action is a two-speed process, and this is a factor that needs to be considered when developing harmonized frameworks for supporting and enhancing LAs. Even if the share of total emission reduction coming from small municipalities is only around 15%, the local climate action generates co-benefits and works in a cross-cutting manner (from resilience to circular economy or inclusion) that justifies the effort.

However, 12% of LAs in the study increased their total emissions in their last monitoring exercise (increasers). Most of these unexpected results are driven by emission changes in sectors that are usually out of the total influence of the local authority, or partly covered, namely, transport and industry. High reductions are observed in these sectors as well (LAs doubling and even tripling their original targets). This supports the evidence of the limitations of climate action at the local level. While there is a need for boosting local climate action, there is a greater need for investigating and quantifying this limitation and deepening the understanding of national influence. This would be the definitive key to anticipating and improving local climate achievements. The key factor for climate action planning seems to be the joint partnership between several government layers from a national perspective. In addition, these "negative" results are more frequent in LAs below 50,000 inhabitants because, as described above, small LAs have less experience, less influence on key sectors of activity like transport or industry, and they have short-term political driven goals as well that rule their action plans. On the other hand, large LAs present a higher level of plan coherence, where baseline emissions and targets are aligned with the achievements obtained. In order to support and enhance the current work conducted by local authorities towards 2030 targets, it would be necessary to conduct a study evaluating how they included and addressed the main key drivers and main barriers described in this paper.

The message should spur small LAs in adopting the long-term objectives, working on both feasible measures to be implemented in the short term (political cycle/mandate) and potential and desirable measures for future political cycles. It would be extremely useful to replicate this exercise once the second phase of the initiative finishes (2030) to assess the evolution of these patterns.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su142215081/s1, Figure S1: Temporal evolution of the total GHG emissions in LAs reporting 3 or more inventories. Only LAs starting the implementation of their plans in the baseline year (40% of total) and following a clear non-linear reduction pattern are shown; Figure S2: Summary of the GHG emissions reduction per subsector. (a) Total emissions reduction per subsector. The label shows the percentage of cities reporting emissions in that subsector. (b) Same as (a) but excluding municipalities not reporting emissions in that subsector; Figure S3: Number of monitoring reports submitted by small and large LA; Figure S4: Correlation matrix of the 24 attributes selected as potential predictors of the total GHG reduction; Figure S5: Correlation matrix of the 11 selected predictors after removing multi-collinearity effects; Table S1: GHG emissions reduction levels aggregated in super reducers (GHG reduction > 20%), average reducers (GHG reduction = 0–20%), and increases (GHG reduction < 0%); Table S2: Variation of SEAP progress with different intervals of total GHG emission reduction; Table S3: Variation of sector GHG emissions reduction with different intervals of total GHG emission reduction; Table S4: Statistical analysis of categorical attributes; Table S5: Mean absolute error of the 40 best sets of independent predictors for large LAs, using the ridge regression model; Table S6: Same as Table S5, but for small LAs.

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4.3 Publication III

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Towards the EU Green Deal: Local key factors to achieve ambitious 2030 climate targets

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ABSTRACT

Cities representing more than one third of the EU population have already developed their mitigation action plans with the support of the Covenant of Mayors initiative. This study digs into the drivers leading European cities in setting ambitious GHG reduction targets by 2030. A total number of 246 local action plans, accepted in the Covenant of Mayors initiative, were evaluated, and ambitious municipalities (with reduction targets over 50%) were compared against those committing to regular targets (40–50%).

Results show that the key factor enabling a higher climate ambition in cities is to develop local mitigation actions in line with the results of the baseline emission inventory, focusing on implementing actions in the most emitting sectors of activity. Furthermore, the study reveals the abilities of specific cities to set highly ambitious mitigation targets: to municipalise energy facilities increasing renewable energy production, and to be able of developing mitigation actions even tackling highly emitting sectors (e.g., transport) that traditionally are not under the competence of local governments.

The study also shows other easy-to-reach solutions that every local authority can take into account to increase its ambition such as developing in-house action plans and conducting a deep stakeholder engagement and participatory processes from the initial stage of the action plan development.

1. Introduction

Local climate action planning in Europe has a long history. For decades, European citizens and governments built on strong efforts to mitigate and adapt our territories to climate change: reducing GHG emissions and increasing resilience (European Commission, 2016). Around 50% of the world's population lives in cities, with a projected increase up to a 68% by 2050 (The World Bank, 2020). This percentage is even higher in Europe, where 75% of the population currently lives in urban areas. Cities account for 60% of the global energy consumption and 78% of the total GHG emissions worldwide (UN-Habitat, 2020). As a consequence, urban areas frequently concentrate citizens in high vulnerable locations, being therefore the focus of risk and change (IPCC, 2014; World bank, 2010). Yet, cities need to be part of the solution (Bertoldi et al., 2018; UN-Habitat, 2014).

Several initiatives tried to pave the way at local level towards a carbon neutral reality, aligning their objectives with EU priorities. The Covenant of Mayors (CoM, 2020) was launched in 2008 by the European Commission to support local authorities in the implementation of sustainable energy policies (Bertoldi. P (ed), 2018a). Signatories committed voluntarily to reduce their emissions by at least 20% by 2020 through the development and implementation of local energy driven action plans. CoM, 2020 engaged 7842 municipalities, representing around 40% of the EU-27 population. The initiative evolved in 2015 to the Covenant of Mayors for Climate an Energy (CoM 2030), integrating adaptation to climate change and raising the minimum GHG reduction target of European municipalities to 40% by 2030, in line with the EU overall target. In January 2017, CoM 2030 merged with the Compact of Mayors initiative into the Global Covenant of Mayors for energy and Climate (GCoM), expanding the coverage of the initiative worldwide.

Nowadays, the first priority on the EU agenda is the so-called European Green Deal (EGD) (European Commission, 2019), a set of policy initiatives with the overarching aim of making Europe climate neutral by 2050. As an intermediate step, the EU Commission presented a responsible plan to increase Europe's GHG reduction target for 2030 to at least 50% and towards 55%, compared with 1990 levels. CoM 2030 plays a key role in this process, since cities will be crucial for the EGD to become a reality. For instance, some CoM 2030 cities have already made

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commitments to reduce their GHG emissions by more than 50% by 2030. Evaluating these cities could help identify the factors behind their great ambition, paving the way towards climate neutrality. Indeed, such a study is recommended by the EGD, which considers the "Covenant of Mayors an essential platform to share good practices on how to implement change locally" (European Commission, 2019, p. 23).

Several studies have evaluated the existing plans to mitigate climate change from different perspectives. A very popular topic is the integration of mitigation and adaptation policies (Kim and Grafakos, 2019; Rashidi et al., 2019; Sharifi, 2020; Xu et al., 2019), extracting co-benefits and barriers from both strategies. Some studies have also identified the factors and barriers driving the implementation of climate action planning (Heidrich et al., 2013; Reckien et al, 2015, 2018). Best practices are generally provided at national level (Gouldson et al., 2015; Morgan et al., 2014), but the number of studies at local level is scarcer, partly because it requires an in-depth analysis of the action plans. Croci et al. (2017) analysed the actions of 124 CoM 2020 cities identiyfing baseline emissions as a driver of intended reductions. Palermo et al. (2020) analysed the policies of 315 CoM cities according to population, GDP and climatic conditions, finding that most policies are focused on municipal assets and that they change with population. Boehnke et al. (2019) analysed 13 small-medium cities in the Netherlands finding that 80% of the best practices identified were related to governing by enabling. Deetjen et al. (2018) extracted best practices from 29 major USA cities applying an analytic scoring rubric, identifying building quality, parking restrictions, and dense development as essential aspects. Wang et al. (2020) ranked the mitigation policies of C40 cities stating that the ranking results could be related to their energy mix and economic structures. Hsu et al. (2016) analysed the commitments of local governments and private sectors using the data platform Non-State Actor for Climate Action (NAZCA), discussing its main gaps and suggesting the need of information to track the achievements. Kuramochi et al. (2020) evaluated the impact of aggregated 2030 targets of sub-national actors at national scale. Hsu et al. (2020) evaluated the progress of CoM signatories finding that cities on track tend to be less ambitious and have larger baseline emissions. Salvia et al. (2021) identified city size, climate network membership, combining mitigation and adaptation, and local motivation as predictors of cities ambition. Overall, existing studies focus on small groups of large cities and lack robust statistical evidence, which may be partly due to barriers to accessing and analysing action-planning data. Likewise, the review conducted by Mi et al. (2019) claimed that most of the existing studies performed quantitative or qualitative analysis on climate change mitigation in cities without providing any practicable policy implications.

The few studies that have analysed statistically the local climate ambition are focused on identifying predictors of the ambition (Croci et al., 2017; Salvia et al., 2021). However, they mostly use variables such as city size, GDP, or the climatic region, among others, that can be correlated with climate ambition but never be a driver of it. Our study goes one step further by trying to identify the key characteristics common to the most ambitious European municipalities that allowed them to increase their GHG reduction targets. To do so, we statistically compare CoM front-runners with targets over 50% by 2030, i.e., the limit proposed by the EGD, against those municipalities only committing to the minimum target. Particularly, we evaluated aspects of the action plans that can be modified by the municipalities during the development of the plans in order to become more ambitious. The study is conducted with the first 246 action plans accepted by CoM 2030, including municipalities homogenously distributed over Europe with a wide range of population sizes. To the authors' knowledge, this is the first study that attempts to find statistically drivers of local climate ambition. The lessons learnt in this article could benefit municipalities all around the world in developing more efficient policies and measures for reaching a neutral carbon future.

2. Materials and methods

2.1. Subset description: CoM 2030 accepted plans

The Covenant of Mayors for Energy & Climate (CoM 2030) was launched in 2015, merging the European Covenant of Mayors (CoM, 2020) and Mayors Adapt initiatives (Bertoldi. P (ed), 2018b). From January 2016, municipalities could join the CoM 2030 initiative, committing to reduce the total GHG emissions in their territories and paving the way to a more resilient city by 2030, through the implementation of a local action plan, so-called Sustainable Energy and Climate Action Plan (SECAP). Signatories need to submit the plan within 2 years of the adhesion date. The European Commission's Joint Research Centre (JRC) has the mandate of conducting a qualitative and quantitative evaluation of the plan prior approval. The evaluation is based on a set of minimum criteria to meet in order to guarantee the overall credibility of the initiative. The JRC provides every signatory with a complete feedback, highlighting the main strengths and weaknesses of the evaluated plans and recommendations for improvement.

As of July 1, 2020, the number of municipalities committed to the CoM 2030 initiative amounted to 2420, representing 23% of the EU-27 population, of which 647 had already submitted their SECAP and 344 had been approved by the JRC. The 334 approved municipalities represent 10.3 million inhabitants (around 2.3% of EU-27 population). Our study focuses only on the approved local action plans, since the evaluation of the plans guarantees the coherence between the reduction target proposed and the actions planned to achieve those reductions. Most municipalities submit their SECAPs individually, although several submit a collective plan under two different options, joint SECAP option 1 and joint SECAP option 2 (Bertoldi. 2018a P (ed)). Groups of municipalities submitting their plans under the option 2 have to be accounted only once, as a group, because the assessment and the actions included in the plan refer to the whole group of municipalities. This reduces the dataset available for this study from 344 accepted municipalities (signatories) to 248 accepted independent SECAPs. For this study, the whole group of 248 SECAPs is analysed (Fig. 1A).

CoM signatories pledge to reduce their emissions by at least 40% by 2030. The European Green Deal has recently proposed raising this target to at least 50% and towards 55% by 2030. Therefore, we used the new EGD target to classify CoM cities according to their objectives in two groups: ambitious (22 out of 248) and regular cities (226 out of 248). We considered as ambitious those CoM signatories with targets greater than the new EGD target ($target_{2030} \geq 50\%$), while regular cities are those CoM signatories committing regular targets ($40\% \leq target_{2030} < 50\%$). The resulting groups are substantially different in size because most CoM signatories pledge to the minimum target (Fig. 1B).

2.2. Attributes: potential drivers of ambitious mitigation plans

Following the common reporting framework elements (Global Covenant of Mayors for Climate and Energy, 2018), several attributes were selected to be further investigated as potential drivers of ambitious mitigation targets. These attributes were classified into four groups (Table 1). The first group comprises general attributes such as geographical location, population and population density. The subsequent groups relate to the main elements of the SECAP: strategy, assessment and action planning.

