Barrio

Renovating neighbourhoods
for a decarbonised future

***Barrio - Fostering deep Building Renovation by Aggregating demand, developing business models and Rolling out IndustRialized prefabricated sOlutions for a decarbonized building stock***

# Report on the clustering methodology

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## STATEMENT OF ORIGINALITY

This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.

## ABOUT THE PROJECT EXECUTIVE SUMMARY

Barrio tackles building renovation fragmentation by combining neighbourhood-level demand, innovative supply business models, and prefabricated solutions for deep energy retrofits. Its core is the Defragmentation Multidisciplinary Toolkit (DMT), which includes an Aggregated Prefabricated Industrialised Plan (APP) generation tool, while also considering standard renovation pathways depending on the local context. This digital tool connects the renovation needs of building clusters with a consolidated range of services and solutions. The DMT simplifies large-scale renovation by grouping buildings and stakeholders, enabling efficient needs assessment and prioritisation. Furthermore, it fosters supply chain collaboration through flexible business models. Prefabricated solutions are key to maximising efficiency and boosting local supply chains. Through detailed renovation roadmaps, the APP generation tool is refined to match aggregate demand with supply, calculating costs and benefits. These plans are validated in diverse real-world settings and improved through stakeholder training. Ultimately, Barrio aims for replicable and scalable business models with lasting impact beyond the project itself.

This report sets out the foundations of BARRIO's clustering methodology, focusing on the establishment of a common indicator framework to characterise building renovation needs. It explains why clustering and demand aggregation are essential to overcome market fragmentation, draws lessons from previous European initiatives, and introduces a structured set of indicators spanning technical, urban-environmental, and socio-economic dimensions. Each indicator is described in terms of its relevance, potential data sources, and applicability for cluster definition. While subsequent steps of the methodology will be detailed in later reports, this document provides the analytical groundwork for evidence-based planning, demand aggregation, and the shift from fragmented interventions to neighbourhood-scale renovation strategies.

# ABBREVIATIONS

| ABBREVIATION | TERM/NOTION/CONCEPT |
|---|---|
| **APP** | Aggregated Prefabricated renovation Plan |
| **CAPV** | Basque Country (País Vasco; CAPV is the acronym in Spanish) |
| **D-LAB** | DEMAND Laboratories (small action groups of strategic local demand side stakeholders) |
| **DBL** | Digital Building Logbook |
| **DMT** | Defragmentation Multidisciplinary Toolkit |
| **FM** | Facility Management |
| **GIS** | Geographic Information Systems |
| **GUP** | General Urban Plan |
| **HVAC** | Heating, Ventilation & Air Conditioning |
| **OSS** | One-Stop-Shop |
| **PERp** | Produced renewable energy |
| **PERc** | Renewable energy consumed onsite |
| **PEC** | Total energy consumption |
| **PERc** | Renewable energy consumed on-site |
| **PV** | Photovoltaic |
| **SECAP** | Sustainable Energy and Climate Action Plan |
| **S-CLUSTER** | SUPPLY cross-sectoral Clusters (small action groups of local supply side stakeholders) |
| **WS** | Workshops |

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## TABLE OF CONTENTS

**1. Introduction** **5**
1.1 Purpose and structure of this deliverable 5
1.2. The EU Renovation Challenge 6
1.3 The Barrio Solution: a holistic, neighbourhood-scale approach 10
**2. A review of core mechanisms to build clusters and aggregate interventions** **13**
2.1. Municipal Coordination Mechanisms: Case Studies 13
2.2 Joint renovation and collective self-consumption: the ARCAS SUDOE approach 17
2.3 Data-driven cluster prioritization and outreach: the AGREE approach 23
2.3.1 Comparative Insights for Barrio: ARCAS vs. AGREE 25
**3. The Barrio approach to characterization and cluster-based renovation** **29**
**4. From Diagnosis to Action: A Framework of Indicators for Local Adaptation** **35**
4.1 Key Clustering Indicators for Barrio - Focus on Step 1 36
4.2 Insights on the Pilot-Specific Indicator Selection 39
**Conclusions** **41**
**Annex I** **42**

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# 1. Introduction

## 1.1 Purpose and structure of this deliverable

The purpose of this  report is to define and detail the methodology used by the Barrio project to characterise building renovation demand and **systematically cluster buildings** for integrated renovation planning at the neighborhood scale. This methodology is designed to overcome the structural fragmentation of the European renovation market by identifying coherent groups of buildings — or "clusters" — that can be addressed collectively through tailored, scalable, and cost-efficient interventions.

