

Progress on urban energy access and energy poverty in the Global Covenant of Mayors initiative

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Energy access and energy poverty affect hundreds of millions of urban residents, yet municipalities lack standardized tools for coordinated intervention. Here we present the Energy Access and Energy Poverty Pillar, a methodological framework enabling municipalities to assess, plan and report on energy interventions across three energy dimensions: security, sustainability and affordability. The framework operationalizes energy action and sets a standardized global mechanism for integrating energy considerations into climate commitments at the municipal level. We demonstrate framework implementation through analysis of 1,354 municipalities across ten regions worldwide representing 296 million people during the first operational year of 2023. Initial adoption patterns reveal that larger cities engage more readily with technical assessment components. We analyse 1,095 actions from European municipalities revealing concentration in sectors under direct local control. The framework marks a step forward in urban climate action providing municipalities with tools to address energy challenges while advancing climate objectives and social equity.

As of 2023, hundreds of millions of urban residents worldwide still lack access to affordable, reliable and modern energy services, with over 101 million lacking access to electricity and over 554 million people lacking access to clean cooking in urban settings¹. The figures are even starker when considering the rural population. Simultaneously, across different geographies, millions suffer from conditions associated directly or indirectly with energy poverty, affecting both developed and developing nations. This manifests in various forms: inability to adequately heat² or cool homes^{3,4}, excessive energy cost burdens relative to household income^{5,6} and limited access to essential energy services. Hence the need to act.

The urgency of addressing energy access and poverty was recognized globally with the inclusion of Sustainable Development Goal 7 (SDG-7) in the United Nations' 2030 Agenda for sustainable

development. This goal seeks to ensure universal access to affordable, reliable, sustainable and modern energy⁷. However, defining energy access and energy poverty (EAP) is challenging due to their deep entanglement with cultural, social, environmental and political contexts^{8–10}.

Several attempts have been taken to define EAP at the national scale, however the local level has the potential to offer a more detailed picture of EAP conditions of households as it is directly connected to a diverse socio, cultural and economic characteristics that highly impact the results and actions on EAP situation^{11–13}. Whereas national-level indicators provide an overview, the situation varies at a more localized level¹⁴. This is particularly evident in regions and countries where disparities exist in the root causes of energy poverty^{15,16}.

Therefore, tackling energy access and poverty should be a priority not only at the national level, but also at the local level¹⁷, where the

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diverse dimensions of energy poverty can be more clearly observed and effectively addressed^{11,18,19}. Proximity to citizens and unique governance capabilities positions municipalities ideally to implement equitable, effective, context-specific interventions crucial in tackling the intertwined issues of energy access and poverty²⁰, alongside other local issues such as climate impacts²¹, energy transition^{22–24} and urban growth^{25,26}. Local governments, being the closest governance tier to citizens, possess crucial competencies in housing and transport, enabling them to support vulnerable populations^{27,28}.

The current literature explores the variability of EAP across different contexts, revealing how factors such as housing conditions, building types, renovation rates and economic ability affect energy usage^{29,30}. From a cultural perspective, specific local barriers, associated with a small cultural heritages^{31,32}, can hinder the transition to healthier energy sources³³. On the other hand, the geographical distribution within a country can also hide alarming situation of access to modern and clean energy sources¹⁶. Whereas access to reliable and clean electricity is generally widespread in major urban centres, rural areas in developing countries face significantly higher rates of energy poverty and low energy access^{16,18}. Furthermore, shifts in temperature patterns due to climate change can alter energy demands³⁴, leading to disproportionately severe summer energy poverty at both global and local scales³⁵.

Against this background, energy poverty and energy access have progressively become a policy question, requiring approaches and methods enabling their assessment and measurement³⁶. Existing frameworks to measure EAP have been evolving, progressively highlighting the need to deal with complexity and the acknowledgement of country-specific contexts³⁷.

Indicators are the core of all developed frameworks^{36,38}, from those having binary logic (access/no access), to multidimensional indices such as the Multidimensional Energy Poverty Index (MEPI)³⁹, which assesses six energy deprivation indicators. The World Bank's Multitier Framework uses graduated tiers to help governments identify energy access gaps and develop solutions⁴⁰. Identifying which indicator(s)^{39,41} is appropriate to accurately assess EAP is essential to ensure suitable metrics are applied to the variety of contexts and cases⁸.

Despite growing research^{8,29,40,42}, existing frameworks lack consistency and harmonisation, with results often remaining linked to the context where the analysis was conducted. Research gaps remain on the availability of comprehensive tools addressing EAP at the local level in a simplified, feasible and flexible way that allows global transparency and comparison¹⁵.

There is an urgent need for frameworks that empower local authorities to tackle these challenges effectively, aligning with the Nationally Determined Contributions under global climate agreements. Energy-related SDGs, including SDG-7 and SDG-11 on sustainable cities, emphasize the co-benefits of addressing urban energy challenges alongside broader development goals⁴³. Integrated approaches can deliver co-benefits for communities, particularly smaller ones, but poorly managed interventions risk negative outcomes^{44,45}. Understanding energy poverty's multifaceted nature is therefore crucial for devising effective mitigation strategies^{13,46}.

The Global Covenant of Mayors for Climate and Energy (GCoM) recognizes the role of local action in the global climate challenge and introduces the energy access and energy poverty pillar (EAPP) as a systematic framework to help municipalities structure and implement their urban EAP strategies. The GCoM initiative stems from merging the European Covenant of Mayors and Mayors Adapt initiatives with the US Compact of Mayors to amplify global impact⁴⁷. GCoM provides harmonized frameworks supporting local governments in addressing mitigation, adaptation, and EAP. The initiative developed a Common Reporting Framework⁴⁸ offering a global methodology for integrated city climate action planning, reporting and monitoring. The EAPP combines with GCoM's mitigation and adaptation methodologies to

provide an integrated approach while leveraging existing collaborations and structures. The EAPP introduces a just energy transition perspective to climate action. Launched in November 2022⁴⁹ and operational in January 2023, first on a voluntary basis, the EAPP enabled signatory cities to begin reporting on this matter. As of January 2025, all GCoM signatories must use the EAPP reporting framework.

The EAPP provides local authorities with a standardized yet flexible methodology to assess household EAP conditions and identify intervention priorities. The framework allows municipalities to select contextually relevant indicators, addressing the limitations of rigid assessment tools. It encompasses multiple dimensions of energy access and poverty linked to sustainable development, adapted to regional characteristics and developed with country experts. The EAPP introduces an increased focus on social justice perspectives⁵⁰, which were less prominent in GCoM's mitigation and adaptation pillars where vulnerable populations were primarily addressed within adaptation frameworks. Energy access and poverty actions specifically target certain population groups, positioning social equity as a central consideration in municipal energy interventions⁵¹.

This study explores the process of creating and adopting the EAPP and analyses the initial evidence from local action globally and draws on the authors' experience working with the GCoM on the EAPP development. It aims to: (1) present results from the methodological development of the GCoM Energy Access and Poverty Pillar, (2) assess city adoption rates and initial evidence from early adopters and (3) analyse EAP actions and measures planned by signatories in the first timeframe. By documenting the GCoM's coordinated system for local climate action, analysing city-level data and extracting insights from first movers, this research sheds light on urban energy practices, offering policy guidance to local governments seeking efficient and comprehensive energy solutions.

The energy access and energy poverty pillar framework

We first present the GCoM EAPP framework structure that emerged from a consultative development process enabling local authorities to assess and address energy access and energy poverty in their territories. The process is further described in the Supplementary Note on the EAPP development process and illustrated in Supplementary Fig. 1. Following the structure of GCoM's mitigation and adaptation pillars, the EAPP employs a three-tier reporting system with increasing detail: mandatory minimum requirements, recommended elements and optional indicators. Over 120 indicators were initially identified during the EAPP consultation process, which through stakeholder engagement were refined to 89 indicators with global and regional relevance that local authorities can use to assess their EAP status.