European signatories are asked to submit their current local action(s) plans, dully approved by the city council, and to translate the main features of the plans into the online tool MyCovenant, using the SECAP template as described in the reporting guidelines (Covenant of Mayors Office - Europe, 2020). This study analyses only the data reported via the online platform. The SECAP template has three main sections: strategy, assessment and action planning. The strategy refers to both, mitigation and adaptation pillars, whereas assessment and action planning have differentiated parts. In this study, only the mitigation part of the SECAP

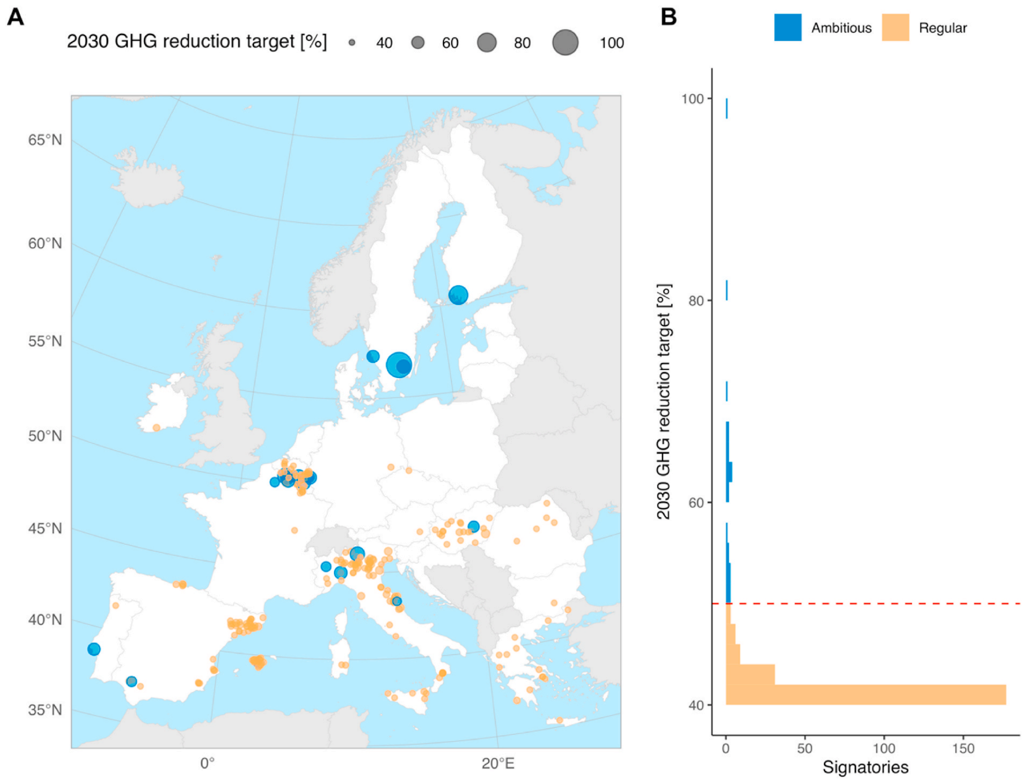

Fig. 1. **(A)** Spatial distribution of the 248 CoM municipalities used in the study. Point size represents their 2030 GHG reduction target. **(B)** Histogram of the GHG reduction target.

is analysed. The following subsections describe the main components used to analyse the ambition of cites from each section of the template. For more details on the template structure and definitions, we refer to the CoM reporting guidelines (Covenant of Mayors Office - Europe, 2020) and to the GCoM common reporting framework (Global Covenant of Mayors for Climate and Energy, 2018).

2.2.1. *Strategy*

The core of a local action plan needs to be synthesized in the so-called strategy of the reporting templates. This common element contains the basic data that will allow the municipality to develop an efficient and feasible action plan for mitigation and adaptation (Bertoldi, 2018c P (ed)). Cities are encouraged to focus on this part of the template, investing as much time as necessary in understanding their vision (short- and long-term strategy for their territories), their real objectives to the due date (2030), and how could turn them into reality. Responsibilities within the municipality, possible investments and necessary participatory processes engaging stakeholders are key elements.

The following parts of the strategy were analysed:

- **Commitment to CoM, 2020**: Percentage of cities with an accepted action plan for the CoM, 2020 initiative as well, also known as overlappers, and GHG reduction target of those cities by 2020.
- **Staff**: Type of staff allocated in the preparation of the SECAP classified as local authority, Covenant coordinator, Covenant supporter, external consultant and others. Multiple selection is available.
- **Stakeholders**: Type of stakeholders engaged in the development of the SECAP classified as local authority staff, external stakeholders at local level, stakeholders at other levels of governance. Multiple selection is available. Note that the level of engagement is a qualitative description selected by the municipality from the three possibilities given on the reporting platforms: high, medium and low, as part of their own progress assessment.
- **Budget**: Overall budget for the implementation of the actions described in the SECAP and type of financing resources used to meet the budget. Multiple selection is available. The overall budget was transformed to annual budget per capita [EUR/cap/year] in order to allow the comparison between signatories.

2.2.2. *Assessment: baseline emission inventory*

Cities are to report an assessment of GHG emissions, including a complete emission inventory, preferably from 1990 or at least from the first year they could gather robust information. This assessment is the base for setting the reduction target objective to 2030, helping cities develop concrete actions to target the most emitting sectors of activity. The emission inventory follows a bottom-up approach; GHG emissions are calculated by applying conversion factors to the energy consumptions of energy-related sectors and then adding the GHG emissions of non-energy sectors. In the Covenant framework, the sectors of activity are grouped into three (macro)sectors: (i) buildings, equipment/facilities and industries, (ii) transport, (iii) and other. The municipalities are allowed to report aggregated data for the whole sector. Within sectors, sub-sectors are detailed, allowing municipalities reporting emission data in sectors of activity when feasible (municipal building, industry, etc.). The non-energy sector includes wastewater treatment and waste management. The inventory includes direct emissions (scope 1) and indirect emissions due to the consumption of grid-supplied energy (scope 2). Subsectors with zero emissions can be due to either the non-existence of

Table 1
Attributes used to analyse the ambition of mitigation plans.

Category		Attribute		Type
Administrative attributes		Location		Spatial
		Population		Numerical
		Population density		Numerical
SECAP	Strategy	SEAP submission year		Numerical
		Overlappers	Accepted plans in both CoM, 2020 & 2030	Categorical
			2020 GHG reduction target	Numerical
		Staff allocated	Local authority	Categorical
			CoM coordinator	Categorical
			CoM supporter	Categorical
			External consultant	Categorical
			Other	Categorical
		Stakeholders	Local authority's staff	Categorical
			External stakeholders at local level	Categorical
			Stakeholders at other levels of governance	Categorical
		Annual budget		Numerical
		Financing sources	Local authority	Categorical
			External: public	Categorical
			External: private	Categorical
			Not allocated	Categorical
	Assessment: Baseline Emissions Inventory	GHG emissions	Total	Numerical
			By sector	Numerical
			By subsector	Numerical
		Local energy supply		Numerical
	Action planning	GHG reductions	By sector	Numerical

emissions or the inability of the cities to collect the data. For a detailed description on the emission sectors we refer to the CoM reporting guidelines (Covenant of Mayors Office - Europe, 2020).

Cities have the flexibility to apply different methodological approaches to calculate their inventories: (i) they can either follow an activity-based approach (IPCC factors) or a LCA approach, (ii) they can report tons of CO2 or tons of CO_2eq (including other GHGs), and (iii) they are recommended to use 1990 as baseline year but they can use the closest subsequent year, preferably before 2005. Consequently, the 248 inventories in this study present several differences.

Regarding the inventory year (Fig. S1), the difference between ambitious and regular municipalities is small (2007 vs 2006, respectively), and we did not observe any trend when analysing the emissions according to their inventory year. Despite this small difference, European emissions are gradually decreasing since 1990, therefore this could lead to think that the so-called ambitious municipalities in this study were able to select more ambitious targets because of their greater baseline emissions per capita. However, we analysed the inventories between 2005 and 06 (51% of signatories) and the trends were similar to those observed in the whole dataset, so the baseline year effect can be neglected in this study (Fig. S1B). Thus, we included all the municipalities not to lose specific characteristics of early local climate planners, with baseline inventories in early years and so-called "frontrunners". Note as well that the 50% threshold used to classify municipalities among regular and ambitious is even higher that what it would have been in case all the municipalities shared 1990 as baseline year. The more recent the baseline year, the lower the initial emissions, and the shorter the path to implement the plan.

As for the reporting units and the emission factors, the number of cities using CO_2 or CO_2eq was very similar and most of the cities used the IPCC emission factors (Fig. S2). The different approaches were harmonised in order to keep the sample size as large as possible when analysing sectors and subsectors. LCA emissions were transformed into IPCC ones by applying a factor of 0.885, which is the average ratio between LCA and IPCC factors (Cerutti et al., 2013). CO_2 was transformed into CO_2eq by applying a factor of 1/0.85 because CO_2 is responsible of the 85% of global warming potential at European scale (Cerutti et al., 2013). Despite the limitations of using these average conversion factors, the resulting harmonised values are in the same order of magnitude (Fig. S2). Once more action plans are available, the same study could be repeated by analysing each methodological approach individually.

In their assessment, cities also report the energy produced locally in the base year in the following four categories: certified green electricity (sold and purchased), local electricity production, renewable electricity production and local heat/cold production. These fields serve to quantify the energy production capacity of the municipality at the inventory year (Kona et al., 2018).

2.2.3. *Action planning*

The third and more important part of the reporting is called action planning. In this section, the SECAP template includes a detailed description of each individual mitigation action included in the action plan and an overview of all the actions aggregated per sectors. Unfortunately, reporting the estimated GHG reduction per action is not mandatory, so this study uses the estimated GHG reduction per sector. Note that the activity sectors in the reporting system covered by the assessment and action parts are not exactly the same. Sectors included in the action part combine BEI sectors and subsectors. Besides, the action plan accounts for the local electricity and local heat/cold production, which are sectors without direct consumption in the assessment.

The total GHG reduction ($\sum GHG\ reduction_{sector}$) is used to verify that municipalities undertake the required actions to achieve their mitigation commitments (*GHG target* [%]):

$$GHG\ target\ [\%] \geq 100\frac{\sum GHG\ reduction_{sector}}{\sum GHG\ emission_{sector}}$$

This part of the study only considered those municipalities with a total GHG reduction consistent with their targets (158 signatories). Municipalities that reported in their templates a total GHG reduction larger than the one included in their formal commitments were discarded.

2.3. Statistical analysis

A statistical analysis was conducted to evaluate the detailed differences between regular and ambitious municipalities. The analysis was performed using nonparametric tests due to the small sample size and the non-normality of most attributes.

Categorical attributes had a binary response, true or false, resulting in 2 × 2 contingency tables when comparing regular and ambitious cities. These attributes were analysed with the Fisher's exact test, a non-parametric test designed to compare the distribution of categorical variables between two groups. The use of Fisher's exact test is particularly recommended for 2 × 2 contingency tables with low frequencies, such as the ones of the current study (Kim, 2017). The null hypothesis H_0 signifies that there is no difference between the distributions of the two groups. Therefore, if H_0 is rejected, a statistical difference in the evaluated attribute exists between regular and ambitious cities.

Numerical attributes were analysed with the Mann-Whitney *U* test, a non-parametric ranked test used to evaluate the differences between two non-normal groups. According to the null hypothesis H_0, the observations of both groups are drawn from the same population, i.e., they have the same median. The alternate hypothesis H_1 stipulates that data from the two groups differ. Additionally, if both groups have the same shape, we can state that the medians of both groups are not equal. In this study, all numerical attributes are per capita values that have positively skewed distributions for both regular and ambitious cities. In this line, several studies in literature confirm that anthropogenic GHG emissions follow lognormal distribution (Cui et al., 2019; Ott, 1990). Therefore, we can state that when H_0 is rejected, the medians of regular and ambitious cities are statistically different.

A significance level of 0.05 was used, rejecting the null hypothesis if *p-value* < 0.05. However, categorising the results into two rigid groups, significant and non-significant, should be avoided (Amrhein et al., 2019). All differences between regular and ambitious municipalities were discussed based on their magnitude, and *p-values* were used as an additional tool in this analysis. Besides, in order to overcome the well-known dependence of *p-value* on sample size (Altman and Krzywinski, 2017), effect sizes were also calculated (Tomczak and Tomczak, 2014): the odds ratio for Fisher's exact test, and Cliff's delta (*d*) for Mann-Whitney test. In both cases, the 95% confidence intervals (CIs) were included. For the odds ratio, if the 95% CI includes 1, the odds for the two groups analysed are the same (McHugh, 2009). Otherwise, the larger the odds ratio the strongest the effect observed. Cliff's delta (*d*) varies from −1 to 1 and can be interpreted as follows: small effect ($0.11 < |d| < 0.28$), medium effect ($0.28 < |d| < 0.43$), large effect ($|d| > 0.43$). All numeric *p-values* and effect size estimates are provided as supplementary material (Tables S1–S4). For quantitative attributes, the median was also reported due to the non-normality of the data.

Note that the results of the statistical tests do not allow to conclude anything more concrete that there is some link between the attributes and the ambition of the plans. It does not necessarily imply that one variable has any causal effect on the other. More data is needed to make extrapolations to upcoming CoM action plans and plans outside the CoM framework.

3. Results

3.1. Administrative attributes

The municipalities included in the study are homogeneously distributed over Europe, with Spain, Italy and Hungary having the largest densities (Fig. 1). Ambitious municipalities are represented in all European regions, but Northern Europe has a particularly high density. Not only all four Scandinavian cities are ambitious but two of them have also the greatest GHG reduction targets (80 and 100%).

The group of municipalities analysed includes a wide range of population sizes, from large cities (810 064 inhab) to small villages (83 inhab). Both, population and population density, are positively skewed (Fig. S3), with the median population being in the range of small-to medium-size town. No statistical difference between regular and ambitious cities was observed regarding population (regular = 13030 inhab, ambitious = 9662 inhab) and population density (regular = 241 inhab/km^2, ambitious = 184 inhab/km^2).