The deliverable outlines a **structured, multi-criteria approach** for clustering, informed by the comprehensive building stock characterisation, which draws on a wide array of technical, socio-economic, and environmental indicators. It supports local authorities, urban planners, and renovation facilitators in:

- **Mapping and diagnosing renovation needs** across multiple dimensions (energy inefficiency, seismic-related risk, social vulnerability, exposure to climatic and environmental hazards);
- **Selecting and operationalizing indicators** based on local relevance and data availability within each Barrio pilot territory;
- **Creating a multidimensional needs matrix** that enables the visualization of overlapping renovation priorities using GIS-like tools;
- **Defining spatial clusters** based on quantifiable rules (e.g. proximity, typology, ownership structure) that maximize the feasibility, impact, and inclusiveness of renovation actions.

This methodology is the analytical foundation for Barrio's **DMT**, enabling the identification of renovation clusters and the generation of **APPs**. By doing so, it not only supports evidence-based decision-making, but also facilitates demand aggregation, stakeholder engagement, and the alignment of renovation efforts with broader policy goals such as energy poverty alleviation and climate resilience.

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## 1.2. The EU Renovation Challenge

Europe's building stock is both an immense challenge and an unparalleled opportunity on the road to climate neutrality by 2050. Today, buildings consume around **40% of the EU's final energy** and generate over **one-third of its energy-related greenhouse gas emissions**[1,2,3]. Most of these structures are decades old: approximately 85% of non-residential buildings were erected before 2001, and two-thirds of the entire stock predates 1980[2]. Worse still, nearly 75 % of existing buildings perform poorly from an energy-use standpoint, underscoring the urgent need for large-scale renovations[4]. Yet only **about 1% of the EU's building stock is retrofitted each year**—and just 0.2% undergoes the "deep renovations" required to reduce energy demand by over 60 % per building[5].

In response, the European Commission launched its Renovation Wave strategy in 2020, aiming to double the annual energy renovation rate to **2% and upgrade 35 million buildings by 2030**[6]. As shown by BPIE, the strategy envisages that at least 70% of these interventions should be "deep renovations," delivering substantial energy savings—and, by extension, cost reductions and emission cuts—for residents[7]. Beyond the sheer technical and environmental imperative, neighbourhood-scale renovation is equally crucial in reshaping the quality of life in Europe's cities. Acting at the community level allows renovation to generate co-benefits that transcend energy savings alone: safer and healthier homes, strengthened social cohesion, and urban spaces that are more resilient, inclusive,

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[1] Climate Action Network Europe. (2019). *The Renovation Wave sets the right direction, but falls short on the needed ambition*. https://caneurope.org/the-renovation-wave-sets-the-right-direction-but-falls-short-on-the-needed-ambition/

[2] European Commission. (n.d.). *Energy performance of buildings directive*. https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en

[3] European Environment Agency. (2025). *Buildings and construction*. https://www.eea.europa.eu/en/topics/in-depth/buildings-and-construction

[4] Garrigues. (2024). *The European Union sets its sights on complete decarbonization of building stock by 2050*. Retrieved from https://www.garrigues.com/en_GB/new/european-union-sets-its-sights-complete-decarbonization-building-stock-2050

[5] Buildings Performance Institute Europe. (2021). *One-stop shops: The missing piece in the home renovation puzzle*. https://www.beuc.eu/sites/default/files/publications/BEUC-X-2024-113%20One_Stop_Shops_The_missing_Piece_the_Home_Renovation_puzzle.pdf

[6] European Commission. (n.d.). *Renovation Wave*. https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en

[7] Buildings Performance Institute Europe. (2021). *Deep renovation briefing*. https://www.bpie.eu/wp-content/uploads/2021/11/BPIE_Deep-Renovation-Briefing_Final.pdf

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and liveable. In this way, the transformation of the building stock becomes not only a climate and energy policy priority, but also a driver of urban regeneration and citizen well-being. However, scaling up to this level confronts entrenched obstacles: the renovation market is highly **fragmented**, with myriad small actors leading to disjointed projects[8], and many owners—especially low-income households or those in **vulnerable situations**—lack the financial means or procedural know-how to embark on complex retrofit schemes[9].

**Building Clustering and Demand Aggregation as Strategic Enablers**

To overcome fragmentation, practitioners and policymakers are turning to **building clustering** and **demand aggregation** as key strategies. Building clustering involves grouping buildings with similar characteristics—typology, age, condition, or location—and planning their renovations together in a coordinated way. Instead of tackling buildings one by one, a **cluster approach** looks at the neighbourhood or district level, enabling standardized solutions to be applied across multiple buildings[10, 11]. For instance, several apartment blocks on one street might all receive façade insulation or heating-system upgrades as part of a single project, reducing per-unit costs through shared procurement and installation processes[10]. Clustering creates a larger, more coherent project that can achieve synergies and **economies of scale**, making industrialised retrofit methods—such as off-site prefabricated panels—financially viable[12].

