Mapping Gaps: Evidence-Based Analysis of Urban Emissions Trends and Climate Commitment in Major Italian Cities

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Abstract. Cities are pivotal to the European decarbonization path, yet the efficacy of their institutional responses remains poorly mapped. This paper assesses the "state of the art" of climate commitment across major Italian cities, exploring the nexus between strategic pledges, financial allocation, and actual emission outcomes. The research adopts a multidimensional methodology by triangulating three key datasets: (i) sectoral CO_2 equivalent emissions (2000–2023); (ii) per capita public investments from Open Coesione (2017–present) directed toward climate-sensitive sectors such as energy efficiency and sustainable mobility; and (iii) institutional progress within the Covenant of Mayors framework (distinguishing between commitment, planning, and monitoring phases).

By correlating these indicators through spatial analysis and bivariate mapping, the study identifies significant misalignments. Preliminary findings suggest that high financial effort and formal strategic adherence do not linearly translate into immediate carbon mitigation. The analysis reveals structural mismatches between dominant local emission sources and targeted funding. From an urban planning perspective, these results challenge the assumption that climate and sustainable transition are a mere financial or bureaucratic exercise. The paper argues that effective mitigation requires strict policy-sectoral alignment, ensuring investments address a city's specific fingerprint, while acknowledging how urban form and institutional inertia may resist rapid decarbonization. This study provides a critical evidence-based framework for evaluating the actual impact of urban climate governance in Italy.

Keywords: Urban Climate Planning · Mitigation · Climate Commitment

1 Introduction

Climate action in urban planning is structured around two distinct yet complementary strategies: adaptation and mitigation [1, 2]. While adaptation focuses on increasing the territorial resilience to unavoidable climatic impacts, such as urban heat islands or extreme flooding, mitigation targets the root causes of the crisis by reducing greenhouse gas emissions [3–5]. For urban planners, managing this duality is a major challenge. For

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example, the measures proposed for each objective often suggest conflicting land-use options [6, 7]. However, given the pursuit of carbon neutrality, mitigation has become a structural objective in European urban planning, driven by the ambitious targets of the Green Deal and the specific "100 Climate-Neutral and Smart Cities" mission [8–10].

In Italy, the institutional response to this challenge is centred on major cities, the capitals of Italian provinces. Such cities serve as primary laboratories for environmental transition but also exhibit deep historical and structural resistance to change [11–13]. For urban planners, decarbonization is not merely a climatological target; it represents a radical reshuffling of territorial assets, from the retrofitting of the historical building stock to the total reorganisation of metropolitan mobility. However, the current state-of-the-art suggests that, despite increases in planning activities and available capital, the correlation between institutional intent and actual emission reductions remains poorly documented [14–16].

The Covenant of Mayors (CoM) framework is a big part of this change because it makes local climate goals official. Italy has adopted this framework widely, making it the European country with the most signing mayors. However, the adoption is still not uniform. The level of municipal commitment is a sign of how mature the administration is. It goes through a clear hierarchy, starting with the first political signal, then the creation of integrated strategies (Sustainable Energy and Climate Action Plans - SECAPs), and finally the strict monitoring of results. From the point of view of territorial and urban governance, the change from planning to monitoring is very important; it represents the juncture at which strategic decisions must undergo empirical evaluation. However, in numerous Italian contexts, the disparity between these phases persists, prompting inquiries regarding whether such commitments serve as authentic catalysts for change or merely as superficial bureaucratic adherence.

Despite the formal commitments made by cities to these initiatives, resources have been extensively directed toward solutions and interventions addressing climate change. Since 2017, the OpenCoesione portal has continuously documented investments explicitly designated as "Climate Change Strategies Focus". Economic resourses have gone to important areas like building infrastructure for sustainable transportation, using renewable energy, and making public assets more efficient. These expenditures embody the tangible implementation of urban policies; however, their efficacy necessitates validation through longitudinal physical data. By cross-referencing these financial flows with CO2 emissions trends from 2000 to 2023, we can go from a story-based state of the art to an evidence-based audit. This longitudinal data encompasses various socio-economic cycles, enabling us to evaluate whether the recent surge of "green" capital has effectively dissociated urban growth from carbon emissions.