Expert analysis and GCoM regional consultations identified and validated three interconnected energy attributes as the organizing structure for the framework: security, sustainability and affordability. Indicators were allocated accordingly. Regional/National Covenant Secretariats, which are intermediate bodies serving as a liaison between local entities and GCoM governance, selected the most relevant attributes for their regions (Table 1). The three energy attributes align with existing literature and international reports, with the consultative process revealing distinct regional priorities. Each GCoM region selected their priority energy attributes based on local context, with non-selected attributes remaining available with their indicators and guidance, allowing signatories to optionally adopt them

Consultations with GCoM regions and the consequent selection of regional energy attributes revealed three distinct groups of choices, as illustrated in Table 1. First, GCoM regions covering developing countries prioritized the energy security attribute, which addresses energy access. For Sub-Saharan Africa region (SSA), this selection aligns with literature and trends emphasizing universal electricity access and stable connections. Efforts for secure connections were also identified

Table 1 | Overview of energy attributes selected by Global Covenant of Mayors regions

	Energy Attributes		
	Security	Sustainability	Affordability
Global Covenant of Mayors regions			
European Union and Western Europe	-	-	X
Eastern Europe and Central Asia	-	-	X
Japan	-	X	-
Latin America and the Caribbean	-	X	-
Middle East and Northern Africa	-	X	-
North America–Canada	-	-	X
North America–USA	-	-	X
Oceania	-	-	X
Republic of Korea	-	X	X
China	-	X	-
Taiwan	X	X	-
South Asia	X	-	-
Southeast Asia	X	-	-
Sub-Saharan Africa	X	-	-

Selected energy attributes (security, sustainability, affordability) across Global Covenant of Mayors regions. Each region emphasizes different combinations of energy attributes based on local contexts and priorities. Fields with 'X' record the attributes selected by each Global Covenant of Mayors region as most relevant for their context. Fields with '-' indicate other energy attributes that can be used voluntarily by municipalities for further assessment, planning and reporting.

as relevant priorities for South Asia and Southeast Asia, as observed in the latest SDG-7 progress reports^{52,53}. In contrast, GCoM regions covering developed countries including Oceania, North America, European Union and Western Europe and Eastern Europe and Central Asia all prioritized the energy affordability attribute, focusing on energy poverty in alignment with existing literature. This pattern reflects that energy affordability often becomes a critical issue in countries with secure infrastructures and a baseline of necessary energy consumption. In contrast, often developing regions face first an urgent need to establish basic energy connections before they can prioritize energy affordability. These different energy attributes selections highlight the varying stages and priorities in addressing energy access and energy poverty across different global contexts and the multidimensional aspects of it^{54,55}. Finally, regional consultations identified a third group composed of Japan, Middle East and Northern Africa, Latin America and China, which prioritized energy sustainability and security. Latin America and the Caribbean have the highest access to renewable energy sources⁵³, yet sustainability remains a key focus due to ongoing challenges such as reliance on non-modern cooking fuels as identified during consultations. Republic of Korea (sustainability and affordability) and Taiwan (security and sustainability) are the only GCoM regions focusing on two energy attributes.

The EAPP adopts a three-step structure mirroring GCoM's established mitigation and adaptation pillars: (1) assess current status, (2) set targets and (3) plan actions (Supplementary Fig. 2). This alignment emerged from consultation feedback emphasizing consistency across the pillars in GCoM reporting framework. Signatory cities progress sequentially through these steps, earning recognition badges (assessment, target and plan) upon completion of each phase through official GCoM reporting platforms.

The assessment phase's structure reflects iterative stakeholder refinement balancing standardization with flexibility for diverse local contexts. Through expert consultations and validation steps, the initial indicator pool converged on specific mandatory requirements for each energy attribute: Secure Energy includes three mandatory

and three non-mandatory indicators; Sustainable Energy has five mandatory and three non-mandatory indicators; Affordable Energy has one mandatory and three non-mandatory indicator (Table 1 and Supplementary Table 2). Recognizing through consultations that single indicators are insufficient to capture EAP across diverse contexts⁵⁰, this multi-indicator approach represents a departure from binary assessment frameworks. An important feature emerging from interactions with stakeholders was the need for measurement flexibility, allowing municipalities to report using their most readily available data formats. This resulted in multiple unit options, for example, the mandatory indicator: average duration of available electricity can be reported as hours per day, hours per week, hours per year or days per year. The framework establishes minimum reporting requirements (at least one mandatory global indicator for each regionally identified energy attribute) while enabling voluntary expansion with additional indicators aligning with local priorities. For example, a municipality in Japan must report on at least one of the five mandatory indicators under Sustainable Energy, whereas a North American municipality must report on the mandatory indicator for Affordable Energy. Both can voluntarily report on additional indicators from any energy attribute if relevant to their local context.

The target-setting phase employs a dual-level structure that resulted from consultations with stakeholders and which aligns municipal action with global commitments. The framework requires an overarching EAP goal addressing energy access increase or energy poverty alleviation by 2030 (consistent with SDG-7 targets), complemented by specific EAP targets linked to regionally selected energy attributes and local priorities. Minimum requirements specify one goal and one specific target, with Supplementary Table 3 in Supplementary Data providing suggested target options corresponding to assessment phase indicators. Municipalities can select from these suggestions or develop custom targets, including attributes beyond regional choices, to reflect local circumstances.

The action planning phase integrates into GCoM's established Climate Actions Plans (CAPs) process, where municipalities develop CAPs covering mitigation, adaptation and energy pillars, either as integrated documents or separately. EAP actions are incorporated within CAPs, ensuring coordination with broader climate commitments. For example, municipalities can design EAP actions addressing their priority energy attributes, such as affordability interventions (for example, aid bonds), access improvements (for example, reduced connection costs) or efficiency and vulnerability measures. The EAPP provides flexibility to develop EAP actions addressing attributes beyond regional priorities. The integrated nature of CAPs allows EAP actions to generate co-benefits across pillars. The GCoM framework encourages actions addressing multiple objectives simultaneously, such as establishing photovoltaic systems in energy communities (integrating mitigation) or developing protocols for individuals at risk from extreme temperatures (integrating adaptation).

The resulting three-phase EAPP framework (assessment, targeting and action planning) provides municipalities with a systematic pathway for addressing energy access and energy poverty within their comprehensive climate planning.

First-year EAPP adoption and municipal characteristics

The analysis of voluntary reporting from GCoM signatories offers early evidence of which EAP approaches municipalities are choosing and the type of challenge they are facing. Of the 13,746 municipalities that by the end of 2023 were GCoM signatories, this study focuses on a subset of 1,354 municipalities that, by that date, had already engaged with the EAPP framework by reporting on assessment, target-setting or action planning. These municipalities represent diverse geographical contexts, with the majority concentrated in the European Union and Western Europe region (1,158 signatories), followed by smaller

