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Assessing alignment of local climate strategies with European green deal priorities: evidence from small settlements

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ABSTRACT

Rural areas are indispensable to achieving the European Green Deal's (EGD) vision of climate neutrality by 2050, yet the extent to which local climate actions reflect this potential remains unclear. This study investigates how small rural municipalities engage with the EGD's thematic domains by analysing over 43,000 local policy measures from the Covenant of Mayors (CoM) database. Through a systematic classification and multiple correspondence analysis, we assess both the thematic alignment and policy instrument diversity across the Green Deal domains. The findings reveal a striking thematic imbalance: while Clean Energy and Sustainable Mobility account for over 80% of measures, critical domains such as Biodiversity Protection, Sustainable Food Systems, and Zero Pollution are severely underrepresented – despite their high relevance and feasibility for rural contexts. Furthermore, local policy portfolios are dominated by informational and operational instruments, indicating a preference for low-barrier interventions over more transformative regulatory or financial tools. Clustering analysis identifies four distinct policy strategies – Public Sector Infrastructure, Technology & Incentive-Based, Awareness & Behavioural Change, and Operational Energy Management – each reflecting differing configurations of policy focus, implementation approach, and local capacity. These results expose structural governance gaps and underscore the need to empower rural municipalities with greater resources, enforcement authority, and cross-sectoral planning capacity. By illuminating how current local actions fall short of the Green Deal's systemic ambitions, this study offers concrete recommendations to rebalance the rural policy landscape and strengthen Europe's multilevel climate governance architecture.

Key policy insights

- Local climate action in small European municipalities is concentrated in energy and transport, while key rural domains—climate adaptation, water quality, biodiversity and sustainable food systems—remain largely absent. EU and national frameworks should incentivize their integration into local strategies.
- Small municipalities rely mainly on informational and operational instruments due to limited capacity. Strengthening their ability to design financial, regulatory and procurement tools is essential for more transformative policies.
- Municipalities exhibit distinct policy profiles, from awareness-based to infrastructure-focused approaches. Support and funding programmes should therefore be tailored to local capacity and implementation maturity.
- Inter-municipal cooperation and regional coordination can help small settlements overcome resource constraints and implement policy instruments that are difficult to achieve individually.

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1. Introduction

Achieving climate neutrality by 2050 is a central objective of the European Union (EU), prominently advanced through the European Green Deal (EGD) – an ambitious roadmap integrating environmental, economic, and social transformation. Achieving this objective requires implementation across diverse territorial contexts, including rural areas, where land use, energy production, and ecosystem management play a critical role in climate mitigation and adaptation. Rural areas cover about 83% of the European Union's land and host approximately 30% of its population (European Commission, 2021). They are essential for climate mitigation and adaptation because they underpin agriculture, forestry, and ecosystem management. Given their roles in renewable energy production (OECD, 2020), sustainable food systems (European Commission, 2020), and biodiversity preservation (European Environment Agency, 2023), rural communities and stakeholders are indispensable to the transition to climate neutrality, as highlighted in the goals of the EU Rural Vision (European Commission, 2021).

EU frameworks like the Common Agricultural Policy (CAP), Agri-Environment-Climate Measures (AECM), and the Farm to Fork Strategy mostly recognize the potential of rural areas in the transition to climate neutrality through agriculture. Therefore, climate and environmental objectives at the local rural level remain inconsistently integrated across sectors. Structural barriers – including population decline, limited infrastructure, and constrained governance capacity – compound the difficulty of implementing comprehensive and trans-sectoral sustainability strategies in small rural settlements. These challenges underscore the need for better alignment between EU-wide policy visions and the operational realities of rural governance.

The European Green Deal (EGD) seeks to address these gaps through a broad and integrative policy framework targeting multiple domains: clean energy, sustainable mobility, circular economy, biodiversity protection, climate adaptation, and just socio-economic transitions. Yet, evidence remains limited on how these domains are reflected in local-level policy implementation, particularly in small rural municipalities.

This study aims to address this gap by explicitly assessing the alignment of local policy measures in small rural settlements with the strategic priorities of the EGD. To achieve this, the research is guided by three main questions: (1) To what extent do current local climate actions cover the diverse thematic domains of the European Green Deal? (2) Which policy instruments are most frequently utilized by small rural municipalities? and (3) Can distinct strategic profiles be identified based on local policy choices?

Methodologically, the study draws on a dataset of over 43,000 policy measures from the Covenant of Mayors (CoM) database. We employ a quantitative approach combining systematic thematic classification with Multiple Correspondence Analysis (MCA) (Greenacre, 2007) and k-means clustering to identify structural patterns, policy gaps, and distinct implementation strategies. By highlighting key imbalances and missed opportunities in the local policy landscape, this paper contributes to the growing discourse on rural climate governance. It demonstrates how local implementation can better reflect the unique capacities of rural territories and supports the development of inclusive strategies to realize climate neutrality.

The remainder of this paper is structured as follows: Section 2 reviews the literature on the role of rural areas in climate transitions and the EGD framework. Section 3 details the data source and the analytical methods used, including the MCA and clustering approach. Section 4 presents the results regarding thematic distribution and policy typologies. Section 5 discusses the implications of these findings for rural governance gaps, and Section 6 provides concluding remarks and policy recommendations.

