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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.

$$Total\ emission\ reduction\ [\mathrm{tCO_2e/cap}] = total\ baseline\ emissions - total\ monitoring\ emissions \quad (1)$$

$$Total\ emission\ reduction\ [\%] = 100 \times \frac{total\ emission\ reduction\ [\mathrm{tCO_2e/cap}]}{total\ baseline\ emissions\ [\mathrm{tCO_2e/cap}]} \quad (2)$$

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) [$\mathrm{tCO_2e/cap}$] and (2) [%]. The progress of each LA towards its target was evaluated as:

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

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:

$$sector\ emission\ reduction\ [\%] = 100 \times \frac{sector\ emission\ reduction\ [\mathrm{tCO_2e}]}{total\ baseline\ emissions\ [\mathrm{tCO_2e}]} \tag{4}$$

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

$$sector\ reduction\ share\ [\%] = 100 \times \frac{sector\ emission\ reduction\ [\mathrm{tCO_2e}]}{total\ emission\ reduction\ [\mathrm{tCO_2e}]} \tag{5}$$

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.

Attributes			Type	Description/Notes
Population			num	Attribute not analyzed directly as predictor variable but used to split the dataset into two groups (small and large LAs).
SEAP 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.
	Approved via CTC grouped evaluation		cat	-
	Signatories committed to both 2020 and 2030 initiatives		cat	Also known as 'overlappers'.
SEAP strategy	2020 GHG reduction target		cat	The target is set based on the foreseen reduction in each sector for the different actions proposed.
	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 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.
		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	

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

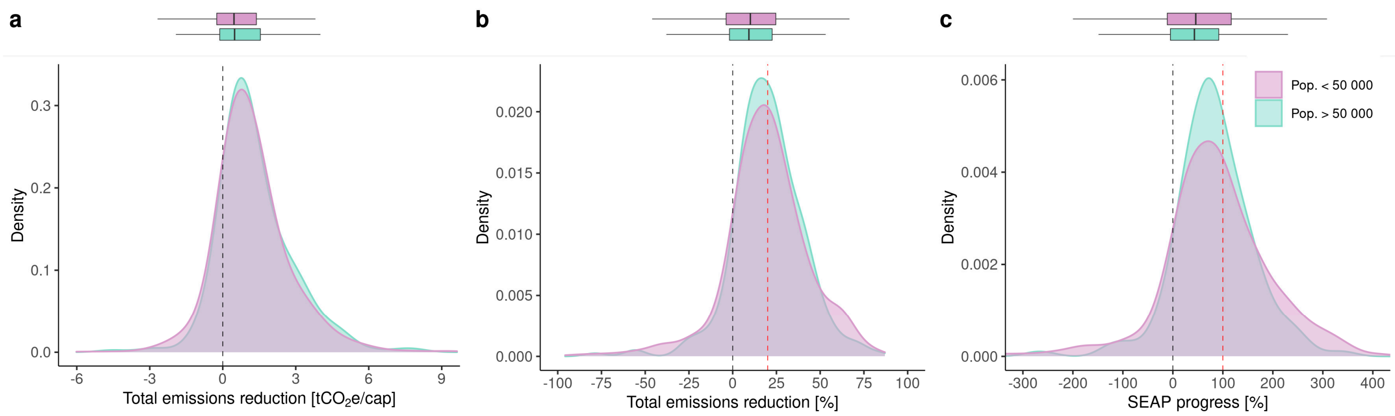

Figure 1. Summary of the GHG emissions reduction reported by CoM 2020 LAs in their last monitoring report. (**a**) Total emissions reduction [tCO_2e/cap]. (**b**) Total emissions reduction with respect to their baseline emissions [%]. The red line shows the CoM 2020 minimum reduction target of 20%. (**c**) 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 (ρ = 0.63 ***), transport (ρ = 0.42 ***), and industry (ρ = 0.40 ***) sectors are those that better explain the change in the total emissions. In small LAs, transport (ρ = 0.68 ***) is the sector most correlated with total emission reductions, followed by residential (ρ = 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.