3.2. SECAP strategy

Ambitious municipalities started their plans on average 3 years before regular ones (2007 vs 2010). They also had slightly older data to compile their baseline inventories (2006 vs 2007) (Fig. 2A). Both facts suggest that ambitious municipalities had more experience in climate action planning than regular ones before joining the CoM initiative. Note that CoM signatories can submit plans that are already implemented before they join the initiative, explaining the existence of plans started since 1990.

We also evaluated if the continuity from 2020 to 2030 CoM initiatives influenced the development of ambitious plans. About a 20% of the signatories evaluated, with accepted plans for CoM 2030, also had an accepted plan for CoM, 2020. These figures are similar between regular (21%) and ambitious cities (23%). However, their 2020 targets differed (Fig. 2B). Cities with ambitious targets by 2030 also had more ambitious targets by 2020 (regular = 22%, ambitious = 29%). The differences in the 2020 targets were smaller than those observed in 2030 for the same municipalities (regular = 40%, ambitious = 60%). The gap between ambitious and regular groups is increasing not only in absolute terms (from +7% to +20%) but also in relative ones (from 1.3 to 1.5). The latter is particularly relevant because theoretically the smaller the total emissions are the harder should be to reduce them.

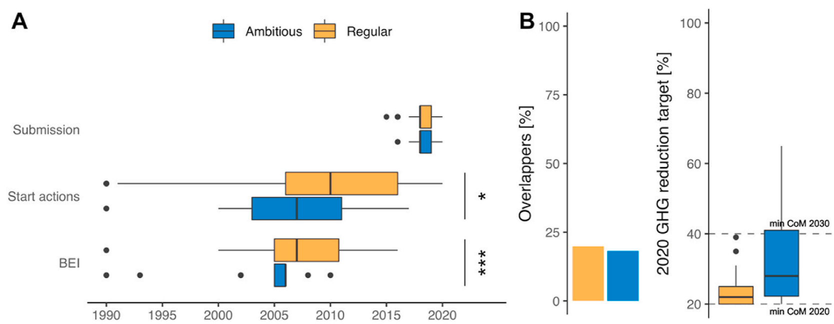

Fig. 2. (A) Comparison of the SEAP submission year, SEAP start year (implementation of the first action), and baseline year (BEI year). **(B)** Percentage of overlappers (municipalities with accepted plans in both CoM, 2020 and CoM 2030) and their GHG reduction target by 2020.

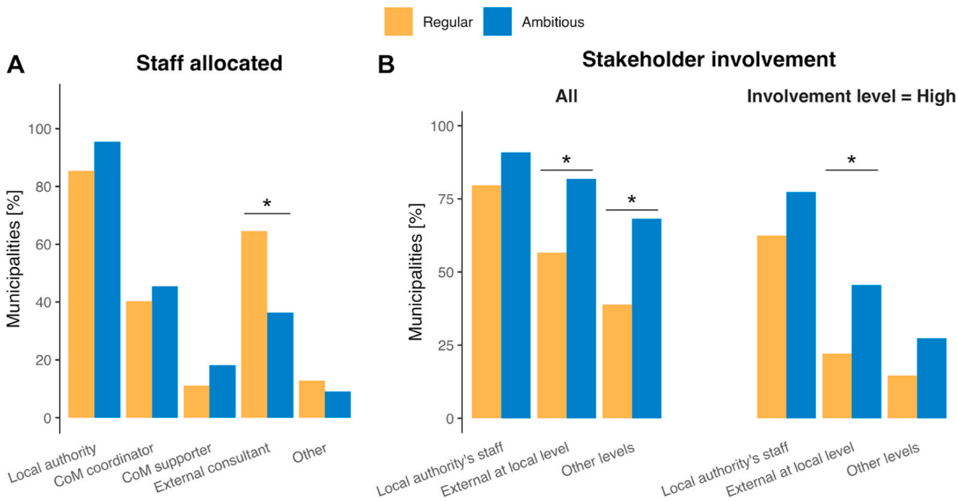

Fig. 3. **(A)** Type of staff allocated and **(B)** stakeholders engaged in the preparation of the SECAP. Asterisks denote $p < 0.05$ (*) by Fisher's exact test.

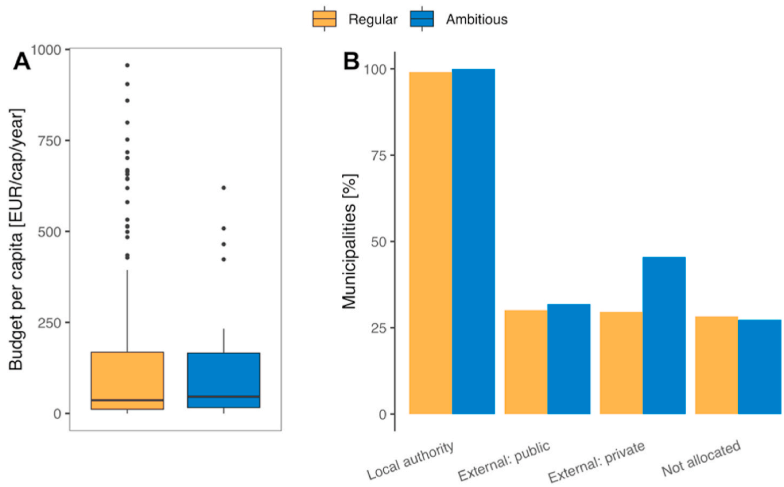

Fig. 4. **(A)** Annual budget and **(B)** financing sources used by the signatory for the implementation of the SECAP.

The type of staff allocated for the development, implementation and monitoring of the action plan (Fig. 3A) and the engagement processes conducted among stakeholders (Fig. 3B) are two key aspects when defining the strategy of the action plan. Staff allocation by regular and ambitious cities was very similar except when it came to support by external consulting. The analysis reveals that 64% of baseline cities are using external consultancy to develop their SECAPs, compared to a 36% of ambitious cities ($p = 0.012$). Thus, the odds of developing ambitious plans are 3.2 times higher when external consultors are not used (*odds* = 0.31). In terms of stakeholder engagement, Fig. 3B shows that despite both groups have similar distributions of the type of stakeholders engaged, ambitious cities are engaging more stakeholders in all the categories recorded. This difference is observed either when analysing all the stakeholders together (All) or when focusing in those with a high involvement level. The statistical analysis reveals particularly strong differences for 'External stakeholders at local level' category ($p = 0.024$ (All), $p = 0.033$ (High)). The odds of developing ambitious plans are 3.2–3.3 times higher when engaging external stakeholders at local level.

No significant differences were found between regular and ambitious cities in terms of annual budgets and financial sources (Fig. 4). The median annual budgets were 46.1 and 36.4 EUR/cap for ambitious and regular cities, respectively. This difference is negligible if compared with the large variability within each group ($sd = 206$ for regular cities, $sd = 192$ for ambitious cities). Besides, both groups use the same financing sources, primarily local authority resources. Note that Fig. 4B only shows if the city is using funding from that source or not. The portion of the total budget provided by each financial source is not available.

3.3. SECAP emission inventory: GHG emissions

The GHG emissions in the base year of ambitious cities (6.18 tCO_2-eq/cap) are greater than those of regular cities (Fig. 5) (5.07 tCO2-eq/cap). This is explained by the existing differences in the two main sectors of the inventory: buildings (regular = 3 tCO_2-eq/cap, ambitious =

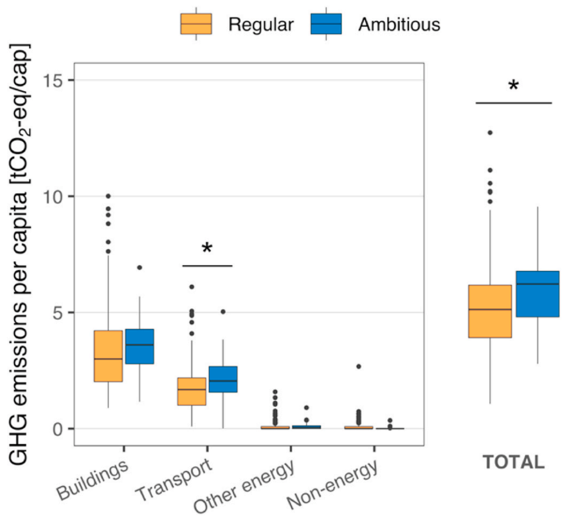

Fig. 5. Total and by sector GHG emissions per capita in the baseline year of regular (40% > $target_{2030}$ < 50%) and ambitious ($target_{2030}$ > 50%) municipalities. Asterisks denote $p < 0.05$ (*) by Mann-Whitney test.

3.61 tCO_2-eq/cap), and particularly in transport (regular = 1.68 tCO_2-eq/cap, ambitious = 2.05 tCO_2-eq/cap, p-value = 0.044, d = 0.26) (Fig. 5). The main subsectors of both sectors present a similar trend: residential buildings (regular = 1.7 tCO_2-eq/cap, ambitious = 2.22 tCO_2-eq/cap) and private transport (regular = 1.45 tCO_2-eq/cap, ambitious = 1.82 tCO_2-eq/cap) (Fig. S4). Overall, despite having similar population sizes, ambitious cities emit more per capita than regular cities in most of the subsectors and sectors analysed. Note that this trend was also observed when comparing only the inventories of 2005 and 2006 (51% of signatories), so ambitious cities emit more per capita regardless their base year.

3.4. SECAP actions

3.4.1. GHG reductions

On average, ambitious cities have planned to reduce 3.3 tCO_2-eq/cap whereas this value is 2.1 tCO_2-eq/cap for regular cities. The larger reductions in the ambitious group are explained by their significant reductions planned for the transport sector (regular = 0.55 tCO_2-eq/cap, ambitious = 0.98 tCO_2-eq/cap) and local/heat electricity production (regular = 0.38 tCO_2-eq/cap, ambitious = 1.14 tCO_2-eq/cap, p-value = 0.04, d = 0.43) (Fig. 6). Ambitious cities also show statistically larger reductions in the local heat/cold production, though in this case the overall reduction is smaller due to the lower share of the sector. By contrast, there are two sectors in which regular cities achieve larger reductions than ambitious ones: residential buildings (regular = 0.61 t CO_2-eq/cap, ambitious = 0.41 t CO_2-eq/cap) and municipal buildings (regular = 0.14 t CO_2-eq/cap, ambitious = 0.06 t CO_2-eq/cap).

The energy production in the inventory year (Fig. S5) reveals that ambitious cities have the capacity to produce their own energy, particularly heat/cold, even before developing their action plans. Two municipalities were already producing over 4 MWh/cap of heat/cold at the baseline year. On the contrary, the capacity to produce energy locally in regular cities is very limited (all medians = 0), since this is generally out of the scope of the local authorities.

3.4.2. Alignment of emissions and reductions

The previous figures are further analysed by comparing the GHG emission share (emissions per sector/total baseline emissions) against the GHG reduction share (reduction per sector/total baseline emissions), using the action sectors as reference (Fig. 7). Note that electricity and heat/cold production sectors are removed because they don't have direct consumptions in the assessment. Overall, the performance of regular and ambitious municipalities in sectors traditionally under the municipality competence is similar and allows them to reach the minimum target of 40% by 2030. Nevertheless, their performance in these sectors is insufficient for setting ambitious mitigation targets (over 50%) towards 2030. Fitted lines showed that municipalities included in the study achieve the greatest relative reduction in municipal buildings (68% of the sector emissions), but the impact on the overall reduction (y-axis) is very reduced due to the small emissions share of the sector. Municipalities reduce on average a 36% and 34% of their emissions in the transport and residential buildings sectors, respectively, which are

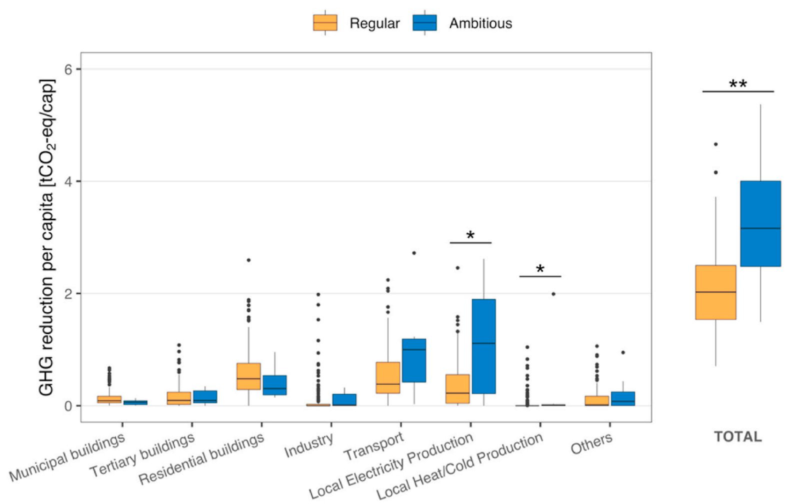

Fig. 6. Total and by sector GHG reductions per capita of the actions planned. Asterisks denote p < 0.05 (*) and p < 0.01 (**) by Mann-Whitney test.