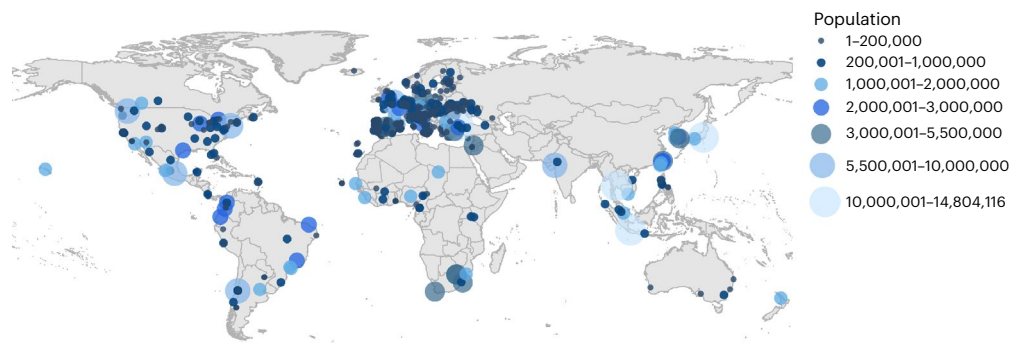


Fig. 1 | Global distribution of municipalities with an energy access and energy poverty badge part of this study. Blue circles represent the 1,354 municipalities included in the analysis, with circle size proportional to population (as indicated by the legend). The map illustrates the geographic coverage with notable concentrations in Europe, North America and emerging clusters in Sub-Saharan Africa, East Asia and Latin America. The spatial distribution reflects varying

levels of municipal climate action engagement and activity on energy access and energy poverty within the Global Covenant of Mayors across different global regions. Basemap generated with QGIS with World Bank Official Boundaries shape files (<https://datacatalog.worldbank.org/search/dataset/0038272/world-bank-official-boundaries>) under a Creative Commons license CC BY 4.0.

representation from North America (53 signatories) and other eight regions (Eastern Europe and Central Asia, 37; Latin America and the Caribbean, 31; Sub-Saharan Africa, 26; Southeast Asia, 16; East Asia, 15; Middle East and North Africa, 10; Oceania, 6; South Asia, 2), providing global coverage. The sample includes municipalities of varying sizes, from small towns to major metropolitan areas, encompassing both capital cities and smaller municipalities. The dataset captures cities at varying stages of climate action maturity, from municipalities implementing their first energy interventions to those with established climate programmes integrating energy considerations across mitigation and adaptation frameworks.

We assessed signatory's engagement through EAPP badges awarded by GCoM for assessment, target setting and planning. Badges provide symbolic recognition of municipal progress in climate and energy action. By the end of 2023, within just one year of launching the EAPP, these municipalities represented 10% of all GCoM signatories. This uptake rate is particularly significant given that reporting requirements became mandatory only in January 2025, suggesting a strong interest rather than compliance-driven participation (Fig. 1).

The geographical distribution shows the European Union and Western Europe region leading with 1,158 municipalities, followed by North America with 53. Among all regions, five out of ten have over 10% of their signatories holding an energy badge (Fig. 2).

The distribution of badge types reveals a clear implementation hierarchy among participating municipalities (Fig. 3). Over 90% obtained plan badges, whereas 22% achieved target badges and 10% completed assessment badges. This concentration on planning indicates municipalities prioritized establishing systematic energy action frameworks before advancing to quantified targets or comprehensive assessments.

Regional badge distribution patterns reveal varying engagement levels. Five regions demonstrate participation across all three badge categories (plan, target and assessment): European Union and Western Europe, Sub-Saharan Africa, East Asia, Latin America and the Caribbean and North America. The remaining five regions (Eastern Europe and Central Asia, Middle East and North Africa, Oceania, South Asia and Southeast Asia) achieved badges in only two categories, with assessment badges absent.

Statistical analysis confirmed that badge distribution patterns differed significantly across GCoM regions ($\chi^2 = 436.54$, d.f. = 18, $p < 0.001$, Cramér's $V = 0.35$; Test 1 in Supplementary Table 4). This moderate regional variation persisted across sensitivity analyses, indicating genuine differences in municipal engagement approaches rather than temporal or sampling artifacts.

Beyond EAPP-only engagement, 832 signatories (61%) demonstrated integration across GCoM frameworks by achieving both

comprehensive engagement in climate mitigation or adaptation (full badge sets: assessment, target, and plan) and at least one EAPP badge. This pattern suggests municipalities are leveraging existing climate governance frameworks as a foundation for expanding into EAP initiatives.

Within this group achieving cross-pillar integration, a smaller subset of 40 signatories (3%) achieved full badge completion across all three pillars. This cohort spans five GCoM regions with notable geographic concentration in Sub-Saharan Africa (45%) and European Union & Western Europe (42.5%). These municipalities range from small towns of 5,000 residents to megacities of 9 million inhabitants, indicating that comprehensive engagement occurs across diverse urban scales and economic contexts.

Statistical analysis examining municipal characteristics of this front-runner group indicated that city size rather than economic wealth predicts comprehensive action within short timeframes (median population 197,700 vs 12,210 for others, $p < 0.001$; Test 2 in Supplementary Table 4).

Municipal characteristics reveal substantial variation in EAPP engagement patterns across regions. The 1,354 signatories with EAPP badges account for over 296 million people, representing almost 25% of the population covered by GCoM-committed cities. Regional population coverage varies substantially: European Union and Western Europe leads with 80 million people, followed by North America, Latin America and the Caribbean and East Asia (approximately 40 million each), whereas Eastern Europe and Central Asia and Oceania account for less than 5 million each (Fig. 4).

Average signatory sizes differ markedly by region. The European Union and Western Europe region shows the highest number of signatories (1,157) with an average population of approximately 66,000 inhabitants. In contrast, other regions demonstrate concentrated participation among larger metropolitan areas, with average signatory sizes exceeding 1 million (M): East Asia (15 signatories, 2.6 M average), Latin America and the Caribbean (31 signatories, 1.2 M average), Middle East and North Africa (10 signatories, 2.9 M average) and Sub-Saharan Africa (26 signatories, 1 M average). Eastern Europe and Central Asia, North America and Oceania show intermediate configurations (100,000–700,000 inhabitants average). Statistical analysis confirmed that city population distributions differed significantly across regions (Kruskal–Wallis $H = 347.75$, $p < 0.001$; Test 3 in Supplementary Table 4).

Population coverage is highly concentrated: 109 large cities (8.1% of sample) represent 82.1% of total population served (Gini coefficient = 0.895), whereas the remaining 1,244 signatories account for 18% of population. Among smaller municipalities, 965 (75% of those under 50,000 population) are located in the European Union and Western

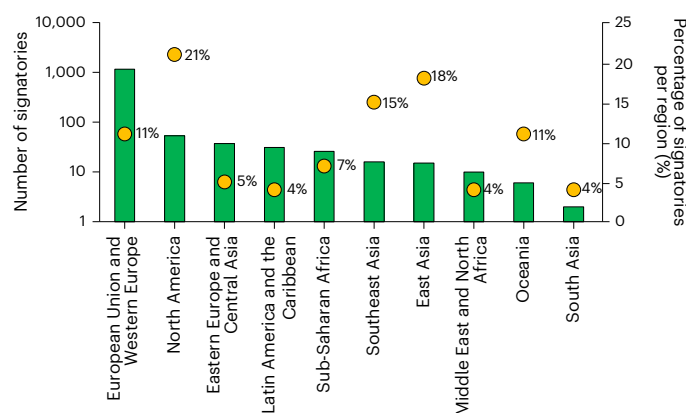


Fig. 2 | Number of signatories with at least one energy access and energy poverty badge and comparison with overall number of Global Covenant of Mayors signatories in the region. In the chart green bars represent the number of cities with at least one energy badge (logarithmic scale, left y-axis), whereas orange circles indicate the percentage of cities with energy badges relative to total regional signatories (right y-axis). The logarithmic scale accommodates the wide range in regional participation, from two cities in South Asia to over 1,000 in European Union and Western Europe ($n = 1,354$ total cities across ten Global Covenant of Mayors regions).