2. Literature review S1 literature review

The European Green Deal (EGD) acts as the EU's flagship strategy to achieve climate neutrality by 2050, combining environmental, economic, and social objectives under a single transformative policy framework. Introduced in 2019, it sets a legally binding target of net-zero greenhouse gas emissions by mid-century and includes interim goals such as reducing emissions by at least 55% by 2030. The EGD addresses multiple sectors – including energy, mobility, agriculture, and construction – and seeks to align economic growth with climate ambition through innovation, circular economy transitions, and social fairness (Stefanis et al., 2024; Wolf et al., 2021). While the vision is set at the EU level, the success of the EGD hinges on its practical implementation across Member States, regions, and local authorities. This multilevel governance is

operationalized through legislation like the Fit for 55 package and funding mechanisms such as the Recovery and Resilience Facility (RRF) and the Just Transition Fund (Carević, 2021; Křemečková & Šreflová, 2024; Muczyńska, 2022; Ovaere & Proost, 2022). However, this downscaling process is uneven across Member States, often struggling with coordination and co-financing (Ciot, 2022; Siddi, 2021). Understanding how these high-level mechanisms interact with specific territorial contexts is essential, particularly regarding the vast and varied landscape of rural Europe.

Rural areas are indispensable to this transition, covering about 83% of the European territory and hosting crucial ecosystems for carbon sequestration and biodiversity (Ottomano Palmisano et al., 2025). Agriculture remains a significant potential mitigator of climate change, supported by EU frameworks like the Common Agricultural Policy (CAP) and the Farm to Fork Strategy, which aim to increase organic farmland and promote afforestation (Klepacka et al., 2025; Wiśniewski et al., 2021). Yet, rural areas also face risks of environmental degradation through urbanization, habitat fragmentation, and intensive agricultural practices that threaten soil and water quality (Lu et al., 2025; Nicholas & Scown, 2024; Tan et al., 2022). Furthermore, the capacity of rural areas to contribute to climate neutrality is often constrained by structural disparities. While some regions benefit from robust infrastructure and dynamic local economies, others suffer from population decline and limited access to services (Prandecki, 2021; Wieliczko et al., 2021). This heterogeneity underscores the need for adaptive, place-based strategies that address not only environmental goals but also spatial justice, ensuring that rural territories do not bear disproportionate transition costs without equitable support.

To bridge the gap between EU ambitions and rural realities, effective local governance is critical. Local governments act as 'anchor tenants' for sustainability, mobilizing community resources and integrating high-level goals into granular practice (Fenton & Gustafsson, 2017). Research highlights that the success of this localization depends heavily on the interplay between political commitment and administrative capacity. For example, Hermelin and Gustafsson (2024) illustrate how municipalities can assume a 'place-leading' role by orchestrating collaborative initiatives, while Honeybun-Arnolda et al. (2024) emphasize the importance of democratizing governance through the inclusion of civic organizations. However, governance structures can also act as constraints; limited resource accessibility and inadequate integration of climate considerations into planning instruments often hinder adaptation efforts (Birchall et al., 2023). Consequently, realizing the European Green Deal in rural areas requires a governance approach that is not only multi-level and coordinated but also deeply participatory and responsive to local structural capacities.

Finally, when assessing local capacity, the historical evolution of policy frameworks must be considered. The Covenant of Mayors, the primary instrument for local EU climate action, was established in 2008 to meet the '20-20-20' targets, predating the systemic scope of the European Green Deal (Raveschoot et al., 2010). Its initial methodological guidelines prioritized energy efficiency and renewable energy in the building and transport sectors. As a result, many local action plans currently in force were designed under a mitigation-centric framework, creating a temporal and thematic lag between existing local strategies and the newer, broader ambitions of the EGD (Bertoldi et al., 2010; Raveschoot et al., 2010).

3. Methodology

3.1. Research design and strategy

This study aims to assess the alignment between local policy measures implemented in small settlements and the thematic domains outlined in the European Green Deal (EGD). A descriptive quantitative research design was used, based on the analysis of a large pre-existing policy database. To ensure academic robustness, the research adopts a dual strategy: a deductive approach to assess compliance with the EGD framework, and an inductive approach using unsupervised machine learning to identify latent policy typologies. The focus on small municipalities was chosen due to their critical but underexplored role in achieving climate neutrality.

Based on the literature regarding rural capacity constraints and multilevel governance gaps, we posit the following working hypotheses to guide the analysis:

H1: Local policy portfolios in small settlements will display a significant thematic imbalance, prioritizing energy and mobility while underrepresenting systemic domains like food systems and biodiversity.

H2: Due to limited administrative authority and financial resources, small municipalities will predominantly rely on soft policy instruments (informational and operational) rather than regulatory or financial tools.

H3: Local climate strategies are not uniform; distinct policy profiles will emerge based on the specific availability of local infrastructure and institutional capacity.

3.2. Data source

The primary data source for this study is the Covenant of Mayors (CoM) database, which contains climate and energy actions plans submitted by participating municipalities. The dataset includes 43,710 policy measures reported by small settlements, defined here as having populations under 10,000. In this study, the terms 'municipality' and 'municipal level' refer to Local Administrative Units (LAU), specifically level 2 (LAU-2), which constitute the lowest level of administrative division and the standard statistical unit for local governance across the European Union. Countries included in this analysis are Italy, Spain, Portugal, Austria, Cyprus, Croatia, Belgium, Sweden, Romania, Greece, Slovenia, Moldova, Ukraine, Hungary, France, and Poland. Most entries originate from Italy and Spain, reflecting a strong support structure for CoM participation in these countries. Italy and Spain stand out as the countries with the highest participation in the Covenant of Mayors, particularly among small municipalities, reflecting strong institutional engagement and support structures. In Italy, regulatory frameworks have played a facilitating role, such as the legal requirement for municipalities with over 50,000 inhabitants to develop energy plans, which aligns well with the CoM methodology. In both countries, national and regional actors have contributed to creating favourable conditions for local climate action, including administrative support and integration with existing planning obligations, helping to explain the exceptionally high number of signatories compared to other EU Member States (Kona et al., 2018; Lucchitta et al., 2024; Salvia et al., 2021). This proactive institutional support has led to a higher reporting rate compared to other EU countries where such support structures are less developed.