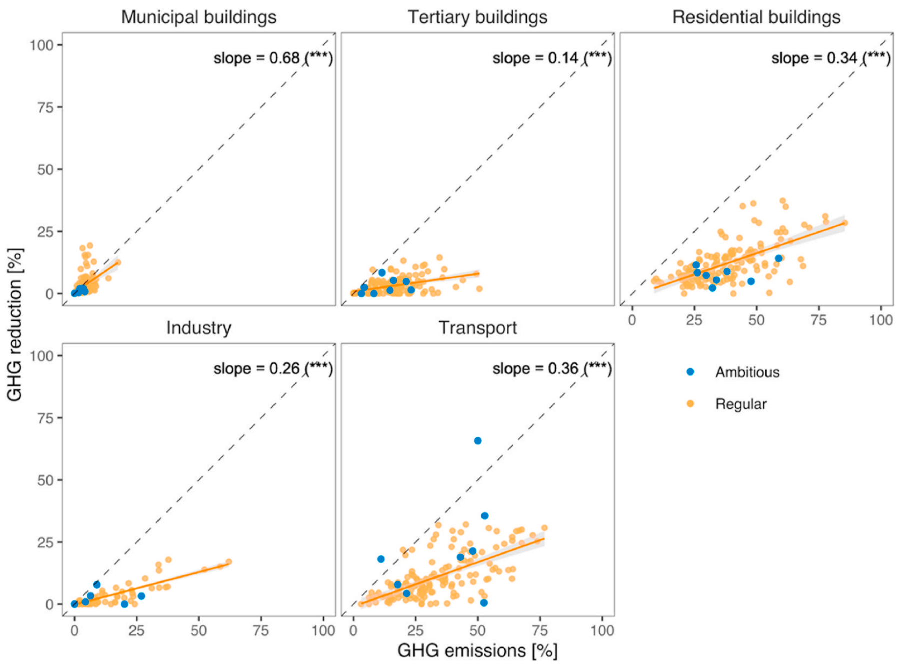

Fig. 7. Planned GHG reductions vs. baseline GHG emissions by sector. Percentages show the emissions/reductions in the sector divided by the total baseline emissions. Linear regression slopes show the reduction obtained per sector (dashed line = 100%). The 95% confidence intervals of the regression lines are in grey. Regressions for ambitious cities were not included due to the small number of samples.

the most emitting sectors. What the figure also shows is that the so-called ambitious cities make the difference in the transport sector, where their reduction commitments are larger than the rest of cities. Note that two municipalities (Växjö and Kungsbacka) reach reductions above 35% from their total baseline emissions only with actions in the transport sector. Therefore, to expect more reduction on this specific sector, and to be able to implement actions in this particular sector, usually not under the municipality influence, appears to be the enabling factor of increasing their global target to 2030.

On the other hand, the overall impact of regular cities in the sectors in which they outperform ambitious cities is very moderate. In residential buildings, despite being one of the most emitting sectors (40–50%), the overall reduction achieved by regular cities is only around 10–20%. In municipal buildings, regular cities plan even larger reductions (15–20%) than the emissions reported in the assessment (5–10%), but again the impact on the overall reduction is moderate due to the small share of this sector.

4. Discussion

Several attributes were identified as potential drivers of ambitious reduction targets. Among them, a key factor for a successful development of a plan is to develop actions in the activity sectors that are responsible for the largest share of GHG in the municipality, i.e., to be coherent with the GHG assessment conducted. Unfortunately, not all the sectors of activity are under the direct influence of the municipality (Palermo et al., 2020). Scope 2/3 emissions are generally outside city boundaries (Wang et al., 2020), therefore local authorities have limited influence on the most significant cases of emissions (Deetjen et al., 2018). In this study, both ambitious and regular municipalities showed two main sectors of activity that are generally out of their scopes: residential buildings and private transport (Fig. 8). The residential buildings sector is related to electricity and heat consumption, whereas the emissions in private transport relates to the consumption of fossil fuels. Consequently, in these sectors, local authorities focus most of their efforts on energy saving actions that have a limited reduction capacity.

The main advantage found in several ambitious municipalities is that they are able to produce their own energy, mostly in a sustainable way. Therefore, instead of being limited to energy savings policies, they can achieve larger reductions by increasing their renewable energy share. For instance, some municipalities (Lincent, Unione dei Comuni della Valsaviore, Turku, Växjö) planned reductions over 2 tCo2/cap in the 'local electricity production' and/or the 'local heat/cold production' sectors by deploying different renewable sources (PV, biomass, hydroelectric). Moreover, the assessment (Fig. S5) revealed that northern cities such as Turku or Växjö already had the capacity to produce their own electricity before taking any actions, thanks to the creation of municipalised energy companies (Växjö Energi, Turku Energia). This allowed them to set the most ambitious reduction targets overall, closing in on carbon neutrality by 2030 (targets 80%–100%)

The success of ambitious municipalities was also explained by their capacity to act on one of the most emitting sectors, the private transport (Fig. 7), leading towards higher reduction targets. Actions undertaken by several municipalities in this sector achieve up to 35% of total emissions, partly because specific transport plans that have been existing in the municipality for years (e.g., Växjö and Kungsbacka). On the other hand, regular cities focused their actions to the residential sector, where both regular and ambitious groups had limited competences, and to the municipal building sector. The latter has a great exemplary role and is under the direct influence and competence of the local authority. However, it accounts for a discrete level of emissions, so the actions undertaken in this sector don't reach a level of emissions reduction high enough to set ambitious targets.

Results also evidenced that, overall and regardless the base year selected, ambitious cities had larger baseline emissions per capita than regular ones. This was also stated by Croci et al. (2017), who found a

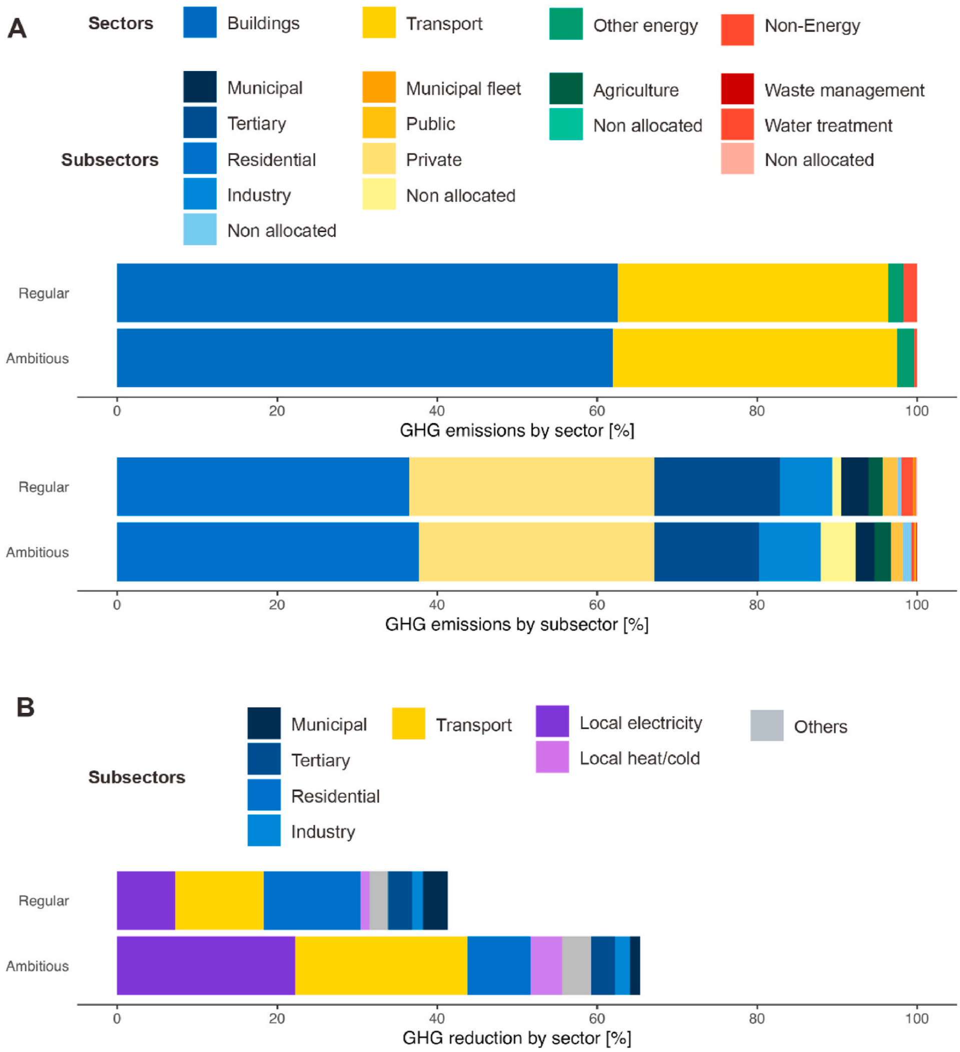

Fig. 8. (A) Average GHG emission share at the baseline year by activity sector in regular and ambitious municipalities. **(B)** Average GHG reduction share of the actions planned by 2030 in regular and ambitious municipalities.

correlation between baseline emissions and intended reductions in a subset of CoM, 2020 cities. We hypothesize that this correlation could be because ambitious cities, have a longer experience in action planning allowing them to develop more detailed emission inventories. Besides, despite the fact that the financial capacity of the municipality has been historically associated with frontrunners' activities and high ambition (Gouldson et al., 2015), we did not find any relationship between the implementation costs and the emissions reduced by the action plans. Neither the annual investment per capita nor the type of financial source differed between ambitious and regular municipalities. Therefore, the results indicate that local climate ambition is independent of the budget available.

The alignment between emissions and reductions explains the main geographical differences observed in the current subset of European municipalities. Despite the homogeneous distribution of ambitious and regular cities across Europe, Northern European municipalities present a higher level of ambition in the subset included in this first analysis of possible drivers leading to carbon neutrality in the frame of the European Covenant of Mayors CoM 2030. And this is not a coincidence. First, most of the cities included in this region have a long experience on local action planning. They were the frontrunners in the implementation of the CoM, 2020 and, as seen before, it gives evidence that previous experience in local climate action initiatives allows municipalities to set more ambitious targets (they are able to develop more accurate inventories and to establish earlier starting years for the actions included in their plans). Moreover, these frontrunners have the advantage of being able to produce local energy for heating buildings, mostly in a sustainable way, which is the main driver to increase mitigation ambition and achieve greater emissions reductions.

When competences cannot be reviewed, local authorities have two main options to increase their ambition level: develop effective stakeholder engagement or develop in-house action plans. It is demonstrated that a local action plan developed and monitored in-house leads municipalities to a higher level of ambition. The odds of being ambitious increased by 3.2 when the action plans were developed in-house. External consultants could lack the necessary level of knowledge on the specificities of the municipality and seem to overlook possible strategies and measures towards a feasible reduction in several sectors of activity. Besides, external contracts generally end after writing the plans without supervising the implementation and monitoring of the actions proposed. To improve both action planning and monitoring, a key staff member of the city should be involved since the first stage.

The level of engagement and the number of stakeholders involved also appeared to be crucial factors, allowing municipalities to raise their target level. The importance of engaging stakeholders has already been highlighted in the literature for both mitigation (Boehnke et al., 2019; Melica et al., 2018; Reckien et al., 2015) and adaptation planning (Rivas et al., 2021). On average, the odds of being ambitious increased by 3.2–3.3 when engaging stakeholders, particularly at local level. Moreover, it seems that the engagement and participatory processes are also developed better when the plan is done in-house.

5. Conclusions

Reaching and indeed exceeding national or EU GHG reduction targets, such as those proposed by the EU Green Deal, is not an easy task. However, many municipalities across Europe are aware of their crucial role and are developing strategies towards carbon neutrality by 2050. The experience of those cities that have already joined the CoM 2030 initiative with ambitious GHG reduction targets could serve as an example for others.

The key enabling factor for higher climate ambition in cities is the development of local mitigation actions in line with the results of the baseline emissions inventory; focusing on implementing actions in the most emitting sectors of activity. In specific cases, previous experience in local climate action initiatives allows municipalities to set more ambitious targets. What enables a city to be ambitious is the influence it has on the major emitting sectors. While this alignment is unfortunately not always possible, as several sources of emissions within the municipal boundaries are outside the direct control of the local authority, it can be achieved by setting up municipal energy facilities for the local production of energy (electricity, heat/cold). On the other hand, operating in the activity sectors controlled by the local authority is of great relevance because of the exemplary role that only the local authority can play, but this usually only allows cities to reach the minimum mandatory target for joining the initiative (40% in the COM 2030 framework).

Nonetheless, there are other ways of improving local action plans that allow municipalities to commit to more ambitious targets: the development of in-house planning, an active and effective involvement of stakeholders, or a combination of both. Alternatively, outsourcing the work could also lead local authorities to a better, more efficient and ambitious local climate action, provided that the strategy proposed is closely supervised.

Disclaimer

The views expressed here are purely those of the authors and may not, under any circumstances, be regarded as an official position of the European Commission.