Europe region (Fig. 5). Large cities demonstrated 9.5 times higher assessment badge completion rates compared to smaller municipalities (57.8% vs 6.1%, $p < 0.001$; Test 4 in Supplementary Table 4), with this pattern strengthening when controlling for regional differences. Municipal economic capacity showed minimal independent relationship with engagement patterns once regional context was controlled (Test 5 in Supplementary Table 4), whereas settlement type significantly influenced both badge-type distribution ($\chi^2 = 82.63$, $p < 0.001$; Test 6 in Supplementary Table 4) and action quantity patterns.

Early evidence from reported actions

Analysis of reported actions provides evidence of how municipalities are operationalizing the EAPP's flexible structure and reveals the types of intervention early adopters are prioritizing to address urban EAP challenges. This analysis focuses on signatories from the European Union and Western Union region due to data limitations.

European municipalities with plan badges ($n = 341$) reported 1,095 EAP-related actions. Of these, 931 actions included detailed implementation information (Fig. 6). Awareness-raising and training represents the most common implementation approach, followed by other miscellaneous measures. Economic and financial tools, including grants and subsidies, constitute a significant portion of municipal strategies, whereas governance and institutional measures such as public procurement and building standards show moderate adoption. Physical and technological interventions, concentrated in energy management systems, are also prominent.

Most EAP actions (95%, $n = 1,023$) are integrated, impacting energy alongside adaptation, mitigation or both. Among integrated actions, 578 actions combine EAP with mitigation, whereas 389 address all three pillars and 56 focus on EAP and adaptation. Only 72 actions are dedicated solely to EAP.

Sectoral analysis carried out using energy macro areas and impacted sectors, as described in Methods, reveals distinct patterns across integration types. EAP-only actions ($n = 72$) show that the socio-economic macro area is the most impacted, accounting for 26 actions, followed by facilities-housing (16), policy-regulatory (16) and participation-awareness (14).

For integrated actions, EAP-adaptation integrated actions ($n = 445$) demonstrate strong focus on buildings (233 actions), energy infrastructure and health interventions. Figure 7 illustrates complete

sectoral distributions across all integration types. EAP-mitigation interventions ($n = 967$) prioritize building-related sectors, with municipal buildings (248 actions), residential buildings, transport and general measures representing the dominant categories. Other sectors including local electricity production, tertiary buildings and industry show substantially lower representation.

Municipality population showed no relationship with either action quantity (Spearman $\rho = 0.031$, $p = 0.565$) or integration rates ($\rho = -0.001$, $r = 0.990$). Settlement type significantly influenced integration patterns ($\chi^2 = 27.35$, $p < 0.001$, Cramér's $V = 0.112$), though the effect size is small. These initial patterns from early European adopters may shift as more municipalities across regions report actions.

Discussion

The EAPP framework aligns with international energy goals and recent literature by operationalizing the call for access to affordable, reliable, sustainable and modern energy for all. The EAPP development process confronted a dual challenge: synthesising heterogeneous data from diverse geographical and local contexts in a coherent manner and abstracting context-specific findings into a framework with broader global applicability. It highlights a first effort to drive energy access and energy poverty local knowledge into a harmonized framework. Developed through extensive stakeholder engagement and building on existing literature, the framework encourages municipalities to explore and reflect on energy access and poverty while acknowledging practical difficulties in data collection and resource constraints. This bottom-up participatory approach moves beyond standard assessment measures, while considering the constraints of data-driven approaches to climate governance⁵⁶, to enact change grounded in lived reality. The inclusion of indicators such as: number of local energy efficiency/renewable programmes and percentage of clean energy investment benefiting low- and moderate-income households demonstrate this commitment to real-world experiences and local action.

Our analysis of the framework's first year of implementation reveals how municipalities are translating this design into local action, while also highlighting the contextual factors that shape engagement patterns and the challenges that constrain comprehensive implementation. The integration of a comprehensive EAP framework with existing climate mitigation and adaptation strategies represents a significant effort to advance local climate action. This approach introduces an innovative perspective that explicitly addresses social considerations in climate and energy interventions, contributing to bridge the gap between energy justice, climate change mitigation and adaptation planning at the municipal level.

The high concentration of planning badges compared to target and assessment badges reflects several factors. Because EAPP reporting only became mandatory in January 2025, cities may vary in their early reporting priorities. Moreover, obtaining a planning badge requires only that a municipality identify at least one relevant energy action, meaning not all signatories may have a complete action plan. Some may have built on existing mitigation or adaptation plans to qualify, highlighting potential for integrated action planning. Overall, this concentration on planning badges suggests municipalities recognize the value of systematic preparation, aligning with literature emphasizing cross-sectoral coordination in urban climate governance and the staged adoption patterns observed in other municipal climate frameworks.

The lower prevalence of assessment badges may reflect the technical complexity and resource requirements associated with comprehensive EAP assessments. Recognizing this complexity, the EAPP provides municipalities two years to complete assessments before mandatory reporting. Comprehensive EAP diagnostics require municipalities to collect and analyse data on energy access, affordability and security, activities demanding technical expertise, staff capacity and data municipalities often do not routinely collect. Energy poverty assessment requires household-level data on energy expenditure, service