This geographic concentration introduces potential biases, limiting the broader generalizability of findings across all EU contexts. Crucially, the dataset exhibits a 'legacy bias' stemming from the specific reporting requirements in place when the majority of these plans were submitted. As the Covenant's initial focus was on meeting the EU's 2020 targets, the reporting framework prioritized mitigation actions in the energy and transport sectors. Since climate adaptation and broader environmental domains were not mandatory reporting fields during the 2010–2020 period, their lower representation in this dataset reflects the institutional design of the time rather than solely a lack of local interest. Finally, it is important to note that these plans represent measures planned by municipalities; actual implementation is tracked separately through monitoring reports. While the dataset relies on bottom-up, self-reported information which may introduce heterogeneity, its reliability is bolstered by the Covenant's institutional framework. Specifically, all analyzed measures originate from Action Plans that have undergone a mandatory compliance and coherence evaluation by the Joint Research Centre (JRC), mitigating potential quality issues inherent to crowd-sourced reporting (Kona et al., 2018; Lucchitta et al., 2024; Rivas et al. 2022). Data selection involved filtering for settlements classified as small, ensuring that the measures analyzed correspond to municipalities likely to face similar challenges and opportunities. We further retained only those measures where the municipality or local authority was indicated as responsible for implementation, excluding actions led exclusively by national, regional, or private actors.

3.3. Analytical framework

Each policy measure was classified according to its alignment with the European Green Deal domains. The domains and subdomains were based on EGD official documentation. Measures were also categorized by type of policy instrument, distinguishing between regulatory, financial, procurement, informational, operational, planning, and voluntary/collaborative instruments (Metz et al., 2007). We assessed each domain's relevance –its importance for rural climate outcomes– and feasibility –the local authority's capacity to implement

measures– using scientific literature, policy frameworks, and governance analyses. High relevance was assigned to domains where local action is crucial for climate neutrality goals, while high feasibility indicated areas where local authorities possess the jurisdiction and practical capability to implement meaningful measures.

3.4. Data processing and classification

The processing involved several steps. Relevant measures were first extracted from the CoM database. Each measure was classified into EGD domains and policy instrument types using a combination of manual coding and automated assistance. Specifically, a large language model (LLM) was employed to generate preliminary classifications based on textual descriptions, which were then reviewed and validated by the research team to ensure accuracy and consistency. Special handling was applied to ambiguous measures, either by dual classification or by assigning them based on their primary focus. Where necessary, cross-referencing with available project descriptions or additional documentation provided by municipalities supported the classification.

3.5. Analytical methods

The core analytical methods applied included descriptive statistics, calculating the number and proportion of measures across domains and instrument types. Cross-tabulation was used to examine the distribution of policy instruments within each domain. Gap identification was conducted by comparing the observed distribution of measures to areas considered highly relevant and feasible for small settlements, highlighting underrepresented domains and subdomains.

To uncover underlying structural relationships in the dataset and test H3, Multiple Correspondence Analysis (MCA) was performed on four categorical variables associated with each policy measure: the action title (categorized), the mitigation action sector, the action area, and the policy instrument. MCA is particularly suitable for this type of categorical data, allowing us to project measures into a reduced-dimensional space while retaining the core variance of the original variables. This dimensionality reduction enabled the identification of latent similarities between policy measures based on their categorical profiles, which would be difficult to detect through descriptive methods alone.

The MCA results served as the input for a k-means clustering algorithm, applied to group policy measures into distinct clusters based on their component coordinates in the reduced MCA space. K-means is a widely used unsupervised machine learning technique that partitions data into k clusters by minimizing intra-cluster variance. To determine the optimal number of clusters (k), we evaluated two diagnostic metrics: the explained variance (inertia) and the silhouette score. The elbow plot (see Supplementary Material, Figure S1) shows a clear inflection point at $k = 4$, beyond which additional clusters offer only marginal gains in explained variance. This is consistent with the traditional elbow criterion, indicating diminishing returns in model fit with increasing k. To further support this choice, we computed silhouette scores for $k = 2$ to $k = 10$. The silhouette score measures how similar each observation is to its own cluster compared to other clusters, with higher values indicating better-defined clusters. As shown in Supplementary Material, Figure S2, the highest silhouette score is observed at $k = 4$, reinforcing the decision to adopt a four-cluster solution. Each cluster was subsequently analyzed and interpreted qualitatively, with reference to the dominant characteristics of the measures it grouped, to derive meaningful policy typologies relevant to small settlements.

3.6. Limitations

Several limitations affect this study. The dominance of measures from Italy and Spain may limit applicability across the EU, introducing geographic bias. Measures are self-reported by municipalities, possibly leading to inconsistencies or overstatements. Some policy measures could overlap multiple domains, and categorization decisions may introduce subjectivity. Additionally, this study assesses the existence of policy measures, not their effectiveness or outcomes. Finally, regarding the definition of 'rural', we acknowledge that population size is an imperfect proxy. While various methodologies exist to define rurality (e.g. density, land use, proximity to urban centres), they often contradict one another across national contexts. Therefore, this study utilizes a

population threshold of under 10,000 inhabitants to identify small settlements, recognizing that while this captures the vast majority of rural municipalities, it may exclude specific rural typologies or include some peri-urban areas. Despite these limitations, the analysis provides a valuable overview of local-level climate policy engagement in small European settlements, supporting the development of more targeted and comprehensive strategies for climate neutrality.