CRediT authorship contribution statement

Silvia Rivas: Conceptualization, Methodology, Investigation, Writing – original draft. **Ruben Urraca:** Investigation, Data curation, Formal analysis, Visualization, Writing – original draft. **Paolo Bertoldi:** Writing – review & editing, Supervision. **Christian Thiel:** Writing – review & editing, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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4.4 Publication IV

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A comparative analysis to depict underlying attributes that might determine successful implementation of local adaptation plans

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ABSTRACT

Current trends in climate change indicate that the impact on the most vulnerable systems will increase. Urban areas, which concentrate population, economic activity and infrastructures, are sometimes at high-risk locations. Yet they are to be considered as vulnerable systems in need of harmonized structures supporting their efforts towards mitigating climate effects and/or adapting their territories to them. One current structure is the Covenant of Mayors for Climate and Energy (CoM) initiative, tackling in a global and harmonized way local adaptation to climate change. Do CoM cities that developed acceptable climate change adaptation plans have similar characteristics? It is still unclear which might be the drivers or key attributes potentially leading to successful planning within the initiative. In this paper, we explore attributes of the first 51 cities that have submitted their adaptation plans to CoM, in order to identify common elements among accepted plans. Therefore, our hypothesis is that there must be attributes determining the acceptance of adaptation plans. In order to do so, the cities were classified as compliant and non-compliant with the CoM principles. Fisher's and Kolmogorov-Smirnov tests were applied to identify attributes that are statistically different between both groups. Results show that the engagement of multiple stakeholders and citizens, particularly at the local level, might significantly facilitate the acceptance of adaptation plans in the initiative. We also found that the benefits of stakeholder and citizen engagement could be greater in small municipalities because citizens and stakeholders have more opportunities to participate.

1. Introduction

Climate change is occurring and poses risks for human and natural systems. The high frequency of heat waves, heavy precipitations, floods, and droughts is already impacting the most vulnerable systems (IPCC, 2014a, 2014b) and the current studies show that increasing effects are expected (Aguiar et al., 2018; Madsen et al., 2014). Urban areas are usually concentrating population, economic activity, and infrastructures in high-risk locations; therefore, taking an increasingly active role in climate policy action is needed (Campos et al., 2017). Cities are in need of harmonized structures supporting or guiding their efforts towards mitigating climate effects and or adapting their territories to them (Araos et al., 2016), like the Covenant of Mayors initiative (EU MEX/15/5840 IP/16/2247).

The Covenant of Mayors for Climate and Energy (CoM) initiative, launched back in 2015 by the European Commission, is a climate change action mainstreamed at local government level tackling adaptation to climate change. This local initiative is based on three pillars: mitigation, adaptation to climate change and secure, affordable and sustainable access to energy. Yet, local authorities engage in climate action with the commitment of producing a feasible and measurable Sustainable Energy and Action Plan (SECAP) on their territories. Particularly, in this paper, we focus on the adaptation strategies that have already been submitted to CoM.

The adaptation to climate change strategy of SECAPs needs to be based on a robust climate risk assessment (Neves et al., 2016). In this assessment, local authorities select the main risks affecting their territories and the most affected sectors of activity by risk identified. These outputs are the base for developing an adaptation strategy, composed of concrete actions tackling selected risks impacting specific sectors of activity. The European Commission's Joint Research Centre (JRC) is the scientific body of the initiative, developing guidance materials (Bertoldi, 2018a, 2018b, 2018c), adapting methodologies in all regions of the world (Rivas et al., 2018), as well as assessing the overall initiative

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(Bertoldi et al., 2020) and ensuring the robustness of the submitted plans by providing guidance and feedback to signatories.

There have been several global-scale analyses of adaptation strategies at the local level. Most studies have focused on identifying drivers in the development of local adaptation plans (Araos et al., 2016; Reckien et al., 2018, 2015) by comparing cities with and without local adaptation planning. Araos et al. (2016) evaluated the degree of development of adaptation measures, whereas Reckien et al. (2018) explored the spatial dimension of the adaptation plans. In this line, Kim and Grafakos (2019) also analysed the level of integration of adaptation and mitigation policies in 44 Latin American cities. Other studies have analysed the adaptation strategies by focusing on the indicators and metrics (Arnott et al., 2016), the resilience and adaptive capacity of the cities (Filho et al., 2019; Woodruff et al., 2018), or by comparing resilience plans with the local adaptation plans.

In this study, we focus on the adaptation plans within a specific harmonized framework, the Covenant of Mayors. Compared to previous works, which are mostly focused on large cities, this study presents an insight from a framework designed for cities of all sizes. In fact, 90 % of the current CoM cities are local authorities under 50.000 inhabitants (Bertoldi et al., 2020). The paper is particularly focused on identifying common attributes leading to the acceptance of adaptation plans in the CoM initiative. Our goal is to help cities around the world aiming at joining the initiative to develop their plans, in order to facilitate their access to CoM technical support and financing tools. To do so, we classified the first 51 adaptation plans submitted into complaint and non-complaint with the CoM evaluation criteria, and then we conducted a comparative analysis between both groups searching for potential drivers of the acceptance of the plans. The list of potential drivers is extracted from the CoM reporting framework. The 51 municipalities used are homogeneously distributed among European countries, covering a wide range of population size, from small-sized towns to large cities.

In Section 2, a literature review of comparative analysis is carried out. In section 3, the materials and methods used are presented. Results are presented in Section 4 and discussed in Section 5. Lastly, Section 6 concludes with final remarks.

2. Comparative analysis in climate change adaptation

Comparative analyses are considered useful tools commonly used by the climate change community to confront different scenarios, situations or actions. In general, comparative analyses can be applied to either quantitative or qualitative information, or both when necessary. A quantitative case approach to be mentioned is the comparison of two surveys conducted with two years of difference in Australia, in order to detect changes in people's opinion with regards to the deployment of renewable energies and nuclear power after the nuclear disaster of Fukushima (Bird et al., 2014). Holt et al. (2016) compared the potential impacts of climate change on the primary production of regional seas using projections for the end of the 21st century.

Qualitative comparative analyses can also be found in the literature. Gasper et al. (2013) compared the Human Development Report 2007/8 and the World Development Report 2010 using a combination of frame and content analysis, focusing on lexical choice (by word counting) so as to depict different worldviews. A similar approach was applied to compare the amount of media attention to climate change in different countries with diverse vulnerabilities (Schmidt et al., 2013). European Union cooperation projects have also been compared by means of fuzzy-set analysis to determine to what extent certain conditions may have an impact on learning outcomes (Vinke-de-Kruijf et al., 2020). A fuzzy-set qualitative comparative analysis has also been applied to illustrate how power is distributed, level of coordination, and adaptive capacity in water governance (Pahl-Wostl and Knieper, 2014). A relevant qualitative comparative analysis was run on five developing countries so that their position on international climate negotiations could be described (Rong, 2010).

Comparative analyses have also been adopted to analyse climate change adaptation in different fields. Lobaccaro and Acero (2015) developed a comparative analysis to evaluate how vegetation in urban areas may improve the thermal comfort, enhancing the adaptability to extreme heat events. Geographic Information Systems were applied to extract variables related to the ability of urban green spaces to promote adaptation to climate change and urban regeneration (Garcia Sanchez et al., 2018). Li et al. (2020) explored the differences and similarities of United Kingdom and China's green infrastructure actions to tackle urban flood risks. Witt et al. (2015) compared three alternative methods to evaluate the cost-effectiveness of retrofitting buildings, useful for climate adaptation. Milwicz and Paslawski (2017) compared diverse heating systems for single family housing through a life cycle analysis approach to estimate costs, adaptability and environmental impacts. Díaz López et al. (2019) evaluated the suitability of existing methods to assess the sustainability of buildings. Kumar et al. (2020) presented a comparative analysis of building insulation materials, in terms of thermal conditions, hygroscopic, acoustic conditions, resistance to fire, environmental impact and cost, as well as their performance in different climate conditions.

Clark (2017) applied a comparative analysis to investigate the potentiality of unmanned aerial systems to monitor coastal erosion triggered by storm events. Xian et al. (2018) compared the different flood protection measures undertaken in two megacities, such as Shanghai and New York, in order to search for risk factors that include flood hazard, exposure and vulnerability. Lereboullet et al. (2013) analysed meteorological data, semi-structured interviews, and field observations to compare two viticulture systems' resilience to climate change. A multi-method approach that integrated surveys, interviews, videos, literature and fieldwork to compare climate change perceptions, policies and knowledge of diverse rural areas can be seen in Smith et al. (2014). Improved water storage and sustainable water use for agriculture in a context of climate change has also been subject of comparative analysis (Baffaut et al., 2020).

Comparative analyses have also been applied to describe how climate change adaptation is mainstreamed into civil protection policies (Groven et al., 2012). More recent work presents the use of indicators to compare the relevance, effectiveness, efficiency, results and impact, sustainability and management of adaptation strategies in Europe (Rutherford et al., 2020).

3. Materials and methods

3.1. Adaptation plans within the Covenant of Mayors

In November 2018, a total of 51 European local authorities completed the submission of their Risk and Vulnerabilities Assessment (RVAs) as well as the set of actions to adapt to the expected risks, the so-called "adaptation plan". European municipalities submitted their plans to MyCovenant platform based on an excel-based reporting tool, now on-line, developed jointly by the Covenant of Mayors Office (CoMOffice) and the JRC. Cities in Europe could commit to adaptation goals in the frame of the CoM only after 2016 and they had two years to complete their adaptation action plans. This is the reason behind the low representation of adaptation plans in the initiative so far. For this study, the whole set of 51 municipalities, which are evenly distributed across Europe (Fig. 1), was included.

JRC has the mandate of conducting an evaluation of the SECAP submitted by the cities. This evaluation is based on a set of evaluation criteria proposed by Barbosa et al. (2018) that contributes to guaranteeing the credibility and reliability of the whole CoM initiative. The purpose of the evaluation is to ensure that the city is fully compliant with the mandatory criteria of the initiative and therefore is accepted (compliant) or non-accepted (non-compliant). Secondly, recommendations for potential improvements are formulated to the city. The

Fig. 1. Covenant of Mayors' municipalities used in the study.

evaluation criteria are divided in five sub-components (Table 1): compliance with the time frame, completeness, coherence, quantification, and progress. These criteria are considered as the minimum requirements such that an adaptation plan can be accepted by the CoM initiative.

The JRC adaptation team evaluated the 51 adaptation plans based on the previous evaluation criteria. As a result, the local action plans were classified in terms of performance within the initiative. Out of the 51 cities, 21 were classified as compliant with the CoM evaluation criteria, while 30 cities were classified as non-compliant.

Table 1
Evaluation criteria within the JRC framework.

Criteria	Key elements
Compliance with the reporting timeframe	RVAs and adaptation action plan
Completeness	Adaptation goals
Internal coherence	Alignment of goals, risks and actions
Quantification	RVAs and adaptation actions
Progress	Adaptation actions

Source: Barbosa et al. (2018).

3.2. *Statistical analysis*

A statistical comparative analysis between compliant and non-compliant cities was conducted based on different attributes of the adaptation plans. We hypothesized that if an attribute shows a statistical different between both groups, the attribute may be a potential driver in the acceptance of adaptation plans. The statistical analysis was performed using nonparametric tests due to the small sample size and the non-normality of most of the attributes.

The attributes selected were extracted from several sections of MyCovenant reporting tool, reflecting all the elements that are considered as mandatory for the city to report. They were grouped into three main categories (Table 2): administrative attributes, financial resources, and high-level hazards currently threatening the cities. The first group includes administrative characteristics of the city and the city plan development, such as city size, population size, administrative structure within the municipality, level of stakeholder engagement, and level of adaptation commitment represented by the definition of concrete adaptation goals. The second group focuses on the different financing lines the city foresees for the development, implementation and monitoring of the adaptation plan. Finally, the third group shows the hazards described by the cities as potential or current climatic threats.

Note that in this study, both the evaluation criteria (Barbosa et al., 2018) and the list of attributes studied as potential drivers (Covenant of Mayors Office - Europe, 2020) were imposed by the CoM framework. Both are the result of several years of international committees that included a group of practitioners represented by cities of all kind and from all regions of the world. Moreover, when the Covenant of Mayors became global in 2016, a specific committee on adaptation was built with representatives from EU, UN habitat, ICLEI, Climate Alliance, Energy Cities, and C40. Therefore, the evaluation criteria and the reporting framework include the feedback of city representatives and adaptation planners gathered throughout different consultation processes.

Most of the attributes were categorical values with a binary response, resulting in 2×2 contingency tables when comparing the two groups of cities. These attributes were evaluated with Fisher's exact test, a nonparametric test designed to compare the distribution of categorical variables between two groups. The chi-square test is the other test used

Table 2
Attributes used to conduct the statistical analysis.

Category	Attribute	
Administrative attributes	Population size	
	Population density	
	Stakeholders with high level of participation	Local authority's staff
		External stakeholders at local level
		Stakeholders at other levels of governance
	Adaptation goals defined	
	Administrative structure coordinating the plan	
Financial resources	Local authority's own resources	
	National funds	
	EU funds	
	Private sources	
High-level hazards	Droughts	
	Extreme heat	
	Floods	
	Forest fires	
	Sea level rise	
	Landslides	
	Storms	
	Extreme cold	

in the literature for this purpose. However, chi-square test applies an approximation assuming a large sample size, whereas Fisher's test is exact. Thus, Fisher's test is better suited for small samples, and particularly for 2 × 2 contingency tables with low frequencies such as the ones of the current study (Kim, 2017). Note that Fisher's test is valid for any sample size and it steadily converges with chi-square test when the sample size increases. The null hypothesis H_0 is that there is no difference between the distributions of the two groups. Therefore, if H_0 is rejected, we can state that there is a significant difference in the evaluated attribute between the two groups.