The research presented here focuses on major Italian cities as the main characters of the national climate strategy. By examining the mismatch between what cities have committed to, what they have spent, and how they have performed in terms of mitigation, this study seeks to identify empirical inconsistencies. Specifically, the paper investigates if current climate funding is correctly aligned with the metabolic profile of the city, addressing the actual dominant sources of emissions, such as residential heating or private transport, or if there is a sectoral misalignment that undermines the path to neutrality. Ultimately, the work questions whether the planning efforts of the last two decades

have been sufficient to transform the carbon trajectory of Italian urban environments, or whether a more radical, spatially driven approach to investment is required.

2 Materials and Method

To address the research questions identified in the previous section, this study employs a multi-dimensional methodological framework grounded in the triangulation of three distinct datasets.

The goal is to look at how climate commitments, financial flows, and emission trends affect each other in Italy's provincial capitals (namely, *capoluogo di provincia*). This method goes beyond merely assessing the quality of urban climate governance; it seeks an empirical framework that spans the entire policy cycle, from formal strategic intent and actual capital investment to verified performance assessment. The next three sections give a detailed look at the datasets that were used and the steps that were taken to make the data consistent and standardise it, to ensure that Italy's major urban centres can be compared in a strong way. The final subsection focuses on a subset of synthetic indicators developed to provide further insights into the empirical framework.

2.1 CO_2 Emissions: Enel YoUrban

The data used to assess trends in CO_2 emissions were drawn from a dataset provided by Enel X, which has developed the new CO_2 City Index 2023 [17]. The tool, designed for policymakers, allows users to navigate, simply and intuitively, via a map, estimates of anthropogenic CO_2 emissions across the whole of Italy from 2000 to 2023, expressed as total CO_2 per square kilometres and CO_2 per inhabitant, both in tons per year. From 2020 to 2023, it also provides a detailed overview of the top 10 emitting sectors. The sectors range from industrial activities, agricultural activities, residential buildings, commercial and public buildings, and extra-urban, logistics, private and local public transport, ports, to airports. The stated aim of this tool is to raise awareness among public administrations regarding emissions in their respective territories and to provide them with an initial assessment that serves as a basis for more detailed territorial analyses.

The CO_2 City Index 2023 uses multi-scalar triangulation of national institutional data and spatial proxies to transform top-down national reporting into evidence-based territorial measurement. The methodology uses national inventory reports from ISPRA [18] and the UNFCCC [19] as a base, so that emission levels are in line with international "Scope 1" direct emissions. The national figures are then downscaled to the municipality using socio-demographic and economic variables from ISTAT [20], including census data and ATECO [21] industrial classes to weigh emissions from houses and businesses.

OpenStreetMap roads and hierarchy and flow data from the Automobile Club d'Italia (ACI) [22, 23] are incorporated. Specific traffic volumes from Assaeroporti and Assoporti [24] will identify the impacts of port-based transport and airports on the ground. For agriculture, the model uses Copernicus Corine Land Cover [25] data and Ministry of Energy and Trade and Industry records from Mase and Mimit [26] about provincial gas and fuel sales. The model is compared against the EDGAR inventory and ODIAC models to produce a high-resolution spatial grid of 1x1km [27, 28]. This integration of

open data sources allows a precise assessment of the urban carbon footprint over the past 23 years.

In order to operationalise the dataset, CO_2 emission records have been normalised to allow comparison across the different case studies among the sample.

2.2 Urban Investments on Climate Change Strategies: OpenCoesione

To define the financial flows, the cohesion policy funds freely available on the OpenCoesione.gov.it website were taken into account [29]. Specifically, the data available in the section entitled 'Focus on Climate Change Strategies' was considered [30]. This section is dedicated to EU cohesion policy interventions which, according to the criteria set out in European Commission Implementing Regulation No 215/2014 for the 2014–2020 programming cycle, contribute to preventing climate change [31]. Based on the common provisions in the regulation, which outline methodologies for calculating contributions to climate change mitigation and the types of interventions funded, the dataset identifies two broad categories of projects. The first category comprises projects that are directly and entirely focused on combating climate change (contributing 100%). Funding is allocated to initiatives that substantially reduce emissions or increase resilience. The second category includes projects that have a positive impact on the climate, although indirectly or partially, or that represent preparatory actions towards environmental sustainability (contributing 40%) [31, 32]. The methodology used aims to provide an initial estimate of the investments made using European funds to achieve the target of reducing CO2 emissions [30]. Although the analysis focuses on climate change strategies, the initiatives have been grouped under 13 broad themes identified by OpenCoesione. The themes of cohesion are "Research and Innovation", "Digital Networks and Services", "Business Competitiveness", "Energy", "Environment", "Culture and Tourism", "Transport and Mobility", "Employment and Work", "Social Inclusion and Health", "Education and Training" and "Administrative Capacity". In particular, the initiatives included in the database focusing on climate change strategies belong to only some of these categories ("Environment", "Competitiveness and Enterprise", "Culture and Tourism", "Energy", "Digital Networks and Services", "Research and Innovation" and "Transport and Mobility"). This classification allows us to see how the climate objective intersects with sectors, providing an overview of investment priorities. All projects in the dataset were taken into account, covering all stages of progress, from those not yet started to those already completed, thereby considering not only what has already been achieved but also the total financial commitment. Consequently, the financial dimension considered is the sum of total public funding, excluding public funding, foreign resources, and other similar items. In order to ensure the greatest possible comparability between the cities in the sample, the thematic categories 'Culture and Tourism', 'Digital Networks and Services' and 'Research and Innovation' were excluded from the analysis. Their exclusion is justified by the highly asymmetrical distribution of funds across these categories. As these are expenditure items present only in a very limited number of cities, their inclusion would have introduced a bias into the IM index, penalising cities lacking such investments and inflating the apparent diversity of those that benefited from them. The analysis is therefore conducted on the four thematic categories with sufficiently widespread coverage in the sample: Energy, Environment, Competitiveness of companies and Mobility and