4. Results

4.1. Territorial distribution

The analysis reveals a significant geographic concentration, with Spain (52% of measures) and Italy (36%) dominating the dataset (for full figures see section S3). This skew is largely attributable to the active role of sub-national governance structures – such as Spanish provincial councils and Italian regional bodies – which provided the technical and financial 'umbrella' support necessary for small municipalities to join the initiative. Furthermore, the overwhelming prevalence of energy and mobility measures reflects the historical trajectory of the Covenant of Mayors (CoM). Launched in 2009 to support the EU's 2020 targets, the initiative's initial reporting frameworks and the 2010 Guidebook focused exclusively on mitigation. Broader domains like adaptation were only introduced in 2016, while biodiversity and circular economy remained outside the mandatory reporting scope during the period covered by the majority of these plans. See Supplementary Material, Section S2 and Figure S3 for full details on Territorial distribution and participating countries.

4.2. Policy domains

This study examined existing policy measures within small European settlements from the CoM database, assessing their alignment with the domains outlined in the European Green Deal (EGD). Analysis of 43,710 policy measures across various domains reveals significant disparities in focus and coverage (for full detailed table see Supplementary materials: Table S1).

The domain of Clean Energy dominates current policy initiatives (Figure 1), accounting for 28,136 measures (64.4%) of all measures, followed by Sustainable Mobility and Transport at 8,074 measures (18.5%). Notably smaller proportions were found in Just Transition and Socio-economic Cohesion with 3,451 measures (7.9%), Circular Economy with 2,142 measures (4.9%), and Research, Innovation, and Digitalization with 1,010 measures (2.3%). Critical domains such as Farm to Fork (Sustainable Food Systems) (47 measures, 0.1%), Zero Pollution (50 measures, 0.1%), and Biodiversity and Ecosystem Protection (631 measures, 1.4%) are substantially underrepresented. Notably, no measures address cross-border cooperation, indicating a policy gap in transnational collaboration at the local level.

Analysis by policy type (Figure 2) reveals a significant reliance on Informational (32%) and Operational (28%) measures. Other policy types, such as Financial (14%), Regulatory (11%), and Procurement (9%), constitute smaller fractions. Notably, Planning (5%) and Voluntary/collaborative (1%) initiatives remain relatively rare.

Energy Efficiency dominates the Clean Energy domain, accounting for 20,748 measures (47.5%) and primarily consisting of operational (43%) and informational (23%) instruments. Renewable Energy follows with 6,313 measures (14.4%), primarily financial (34%) and operational (22%) policies. Conversely, the subdomains Decentralized Energy Systems (1,070 measures, 2.5%) and Energy Security & Affordability (5 measures, 0.01%) demonstrate considerably lower engagement, reflecting limited implementation despite their high local relevance.

Further scrutiny against domains highly relevant and actionable at the rural level suggests a mismatch between local potential and actual policy implementation. Although domains like Clean Energy, Climate Adaptation, and Circular Economy are recognized as highly relevant and actionable, others crucial for rural sustainability, such as Sustainable Food Systems, Biodiversity Protection, and Zero Pollution, remain neglected.

Specifically, certain domains and subdomains marked as highly relevant with high feasibility show notably low implementation. Climate Adaptation (Risk Management and Resilience-building) accounts for only 58 measures (0.1%), despite its direct local applicability for safeguarding rural livelihoods and infrastructure. Similarly, the subdomain Water Quality (under Zero Pollution), essential for ensuring safe drinking water and

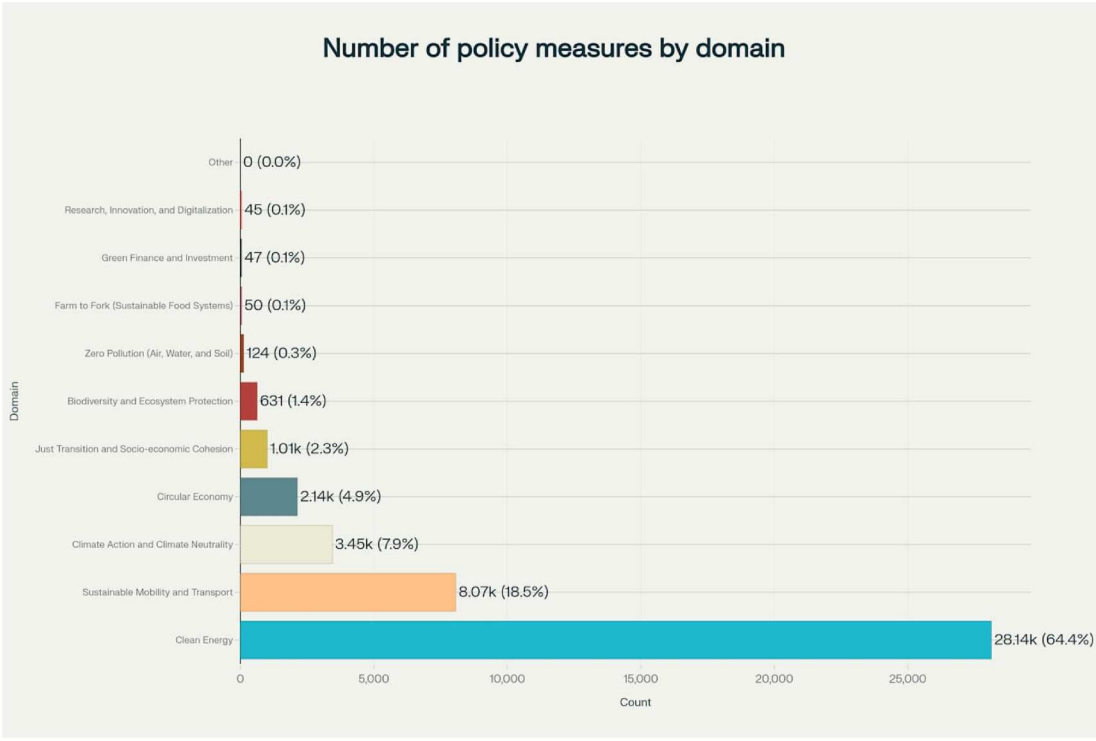

Figure 1. Policy measures by domain.

protecting local aquatic ecosystems, comprises just 49 measures (0.1%). Social Equity & Inclusion within the domain of Just Transition, crucial for supporting vulnerable populations during the green transition, represents merely 290 measures (0.7%). Strikingly, the subdomain Support for Green SMEs and Startups, despite its significant local economic potential and feasibility, has no recorded measures, indicating a substantial missed opportunity in fostering rural entrepreneurship.