[8] Lassandro, P., Bancic, D., Bellazzi, A., De Aloysio, G., Devitofrancesco, A., Lukasik, M., Navarro Escudero, M., Paoletti, G., Sanchis Huertas, A., Vetršek, J., & Malvezzi, R. (2025). A transition pathways approach for energy renovation in EU building market ecosystems. *Sustainability, 17*(5), 2219. https://doi.org/10.3390/su17052219

[9] European Commission Joint Research Centre. (2021). *One-stop shops for building renovation: An integrated solution to close the gap between customers and suppliers*. https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/one-stop-shops-building-renovation-integrated-solution-close-gap-between-customers-and-suppliers-2021-07-19_en

[10] Terés-Zubiaga, J., Bolliger, R., Almeida, M. G., Barbosa, R., Rose, J., Thomsen, K. E., Montero, E., & Briones-Llorente, R. (2020). Cost-effective building renovation at district level combining energy efficiency & renewables – Methodology assessment proposed in IEA EBC Annex 75 and a demonstration case study. *Energy and Buildings, 224*, 110280. https://doi.org/10.1016/j.enbuild.2020.110280

[11] Andreazzoli, I. (2022). Housing clustering to accelerate the energy transition: Parametric simulation approach for multi-objective optimization of sustainable housing renovations. Technische Universiteit Eindhoven. https://pure.tue.nl/ws/portalfiles/portal/216622869/2022_08_29_Andreazzoli_I._SBC.pdf

[12] Papapietro, L. (2025, January 9). Infinite project: Case study of sustainable building retrofit in Slovenia. *BUILD.UP*. https://build-up.ec.europa.eu/en/news-and-events/news/infinite-project-case-study-sustainable-building-retrofit-slovenia

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This strategic orientation is now reflected in the recast of the **Energy Performance of Buildings Directive (EPBD),** formally adopted in 2024, which places increasing emphasis on aggregated renovation strategies. The revised EPBD introduces the concept of an **"integrated district or neighbourhood approach,"** encouraging Member States to identify and support areas where coordinated, large-scale interventions can maximise impact, in line with the directive's overarching objective of achieving a zero-emission building stock by 2050. Moreover, the Annexes detailing its implementation—adopted on 30 June 2025—provide the operational foundation for National Building Renovation Plans and ensure that project initiatives are consistent with the most up-to-date legislative framework. This alignment explains why the proposal has strategically synchronised its timeline with these latest regulatory developments, even at the cost of a slightly later submission, to guarantee full policy relevance and durability.

This vision is not merely theoretical: across Europe, pioneering initiatives already demonstrate the added value of aggregated and neighbourhood-scale renovation. In Barcelona, a NextGenerationEU-funded municipal programme has clustered entire apartment blocks into joint retrofit projects, securing bulk discounts on materials and streamlining administrative processes[13]. Vienna's "Plus-Energy Office" case highlighted the power of coordinated stakeholder cooperation, where research institutions, contractors, and public bodies joined forces to deliver high-performance refurbishments at scale. In Belgium, integrated one-stop-shop platforms now bundle financing, technical support, and contractor services, making deep renovation financially and logistically accessible to a much broader demographic[14]. These examples illustrate how collective approaches can overcome fragmentation, lower costs, and democratise access to quality renovation—principles that BARRIO seeks to systematise and replicate.

At the EU projects level, as detailed in the following sections, the Interreg initiative **ARCAS SUDOE** has crafted a multicriteria methodology for assessing and designing the rehabilitation of social-housing

[13] European Commission. (n.d.). *Boost on the rehabilitation and urban regeneration in the city of Barcelona*. Retrieved from https://commission.europa.eu/projects/boost-rehabilitation-and-urban-regeneration-city-barcelona_en
[14] Climact. (2024). *Upscaling the financing of residential renovation in Belgium*. https://climact.com/wp-content/uploads/2024/03/Upscaling-the-financing-of-Residential-Renovation-in-Belgium-Final-deliverable-v2.pdf

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clusters, explicitly targeting energy poverty, sustainability, and indoor-environment quality[15]. The **HORIZON AGREE** Initiative, active in the Basque Country, has deployed demand-activation mechanisms, improved governance frameworks, and bespoke funding solutions to leverage residential renovation investments[16].