Transport. The Energy theme covers the construction of facilities for generating energy from renewable sources and the promotion of energy saving among citizens, businesses and the public sector, including schools. It also includes measures to promote district heating and cooling, and the development of cogeneration (electricity and heat) and trigeneration (electricity, heat and cooling). As far as the Environment theme is concerned, it covers measures relating to waste and wastewater management. It also includes actions to prevent environmental risks, coastal erosion and hydrogeological instability, including measures to adapt to climate change, promote biodiversity and protect nature. The Business Competitiveness theme includes incentives and practical support for the creation of new businesses and new production facilities, or for the expansion and modernisation of existing plants and production areas. It also includes support for financial engineering instruments for businesses (guarantee funds, loan funds and access to credit, and venture capital funds). In the end, the Mobility and Transport theme covers the upgrading of railway lines, the road network, port connections and intramodality. It also includes measures to encourage sustainable mobility and those promoting public transport in congested urban areas [29].

2.3 Commitment Level: Covenant of Mayors

The third dataset is based on an open database relating to the Covenant of Mayors (CoM) [31]. This database tracks the Italian cities participating in the CoM and monitors their progress through the various stages [33]. The CoM represents one of the largest voluntary institutional movements for local authorities on climate governance [34]. The initiative initially united mayors who pledged to exceed the EU's target of reducing CO_2 emissions by at least 20% in their territories by 2020. The rapid growth of the EU Covenant underscored the determination and leadership of local authorities in confronting the climate crisis from the ground up. It was launched in 2008 and currently has around 10,800 signatories representing 220 million citizens [34]. By signing up, mayors formally commit to implementing European climate and energy objectives at the local level [34]. By joining the EU Covenant of Mayors, cities and towns pledge to develop, implement and monitor Sustainable Energy and Climate Action Plans (SECAPs) [35]. The first step is to sign the Pact and formalise the commitment before the local council. This is a necessary declaratory step and has no operational content whatsoever. The second step involves planning the presentation of the SECAP, which must take place within two years of signing [35]. The SECAP is a plan in which local authorities outline the measures and policies the administration intends to implement to achieve its climate governance objectives [35]. Both the commitments and the drafting of the SECAP are envisaged across three different timeframes: 2020, 2030 and 2050. Signatory municipalities commit to reducing CO_2 emissions by at least 20% by 2020, with an obligation to submit a Sustainable Energy Action Plan (SEAP) focused exclusively on mitigation [34]. With the second update, launched in 2015, the target was raised to a 40% reduction in climate-changing emissions by 2030 and the framework was extended to include adaptation, with the SEAP replaced by the more comprehensive SECAP [35]. With the third update, however, the scheme aligns with the European Green Deal and the European Climate Law, guiding signatories towards carbon neutrality by 2050, with an indicative interim target of a 55% reduction by 2030 compared to 1990 levels [34]. A key analytical

feature is the flexibility introduced with respect to the 2030 horizon: municipalities that commit to 2050 are not obliged to set a binding interim target for 2030, allowing them to structure their own milestones toward climate neutrality autonomously [34]. This option creates structural heterogeneity within the sample between municipalities with dual 2030/2050 targets and those with exclusively long-term commitments. The final step for the signatories of the pact is to commit to submitting monitoring reports [35]. The local authorities undertake to monitor the extent to which the actions and measures contained in the SECAP are being implemented [35]. This step represents the most demanding operational challenge for the local authorities, who will have to prepare up-to-date inventories of emissions and implement climate policies.