Some of the categorical attributes can be grouped in one of the following categories: stakeholder engagement, financial resources, and hazards. In these cases, Fisher's test was also calculated for the accumulated values, e.g., the total number of hazards identified by a city. Combining different categories is recommended when having low frequencies to increase the identification of significant relationships (Allam et al., 2017). Note that these three categories cannot be treated as three categorical variables because the cities can report more than one attribute within each category, e.g., a city can identify several types of hazards.

There are also two attributes that are not strictly categorical variables: defining adaptation goals, and the three types of stakeholders. In these cases, cities can have more than one attribute of the same class, e.g., a city can define five adaptation goals or report the participation of six local stakeholders. These attributes could have been analysed as quantitative variables (e.g., number of adaptation goals per city) if a sufficiently large sample size was available. However, due to the small sample size, they were analysed as two categorical scenarios to enlarge significant relationships: (i) cities with at least one adaptation goal or one stakeholder engaged, and (ii) cities with more than one adaptation goal or more than one stakeholder engaged.

The two quantitative attributes, population size and density, were evaluated with the two-sample Kolmogorov-Smirnov (KS) test. The KS is a nonparametric test that makes no assumption about the distribution of the data. It evaluates whether two samples come from the same distribution by comparing their cumulative distribution functions (CDFs). The *p-value* is calculated based on the maximum distance between both CDFs. The null hypothesis H_0 is that both groups were drawn from the same distribution. Therefore, if H_0 is rejected, we can state that the distribution of the evaluated attribute is significantly different between the two groups.

A significance level of 0.05 was used, rejecting the null hypothesis if *p-value* < 0.05. Nonetheless, it should be noted that statistical tests are sensitive to sample size. As sample size increases, absolute differences become a smaller and smaller proportion of the expected value. What this means is that a reasonably strong association may not come up as significant if the sample size is small, and conversely, in large samples, we may find statistical significance when the findings are small and uninteresting, i.e., the findings are not substantively significant, although they are statistically significant. Consequently, the results obtained will also be discussed and confronted with the existing literature on the matter.

Note that the results of the statistical tests do not allow concluding anything more concrete that there is some link in the sample between the attributes and the performance of adaptation plans (Voelker et al., 2001). It does not necessarily imply that one variable has any causal effect on the other.

4. Results

4.1. Administrative attributes

The two-sided KS test was used to (Fig. 2). Results show that that there is a significant difference between the population size of compliant and non-compliant cities ($p = 0.020$). The number of small municipalities (population < 50,000) in the compliant group almost doubles that in the non-compliant one (Fig. 2). The 76.2 % of compliant municipalities have less than 50 000 habitants, while this value decreases to a 43.3 % for non-compliant ones. On the contrary, the population density distributions (Fig. 3) of both groups are statistically similar ($p = 0.979$).

The influence of the number of stakeholders involved in the development of adaptation plans was studied with two comparative analyses. Table 3 shows the statistical significance of having at least one stakeholder engaged in the different categories defined. In this case, neither the individual types of stakeholders nor the cumulative sum showed a link with the acceptance of adaptation plans. However, the results changed when analysing the participation of multiple stakeholders (Table 4). In this case, a significant difference ($p = 0.009$) was observed between compliant and non-compliant cities in terms of the participation of local authority's staff, i.e., all the Departments of the Municipality involved in climate change-related matters. Besides, the cumulative sum also shows that overall, extending the participation to multiple stakeholders has a link with the acceptance of adaptation plans ($p < 0.001$). This fact was corroborated with the analysis exact number of stakeholders participating per city (Fig. 4). The bar plots show that for all types of stakeholders, the number of stakeholders engaged per city in compliant cities doubles that of non-compliant ones.

Concerning the number of goals defined in the adaptation plans (Table 5), neither defining adaptation goals ($p = 0.978$) nor defining multiple adaptation goals ($p = 0.744$) were found to have a statistical

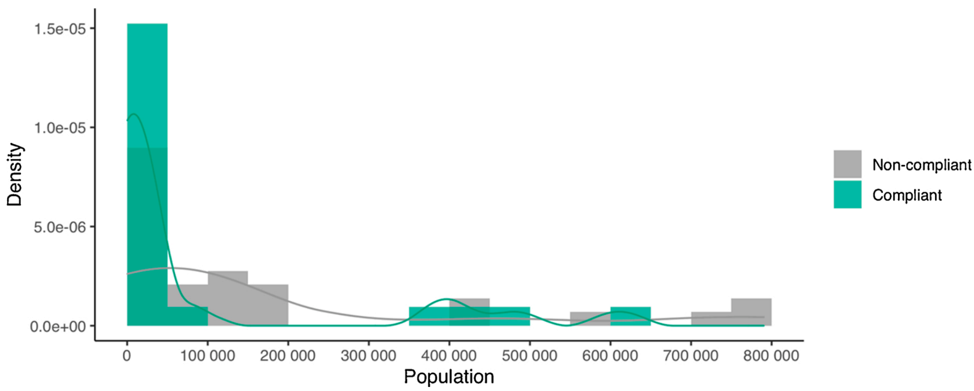

Fig. 2. Histogram of population size with a density curve calculated with a cosine kernel function. The statistical significance between both groups was calculated with the two-sided KS test (***p-value*** $= \mathbf{0.020}$).

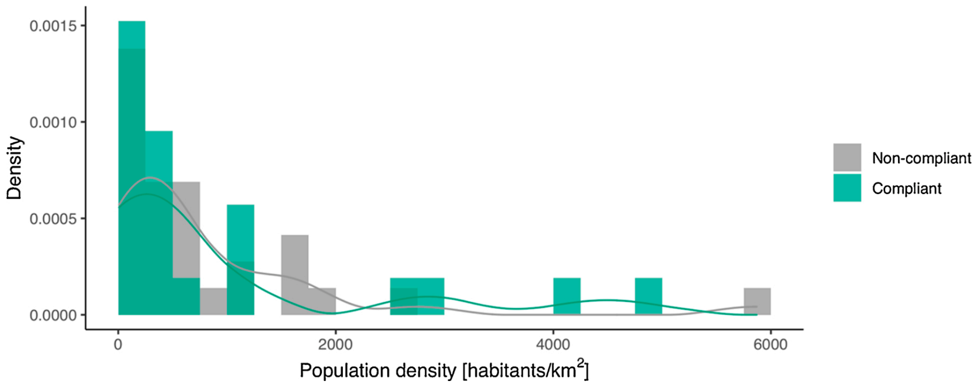

Fig. 3. Histogram of population density with a density curve calculated with a cosine kernel function. The statistical significance between both groups was calculated with the two-sided KS test (*p-value* = 0.979).

Table 3
Cities with at least one stakeholder engaged at high level of participation. The percentage of cities per group is shown in brackets. *p-values* were calculated with Fisher's exact test. Bold values indicate $p < 0.05$.

Attribute	Compliant	Non-compliant	*p-value*
Local authority's staff	15 (71 %)	15 (50 %)	0.156
External stakeholders at local level	9 (43 %)	6 (20 %)	0.119
Stakeholders at other levels of governance	3 (14 %)	3 (10 %)	0.680
Total	27 (43 %)	24 (27 %)	0.055

Table 4
Cities with multiple stakeholders engaged at high level of participation. The percentage of cities per group is shown in brackets. *p-values* were calculated with Fisher's exact test. Bold values indicate $p < 0.05$.

Attribute	Compliant	Non-compliant	*p-value*
Local authority's staff	5 (24 %)	0 (0%)	**0.009**
External stakeholders at local level	2 (10 %)	0 (0%)	0.165
Stakeholders at other levels of governance	1 (5%)	0 (0%)	0.412
Total	8 (13 %)	0 (0%)	**<0.001**

link with the acceptance of adaptation plans. Besides, neither the existence of an administrative structure in charge of coordinating the adaptation plan (Table 6) had a link with the acceptance of the plans ($p = 0.083$).

4.2. Financial sources

Financial resources used by CoM signatories are classified in four main categories (Table 7 and Fig. 5). Cities can use different types of financial resources, so each category was statically analysed individually. According to the test carried out for our sample, the acceptance of the plans was statistically independent of the availability of local funds ($p = 0.563$), national funds ($p = 0.445$), EU funds ($p = 0.490$), and private funds ($p = 0.217$). These two variables are also independent when analysing the financial resources altogether ($p = 0.087$).

Table 5
Number of cities with adaptation goals defined. The percentage of cities in each group is shown in brackets. *p-values* were calculated with Fisher's exact test.

Attribute	Compliant	Non-compliant	*p-value*
Adaptation goals defined	6 (29 %)	8 (27 %)	0.978
Multiple adaptation goals defined	5 (24 %)	6 (20 %)	0.744

Table 6
Number of cities having an administrative structure coordinating the plan. The percentage of cities per group is shown in brackets. *p-values* were calculated with Fisher's exact test. Bold values indicate $p < 0.05$.

Attribute	Compliant	Non-compliant	*p-value*
Administrative structure coordinating the plan	9 (43 %)	21 (70 %)	0.083

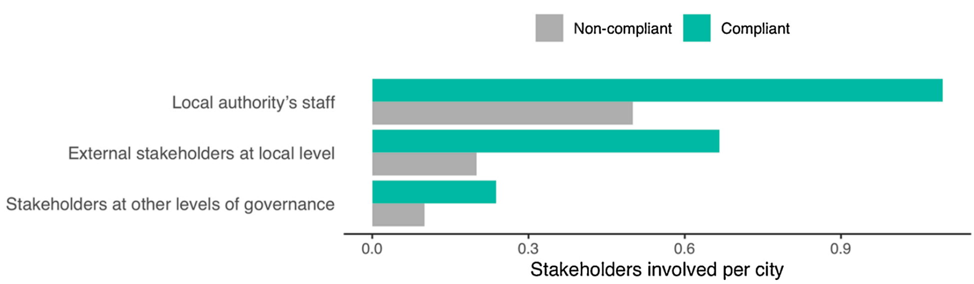

Fig. 4. Number of stakeholders with a high level of participation engaged per city.

Table 7
Financial resources used by each city. The percentage of cities per group is shown in brackets. *p-values* were calculated with Fisher's exact test. Bold values indicate $p < 0.05$.

Attribute	Compliant	Non-compliant	*p-value*
Local authority's own resources	13 (62 %)	21 (70 %)	0.563
National funds	2 (10 %)	6 (20 %)	0.445
EU funds	3 (14 %)	8 (27 %)	0.490
Private sources	1 (5%)	6 (20 %)	0.217
Total	19 (23 %)	41 (34 %)	0.087

4.3. *Exposure to climate hazards*

The number and type of climate hazards vary with the location of the municipality as well as with the degree of completeness of the adaptation plan. The number of individual hazards was statistically similar between compliant and non-compliant cities (Table 8): droughts ($p = 0.495$), extreme heat ($p = 0.277$), floods ($p = 0.113$), forest fires ($p = 0.277$), sea level rise ($p = 0.561$), landslides ($p = 0.134$), storms ($p = 0.259$), and extreme cold ($p = 0.506$). However, the results changed when analysing the aggregated values. The total number of hazards defined by compliant and non-compliant groups are statistically different ($p = 0.003$). Fig.6 shows that for this subset of municipalities, the number of hazards identified by non-compliant cities is slightly larger than that for compliant ones.

5. Discussion

The involvement of stakeholders and citizens with a high level of participation was the attribute showing the strongest statistical significance. A link was found between the engagement of multiple stakeholders, particularly at the local level, and the acceptance of adaptation plans (Table 4). Besides, for all types of stakeholders, the number of engagements in compliant cities doubles that of non-compliant ones (Fig. 4). These results might indicate that a higher participation of citizens and stakeholders, particularly at the local level significantly facilitates the acceptance of adaptation plans. Literature available on stakeholder and citizen engagement in climate adaptation supports these results.

Stakeholders are generally engaged in the development of local adaptation strategies (Aguiar et al., 2018). According to Christoforidis et al. (2013) "*the success of possible adopted measures by the local governments is heavily based on the public acceptance and the citizens' active participation.*" It is said that environmentally sustainable cities are likely to have engaged citizens in their environmental plans (Elelman and Feldman, 2018).

Public participation is believed to be useful for adaptation planning due to several reasons. For example, it has been alleged to be meaningful to evaluate the *statu quo* of adaptation planning and the understanding of existing policies and barriers (Hernandez et al., 2018a). Consequently, public participation prepares the conditions for long term climate goals formulation and visions (Hernandez et al., 2018b; Hilden et al., 2017; Mendizabal et al., 2018). Similarly, citizen participation is said to reinforce the government's ability to attain the goals established (Larsen et al., 2011).