Demand aggregation complements building clustering by **consolidating the renovation needs of multiple building owners** so they procure services as a group rather than individually. By **bundling many small renovation interventions into one larger portfolio**, aggregation sends a stronger market signal to the supply chain[17,18]. This approach helps to:

- **Attract suppliers and innovative solutions** through collective procurement—larger aggregated tenders entice specialist contractors and justify investment in cost-saving innovations (like prefabricated retrofit panels) that require scale to deploy[20].
- **Provide predictable demand**, giving manufacturers and service providers the confidence to invest in capacity (workforce and equipment) when they see a stable pipeline of projects[19]. At this scale, **larger companies** are also more likely to get involved in renovation, since bundled projects overcome the barrier of single-building interventions being too small or fragmented to be viable.
- **Mitigate risks for individual owners**—when many owners act together, each is less a "first mover" and can share transaction costs and performance guarantees[9].
- **Achieve bulk discounts and lower unit costs** thanks to economies of scale—materials and services bought in volume are cheaper, and transaction costs per building drop[19, 22].

[15] ARCAS SUDOE. (2019-2022). https://www.arcassudoe.eu/about/?lang=en
[16] HORIZON Agree. (2023). *HORIZON Agree: An innovative approach to energy renovation*. https://agree-basquecountry.eu/en/una-innovadora-propuesta-para-la-rehabilitacion-energetica/
[17] Wakili, K. G., Dworatzyk, C., Sanner, M., Sengespeick, A., Paronen, M., & Stahl, T. (2018). Energy efficient retrofit of a prefabricated concrete panel building (Plattenbau) in Berlin by applying an aerogel based rendering to its façades. *Energy and Buildings, 165*, 293–300. https://doi.org/10.1016/j.enbuild.2018.01.050
[18] Buildings Performance Institute Europe. (2016). *Scaling up deep energy renovation: The aggregation of demand*. https://www.bpie.eu/wp-content/uploads/2016/11/BPIE_i24c_deepretrofits.pdf
[19] Boza-Kiss, B., Bertoldi, P., Della Valle, N., & Economidou, M. (2021). *One-stop shops for residential building energy renovation in the EU: Analysis & policy recommendations* (EUR 30762 EN). Publications Office of the European Union. https://doi.org/10.2760/245015

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- **Standardize quality and approaches**, making it easier to ensure high standards under a single project management structure overseeing multiple buildings[20].
- **Enable tailored financing and business models** like Energy Service Companies (ESCOs) or on-bill financing, which become viable at a larger project scale and can further de-risk investments by structuring repayments through energy savings[21].

In practice, *intermediary actors* such as **One-Stop-Shops (OSS)** often facilitate clustering and aggregation. These intermediaries coordinate among homeowners, suppliers, and financiers – effectively acting as an aggregator on the ground[23,24]. Aggregation can be especially powerful when linked to **project financing**: bundling projects can de-risk loans or attract third-party investors by creating investment packages of sufficient size and predictable returns. Overall, building clustering and demand aggregation are **strategic enablers** that directly address fragmentation: they turn scattered single renovations into unified programs, unlocking efficiencies that make it easier – and more affordable – to renovate at scale.

## 1.3 The Barrio Solution: a holistic, neighbourhood-scale approach

The Barrio EU LIFE project responds directly to the fragmentation that hampers deep building renovation efforts across Europe. Rather than focusing on single buildings, Barrio adopts a **neighbourhood-scale approach** to unlock economies of scale, foster collaboration among stakeholders, and deploy **industrialised prefabricated solutions** for staged deep renovation. The ultimate goal is to contribute to a **zero-emission building stock** by creating a replicable, scalable model aligned with EU climate goals.

At its core, Barrio offers the **Defragmentation Multidisciplinary Toolkit (DMT)**—a digital and collaborative framework that enables the aggregation of renovation demand (via building clusters),

[20] Bertoldi, P., Boza-Kiss, B., Della Valle, N., & Economidou, M. (2021). The role of one-stop shops in energy renovation – A comparative analysis of OSSs cases in Europe. *Energy and Buildings, 250*, 111273. https://doi.org/10.1016/j.enbuild.2021.111273
[21] Renovation Hub. (2024). Enhanced Energy Performance Contracting. https://renovation-hub.eu/business-models/enhanced-energy-performance-contracting/

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the alignment of suitable supply chains, and the creation of **Aggregated Prefabricated Plans (APPs)**. These APPs leverage digital automation to generate tailored renovation roadmaps and business models, connecting stakeholders and solutions efficiently.