2.4 Data Integration and Synthesis

Having three heterogeneous databases poses an analytical challenge in terms of how to compare the data analytically in order to identify patterns between cities, investments and CO_2 emissions. To this end, data integration was achieved through various methodological operations: (i) the normalisation and standardisation of data relating to changes in CO2 emissions and total public investment extracted from OpenCoesione; (ii) the construction of two composite indicators that simplify the complexity of the information; (iii) the use of bivariate graphs as the primary tool for interpreting the relationships between the three dimensions

CO_2eq emissions had already been calculated in tCO_2eq per capita, while the following percentage formula was used to assess the change in emissions over the period 2000–2023:

$$\Delta CO_{2,i} = \frac{CO_{2,i,2023} - CO_{2,i,2000}}{CO_{2,\ i,\ 2000}} \times 100$$

Where ΔCO_2,i,t represents the total emissions of municipality i in year t. A negative value indicates a trajectory towards decarbonisation, whereas a positive value indicates an increase in emissions over this period. OpenCoesione Public investment has also been expressed in per capita terms (€ per inhabitant), calculated based on the ISTAT population at 31 December 2024.

The first composite indicator is the Investment Mix Index (IMI), which measures the degree of sectoral diversification of investments, based on the 13 composite themes of OpenCoesione. The index was constructed on the basis of the entropy index, which has been used in numerous studies to represent the land use mix [36, 37]. The land use mix measures the distribution of heterogeneous categories within a spatial unit. Entropy scores range from 0 to 1, where 0 indicates a homogeneous land use and 1 indicates a balanced mix of the categories present. This same approach was applied to the thematic investment categories extracted from OpenCoesione, whilst maintaining the logic of the entropy index. The formula used is as follows:

$$IMI_i = -\frac{\sum_{s=1}^{n} \left(p_{i,s} \bullet \ln\left(p_{i,s}\right)\right)}{\ln(n)}$$

Where $p_{i,s} = I_{i,s}/I_{i,tot}$ is the share of thematic category s in the total OpenCoesione investment of municipality i, and n is the total number of thematic categories considered. The denominator $\ln(n)$ normalises the index within the interval [0,1], making it possible to compare cities with investments spread across a different number of active sectors. An IMI value close to 1 indicates an even distribution of expenditure across all available categories; a value close to 0 indicates that almost all investments are concentrated in a single sector.

The second composite indicator is the Level of Commitment (LoC), which measures institutional governance by distinguishing between cities that are only formal members of the CoM and those that are actively committed to achieving the objectives. The LoC summarise the ability to complete the institutional cycle of three phases described above in a scalar index ranging from 0 to 1, divided into four thresholds, as summarised in the following Table 1.

It is important to emphasise that the LoC does not measure the quality of the plan or the ambition of the stated targets, but solely the degree to which the institutional cycle set out in the CoM framework has been completed. In this sense, the index serves as a proxy for the municipal administration's administrative capacity and procedural consistency, rather than as a direct indicator of climate performance. The association between the LoC and changes in emissions is therefore one of the central interpretative axes of the analysis, allowing us to test empirically whether more structured climate governance translates, and to what extent, into actual decarbonisation outcomes.

Table 1 Structure of the LoC Index_ values assigned to the institutional phases of the CoM

Level of commitment	LoC value
Municipality not signed the CoM	0
Commitment to the CoM (2020, 2030, 2050)	0.33
Submission of Action Plan (SEAP or SECAP)	0.66
Monitoring latest Action Plan	1

Once the indicators had been developed, the three datasets were integrated using a series of bivariate graphs. The aim is to identify possible relationships between the commitment of cities and local authorities, the economic resources at their disposal, and actual changes in emissions.

3 Results

This section presents the results of the analysis, structured on different levels of interpretation. Firstly, it describes the emissions trajectories of Italy's provincial capitals over the period 2000–2023.

It then analyses the structure of the cities' institutional commitment within the CoM framework. Finally, the two analyses are integrated with the dimension of public investment in climate strategies through bivariate graphs constructed using the synthetic LoC index.