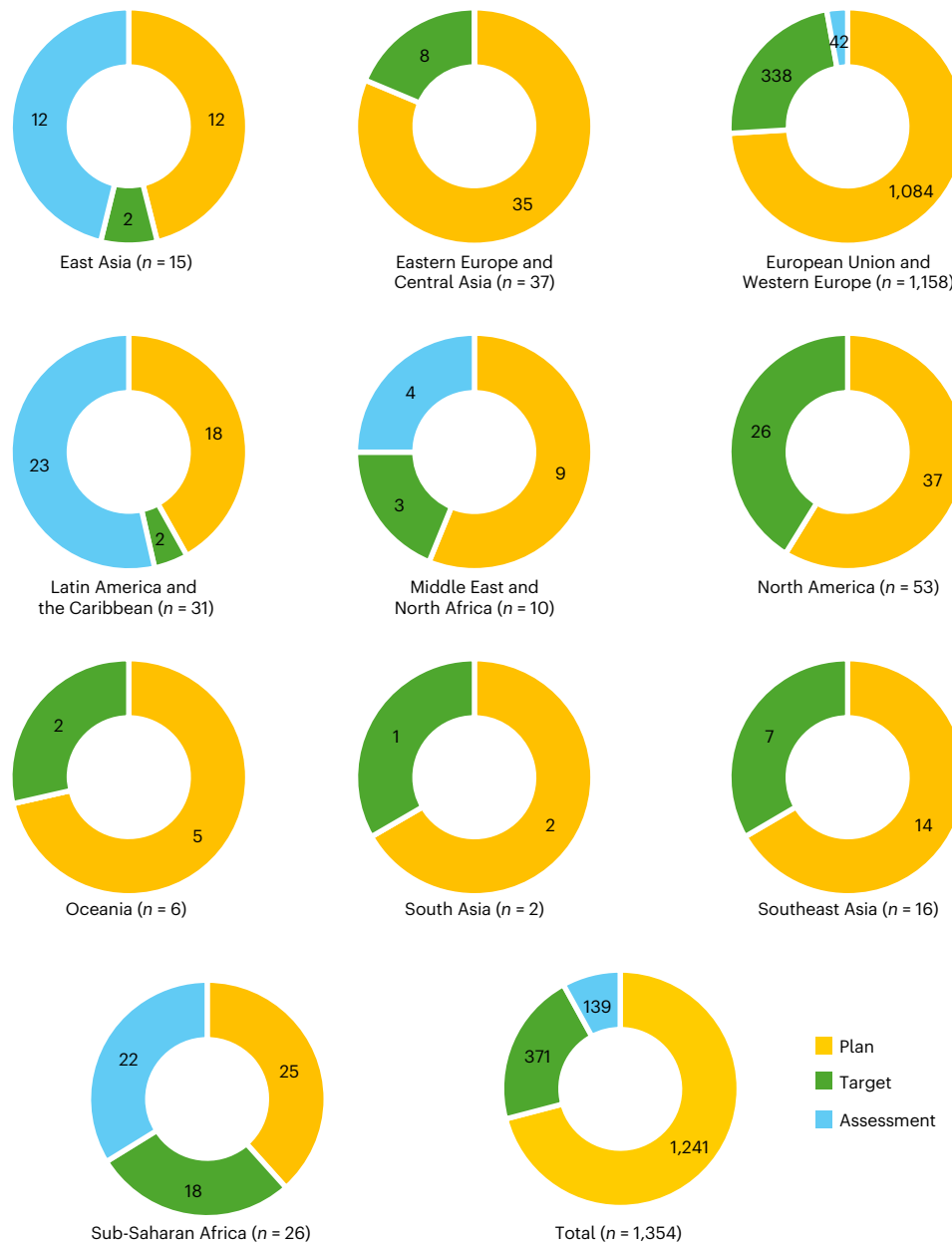


Fig. 3 | Small multiples comparison of type and number of badges assigned per Global Covenant of Mayors region. The doughnut charts display absolute counts of cities with energy access and poverty plan badges (yellow), energy access and poverty target badges (green) and energy access and poverty assessment badges (blue), across ten Global Covenant of Mayors regions

($n = 1,354$ cities). European Union and Western Europe represents the largest cohort (1,158 cities), whereas Sub-Saharan Africa demonstrates the highest proportional engagement across all three energy metrics despite smaller participation (26 cities).

reliability and fuel types that may be difficult to obtain, especially for smaller municipalities^{57,58}. This technical complexity could explain why assessment badges are entirely absent in five regions and rare even in regions with substantial overall participation⁵⁹.

Leveraging the existing experience of GCOM in climate action planning enables municipalities to address EAP in an integrated way, and even though assessing it can be time consuming and data limited, proactive measures on EAP can commence with integrated local climate and energy transition actions and strategies. We foresee that over time, actions will be more focused on EAP, together with improved data quality as guidelines and support options become available to signatories⁵⁷.

The high level of cross-pillar integration observed in reported actions demonstrates how municipalities are leveraging GCoM's existing climate action planning experience to address energy access and

energy poverty within broader mitigation and adaptation strategies. Municipalities can then commence EAP measures leveraging existing climate and energy transition interventions. We foresee that over time, actions will become more specifically focused on energy access and poverty, with improved data quality as guidelines and support options become available to signatories⁵⁷.

The finding that 95% of EAP actions are integrated across pillars can be attributed to several factors. First, the EAPP methodological framework may have enabled municipalities to retroactively flag existing actions as energy relevant, given that they now have the analytical tools to identify these connections. Second, energy access and poverty issues are interconnected with climate adaptation and mitigation challenges, favouring the design of energy measures that look at broader climate co-benefits and synergies, for instance, photovoltaic (PV) systems

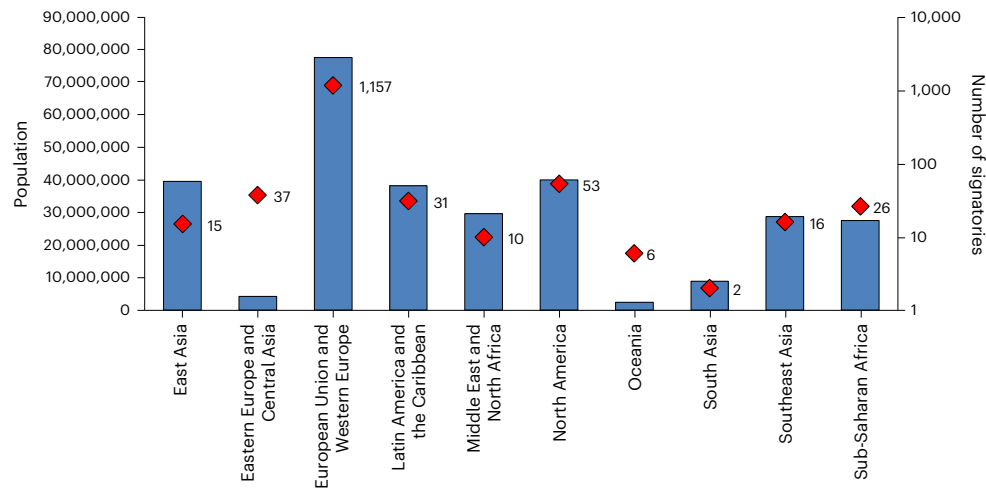


Fig. 4 | Regional population coverage and number of signatories with an energy access and energy poverty badge. Regional distribution of municipalities with energy badges showing total population served (blue bars, left y axis) and number of signatory cities (red diamonds, right y axis) across

Global Covenant of Mayors regions. European Union and Western Europe leads in both participation (1,157 cities) and population coverage (77 million residents), whereas regions such as East Asia demonstrate high population engagement through fewer but larger urban centres.

simultaneously address energy generation and mitigation goals, and when considering PV systems for energy poverty interventions, they aim to target vulnerable populations, who can also be priorities for adaptation measures. Finally, municipalities face budget and capacity constraints that could incentivize them to design multi-purpose actions addressing energy, adaptation and mitigation objectives simultaneously, maximizing the impact of limited resources. For example, awareness campaigns, which represent the most common measure, can efficiently cover all three pillars rather than being organized separately for each domain.

Comprehensive engagement across all three pillars provides further evidence of capacity requirements. The analysis of these first movers may indicate strong organizational capacity and commitment, successfully coordinating comprehensive climate action across multiple interconnected domains simultaneously. Their progress suggests the presence of solid institutional frameworks and potentially innovative approaches to integrated climate planning that could serve as models for other municipalities and should be further analysed in the future. The front-runner group's concentration in Sub-Saharan Africa and Europe reflects differing enabling factors. Sub-Saharan African municipalities benefited from earlier regional EAPP access (2018 vs 2023 for other regions), providing additional years to structure energy activities. European municipalities' representation relates to the region's extensive GCoM adoption and long-term involvement (many joining 2008–2010). These temporal advantages underscore that comprehensive engagement requires sustained commitment.

Examining which municipalities achieved different levels of engagement reveals the role of capacity rather than affluence in shaping participation patterns. The dual nature of early EAPP engagement, population coverage concentrated in large metropolitan areas (82%) while driven by extensive small-municipality participation (particularly in Europe), reflects both capacity differences and regional governance structures.

The finding that city size rather than economic condition predicts engagement patterns challenges assumptions that climate action requires affluent municipalities. The high assessment badge completion (9.5× advantage) of large municipalities probably reflects technical capacity and data infrastructure rather than financial resources per se. This suggests that supporting smaller municipalities' technical capacity may prove more effective for expanding comprehensive EAPP engagement⁵⁹.

City size links with badge achievement patterns. The tiered engagement of cities suggests that while urban EAP may represent a natural progression for municipalities with established climate programmes, achieving comprehensive integration across all three areas (energy access and energy poverty, mitigation, adaptation) in this initial phase remains challenging and requires solid organizational capabilities and possibly additional external support options such as capacity-building programmes for cross-sectoral planning, integrated assessment tools that link energy–climate interventions and peer-learning networks that facilitate knowledge exchange on comprehensive integration strategies. The different distribution of badges (assessment, target and planning) linked to settlement type shows the capacity of urban areas to timely frame and set up approaches addressing the EAP question, whereas suburban settlements focus on target setting (36.5%) and rural settlements directly on implementing actions to address needs.