The project innovates by integrating lessons from previous EU initiatives- see Figure 1 (e.g., TABULA, re-MODULEES, HAPPEN, OneClickRENO and BuildUpSpeed) and evolving their functionalities—adding modules for **clustering buildings**, **stakeholder aggregation**, and **APP matchmaking**. These tools are validated in **four diverse pilot ecosystems**—Emilia-Romagna (Italy), Comunitat Valenciana (Spain), Ravne na Koroškem (Slovenia), and Gabrovo District (Bulgaria)—ensuring that Barrio's solutions address a wide range of climatic, regulatory, and market conditions.

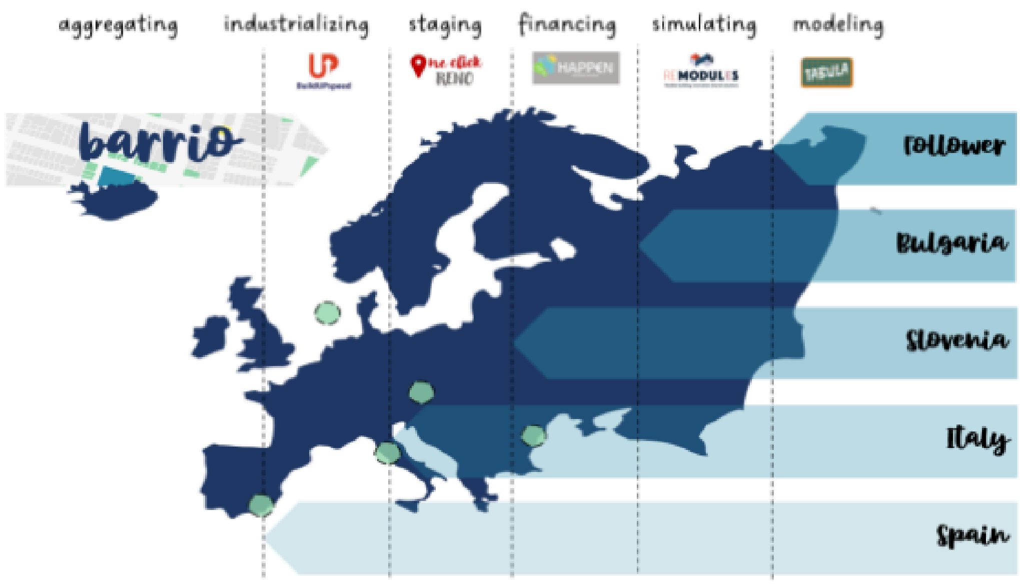


**Figure 1.** The figure shows the synergies between Barrio and previous EU Projects, outlining the features to be evolved and the countries involved in each.

Barrio's participatory approach includes **Demand-Side Laboratories (D-LABs)** and **Supply-Side Clusters (S-Clusters)**, co-design spaces where building owners, local authorities, SMEs, and financial institutions collaboratively shape and implement renovation strategies. Strategic oversight is provided by an

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**Advisory Board** composed of experts across science, policy, society, and industry, ensuring alignment with broader EU priorities.

Once completed, BARRIO is expected to deliver measurable impacts within five years, including around a 10% increase in deep renovations, 156 GWh/year of energy savings, €215 million mobilised in investments, and 2,480 $tCO_2$/year avoided. By combining digital, technical, and social innovations in an integrated framework, BARRIO will provide a practical reference for moving from individual retrofits towards more coordinated, district-level decarbonisation strategies.

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# 2. A review of core mechanisms to build clusters and aggregate interventions

## 2.1. Municipal Coordination Mechanisms: Case Studies

One effective means of operationalizing clustering and demand aggregation is through proactive municipal or regional coordination. Local authorities, by virtue of their close ties to citizens and mandate over urban planning, can serve as orchestrators—bundling individual renovation requests into unified programmes that leverage economies of scale and streamline processes[22]. Several EU-funded pilot programmes illustrate how such public-sector leadership markedly increases renovation uptake. Below three emblematic cases are examined—**Opengela** in Spain, **RenoBooster** in Austria, and **RenoWatt** in Belgium—where local governments have established innovative coordination mechanisms. These real-world examples demonstrate that, by combining hands-on technical support, structured stakeholder engagement, and smart financing models, municipalities and regions can decisively overcome market fragmentation.