In summary, the existing policy landscape in small rural settlements is significantly skewed toward energy and mobility, with insufficient attention given to equally vital domains integral to comprehensive rural sustainability under the European Green Deal.

4.3. Policy instrument types in dominant domains

A deeper examination of the three most prevalent domains – Clean Energy, Sustainable Mobility and Transport, and Circular Economy – reveals distinct patterns in the use of policy instruments, shaped by both the technical nature of interventions and the decision-making authority available at the local level.

4.3.1. Clean energy: operational focus with financial and informational support

With 28,136 policy measures (64.4%), the Clean Energy domain overwhelmingly leads the policy landscape, particularly through measures targeting Energy Efficiency and Renewable Energy (see Supplementary Material, Figure S4). The domain demonstrates a strong operational character, with 43% of Energy Efficiency policies and 22% of Renewable Energy policies categorized as Operational. These typically involve local retrofitting programmes, municipal upgrades, or community-scale deployments of technologies. Notably, Financial instruments make up 34% of Renewable Energy policies, indicating active municipal involvement in subsidies, grants, or investment incentives – critical for enabling renewable deployment at the village scale. Informational measures, representing 23% of Energy Efficiency and 16% of Renewable Energy policies, are often used to drive

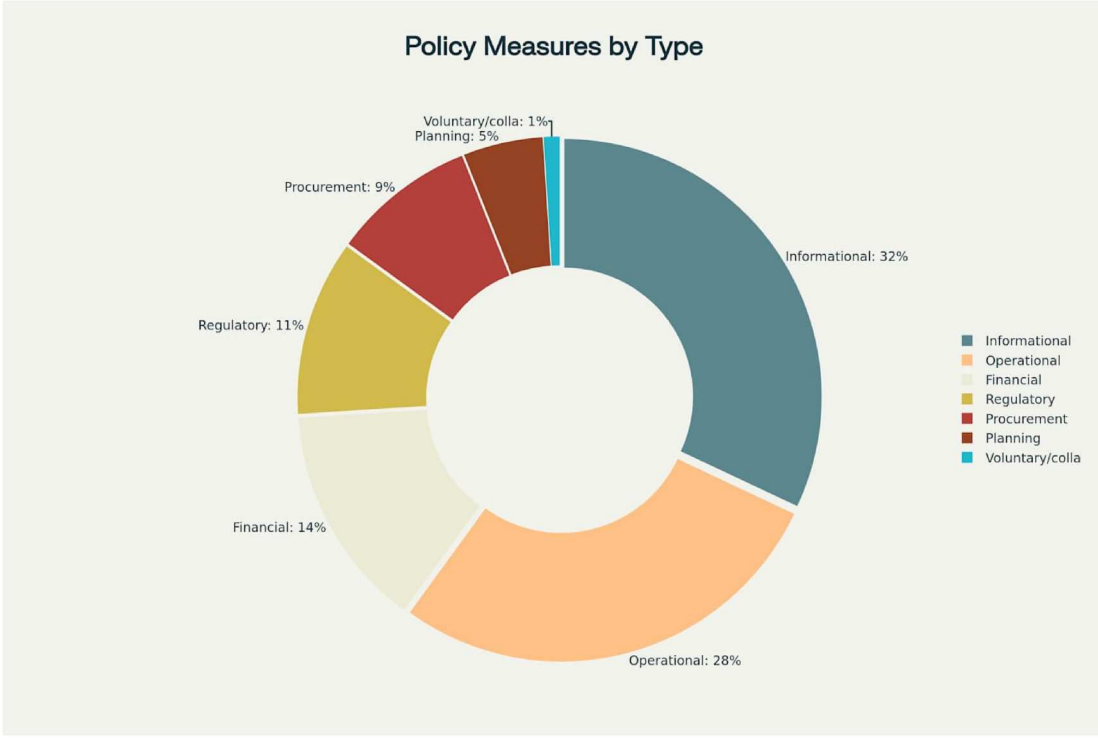

Figure 2. Policy measures by type.

adoption through awareness campaigns, training, or public guidance. In contrast, Decentralized Energy Systems show more mixed implementation, with a plurality (48%) of policies being financial – likely due to the capital-intensive nature of such infrastructure – while Energy Security & Affordability, though highly relevant to rural resilience, is almost absent, with only 5 measures recorded.

4.3.2. Sustainable mobility and transport: informational and operational instruments

The second most represented domain, Sustainable Mobility and Transport (see Supplementary Material, Figure S5), includes 8,074 measures (18.5%) and is dominated by Informational and Operational instruments, particularly in the subdomains of Electrification and Public & Shared Transport. Specifically, 42% of Electrification policies are Informational, complemented by 23% Financial and 17% Procurement measures – reflecting efforts to promote electric mobility through awareness and incentives. Similarly, Public & Shared Transport policies rely on Informational instruments (39%), supported by a mix of Regulatory (28%), Operational (10%), and Voluntary/Collaborative (5%) approaches. This pattern reflects the practical actions rural municipalities can take to improve accessibility while reducing emissions. Subdomains such as Alternative Fuels and Logistics & Freight, by contrast, remain marginal in number and are often constrained by limited local control over broader infrastructure.