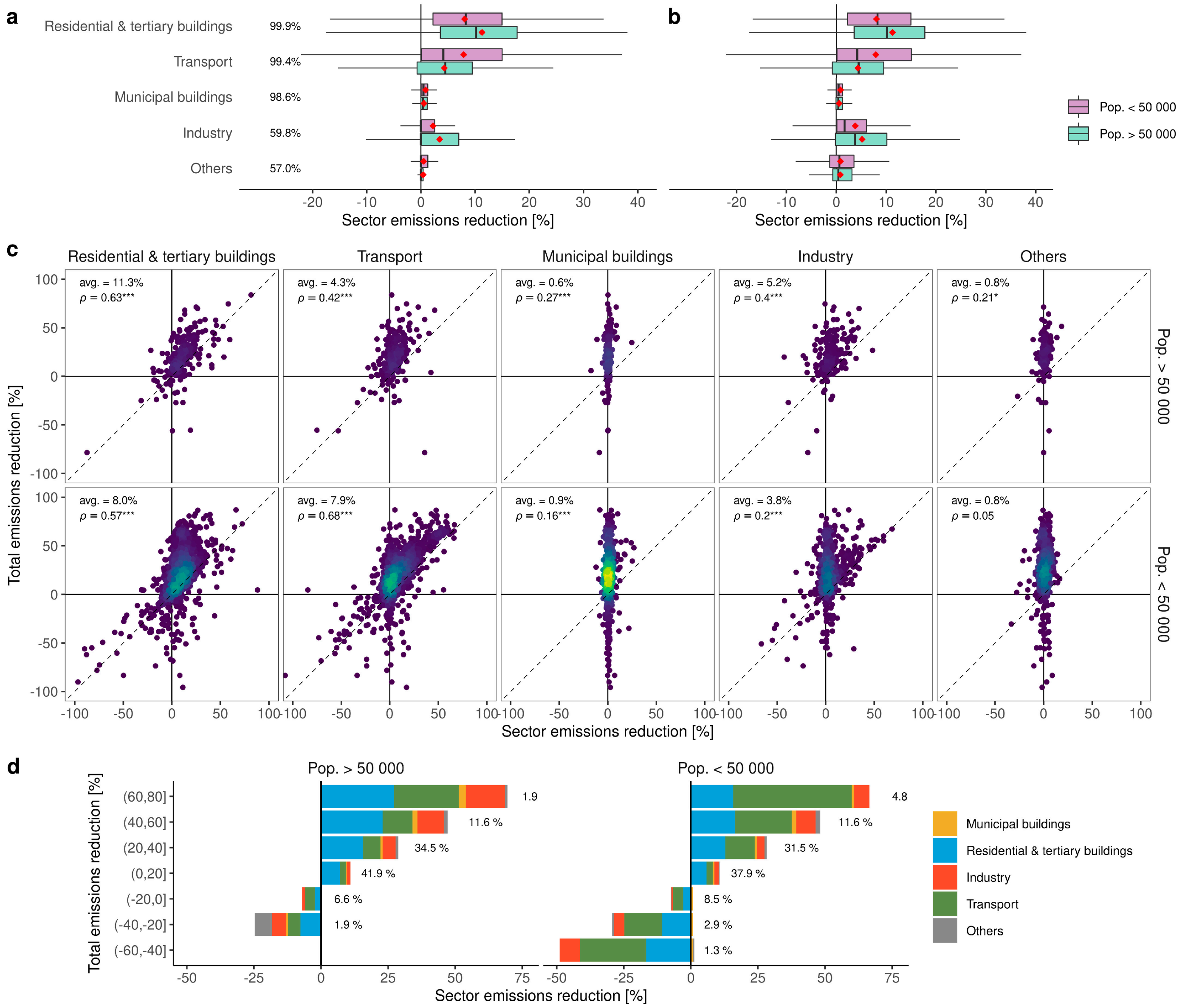

Figure 2. Summary of the GHG emissions reduction per sector. (**a**) Total reduction per sector. The label shows the percentage of LAs reporting emissions in that sector. (**b**) Same as (**a**) but excluding LAs not reporting emissions in each sector. Red diamonds show the mean. (**c**) Scatterplots 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].