- **Opengela (Basque Country, Spain)[23]:** District "neighbourhood offices" act as one-stop-shops providing turnkey renovation services—ranging from energy audits and administrative assistance to social-impact loan facilitation—enabling nearly 800 homeowners to undertake deep façade, heating, and accessibility upgrades as integrated projects, mobilising €9.6 million for 3.9 GWh/year of savings.
- **RenoBooster (Vienna, Austria)[24]:** Housed within the municipal housing fund, this smart renovation hub offers free in-person consultations, aggregates dozens of retrofit requests into joint procurements (e.g., bulk purchase of heat pumps and solar panels), and provides

[22] HORIS Project. (2024). *D3.1 – Existing OSS lessons learned*.
https://ieecp.org/wp-content/uploads/2024/07/HORIS-D3.1-Lessons-learned-from-one-stop-shops.pdf
[23] Opengela Project. (2019–2022). *Cases*.
https://opengela.eus/cases
[24] RenoBooster Project. (2019–2022).
https://www.wien.gv.at/wohnen/wohnbautechnik/foerdern/projekt-renobooster/index.html

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concierge-style project management—triggering an anticipated €110 million in investments, 5.5 GWh/year of primary energy savings, and 1,000 t $CO_2$/year reductions.

- **RenoWatt (Wallonia, Belgium)**[25]**:** Operating as a regional "delegated mission," RenoWatt pools public buildings (schools, town halls, cultural centres) into energy-performance contracting clusters, centralised procurement, and supplies no-cost technical assistance to all 262 municipalities. Its Liège pilot alone delivered five EPCs (€59 million) across 136 buildings, achieving 53 GWh/year savings and 15,600 t $CO_2$/year cuts, and is now scaling to 500+ sites with €100 million in investments.

### Opengela (Basque Country, Spain) – Neighborhood One-Stop-Shops

Opengela is an EU-funded initiative in the Basque Country that establishes **neighbourhood renovation offices**—physical one-stop-shop hubs embedded in disadvantaged districts to drive integrated building upgrades. Each Opengela office functions as a **local community hub for renovation**, where residents—often elderly or low-income—receive in-person guidance on retrofitting their apartment blocks. These offices centralize every phase of the renovation process—technical advice, permit applications, contractor coordination, and subsidy or financing facilitation—ensuring a seamless, end-to-end service. By **embedding renovation services directly within the neighbourhood**, Opengela builds trust among residents and aggregates demand by organizing retrofit works **building-by-building or block-by-block**.

In the pilot districts of Otxarkoaga (Bilbao) and Txonta (Eibar), Opengela partnered with local homeowners' associations to bundle multiple buildings into unified renovation schemes, helping to implement and apply public subsidies for simultaneous upgrades such as new elevators, thermal insulation, and efficient heating systems. Municipal and regional authorities convene key stakeholders—homeowners, construction cooperatives, banks, and subsidy bodies—to craft integrated neighbourhood renovation plans that align technical, financial, and social goals.

[25] RenoWatt Project. (2019–2022).
https://www.renowatt.be/

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A hallmark of Opengela is its **area-based strategy**: instead of isolated renovations, it rehabilitates entire urban quarters, yielding clear economies of scale by enabling one office to serve multiple sites and by bulk-procuring works across the neighbourhood. This approach amplifies social impact by improving safety, accessibility, and the local urban fabric in tandem with energy performance, thus raising overall living standards. Thanks to strong public leadership, visible on-the-ground presence, and the coupling of **energy upgrades** with valued **urban regeneration measures** (such as new elevators and enhanced comfort), Opengela has achieved high uptake in its pilot areas. Designed for easy replication, the Opengela model demonstrates how **publicly backed one-stop-shops** can defragment renovation demand at the neighbourhood scale and be scaled to other vulnerable districts across Europe.

### RenoBooster (Vienna, Austria) – City-Level Retrofit Facilitation

RenoBooster is a Horizon 2020 initiative established by the City of Vienna to **promote energy-efficient retrofitting of privately owned apartment buildings** through the institution of a centralised "Smart Renovation Hub" that functions as a one-stop-shop for condominium proprietors and their associations. Exercising its municipal authority, Vienna aggregates the renovation requirements of multiple condominium groups and offers a comprehensive suite of services: professional energy assessments, specialised technical guidance, assistance with permitting procedures, and facilitation of **subsidised renovation financing via local banking partners**. By standardising contractual frameworks and consolidating numerous homeowners' associations into collective tender processes, the programme renders substantial deep-retrofit measures—such as thermal insulation enhancement and heating-system modernization—both practicable and economically accessible to property owners who might otherwise lack the organisational capacity or financial means to undertake such interventions independently.