4.3.3. Circular economy: reliance on informational instruments

Although Circular Economy accounts for just 2,142 measures (4.9%), its implementation is highly concentrated in certain subdomains, with a strong reliance on Informational instruments (see Supplementary Material, Figure S6). In Waste Management & Recycling, which alone makes up the vast majority of measures in this domain, 86% of policies are informational – typically involving educational campaigns, awareness-building, or public engagement activities. Similarly, Consumer Empowerment & Sustainable Consumption relies exclusively on Informational measures (100%), indicating a focus on behaviour change rather than structural or regulatory

interventions. This heavy informational emphasis reveals the limited variety of instruments deployed in the Circular Economy domain, despite its high relevance and feasibility at the rural local level. Other subdomains, such as Sustainable Industrial Processes, show a more balanced approach with Operational (48%) and Planning (32%) policies, but these remain the exception.

4.4. MCA and clustering analysis

A Multiple Correspondence Analysis (MCA) was conducted to explore how local climate and energy policy measures group according to their thematic sectors, action areas, policy instruments, and measure types. The analysis used a two-dimensional configuration, capturing 27.4% of the total variance. While this proportion may appear modest, it is typical in MCA applications involving categorical policy data and still allows for meaningful interpretation of underlying structures. Notably, Dimension 2 alone accounted for 20.2% of the total inertia, making it the dominant axis for differentiating policy profiles.

The first dimension primarily captures a structural contrast between technical and infrastructure-focused interventions and broader or non-infrastructure actions. The strongest contributors to this dimension were policy measures targeting the municipal buildings sector, operational types, and instruments related to energy management. This dimension reflects a clear orientation toward implementation-heavy actions such as retrofitting public infrastructure and improving system efficiencies, typically found in policies initiated by municipalities with a strong institutional and technical capacity.

Dimension 2 presents a different contrast, one defined by the degree to which policies rely on behavioural, informational, and awareness-raising approaches. The highest contributing variables along this axis were informational measures and training-focused instruments, often reported in association with the broad and ambiguous 'others' sector. This suggests a dominant reliance on low-cost, soft instruments among many municipalities, especially those with limited capacity to implement technical upgrades. In effect, this dimension captures a strategic orientation toward public engagement, education, and communication, contrasting sharply with the technically focused strategies aligned with Dimension 1.

To further explore these latent structures, a k-means clustering procedure was applied to the MCA projection, identifying four analytically distinct groups of policy measures. These clusters represent meaningful typologies of local climate neutrality implementation strategies and were interpreted based on the dominant characteristics of the measures in each group (Figure 3).

The first group, labelled Public Sector Infrastructure, consists of measures that focus on municipal-level investments and retrofitting, particularly in public buildings and services. These policies often emphasize long-term operational improvements and are typically adopted by municipalities with access to institutional, financial, or technical capacity. Although not the largest group, this cluster is structurally distinct, representing actors able to pursue capital-intensive climate strategies.

The second group, Technology & Incentive-Based, includes policies oriented around technological upgrades, energy-efficient equipment, and financial mechanisms such as subsidies or grants. These measures often target private-sector or residential actors and reflect an implementation strategy based on enabling action through supportive instruments, rather than direct public investment.

The third group, Awareness & Behavioural Change, constitutes a broad share of measures that rely predominantly on information dissemination, education, and behavioural influence. These measures are often cross-sectoral and framed in general terms. The prevalence of this cluster suggests that many municipalities, particularly those with limited administrative capacity, focus on low-barrier actions that encourage voluntary participation rather than enforce structural transformation.

Finally, the Operational Energy Management cluster includes measures aimed at optimizing day-to-day energy use, such as energy monitoring systems, control technologies, or consumption routines. These actions often represent targeted interventions in facility-level operations and may complement broader strategies in more advanced municipalities.

Taken together, the MCA and clustering analyses reinforce the study's earlier findings regarding the fragmented landscape of local climate neutrality action. The prominence of informational and low-cost measures suggests a tendency toward minimal-resource strategies, while more technically ambitious interventions