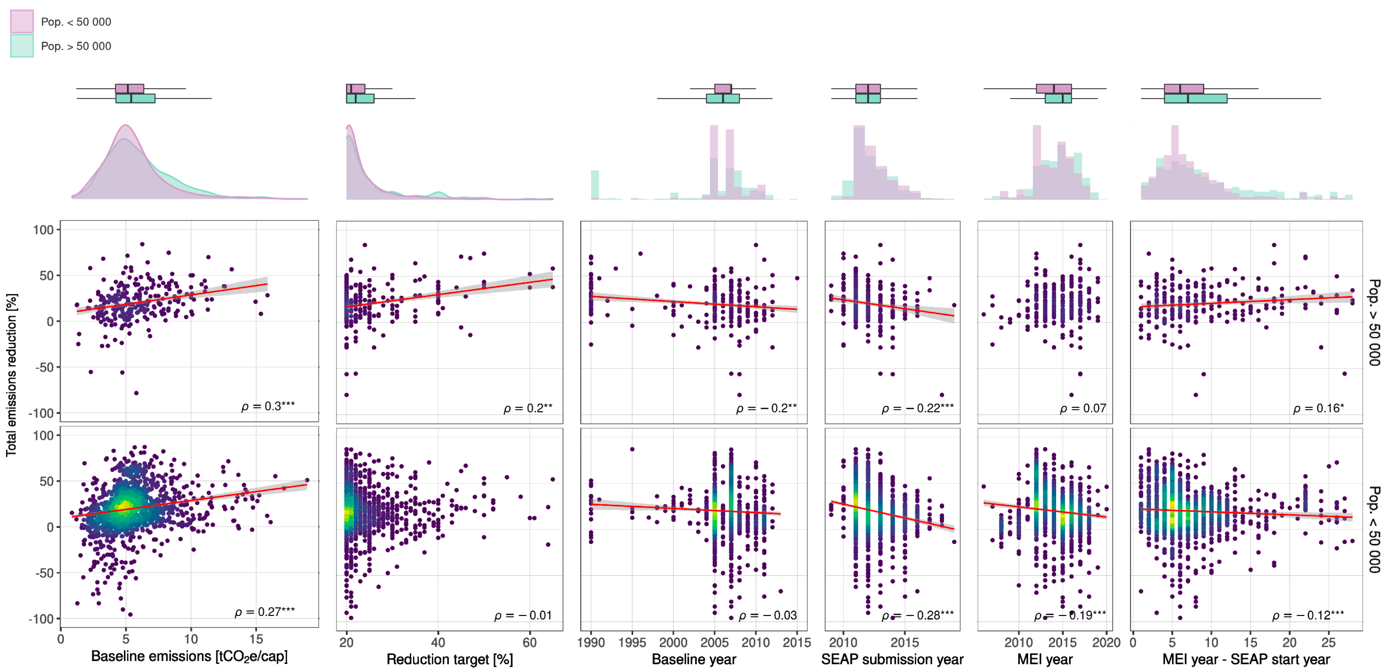

Figure 3. Statistical analysis of numerical attributes. ρ represents Spearman's rank correlation coefficient. Only statistically significant ($p < 0.05$) regression lines are plotted. Asterisks denote $p < 0.05$ (*), $p < 0.01$ (**), $p < 0.001$ (***).

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.