Concurrently, RenoBooster implements strategic **policy and regulatory refinements**—streamlining the building-permit workflow and harmonising municipal subsidy criteria—to fortify the overarching "framework conditions" conducive to large-scale renovation across the city. These measures have engendered a robust **pipeline of retrofit projects**, thereby furnishing private-sector providers with a broader and more predictable market demand: as of early 2022, the Smart Renovation Hub was

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fielding approximately 370 homeowner consultations per month—an increase from roughly 80 at programme inception—with predominant inquiries concerning high-efficiency heating systems and façade insulation, frequently coupled with financing advisement. This integrated, governance-driven model underscores that institutional coordination and comprehensive support structures are as indispensable as financial incentives. By serving as a singular point of entry and orchestrating the end-to-end renovation process, RenoBooster amplifies the market's demand signal and precipitates a significant escalation in **on-the-ground deep-renovation activity**.

### RenoWatt (Wallonia, Belgium) – Bundling Public Building Retrofits

RenoWatt, in Wallonia, took a different angle by **focusing on the public sector**, but it offers valuable lessons for residential renovation as well. RenoWatt was a regional project (initiated in Liège) that aggregated the renovation of **dozens of municipal and public buildings**—such as schools, offices, and hospitals—into large-scale tenders for energy performance contracts. Acting as a **central project facilitator** under a regional development agency, RenoWatt essentially functioned as a one-stop-shop for local authorities: it performed energy audits on public buildings, identified packages of energy-saving measures, assembled pools of buildings, and conducted joint procurement on behalf of the municipalities. **By pooling buildings from different towns to reach a critical mass**, RenoWatt made the projects attractive to Energy Service Companies (ESCOs) that implement retrofits under guaranteed savings contracts.

The aggregation achieved through RenoWatt had clear benefits: it **drove down costs** (one procurement for many sites, bulk purchasing of equipment) and diversified risk (strong-performing buildings could compensate for others). Indeed, participating municipalities obtained better contract terms from ESCO bidders thanks to the larger-scale bundles than they could have by tendering alone.

By the end of its pilot, RenoWatt had engaged 10 municipalities and bundled **over 200 buildings (120 sites)** into approximately €40 million worth of energy retrofit works. These contracts were projected to deliver around 25–35 percent energy savings on electricity and heating across the portfolio. While RenoWatt focused on public buildings, its model is being looked at for private housing clusters as well—especially social housing blocks or groups of apartment buildings that a city might help aggregate.

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The key takeaway is the power of a neutral facilitation entity: RenoWatt acted on behalf of owners (in this case, cities) to handle technical, financial, and procurement tasks, greatly reducing complexity for the individual building owners. It shows that standardization and bundling at a regional level can overcome fragmentation: even small towns were able to retrofit buildings because a central program organized everything for them. Cities aiming to aggregate residential renovations could emulate this by issuing one tender for many privately owned buildings, with the city or a dedicated agency as the organizer. In essence, RenoWatt demonstrates a successful one-stop-shop for multi-building retrofits that achieved scale and mobilised private investment—validating the concept of demand aggregation in practice. A similar mechanism is offered by the European Local Energy Assistance (ELENA) facility, managed by the EIB, which provides technical assistance grants to prepare large-scale energy efficiency and renewable investments. By helping projects reach sufficient scale and bankability, ELENA has proven effective in leveraging substantial private financing beyond public subsidies.

## 2.2 Joint renovation and collective self-consumption: the ARCAS SUDOE approach

The ARCAS SUDOE project, an acronym for "Architecture for Climate" in the Sudoe region (SOE3/P3/E0922), operated as an EU Interreg SUDOE Programme initiative[26]. Implemented across Spain, Portugal, and France, its overarching goal was to foster the energy-efficient refurbishment of multi-family buildings, notably through the integration of collective renewable energy systems[27]. The project's English title, "New assessment Methodology for social, sustainable and eco-friendly housing. Climate architecture for the Sudoe's area," underscores its focus on developing replicable solutions

[26] Terés-Zubiaga, J., González-Pino, I., Álvarez-González, I., & Campos-Celador, Á. (2023). Multidimensional procedure for mapping and monitoring urban energy vulnerability at regional level using public data: Proposal and implementation into a case study in Spain. *Sustainable Cities and Society*, *89*, 104301. https://doi.org/10.1016/j.scs.2022.104301
[27] *Interreg South West Europe (SUDOE)*. Interreg. https://interreg.eu/programmes/south-west-europe-sudoe/

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tailored to the specific climatic conditions of South-West Europe[28]. The Interreg SUDOE framework inherently promotes transnational cooperation, and ARCAS capitalized on this by involving partners from these three countries, facilitating cross-border knowledge exchange and aiming to harmonize renovation approaches in regions sharing similar climatological characteristics[37]. The project's timeline coincided with a period of intensifying EU policy focus on energy efficiency and renewable energy, likely influencing its strategic direction and urgency.