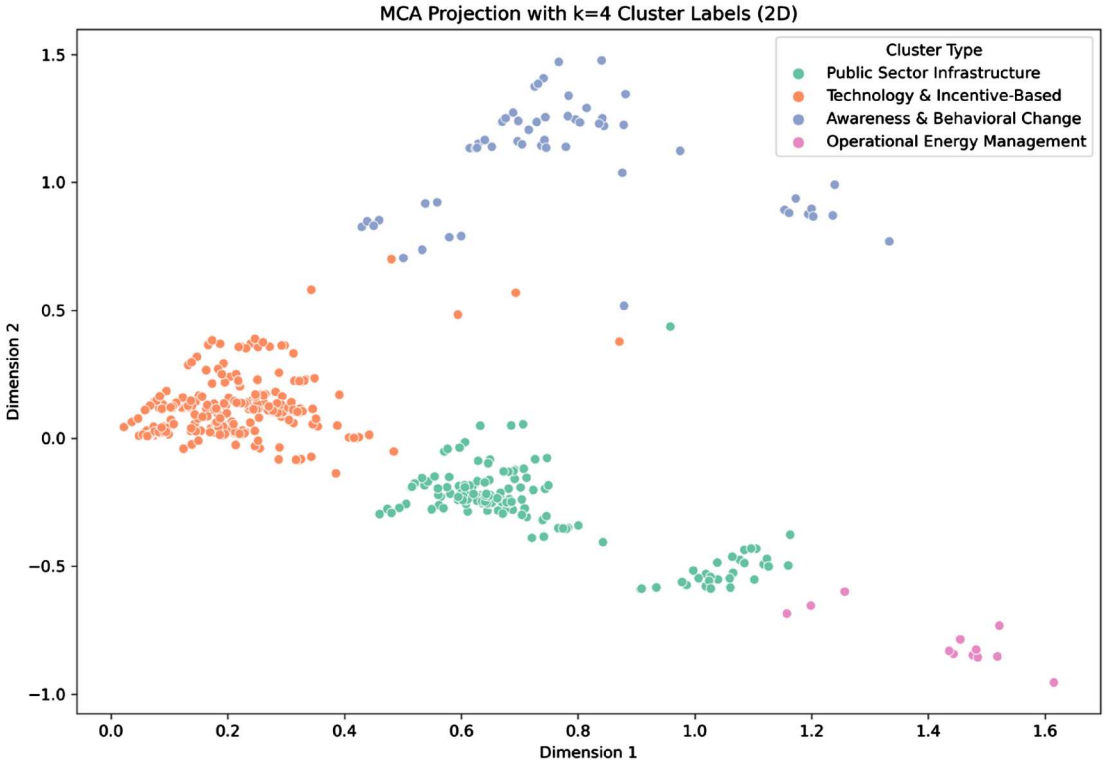

Figure 3. MCA Project with $k = 4$ Cluster Labels (2D).

remain the domain of a smaller subset of capable actors. The identification of these four clusters provides a data-driven typology that can inform more nuanced guidance, funding frameworks, and capacity-building efforts tailored to the varied profiles of municipalities.

5. Discussion

The findings reveal a strong thematic skew in local climate policy implementation within small rural settlements. While domains like Clean Energy and Sustainable Mobility dominate, other key pillars of the European Green Deal (EGD) – particularly Biodiversity and Ecosystem Protection, Sustainable Food Systems, and Zero Pollution – remain significantly underrepresented. This is in stark contrast to the academic literature, which consistently emphasizes the vital role of rural areas in achieving climate neutrality through sustainable agriculture, ecosystem services, and food systems transformation (Klepacka et al., 2025; Ottomano Palmisano et al., 2025; Wiśniewski et al., 2021). This suggests that the concept of climate neutrality, as operationalized at the local level, is largely reduced to energy and transport interventions. This reductionist approach is largely a reflection of the institutional history of the Covenant of Mayors. As established in the initiative's foundational scientific reviews (Raveschoot et al., 2010) and operational guidelines (Bertoldi et al., 2010), the CoM was explicitly designed to operationalize the EU's '20-20-20' climate and energy package. Consequently, local authorities were incentivized to focus their limited resources on quantifiable mitigation measures – specifically in buildings and transport – while broader ecological domains like biodiversity and food systems fell outside the core reporting scope. While these are crucial, they do not fully capture the systemic sustainability transformation envisioned by the EGD. This reductionist approach results in a notable disconnect between the domains identified as highly relevant for rural contexts and their actual level of implementation. For instance, despite the clear applicability of Climate Adaptation strategies to rural livelihoods and infrastructure, the number of corresponding

measures remains very low. Similarly, domains like Water Quality and Sustainable Agriculture show limited local policy engagement, even though they fall well within the jurisdiction and technical capability of local authorities. This underrepresentation is especially notable considering the strong policy and academic focus on agri-environmental practices under frameworks such as the CAP and the Farm to Fork Strategy (Prandecki, 2021; Wieliczko et al., 2021; Wiśniewski et al., 2021).

Beyond environmental domains, the social dimension of the transition also suffers from neglect. The domain of Just Transition and Socio-economic Cohesion receives notably less attention than technical domains. Measures aimed at supporting vulnerable populations, fostering skills transitions, or enhancing territorial cohesion appear marginal. This underrepresentation risks reinforcing existing social inequalities within rural areas and undermines the EGD's commitment to a fair and inclusive transition (Ottomano Palmisano et al., 2025; Wieliczko et al., 2021). The limited scope of policy domains is mirrored by a similar constraint in the diversity of policy instruments. The predominance of Informational and Operational instruments reflects the constrained capacity of rural municipalities to engage with more transformative policy tools. While these approaches are practical, their overuse may limit the long-term structural changes required for a comprehensive transition. Financial, Regulatory, and Planning instruments are markedly underutilized, mirroring concerns in the literature regarding the lack of institutional capacity in rural areas (Prandecki, 2021; Wieliczko et al., 2021).

These instrumental limitations are further illuminated through the Multiple Correspondence Analysis (MCA) and clustering results. The MCA reveals that informational instruments form a structurally distinct group, labelled Awareness & Behavioural Change, which relies heavily on communication strategies. In contrast, the Public Sector Infrastructure group contains capital-intensive measures like retrofitting, reflecting stronger institutional support. A third cluster, Technology & Incentive-Based, leverages financial mechanisms often directed at the private sector, while the fourth group, Operational Energy Management, focuses on optimizing day-to-day utility use. Together, these clusters confirm that instrument choice is not merely a matter of strategic preference but reflects the structural conditions under which policy measures are designed. This finding is consistent with recent evidence from Franco et al. (2025), who applied similar machine learning techniques to CoM data and found that specific policy mixes – particularly those integrating building standards with transport modal shifts – are statistically more likely to achieve mitigation targets. These conditions are largely defined by broader governance constraints and structural disparities. Several domains – especially those involving economic systems or international coordination – lie largely outside the direct control of rural municipalities. However, the absence of engagement in feasible areas like Local Biodiversity Protection points to issues where national frameworks retain control, limiting decentralization.