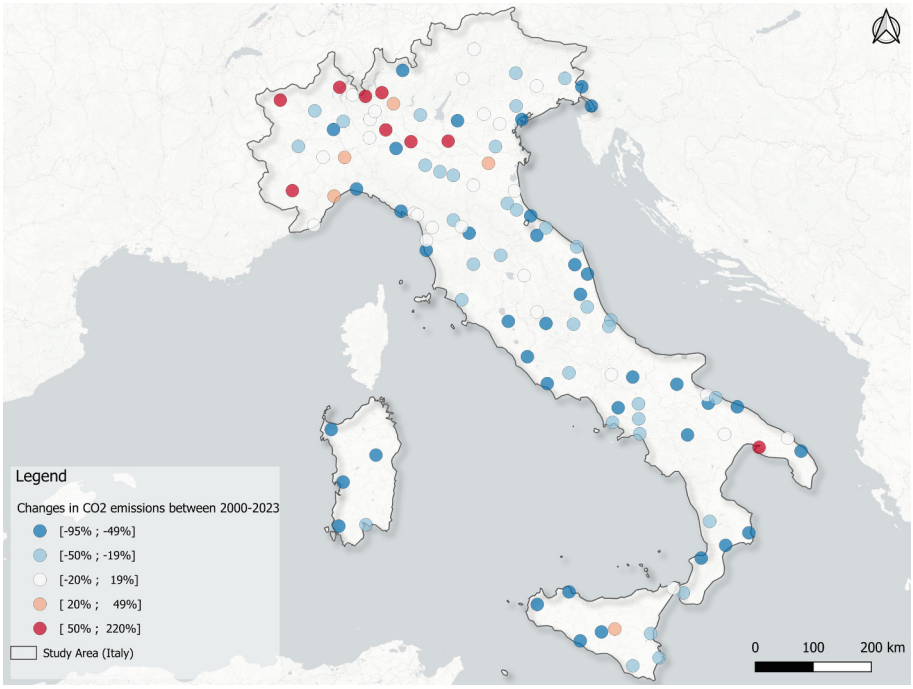

Fig. 1 Spatial analysis of CO_2 emissions trend in Italian provincial capitals, from 2000 to 2023. Authors' elaboration from Enel YoUrban database.

The study aims to identify recurring patterns or misalignments between the three analytical dimensions.

The analysis of the percentage changes in CO2 emissions over the period 2000–2023 (Fig. 1) shows an overall positive trend, with an average decrease of 23%. The most significant reductions, ranging from 50% to 95%, were observed mainly in cities in northern Italy and in some in central Italy. Cases of increased emissions are in the minority, but are not to be overlooked, given that the increases reach up to 220% (in Lecco). The moderate variation range (−20% to +19%), which includes provincial capitals with essentially stable trends, is distributed across the entire country, representing a widespread condition independent of regional location.

The Sankey diagram (Fig. 2) provides an immediate overview of the structure of institutional commitment among the 112 provincial capitals in relation to the CoM framework, revealing a gradual decline in the number of cities as the operational demands of each phase increase. The rate of formal participation is very high, with around 94% of cities having signed the Covenant. However, the distribution by level of commitment shows that most cities have committed only to 2020, with just a small number also committing to 2030. By 2050, only 19 cities have committed to producing a SECAP, suggesting that most cities have not yet renewed their commitment to more ambitious timeframes. The transition to the planning phase reveals a significant initial decline: whilst 80 cities submitted an Action Plan under the CoM 2020, only 43 did so for 2030

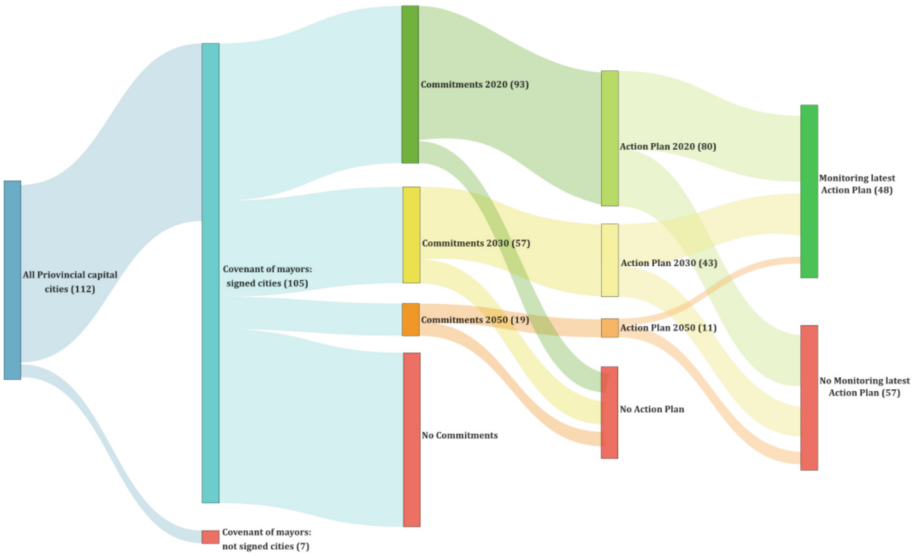

Fig. 2 Institutional funnel of Covenant of Mayors participation among Italian provincial capitals (n = 112).