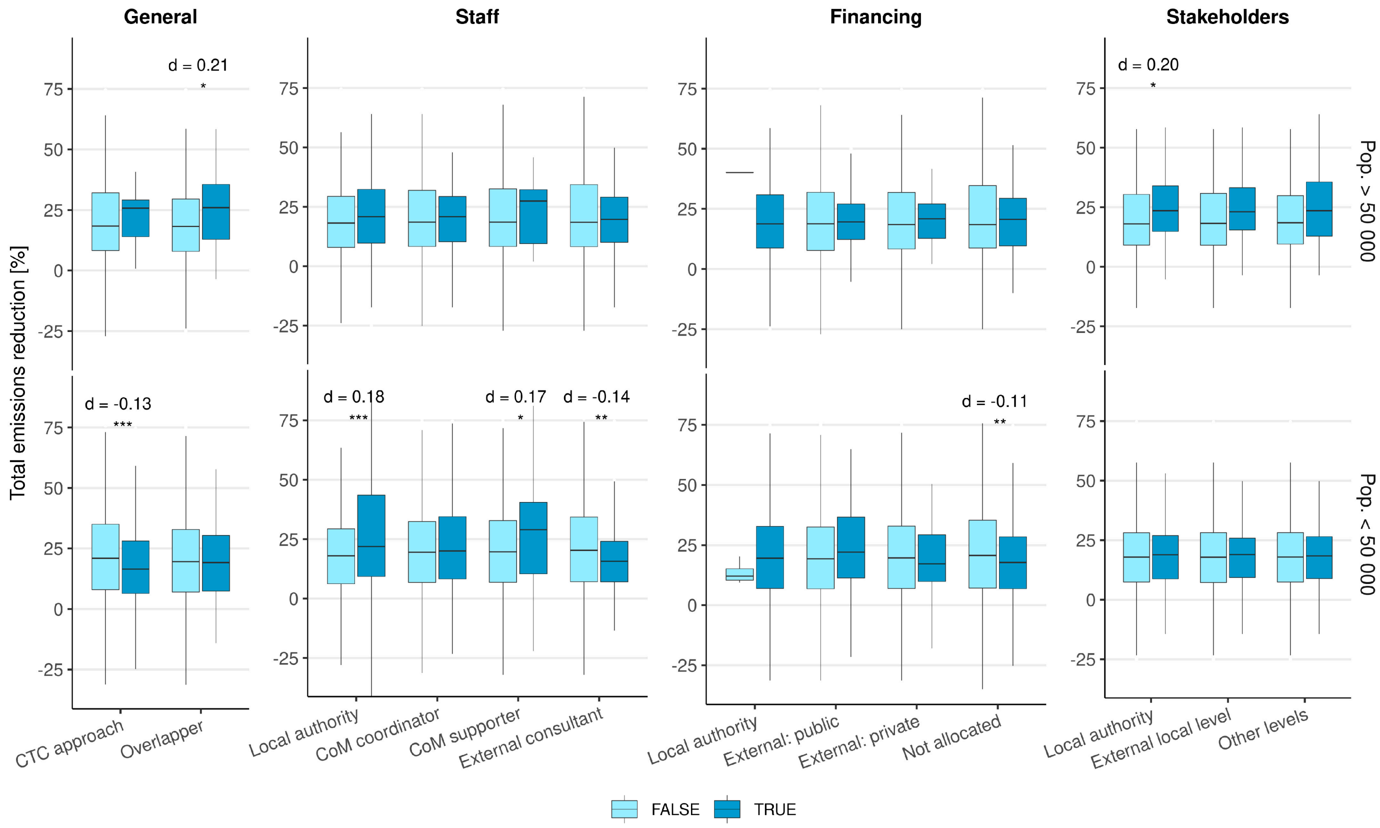

Figure 4. Statistical analysis of categorical attributes. Medians are statistically compared based on Mann–Whitney test. *d* represents Cliff's delta with its corresponding 95% confidence intervals. Asterisks denote $p < 0.05$ (*), $p < 0.01$ (**), $p < 0.001$ (***).

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.

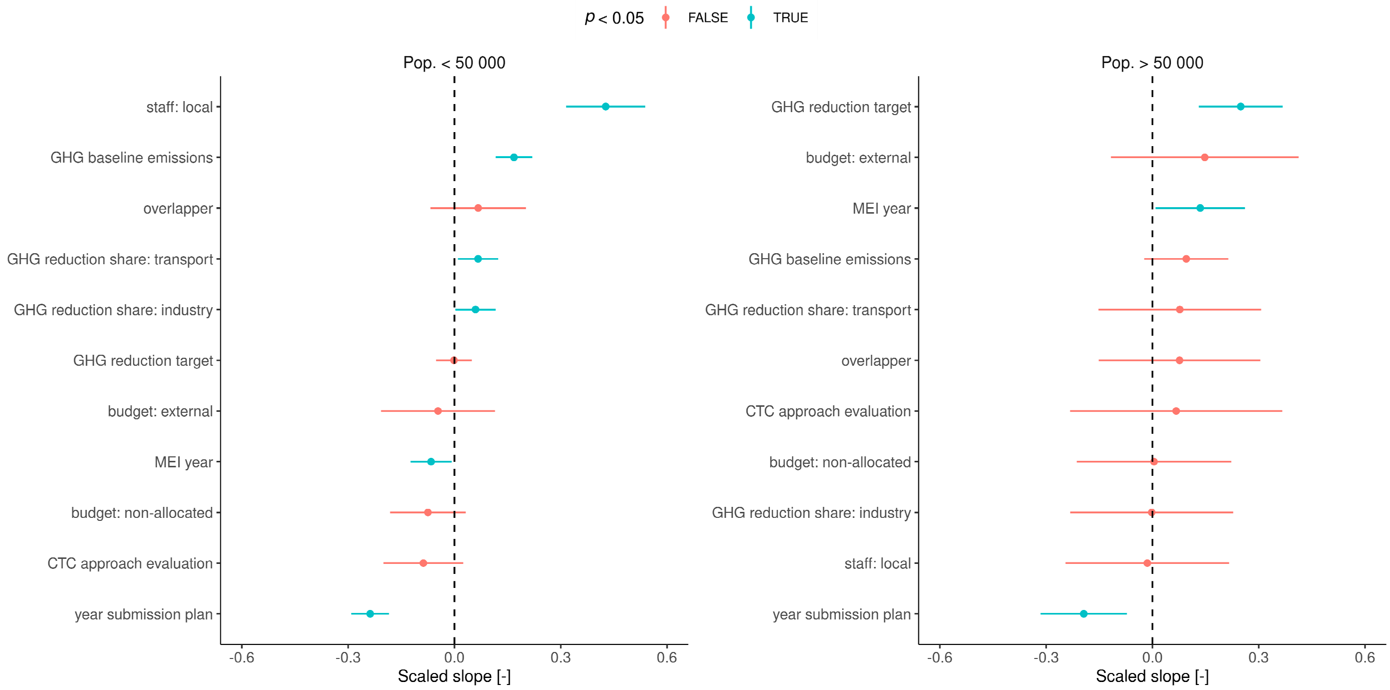

Figure 5. Ridge regression model coefficients with their 95% confidence interval for the 11 selected features.

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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