This governance disconnect explains why domains like Sustainable Food Systems remain peripheral. Local authorities may not perceive these areas as within their mandate or may lack the technical incentives to engage with them. Moreover, agri-environmental measures are frequently addressed through national instruments like the CAP, which often bypass municipal plans. The challenge is compounded by the absence of strong multi-level coordination mechanisms for cross-boundary management. Specifically, the strong representation of Italian and Spanish municipalities in this study can be attributed to the active role of Covenant Territorial Coordinators (CTCs) – such as provinces and regions – which provide the financial and technical 'umbrella' support necessary for small local authorities to participate (Melica et al., 2018). Previous research highlights the importance of flexible governance models, such as France's Plans Climat-Air-Énergie Territoriaux (PCAET), which institutionalize a multilevel interface allowing local actors to adapt national objectives to territorial realities (Dobravec et al., 2021; Poupeau, 2020). Finally, the reliance on soft instruments without corresponding structural measures points to a critical absence of monitoring and evaluation (M&E) structures. Without clear frameworks to assess the outcomes of awareness-raising or behavioural change, it becomes difficult to ensure accountability. This gap is frequently exacerbated by the outsourcing of SECAP development to external consultants who often disengage after the planning phase, leaving small municipalities without the internal capacity to track progress or update emission inventories (Rivas et al., 2022). The importance of integrating local monitoring into sustainability governance systems is essential for creating stronger linkages between local action and EU policy frameworks (Garcia-Alvarez-Coque et al., 2016; Nicholas & Scown, 2024).

6. Conclusion

This study assessed the alignment of local policy measures from small rural settlements with the domains of the European Green Deal (EGD), using a large dataset from the Covenant of Mayors (CoM) initiative. The results reveal a significant thematic imbalance: while Clean Energy and Sustainable Mobility dominate local policy landscapes, accounting for 64.4% and 18.5% of measures respectively, critical domains such as Sustainable Food Systems, Biodiversity and Ecosystem Protection, and Zero Pollution remain severely underrepresented. This contrasts sharply with the academic and policy literature, which consistently emphasizes the vital role of rural areas in achieving climate neutrality through sustainable agriculture, ecosystem stewardship, and food system transformation.

Moreover, there is a clear mismatch between domains that are both highly relevant and feasible for rural municipalities and their actual degree of implementation. Despite their direct relevance to rural resilience and livelihoods, domains like Climate Adaptation, Water Quality, and Sustainable Agriculture are largely absent from local policy portfolios. The reliance on Informational and Operational instruments further limits the capacity of rural municipalities to effect systemic change, as more transformative Financial, Regulatory, and Planning tools are underutilized.

Based on these findings, specific policy implications emerge for governance at multiple levels. For EU policymakers, the disconnect between the EGD's systemic goals and local implementation suggests a need for integrated reporting frameworks. The Covenant of Mayors reporting structures should be harmonized with rural-specific instruments, such as the Common Agricultural Policy (CAP), to incentivize municipalities to report on biodiversity and sustainable food systems. Furthermore, recognizing the distinct policy clusters identified in this study – ranging from 'Awareness' to 'Infrastructure' – funding mechanisms should be tailored to local maturity levels. Rather than uniform competitive grants, tiered funding streams should be established: seed funding for soft measures in capacity-constrained villages, and large-scale capital investment for municipalities ready to move from the 'Operational' to the 'Infrastructure' cluster.

For local governments, the analysis highlights the limits of acting alone. To overcome the reliance on 'soft' informational measures, small settlements must aggressively pursue inter-municipal cooperation and aggregation strategies. By pooling resources with neighbouring villages, local governments can achieve the critical mass necessary to implement financial instruments (e.g. joint renewable energy subsidies) or regulatory enforcement that would be unfeasible individually. Administratively, local leaders should break down internal silos by creating cross-departmental climate task forces that bring together energy managers, urban planners, and environmental officers to ensure neglected domains like water and biodiversity are integrated into climate action plans.

For practitioners and agencies supporting local climate action, the focus must shift from 'quantity of measures' to 'diversity of instruments'. Technical assistance programmes should prioritize training on legal and financial engineering, empowering municipal staff to design procurement and regulatory measures rather than defaulting to awareness campaigns. Practitioners should also utilize the clusters identified in this study as a benchmarking tool, helping municipalities diagnose their current strategic profile and identify specific gaps in their transition toward a comprehensive EGD alignment.

This study also acknowledges several important limitations. The CoM database used is heavily dominated by policy entries from Italy and Spain, which together account for approximately 87% of all recorded measures. This dominance reflects the strong support systems these countries have established for CoM participation, including regional integration into planning frameworks and the development of national platforms to support local action planning. While these structures have successfully facilitated widespread participation, they also introduce a geographic bias that may limit the generalizability of the findings across the European Union. To address this imbalance, more EU member states should consider systematically integrating the Covenant of Mayors framework into their national and regional climate governance architectures, potentially making participation mandatory or linking it to access to EU funding streams.

Future research should focus on understanding the barriers to participation among underrepresented countries and exploring how governance structures at multiple levels influence local climate action. Comparative case studies across a wider range of national contexts, as well as longitudinal analyses tracking the impacts

of implemented measures over time, would further enrich the understanding of how rural areas can most effectively contribute to the EU's climate neutrality ambitions.

In sum, achieving climate neutrality across Europe will require not only technological innovation and top-down policy ambition but also deeper, broader, and more empowered climate action at the local rural level.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT by OpenAI in order to improve the readability and flow of the manuscript. Specifically, the tool was employed to rephrase sentences, correct grammatical errors, and refine the structural organization of text originally drafted by the authors. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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