Sectoral patterns in reported actions indicate the practical constraints municipalities face in implementation and several considerations inform their interpretation. First, the sectoral classifications differ between action types due to varying data availability and reporting frameworks for each pillar. Sectors for mitigation differ from adaptation sectors and are self-declared by signatories, whereas for energy-only actions, the categorization of macro areas is applied by authors (Methods). Additionally, not all actions have a declared impacted sector associated. This means that the granularity and accuracy of sectoral data vary depending on the consistency of municipal reporting practices. Second, reflecting on the impacted sectors, the sectoral distribution patterns show municipal orientation for interventions in areas under direct municipal control or influence. Municipal and residential buildings sectors across all integrated actions are the most reported and local electricity production in energy access and poverty–mitigation actions and municipal infrastructure (energy systems, water, civil protection) in energy access and poverty–adaptation measures. On the other side, sectors requiring extensive coordination with private actors (such as industry, tertiary services) or involving shared competencies with other government levels (such as agriculture and waste management) show lower representation across all categories, suggesting that implementation feasibility and governance authority influence municipal action prioritization.

These findings shed light on barriers that are faced by local authorities and may constrain comprehensive EAPP implementation, particularly in the initial phase⁶⁰. A major constraint stems from often limited

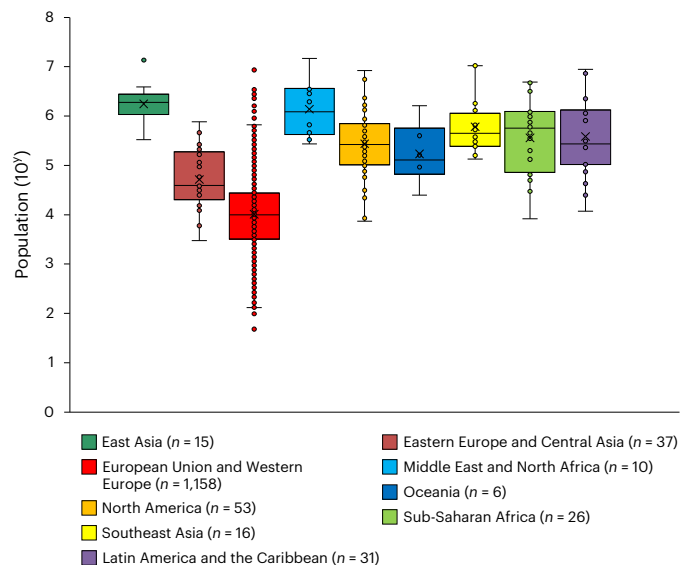


Fig. 5 | Population distribution of signatories with energy badges per each Global Covenant of Mayors region. Box plot showing the population distribution of municipalities with energy access and poverty badges across Global Covenant of Mayors regions. Each box represents the interquartile range with median values marked, outliers are shown as individual points.

jurisdictional authority, as many aspects of energy governance, such as pricing, energy mix and large-scale infrastructure are determined at national or state levels or by private actors. This limits the capacity of local governments to act decisively or set ambitious targets. A second challenge lies in the scarcity of disaggregated, city-level data. Municipalities frequently lack access to the necessary energy data and are unsure whether and how to use national statistics to reflect their local reality⁶¹. Third, in some cases cities face conceptual and procedural confusion when setting goals: distinguishing between general and specific targets and understanding the intended focus of the EAPP compared to, for example, mitigation actions are recurrent issues^{62–64}.

Together, these barriers underscore the importance of tailored support, guidance and capacity-building mechanisms^{65–67} accompanying the release of the methodological framework to enhance the effectiveness of local action planning under the EAPP. Furthermore, addressing these challenges calls for a coordinated governance approach that bridges local, national and supranational actors, each playing a distinct yet complementary role. At the local level, municipalities are central to identifying context-specific priorities and implementing targeted actions, by demonstrating innovation, piloting integrated approaches and mobilizing local communities. National governments and regulatory bodies should play an enabling role by creating coherent policy frameworks, aligning subsidies and incentives and facilitating vertical coordination mechanisms that empower cities to act within the broader energy system⁶⁸. Civil society organizations and private sector actors, utility companies, national statistical offices and academic institutions are also essential, both in extending service delivery, support with data and in co-producing solutions that respond to community needs, particularly in areas such as energy affordability or decentralized renewables^{69,70}. In parallel, transnational city networks and peer-learning platforms can foster horizontal collaboration and knowledge exchange, and other forms of multi-level governance might be explored to support local initiatives considering their own capacities and limitations⁷¹.

Finally, the success of the Energy Access and Poverty Pillar also depends on the active engagement of citizens. Local communities are not only the beneficiaries of energy policies but also key agents in shaping them. Empowering residents, particularly vulnerable groups, to participate in planning processes can lead to more equitable and

context-sensitive solutions⁷², also reflected by the observed prevalence of awareness-raising actions. By fostering inclusive consultation mechanisms and supporting community-led initiatives, municipalities can move beyond reliance on national frameworks and build locally rooted strategies that reflect real needs and capacities^{69,70,73–75}. Only through such an integrated multi-level governance framework, one that aligns responsibilities, resources and information flows across sectors and scales, the EAPP can be meaningfully implemented and contribute to equitable energy transitions^{72–78}.

Conclusion

Our study presents some limitations related to the timeframe of the EAPP and the ongoing adoption of the methodology by GCoM signatories. The temporal scope of the adoption statistical analysis is constrained by the recent activation of the pillar in 2023, and the timeframe considered of the first 12 months of activation. In this initial period of voluntary reporting municipalities had limited time to become familiar with the new methodology and reporting practices, also influencing the quality of data submitted. As reporting becomes mandatory and cities gain experience with the framework, data coverage and depth are expected to improve substantially. As the framework was activated in 2023, best practices are still emerging, and networking among cities to share experiences and learning through peers is in its initial stages, which also influences the quality of data submitted. These factors currently limit the analytical depth possible at this early implementation stage, though they represent areas of expected improvement as the pillar matures. Geographic limitations substantially affect generalizability, particularly for action analysis. The sample's heavy concentration in European Union and Western Europe (85.5% of adopters) limits geographic diversity, though sensitivity analyses confirmed that regional patterns persist beyond European influence. Additionally, due to data quality constraints, action analysis focuses exclusively on European municipalities. Findings in this study reflect the characteristics of EAPP early adopters rather than typical municipal practice. The 1,354 municipalities analysed voluntarily reported during 2023 and may possess greater institutional capacity, stronger climate commitment or more established governance frameworks than typical GCoM members. Results therefore characterize early adopter cities rather than municipal climate action broadly, and patterns may shift as EAPP participation becomes universal. Finally, some regions have insufficient sample sizes for meaningful regional analysis, limiting robustness and generalizability.

Future investigations will aim to quantify the EAPP's influence and impact on the formulation and implementation of local energy strategies, moving beyond descriptive analysis to assess implementation effectiveness and outcomes. Longitudinal studies examining the evolution of energy actions over multiple reporting cycles will provide insights into municipal learning processes and strategic adaptation. Additionally, focused analysis of actions targeting vulnerable populations will enhance understanding of social justice integration within municipal energy governance, contributing to managing climate transition addressing related social issues⁵¹. Research should also assess the framework's impact on local capacity-building needs and identify areas requiring enhanced flexibility or methodological refinement. Future research could also consider inputs related to enabling contextual indicators, such as local policy readiness, capacity development, intergovernmental coordination and the role of policy coherence between national energy frameworks and municipal action plans and local governance modes. Expanded geographic analysis as EAPP adoption grows beyond Europe is essential, as action patterns may differ substantially across regions with different priorities, governance structures and energy challenges.