and just 11 for 2050. Overall, therefore, a not insignificant proportion of signatories have not yet translated their political commitment into an operational planning tool. As regards the monitoring phase, less than half of the signatories have drawn up a monitoring report on the latest actions implemented.

The scatter plot in Fig. 3 plots the 112 cities on a bivariate graph defined by per capita investment (X-axis) and the percentage change in CO_2 emissions (Y-axis), grouping the cities by LoC class. The linear regression lines for all four LoC classes show a negative slope, indicating that, regardless of the level of institutional commitment, higher per capita investment tends to be associated with greater reductions in emissions. However, the slopes are similar to one another, and the 'No commitment' class (LoC = 0) exhibits the regression with the steepest slope, an apparently counterintuitive result suggesting that the effect of investment on emissions reduction is not associated with the commitment generated by the CoM. Most cities fall within a range of an average per capita investment of €0–200 per inhabitant and a reduction in emissions, regardless of the LoC group to which they belong.

Figure 4 completes the analysis of these data, grouping the cities by LoC and simultaneously showing, in a combined graph, the average CO_2 emissions (in gold, left-hand axis) and the average per capita investment (in green, right-hand axis). The most striking finding is that, in both cases, the differences between the groups do not follow the expected gradient. It is the LoC = 0.33 group, which corresponds to cities that have signed the Covenant of Mayors but have not produced either an action plan or a monitoring report, that shows the most pronounced average reduction in emissions across the entire sample. Cities with the most comprehensive institutional cycle (LoC = 1, active monitoring) show a more modest average reduction. In terms of investment, it is the LoC

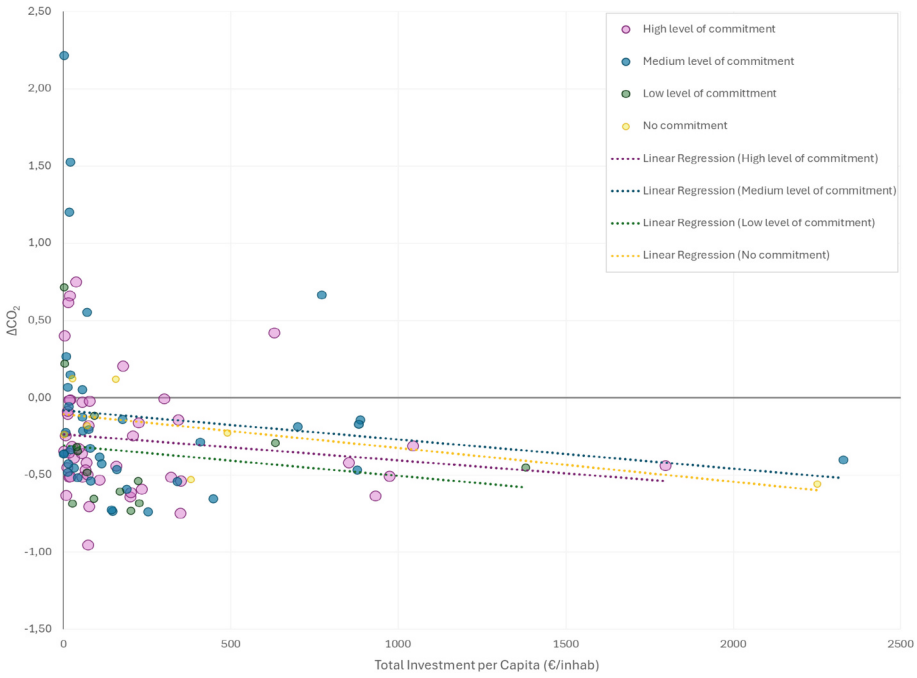

Fig. 3. Bivariate scatter plot of total public investment per capita (€/inhabitant, x-axis) and percentage change in CO_2 emissions 2000–2023 (ΔCO_2, y-axis), stratified by Level of Commitment (LoC).