Stakeholder and citizen engagement also facilitates a common understanding of climate risks, establishing a platform to share knowledge on how to better adapt the risks foreseen (Mendizabal et al., 2018). Furthermore, public participation reinforces deliberation with regards to desirable futures aiming at sustainability (Larsen et al., 2011), stimulating transitions towards more climate-resilient cities (Mendizabal et al., 2018). Public participation also provides a more holistic framework to design (Allam et al., 2017) climate change adaptation actions (Endo et al., 2017; Hernandez et al., 2018a).

The total number of hazards identified per city and population size was also correlated with the acceptance of adaptation plans. However, and compared to stakeholder engagement, these attributes cannot be strictly considered potential drivers for the acceptability of adaptation plans because they are intrinsic characteristics of the municipalities that cannot be modified.

The total number of hazards reported by non-compliant cities was statistically larger than that reported by compliant ones (Table 8), which is in agreement with existing literature. Reckien et al. (2015) found that cities at risk of severe climate change impacts and with a high degree of future vulnerability have fewer adaptation plans. Particularly, they found that cities in low-lying coastal areas and hot climates do not engage more in climate planning, but on the contrary, they engage less. A survey conducted among Norwegian municipalities confirmed that adaptation efforts are driven by past extreme events and not by projected future hazards (Amundsen et al., 2010). Moreover, Reckien et al. (2015) hypothesised that the existence of multiple hazards could be even a barrier due to the financial resources and the infrastructure

Table 8
High-level hazards identified by each city. The percentage of cities per group is shown in brackets. *p-values* were calculated with Fisher's exact test. Bold values indicate $p < 0.05$.

Attribute	Compliant	Non-compliant	*p-value*
Droughts	3 (14 %)	7 (23 %)	0.495
Extreme heat	2 (10 %)	7 (23 %)	0.277
Floods	3 (14 %)	11 (37 %)	0.113
Forest fires	2 (10 %)	7 (23 %)	0.277
Sea level rise	2 (10 %)	1 (3%)	0.561
Landslides	0 (0%)	4 (13 %)	0.134
Storms	0 (0%)	3 (10 %)	0.259
Extreme cold	0 (0%)	2 (7%)	0.506
Total	14 (7%)	57 (21 %)	**0.003**

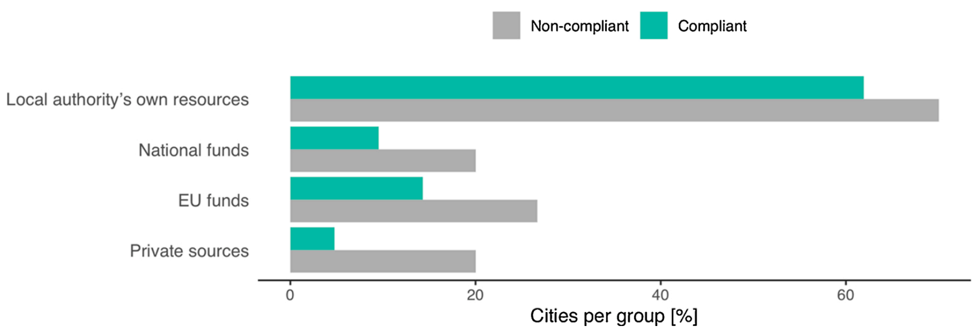

Fig. 5. Number of cities using each type of financial resource.

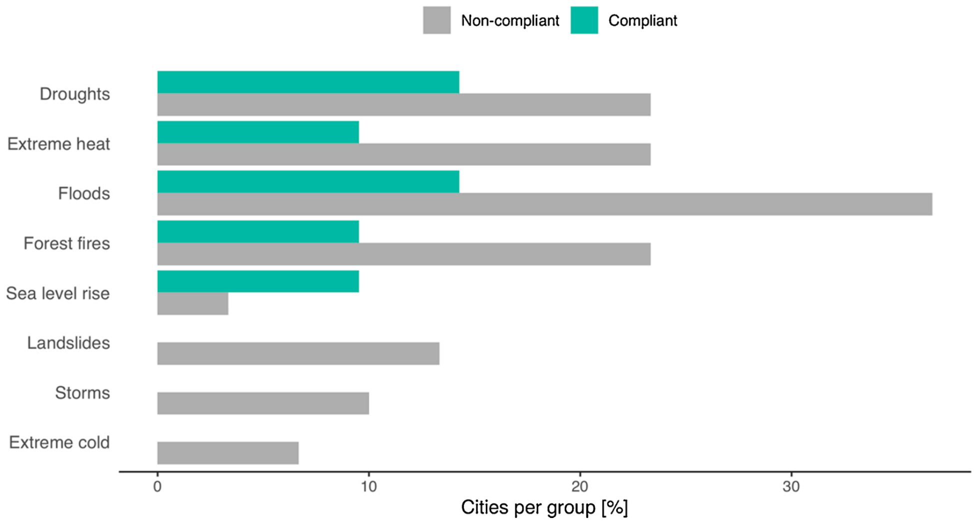

Fig. 6. Number of cities reporting each type of hazard (current level high).

required for adapting to these hazards. In this line, our results might corroborate that the existence of multiple hazards could be negatively correlated with an effective adaptation planning.

Concerning population size, the population of compliant cities was statistically smaller than that of non-compliant ones (Fig. 2). Literature available about this relationship shows contradictory conclusions. Reckien et al. (2015) and Reckien et al. (2018) analysed the presence of adaptation plans in 200 and 885 medium and large-sized European cities, respectively, finding that large cities are more likely to have adaptation plans than small ones. This could be because small cities have fewer resources and are less likely to be engaged in national and international networks (Lioubimtseva and da Cunha, 2020). On the other hand, other studies suggested that there is not a statistical relationship between population size and the adaptive capacity of large cities (Filho et al., 2019; Kim and Grafakos, 2019). These results contrast with our analysis, but it should be noted that neither the dependent variable nor the characteristics of the cities are comparable with our study. For instance, some of these studies evaluate the presence of adaptation plans while ours focuses on the quality of those adaptation cities. Besides, literature studies are mostly focused on large cities while our subset is composed of the first 51 cities submitting their adaptation plans to CoM. Thus, all municipalities have an adaptation plan, belong to an international climatic network, and have a substantially smaller population than the abovementioned studies. All these differences hinder the comparison of our results with those in existing literature. Nonetheless, if a relationship exists between population size and an acceptable adaptation strategy, this relationship may be weak and strongly dependent on the characteristics of the cities analysed.

A potential link between population size and stakeholder engagement might explain the smaller population of compliant cities. Dahl and Tufte (1973) already pointed out that citizens have more stimulus to participate in decision-making when states are smaller. Similarly, Gilbert et al. (1974) observed a moderate positive correlation between community size and the magnitude of citizen influence in local decision making. However, the opposite was highlighted by Newton (1982) who stated that the democratic advantages of small units of government had often been overestimated whereas their democratic disadvantages concealed. Furthermore, he said that larger units of government are not necessarily more democratically deficient, instead, they could be even more democratic. In this latter current of thought, Martins (1995) indicated that amalgamating local small authorities is positive to guarantee a growing citizens' familiarity and interest in local public affairs, concluding that small municipalities are not linked to higher levels of citizen participation. However, Frandsen (2002); Larsen (2002) and Rodrigues and Tavares (2020) have recently reached the opposite conclusion, i.e., the amalgamation of small municipalities has resulted in lower participation in the elections. A possible explanation is that people in larger cities are much less inclined to contact officials, attend to community or organizational meetings, or vote in local elections, i.e., generally speaking, people in big cities are less interested in local affairs (Oliver, 2000).

Larsen (2002) also detected that, even though participation is higher in smaller units of government, municipal size does neither influence citizens' interest in and knowledge of their local politics, nor their perception of local politicians and their trust in local political decisions. In fact, according to Guerring and Zarecki (2014), smaller municipalities may compromise the electoral and liberal dimension of democracy. Besides, they suggested that larger population enhances greater democracy, understood here as voting regularly. Their explanation to this is that larger populations have a more developed check-and-balance system, a more developed capacity to contain conflicts, a more developed political infrastructure, and a higher degree of political institutionalization. More recently, it has been said that jurisdiction size has a causal and sizeable detrimental effect on citizens' internal political efficacy (Lassen and Serritzlew, 2011), maybe because citizens who live in smaller municipalities feel a greater sense of political efficacy and participate more in local politics (McDonnell, 2020).

Even though there has been a long discussion on this topic, where both sides have indicated their pros and cons, the possible link between smaller population size and citizen and stakeholder engagement seems to have a rationale behind that might be summarised as a larger sense of closeness. Therefore, we believe that the higher acceptance rate of adaptation plans in small municipalities may be partly explained by the greater ability for stakeholder and citizen participation.

6. Conclusions

In this period of developing adaptation strategies in the framework of the Covenant of Mayors initiative, it was unclear which might be the drivers or key attributes that could potentially lead to developing acceptable adaptation plans. In order to identify those potential drivers, we have analysed the first 51 municipalities that have submitted their adaptation plans to the Covenant of Mayors. This analysis was conducted aiming at having a first clue of attributes that might explain the acceptability of the adaptation plans.

The limitations of the study, due to the few plans submitted at the moment, do not allow us to have a thorough understanding to what extent other attributes could play a role in the potential success of the Energy and Climate Action Plans. Actually, we do not deny the importance of all the attributes analysed here, such as having an administrative structure, clear adaptation goals, or allocated funding. Until further analysis is developed, we could only state that the engagement of multiple stakeholders and citizens might drive to effective adaptation planning. We also observed that the benefits of stakeholder and citizen engagement could be greater in small municipalities because participatory processes can be developed more easily. Our findings could be relevant for the more than 9 000 cities (10 % of world population) that are nowadays developing adaptation strategies under the Covenant of Mayors framework. Helping them in joining the initiative could give them harmonized tools to develop successful local action adaptation strategies. Furthermore, joining could lead them to engage in international processes of technical and financial support that would facilitate the actual implementation of the plans.

CRediT authorship contribution statement

Silvia Rivas: Conceptualization, Methodology, Investigation, Writing - original draft. **Yeray Hernandez:** Conceptualization, Methodology, Investigation, Writing - original draft. **Ruben Urraca:** Formal analysis, Writing - original draft, Visualization. **Paulo Barbosa:** Writing - review & editing.

Declaration of Competing Interest

The authors report no declarations of interest.

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5 CONCLUSIONS

This Thesis aimed at developing a comprehensive evaluation of the current status of the local climate action in Europe, to identify best practices and main drivers that could benefit mitigation and adaptation action not only in Europe but beyond. This Thesis aims at serving as a practical tool for researchers, governments and practitioners in their joint path toward a carbon-neutral and resilient future, in their path toward sustainability.

Despite the current limitations, mostly due to the lack of real and accurate data at this early stage of the local climate action revolution, in addition to the inner ones related to the statistical and regression analyses applied, these are the main conclusions based on the results obtained and explained in the four publications that build this work.

On the local action towards mitigate climate change

Local authorities are already substantially contributing towards climate change mitigation. Results of the evaluation of the first phase of the Covenant of Mayors (CoM 2020) reveal that on average EU LAs achieved 85.6% of their commitments already 6 years before the due date in 2020 and that 48% of them had already reached and even surpassed their committed targets before the end of the first phase of the initiative; **European LAs are on track towards their targets**

However, extracting these results was not a straightforward exercise, due to (i) the lack of intermediate and final monitoring exercises (only 32% of the total LAs), and (ii) the flexibility of the framework applied that translates into heterogeneous data impossible to aggregate. Therefore, the first key message to extract is that **it is impossible to evaluate what is not accountable. Local action initiatives in Europe lack a strong and implemented monitoring system,** which apart from preventing complete accurate achievements studies, reduces the efficiency of the measures implemented since doesn't provide an understanding of the feasibility and real impact of local action measures, which can also be readjusted according to needs.

Even though, our study on the monitoring exercise of mitigation to climate change local action in Europe, reveals that **previous climatic experience** with initiatives like the Covenant of Mayors **enables the development of monitoring exercises**.

This study shows how frontrunners, which are usually large LAs,(over 50,000 inh) have access to older and more accurate GHG inventories and can develop, implement and submit plans sooner, that is usually carried out in-house. On the contrary, small LAs showed an inexperienced approach to climate action, defined by the late enrolment to the initiative, and reliance on very recent data.

The study reveals as well other **enabling factors for a successful local action plan monitoring:** (i) direct and long-lasting involvement of local staff, (ii) avoidance of external consultants, whose contribution may be limited to the development of the plan, (iii) stakeholders engagement and the organization of participatory processes, (iv) accurate budget allocation at the start of the plan, (v) early development of the plan and deployment of the actions. In contrast, neither an increase in the total planned budget nor higher ambitions can be considered determining factors for the successful finalization and monitoring of the plan, and ultimately for higher achievements.

When evaluating the **actual achievements** reached by the LAs, in the second publication, results show again this **differential behavior between large and small LAS**. Larger LAs tend to focus on a long term-target and base their objectives and timelines on a coherent study of the initial emissions and the local capabilities. On the other hand, larger reductions in small LAs are obtained by frontrunners (early submission) that in 4-5 years, in coincidence with the political cycle, are achieving or surpassing their targets already in the first monitoring report.

For large LAs, the key drivers for obtaining positive achievements are (i) an early start of climate action, (ii) conducting a good stakeholder engagement process (joint partnership). **For small LAS**, the development of plans in-house, in close collaboration with the local authorities and supporters increases the chances of obtaining greater emission reduction.