This study demonstrates that municipal energy governance is rapidly evolving towards integrated approaches that recognize the interconnected nature of energy, climate mitigation, adaptation challenges and

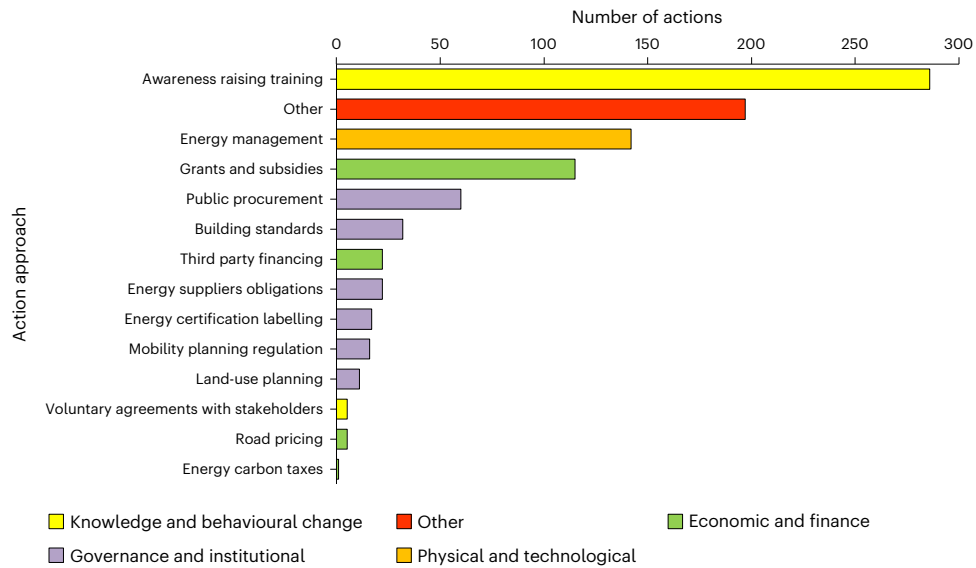


Fig. 6 | Energy access and energy poverty action approaches categorized by key type measures. Distribution of action approaches used by municipalities, categorized according to key type measure, as defined in Methods. Key type measure categories are knowledge and behavioural change (yellow), economic and finance (green), governance and institutional (purple), physical and technological (orange) and other (red). Awareness-raising training shows the

highest frequency at 286 instances, followed by other approaches at around 197 instances. Energy management and grants and subsidies represent the next most common approaches, respectively, at 142 and 115 instances. Knowledge and behavioural change measures represent the most frequently adopted key type measure category.

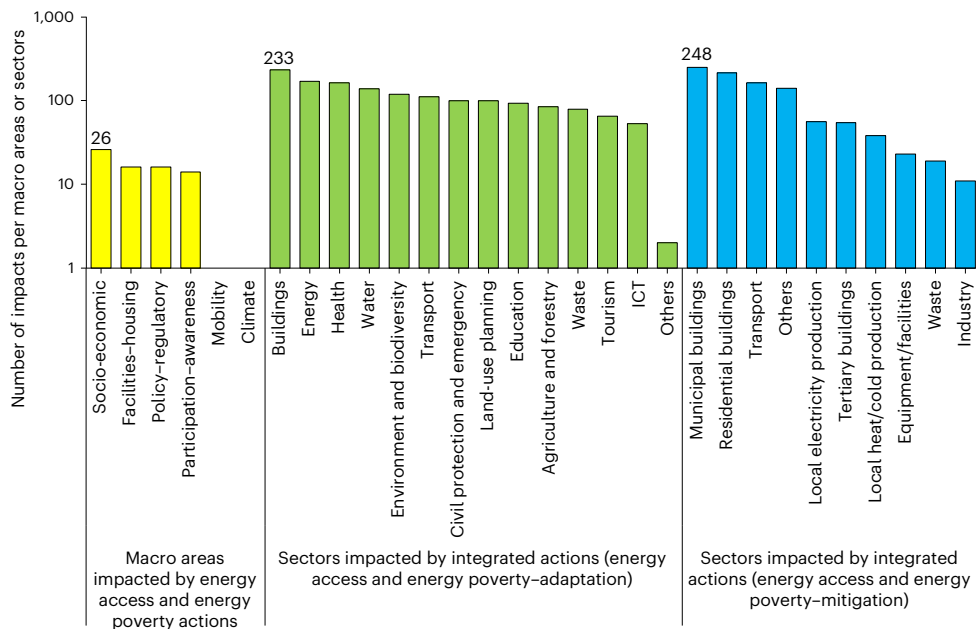


Fig. 7 | Sectoral distribution and number of impacts of energy access and energy poverty actions by integration type. Distribution of the impacts of energy access and energy poverty actions and integrated in energy macro areas and sectors as defined in Methods. Sectoral distribution of municipal energy access and poverty actions across three categories: (1) energy access and poverty-only actions ($n = 72$, yellow) concentrate in facilities/housing and awareness-raising, (2) energy access and poverty-adaptation-integrated actions ($n = 445$, green) prioritize buildings, energy and health sectors, (3) energy access and poverty-mitigation-integrated actions ($n = 967$, blue) focus primarily on municipal and residential buildings. The distribution patterns reflect municipal

preference for interventions in sectors under direct municipal control. For integrated actions, n is calculated by including inputs from three categories: energy access and poverty-adaptation actions, energy access and poverty-mitigation actions and energy access and poverty-adaptation-mitigation actions. The third category (energy access and poverty-adaptation-mitigation) contributes to both energy access and poverty-adaptation and energy access and poverty-mitigation totals presented in the chart. For energy access and poverty-only actions, n equals the number of actions designated as relevant exclusively to energy. ICT, Information and Communication Technologies sector.

justice and equity concerns. The EAPP represents an effort to advance municipal climate action frameworks by explicitly incorporating social justice perspectives and providing structured pathways for comprehensive energy planning. While implementation challenges remain, the

important level of initial voluntary adoption indicate strong municipal recognition of energy's significant role in climate strategies, reinforcing the GCoM integrated approach and the need of multiple perspectives in dealing with energy access and energy poverty^{22,29,48}.

As the framework matures and reporting practices standardize, the EAPP has the potential to transform and advance urban energy action by providing municipalities with the tools and guidance necessary to address energy challenges holistically while advancing climate objectives and social equity simultaneously.

The first-year patterns documented in the study establish a baseline against which this evolution can be measured. Whether smaller municipalities progressively build capacity to complete assessments, whether regions beyond Europe develop distinct implementation approaches and whether the integrated CAP structure successfully balances cross-pillar synergies with dedicated attention to energy poverty's unique dimensions. These questions will determine the EAPP's long-term contribution to climate and urban energy transitions and energy justice globally.

Methods

Dataset curation and data analysis

The dataset used in this analysis is derived from city-level climate and energy reporting submitted under the GCoM initiative. Data are primarily collected through two official reporting platforms: MyCovenant and CDP-ICLEI Track. The MyCovenant data are available in the Joint Research Centre (JRC) Data Catalogue in the Global Covenant of Mayors collection. The dataset refers to a comprehensive and harnessed collection of action plans and monitoring reports from MyCovenant platform in the context of the GCoM initiative after a quality scrutiny by JRC. The CDP-ICLEI Track data are available in the CDP Cities, States and Regions Open Data Portal. The CDP Full Cities dataset consists of self-reported data from cities, collected annually and made publicly available through the CDP Cities, States and Regions Open Data Portal. These data are gathered through the CDP-ICLEI Track reporting platform, which also enables cities to report in alignment with the GCoM framework. For consistency with GCoM reporting, the dataset is filtered to include only entries explicitly submitted under the GCoM framework.

To facilitate robust cross-platform analysis, data from both sources are integrated into a unified dataset encompassing three thematic pillars: mitigation, adaptation and energy access and poverty. The integration process involves selecting the most recent submission per city to ensure temporal consistency and relevance. A harmonization protocol is applied to reconcile structural and semantic differences between the platforms, aligning variable definitions and response formats. This ensures that equivalent indicators reported through different systems are merged coherently, allowing for comprehensive and comparative analysis across cities and regions. This harmonized dataset supports global evidence-based insights into local climate action under the GCoM initiative.