= 0 group: cities with no commitment to the CoM show the highest average per capita investment in the sample, with a particularly pronounced upward dispersion

To explore the unexpected patterns revealed by the bivariate analysis, the internal sectoral composition of investment for the cities in these two groups was examined by visualising the investment by thematic category (Environment, Energy, Mobility and Transport, Competitiveness of companies) in the Fig. 5. For the group of cities with Loc = 0.33 (Fig. 5a), the average IM index is 0.39. This is also evident when examining the investment sectors, which are heterogeneous. Some cities show a clear dominance of the Energy category (Avellino, Gorizia, Sondrio, Terni, Crotone), others are almost entirely focused on Mobility and Transport (Carbonia, Caserta, Rovigo), whilst

Como concentrates almost all of its expenditure in the Environment category. Ferrara has a significant share in the Competitiveness of companies category, even though this is not directly linked to a sectoral decarbonisation strategy, accounting for over 65% of total investment. The graph for cities with LoC = 0 (Fig. 5b) shows an even more pronounced pattern of mono- or bi-sectoral concentration. Indeed, from the perspective of the IM index, most cities have low values. Almost all cities in this group have investments spread across no more than two categories, with a clear alternation between Energy and Mobility and Transport. Imperia and Padua concentrate almost all their expenditure on Energy; Carrara, Catanzaro, Reggio Calabria and Vibo Valentia are dominated by Mobility and Transport, with varying shares of Energy; Reggio Emilia has the most varied

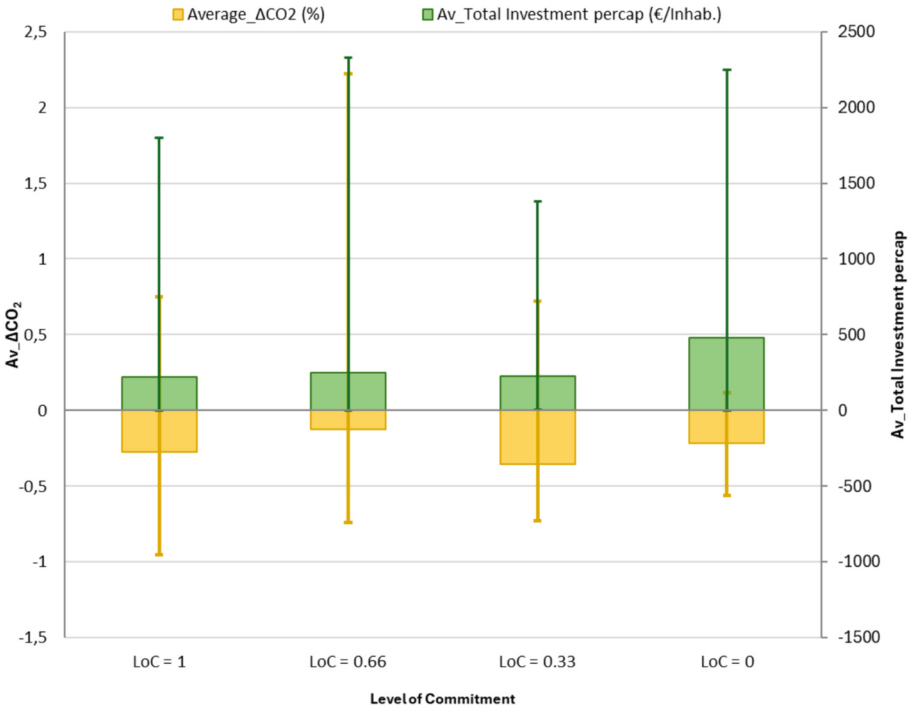

Fig. 4. Grouped bar chart comparing average ΔCO_2 (%, left axis, gold) and average total investment per capita (€, right axis, green) across Level of Commitment tiers (LoC = 1, 0.66, 0.33, 0).

distribution in the group, with a significant Environment component alongside Energy and a residual share of Mobility. The most significant finding for interpretative purposes is that no city in this group exhibits a diversified portfolio, and the 'Competitiveness of companies' category is virtually absent, unlike what was observed in the LoC = 0.33 group. This suggests that the high levels of investment recorded in the LoC = 0 group are concentrated in infrastructure sectors with a more direct climate relevance, namely energy and mobility



Fig. 5. Sectoral composition of climate-sensitive investments as used in the construction of the Investment Mixité Index (IMI), for the two groups showing the most anomalous patterns relative to the expected LoC–performance gradient: cities with LoC = 0.33 (a) and cities with LoC = 0 (b). Bars represent the proportional share of expenditure by thematic category (Environment, Energy, Mobility and Transport, Competitiveness of companies) over total per capita investment. Authors' elaboration on Open Coesione data.