One of the relevant outcomes of the studies is that, it is needed to acknowledge the **potential limitation of climate action at the local level**. 12.9% of LAs increased their total emissions and most of these unexpected results are driven by emission changes in sectors that are usually out of the total influence of the local authority, or partly covered, namely transport and industry. High reductions are as well observed in these sectors (LAs doubling and even tripling their original targets). These "negative" results are more frequent in LAs below 50,000 inhabitants potentially because, small LAs have less experience, less influence on key sectors of activity like transport or industry and they have as well short-term political driven goals that rule their action plans.

So, the ultimate factor for climate action planning seems to be the joint partnership between several government layers.

Increasing the ambition level could as well trigger better reduction results? In this sense, our third study have shown that the key enabling factor for higher climate ambition in cities is the **development of local mitigation actions in line with the results of the baseline emissions inventory; focusing on implementing actions in the most emitting sectors of activity.** Following the results of our third paper, and in line with the results obtained when studying the monitoring exercises as well as the achievements of the LAs, **other ways that allow municipalities to commit to more ambitious targets are**, (i) the development of in-house planning, (ii) an active and effective involvement of stakeholders, or (iii) a combination of both. Alternatively, (iv) outsourcing the work could also lead local authorities to a better, more efficient and ambitious local climate action, provided that the strategy proposed is closely supervised. In specific cases (v) previous experience in local climate action initiatives allows municipalities to set more ambitious targets.

On the local action toward climate change adaptation

The limitations of the fourth study focused on adaptation, due to the limited population, did not allow us to have a thorough understanding of to what extent other attributes could play a role in the potential success of a local climate action plan on Adaptation. Without denying the potential relevance of all the attributes included in the reporting system, and aware that the results of the statistical analysis concluded that there is some link in the sample between the attributes and the performance of adaptation plans and it doesn't necessarily imply that one variable has any causal effect on the other, we could only state that **the engagement of multiple stakeholders and citizens might drive to effective adaptation planning**. We also observed that joining current initiatives could lead LAs to **engage in international processes of technical and financial support** that would facilitate the actual implementation of the plans.

General recommendations

(a) It is paramount to ensure the correct implementation of monitoring exercises in local climate action initiatives.

(b) Small LAs need to be supported in adopting long-term objectives, working on both, feasible measures to be implemented in the short term (political cycle/mandate) and potential and desirable measures for future political cycles.

(c) Local climate action is a two-speed process, and this is a factor that needs to be considered when developing harmonized frameworks for supporting and enhancing LAs. Because even if the share of total emission reduction coming from small municipalities is only around 15%, the local climate action generates co-benefits and works in a cross-cutting manner (from resilience to circular economy or inclusion) that justifies the effort.

(d) While there is a need of boosting local climate action, there is a greater need of investigating and quantifying this limitation and deepen the understanding of the national influence

Recommendations for future studies

(1) CoM2030 Achievements: It would be extremely useful to repeat this exercise, analyzing the results obtained at the end of the second phase of the European local climate action plan (2020-2030)

(2) Adaptation achievements. In that future study, an important new goal would be to evaluate the real achievements obtained by LAs of all sizes regarding the Adaptation part of their local action climate plans

(3) Adaptigation. A specific study of co-benefits between mitigation and adaptation strategies (Adaptation) like the ones already developed in terms of only commitments (Sharifi 2021) could show the light of new efficient approaches.

(4) National influence. In the case of the mitigation action, studies focusing on the real influence of the national actor and regulations on the final GHG final reduction per sector would be of extreme interest to fine tunned recommendations and joint structures at the national level.

(5) Air quality. Interesting will be, as well, to continue the line opened by research colleagues (Peduzzi et al. 2020), on the synergies between GHG and air quality pollutants local action and regulations.

6 CONCLUSIONES

El objetivo de esta Tesis ha sido el desarrollar una evaluación integral del estado actual de la acción climática local en Europa, para así identificar las mejores prácticas y los principales impulsores que podrían beneficiar la acción de mitigación y adaptación no solo en Europa sino en todo el mundo. Esta Tesis es pues una herramienta práctica para investigadores, gobiernos y profesionales en su lucha conjunta hacia un futuro resiliente y carbono-neutral, en su camino hacia la sostenibilidad.

A pesar de las limitaciones actuales, en su mayoría debidas a la falta de datos reales y precisos en esta etapa temprana de la revolución de la acción climática local, y teniendo en cuenta limitaciones internas relacionadas con los análisis estadísticos y de regresión aplicados, estas son las principales conclusiones a partir de los resultados obtenidos, incluidas en las cuatro publicaciones que componen este trabajo.

Sobre la acción local para mitigar el cambio climático

Las autoridades locales ya están contribuyendo sustancialmente a la mitigación del cambio climático. Los resultados de la evaluación de la primera fase del Pacto de los Alcaldes (CoM 2020) revelan que, en promedio, las administraciones locales (AL) de la UE lograron el 85,6 % de sus compromisos ya 6 años antes de la fecha de vencimiento en 2020, y que el 39,9 % de ellos ya habían alcanzado e incluso superado sus objetivos antes del final de la primera fase de la iniciativa; **Las AL europeas van por buen camino hacia sus objetivos gracias en parte al apoyo de estructuras e iniciativas armonizadas**

Sin embargo, extraer estos resultados no fue un ejercicio sencillo, debido a (i) la falta de ejercicios de seguimiento o monitoreo intermedios y finales (solo el 32 % del total de AL), y (ii) la flexibilidad del marco aplicado que se traduce en datos de una gran heterogeneidad imposibles de agregar. Por lo tanto, el primer mensaje clave a extraer es que **es imposible evaluar lo que no se ha medido. Las**

iniciativas de acción local en Europa carecen de un sistema de seguimiento fuerte y correctamente implementado, lo que además de impedir completar estudios de eficiencia precisos, reduce la eficiencia real de las medidas implementadas ya que no existe una comprensión de la viabilidad y el impacto real de las medidas de acción local, que permita reajustes y correcciones,

Sin embargo, nuestro estudio sobre el ejercicio de seguimiento de la acción local de mitigación del cambio climático en Europa revela que **la experiencia climática previa en iniciativas como el Pacto de los Alcaldes ayuda al desarrollo de ejercicios de seguimiento.**

Este estudio muestra cómo los pioneros, que suelen ser grandes AL (mayores de 50.000 hab), tienen acceso a inventarios de GEI más antiguos y precisos y pueden desarrollar, implementar y presentar planes antes, lo que generalmente se lleva a cabo internamente. Por el contrario, las AL pequeñas mostraron poca experiencia en la acción climática, inscribiéndose de forma tardía a la iniciativa y aportando datos muy recientes.

El estudio también revela otros **factores favorables para un correcto seguimiento del plan de acción local:** (i) participación directa y duradera del personal local, (ii) limitar la participación de consultores externos, cuya contribución puede limitarse al desarrollo del plan, (iii) involucramiento de las partes interesadas y organización de procesos participativos, (iv) asignación presupuestaria precisa al inicio del plan, (v) desarrollo temprano del plan y de las acciones concretas en los sectores de actividad. Por el contrario, ni un aumento en el presupuesto total planificado ni objetivos más ambiciosos pueden considerarse factores determinantes para la finalización y el seguimiento exitoso del plan y, en última instancia, para lograr mayores resultados.

Al evaluar los **resultados reales alcanzados** por las AL, en nuestro segunda publicación, los datos muestran nuevamente este **comportamiento diferencial entre Als grandes y pequeñas**. Las AL más grandes tienden a centrarse en un objetivo a largo plazo y basan sus objetivos y plazos en un estudio coherente de las emisiones iniciales y las capacidades locales. Por otro lado, las mayores reducciones en AL pequeñas las obtienen aquellas que se unieron a la iniciativa al principio y que en 4-5 años, en coincidencia con el ciclo político, están logrando o superando sus objetivos ya en el primer informe de seguimiento.

Para las grandes AL, los factores clave para obtener resultados positivos son (i) un inicio temprano de la acción climática, (ii) llevar a cabo un buen proceso de participación de las partes interesadas. **Para las ALs pequeños**, el desarrollo de planes internos, en estrecha colaboración con las autoridades locales aumenta las posibilidades de obtener una mayor reducción de emisiones.

Uno de los resultados mas relevantes de los estudios es que es necesario reconocer la **potencial limitación de la acción climática a nivel local**. El 12,9 % de las AL aumentó sus emisiones totales y la mayoría de estos resultados inesperados se deben a cambios en las emisiones en sectores que normalmente están fuera de la influencia total de la autoridad local, o están parcialmente cubiertos, a saber, el transporte y la industria. También se observan reducciones elevadas en estos sectores (las AL duplican e incluso triplican sus objetivos originales). Estos resultados "negativos" son más frecuentes en las AL por debajo de los 50.000 habitantes porque las AL pequeñas tienen menos experiencia, menos influencia en sectores clave de actividad como el transporte o la industria y también tienen objetivos políticos a corto plazo que rigen sus planes de acción.

La tercera publicación, que estudia si **aumentar el nivel de ambición** también podría desencadenar mejores resultados de reducción. En este sentido, los estudios han demostrado que el factor habilitador clave para una mayor ambición climática en las ciudades es el **desarrollo de acciones locales de mitigación en línea con los resultados del inventario de emisiones de línea de base; concentrándose en la implementación de acciones en los sectores de actividad más emisores**. Siguiendo los resultados de nuestro tercer trabajo, y en línea con los resultados obtenidos al estudiar los ejercicios de seguimiento y monitoreo, así como los resultados de las AL, se infiere que **otras vías que permiten a los municipios comprometerse con metas más ambiciosas son**, (i) el desarrollo de del plan con medios municipales, (ii) una participación activa y efectiva de las partes interesadas, o (iii) una combinación de ambos. Alternativamente, (iv) la externalización del trabajo también podría llevar a las autoridades locales a una acción climática local mejor, más eficiente y ambiciosa, siempre que la estrategia propuesta sea supervisada de cerca. En casos específicos (v) la experiencia previa en iniciativas locales de acción climática permite a los municipios establecer metas más ambiciosas.

Sobre la acción local hacia la adaptación al cambio climático

Las limitaciones del cuarto estudio centrado en la adaptación, debido a la población limitada, no nos permitieron tener una comprensión profunda de hasta qué punto otros factores podrían desempeñar un papel en el éxito potencial de un plan de acción climático local sobre Adaptación. Sin negar la relevancia potencial de todos los atributos incluidos en el sistema de reporte, y conscientes de que los resultados del análisis estadístico indican que existe algún vínculo en la muestra entre los atributos y el desempeño de los planes de adaptación pero no necesariamente implica que una variable tiene un efecto causal sobre la otra, solo podemos afirmar **que la participación de múltiples partes interesadas y ciudadanos podría conducir a una planificación de adaptación efectiva**. También observamos que unirse a las iniciativas actuales podría llevar a las AL a **involucrarse en procesos internacionales de apoyo técnico y financiero** que facilitarían la implementación real de los planes.

Recomendaciones generales

(a) Es primordial asegurar la correcta implementación de ejercicios de monitoreo en las iniciativas locales de acción climática.

(b) Las AL de menor tamaño deben ser apoyados en la adopción de objetivos a largo plazo, trabajando tanto en medidas factibles para ser implementadas en el corto plazo (ciclo político/mandato) como en medidas factibles para futuros ciclos políticos.

(c) La acción climática local es un proceso de dos velocidades, y este es un factor que debe tenerse en cuenta al desarrollar marcos armonizados para apoyar y mejorar las AL. Porque si bien el porcentaje de la reducción total de emisiones proveniente de pequeños municipios es solo del orden del 15 %, la acción climática local genera cobeneficios y funciona de manera transversal (desde la resiliencia hasta la economía circular o la inclusión) que justifica el esfuerzo.

(d) Si bien existe la necesidad de impulsar la acción climática local, existe una mayor necesidad de investigar y cuantificar esta limitación y profundizar en la comprensión de la influencia nacional.

Recomendaciones para futuros estudios

(1) Resultados del CoM2030: Sería de gran utilidad repetir este ejercicio, analizando los resultados obtenidos al final de la segunda fase del plan de acción climático local europeo (2020-2030)

(2) Resultados de adaptación al cambio climático. Un futuro objetivo importante sería evaluar los resultados reales obtenidos por las ALs de todos los tamaños con respecto a la parte de Adaptación de sus planes de acción climática locales.

(3) Adaptigation. Un estudio específico de co-beneficios entre estrategias de mitigación y adaptación (Adaptigation) como los ya desarrollados en términos de objetivos (Sharifi 2021) podría arrojar la luz de nuevos enfoques eficientes.

(4) Influencia nacional. En el caso de la acción de mitigación, los estudios centrados en la influencia real del actor nacional en la reducción final de GEI final por sector serían de sumo interés para desarrollar recomendaciones y estructuras conjuntas a nivel nacional. nivel.

(5) Calidad del aire. También será interesante continuar la línea abierta por colegas investigadores (Peduzzi et al. 2020), sobre las sinergias entre GEI y contaminantes de la calidad del aire, acciones y regulaciones locales.

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