Municipal characteristic data was enriched through multiple sources, including gross domestic product (GDP) per capita estimates⁷⁹, settlement-type classifications (urban, suburban, rural)⁸⁰. If municipalities had wrong geographic coordinates, manual corrections have been applied. Figure 1 has been produced using data from the curated dataset described above and using the free open-source software QGIS; the basemap used is the World Bank Official Boundaries shape file. Actions analysis focused on signatories from the European Union and Western Europe GCoM Region due to data quality limitations in other regions. We analysed actions from municipalities that obtained a plan badge ($n = 341$ municipalities, 1,095 actions). Regarding energy access and energy poverty action approaches depicted in Fig. 6, the other category allows cities to report actions that do not fit into predefined options, providing flexibility in their reporting. Cities typically include explanations of the actions they report⁸¹. However, due to capacity constraints, these responses have not been reanalysed or grouped into specific categories. Implementation approaches were classified using an adapted categorization of key types of measure^{82,83} with four types: (1) physical and technological, (2) governance and institutional,

(3) economic and financial and (4) knowledge and behavioural change, where we merged the key types of measure category nature-based solutions and ecosystem-based approach with physical and technological.

This classification was applied to a sub-sample of 931 energy access and poverty actions recorded with sufficient implementation details. Actions were classified by their level of integration across GCoM's three pillars (mitigation, adaptation and energy). When actions are expected to impact more than one thematic pillar, they are labelled as integrated. For example, an energy poverty action with positive effects on mitigation is reported as integrated, impacting both the Energy Access and Poverty Pillar and mitigation to climate change. For sectoral analysis, EAP-only actions were classified based on energy poverty macro areas used in the Covenant of Mayors Europe region: climate, socio-economic, facilities and housing, policy and regulatory, mobility, participation and awareness raising and other⁸⁴. For integrated actions, we analysed the mitigation or adaptation sectors declared by signatories during the reporting phase. Not all actions have an associated sector, and signatories can declare more than one sector as impacted by a single action; hence sector counts exceed action counts.

The data analysis employs statistical counting and categorization methods to examine municipal energy action patterns across the integrated dataset. We calculate frequency counts (how often diverse types of action appear) to determine the prevalence of different action types, integration patterns and sectoral focuses within the 1,987 recorded energy actions from 1,354 municipalities. Cross-tabulation analysis, which involves creating tables that show relationships between two variables (for example, showing how integration types relate to different sectors), is conducted to explore connections between integration levels (energy only, energy–mitigation, energy–adaptation and comprehensive three-pillar approaches) and sectoral targeting. We categorize implementation status to assess how actions are distributed across completion phases (completed, ongoing, not started, postponed, cancelled) and to identify the proportion designated as key actions by municipalities. Geographic distribution analysis examines energy badge adoption rates across Global Covenant regions by counting and comparing regional totals, whereas categorical analysis of energy attributes (security, sustainability, affordability) reveals regional prioritization patterns through simple percentage calculations.

Supplementary Fig. 1 has been produced using Microsoft Power Point, including the icons displayed. The illustration and icons displayed in Supplementary Fig. 2 are extracted from the Global Covenant of Mayors website.

Statistical testing

To systematically examine the relationships between municipal characteristics and energy access and poverty action engagement, we conducted six complementary statistical tests across the full EAPP sample ($n = 1,354$ municipalities), with sensitivity analyses to control for temporal and regional confounds.

In Test 1, to test whether badge distribution patterns (Plan, Target, Assessment) differed significantly across GCoM regions, we used Fisher's exact test with Monte Carlo simulation (10,000 iterations), as chi-square assumptions were violated (>40% of cells had expected frequencies <5). Cramér's V was calculated for effect size. Sensitivity analyses excluded regions with temporal advantages (Sub-Saharan Africa, which had access since 2018 versus 2023 for others) and sample dominance (European Union and Western Europe, representing 85.5% of the sample) to assess robustness. In Test 2, to test whether city population distributions differed across regions among early EAPP adopters, we used the Kruskal–Wallis H test (non-parametric alternative to ANOVA) due to non-normal distributions and unequal variances. Post-hoc pairwise comparisons used Mann–Whitney U tests with Bonferroni correction ($\alpha = 0.05 / 10 = 0.005$). Effect sizes were calculated using epsilon-squared (ϵ^2). To assess whether initial EAPP uptake showed selection bias, we compared EAPP participants to the

full GCoM membership ($n = 13,506$) using Mann–Whitney U tests. For Test 3, among the subset of municipalities achieving comprehensive climate action across all three GCoM pillars ($n = 40$), we examined population and GDP per capita differences using Mann–Whitney U tests. Given Sub-Saharan Africa's earlier EAPP access (2018 vs 2023 for other regions), we conducted sensitivity analyses excluding SSA to isolate characteristics independent of temporal advantages. In Test 4, to examine whether city size influences badge engagement patterns, we compared large cities ($> 500,000$ population, $n = 109$) with smaller municipalities ($n = 1,245$) using chi-square tests of independence. Given Sub-Saharan Africa's earlier EAPP access (2018 vs 2023), we conducted sensitivity analyses excluding SSA to isolate size effects from temporal advantages. Regional variation was examined through stratified analysis across well-represented regions ($n \geq 25$). In Test 5, to examine whether municipal economic capacity relates to energy engagement patterns, we analysed GDP per capita effects on badge completion using chi-square tests across income groups (low: $< \text{US}\$12,000$; middle: $\text{US}\$12,000\text{--}40,000$; high: $> \text{US}\$40,000$). Sensitivity analyses controlled for Sub-Saharan Africa's 5-year EAPP exposure advantage by testing both with and without SSA. Within-region Mann–Whitney U tests assessed whether GDP effects persisted when holding regional context constant ($\alpha = 0.05$). In Test 6, to examine whether settlement type influences municipal energy engagement, we analysed badge completion profiles and engagement intensity across urban ($n = 674$), rural ($n = 554$) and suburban ($n = 126$) settlements as classified by the Global Human Settlement Layer. Chi-square tests examined associations between settlement type and (1) badge-type completion (Plan, Target, Assessment) and (2) badge intensity (number of distinct badge types, range 1–3), with Cramér's V effect sizes reported. Sensitivity analyses excluded Sub-Saharan African municipalities ($n = 26$) to control for their earlier EAPP access (2018 vs 2023).

Finally, to examine whether municipality characteristics influence action reporting patterns, we analysed 341 municipalities that collectively reported 1,095 energy actions. We tested relationships between (1) population size and action quantity using Spearman rank correlation; (2) population size and integration rate (percentage of actions spanning multiple pillars) using Spearman correlation and (3) settlement type (urban, suburban, rural; Global Human Settlement Layer classification) and integration patterns using chi-square tests with Cramér's V effect sizes. Integration was defined as actions addressing more than one pillar (mitigation, adaptation, energy poverty/access).

Data availability

The datasets analysed in the study are publicly available in the following repositories: GCoM MyCovenant, 5th Release, from the European Commission Joint Research Centre Data catalogue at <http://data.europa.eu/89h/9575255b-5807-4494-9f53-3c382c89df10> and the 2023 Full Cities Dataset from CDP/ICLEI Track at https://data.cdp.net/Cities/2023-Full-Cities-Dataset/7hmg-eagz/about_data. The basemap used in Fig. 1 is available at <https://datacatalog.worldbank.org/search/dataset/0038272/world-bank-official-boundaries>.

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Competing interests

The authors declare no competing interests.

Additional information

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