4 Discussions and Conclusions

The results driven by this contribution aim to empirically delineate the status of urban climate governance in Italy by triangulating three distinct yet complementary dimensions: the actual trajectory of CO_2 emissions in Italian provincial capitals from 2000 to 2023, the volume and sectoral composition of public investments facilitated by EU

cohesion policy funds, and the institutional maturity of cities within the Covenant of Mayors framework. The evidence obtained contradicts numerous established beliefs about the relationship among climate commitment, financial investment, and decarbonisation outcomes.

The spatial analysis of emission trends shows that most of Italy's provincial capitals have been able to lower their per capita CO_2 emissions over the study period. There is a clear concentration of deep reductions (over 49%) in mid-sized and smaller cities, especially in the Centre-South. Nonetheless, a substantial cluster of cities, particularly in the North-West, has experienced considerable increases in emissions, highlighting the spatial heterogeneity of Italy's decarbonisation trajectory and the dangers of using national or regional aggregates as a substitute for urban climate performance.

The institutional landscape, as highlighted in Fig. 2, reveals a system with broad but uneven formal participation. The CoM has been signed by 105 of the 112 provincial capitals, but as governance improves, the number of cities that have reached the monitoring phase, which is the stage that requires real accountability, drops to only 48. The fact that many cities were arrested during the commitment or planning phases suggests that institutional participation is more common than institutional performance. This supports the idea that signing the CoM is often more of a statement than an action.

The bivariate analysis of investment intensity and emission change, categorised by LoC, leads to a result that is simultaneously promising and warning. The regression trends indicate a negative relationship between investment per capita and ΔCO_2 across all commitment groups. This means that more investment is linked to less emissions. But the link is weak, especially when investments are low, and the wide range of outcomes within each group shows that the amount invested does not determine climate outcomes. Cities with the highest Level of Commitment (LoC = 1) show the widest range of emission trajectories, with some of the biggest drops and some of the biggest rises. This finding carries a potentially important interpretive implication: in cities where climate commitment is most seriously institutionalised, mitigation may not be the only objective shaping urban policy. The integration of adaptation, resilience, and quality-of-life targets within mature governance frameworks may partially explain why emission reduction alone does not emerge as a linear outcome of high institutional commitment, pointing to the inherent multi-objective complexity of advanced urban climate governance.

On the other hand, the grouped bar chart comparing average ΔCO_2 and average investment per capita across LoC tiers shows a surprising pattern: cities that do not have a CoM commitment (LoC = 0) invest more money per person on average than cities that do, but they also cut emissions by about the same amount or a little less. This finding does not absolve institutional disengagement; however, it reveals the structural disconnection between the channels for fund allocation and the governance frameworks that formalise climate objectives. These two systems seem to operate simultaneously rather than together, which limits their potential for synergistic impact.

A wider look at the results of this empirical research shows a major problem with how Italy manages its urban climate: there is a gap between investments, what cities have officially committed to, and what emissions trajectories really look like on the ground. The implication for urban planning is clear. Decarbonization is not a straightforward

result of financial volume or bureaucratic compliance. It depends on how well investments are tailored to each city's unique metabolic profile, focusing on the main sources of emissions in that area rather than using general sectoral templates. It also depends on whether institutional frameworks create real operational accountability instead of just following procedures [38].

Future research should deepen the sectoral decomposition of both investments and emissions, moving beyond aggregate indicators to map whether cohesion funds are actually directed toward the emission sources that most characterise each city's carbon fingerprint. The integration of urban features to capture the unique urban footprint (e.g. as building stock age, land use mix, and transport network density) would further enrich the analytical framework and begin to account for the structural inertia that this study has identified as a persistent mediating factor between policy intent and territorial outcomes [39]. As the European climate mission accelerates toward Net-Zero targets, the evidence produced here suggests that Italy's major cities need not more commitments, but better-aligned ones. In this sense, the empirical framework developed here is intended as a first step toward a broader research agenda: one that treats major Italian cities not merely as objects of analysis, but as the primary drivers of national climate transition. The heterogeneity of urban profiles documented in this study, ranging from emission trajectories, investment intensities, and governance maturity, ultimately motivates the need for decision-support tools capable of translating this complexity into actionable, city-specific guidance for policymakers, moving from the diagnosis of misalignment to the design of tailored climate solutions.

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