Its central aim was to develop a comprehensive evaluation and design methodology for rehabilitating clusters of social housing, with a holistic emphasis on energy performance, indoor comfort, and tackling energy poverty[29]. This methodology is structured around three primary research axes: autonomy/energy efficiency, social quality/energy poverty, and air quality/health (which encompasses indoor comfort aspects like thermal, acoustic, and light comfort, alongside air quality metrics such as $CO_2$ levels and rate of ventilation)[39]. The explicit incorporation of energy poverty, assessed via indicators like the proportion of net household income allocated to energy expenditure, signifies a significant socio-technical dimension, moving beyond purely technical energy savings to address critical social equity concerns[30]. This holistic integration of energy performance, occupant well-being, and social impact reflects a mature understanding of sustainable renovation.

One of the project’s key innovations lay in incorporating solar photovoltaic (PV) “self-consumption” systems directly into renovation workflows, thereby increasing the attractiveness of participation for building owners[31]. The ARCAS methodology includes specific indicators to assess renewable energy integration, such as the renewable energy self-consumption ratio (*produced renewable energy*

[28] Fundación Estudios Calidad Edificación Asturias. (2019–2022). *New assessment methodology for social, sustainable and eco-friendly housing: Climate architecture for the Sudoe's area (ARCAS)*. Interreg VB South West Europe Programme. https://keep.eu/projects/23991/New-assessment-Methodology--EN/

[29] Universidad del País Vasco/Euskal Herriko Unibertsitatea, EHUrOPE – International R&D Office. (n.d.). *POCTEFA_ARCAS – New Evaluation Method for Sustainable and Energy Efficient Housing of Social Interest*. https://www.ehu.eus/en/web/europeanprojects/sudoe/-/asset_publisher/MOvvOodrfhwa/content/poctefa_arcas

[30] de Bruyn, S., & Warringa, G. (2023). *P9.1 – Action plans for regions where demonstration buildings belonging to civil services are located* (Deliverable SOE3/P3/E0922). ARCAS Project: New Evaluation Method for Homes of Social, Sustainable and Energy Efficient Interest – Architecture for Climate in the SUDOE Territory (Interreg Sudoe). https://keep.eu/api/project-attachment/56694/get_file/

[31] Fundación Estudios Calidad Edificación Asturias. (2019–2022). About – ARCAS: New Evaluation Method for Social Interest, Sustainable and Energy Efficient Homes – Architecture for the Climate in the Sudoe Territory (SOE3/P3/E0922). ARCAS. https://www.arcassudoe.eu/about/?lang=en

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*(PERp)* that is *consumed on-site (PERc)*- PERc/PERp) and the renewable energy self-sufficiency ratio *total energy consumption (PEC)* that is covered by *renewable energy consumed on-site (PERc)* (PERc/PEC)[32]. Furthermore, action plans developed within the project recommend the creation of energy communities to generate renewable energy in proximity to homes, supplementing building-specific installations[40].

The emphasis on self-consumption and energy communities points towards maximizing on-site renewable energy use, which can empower building occupants by giving them greater control over their energy supply and generating tangible economic benefits, thus enhancing the appeal of renovations.

ARCAS effectively showed that combining deep renovation with collective ownership of rooftop PV installations enhances the feasibility and appeal of group retrofits[40]. The project aimed to validate its certification procedure in various buildings across the SUDOE territory, developing reference criteria to improve future application regulations[41]. The concept of collective ownership aligns strongly with the promotion of energy communities, which inherently involve shared models for benefit and management[40]. Such models are critical for overcoming the fragmented ownership barriers prevalent in multi-family buildings, particularly in Southern European contexts[30].

**Demand Aggregation Strategy:** ARCAS applied an assessment methodology for buildings and groupings of collective buildings[39]. The project's scientific publication indicates that this methodology was tested in six demonstrator buildings located in La Rochelle (France), Braga (Portugal), and Vitoria-Gasteiz (Spain)[33]. The available documentation does not specify a "neighbourhood-based clustering model" being piloted by ARCAS in locations such as Bilbao (ES) or Porto (PT) in the same manner as projects like AGREE. Instead, ARCAS focused on developing its assessment tool and promoting energy communities[40].

The project then provided support for forming resident groups (e.g. condominium assemblies or

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[32] ARCAS Project. (2023). ARCAS – New assessment methodology for social, sustainable and eco-friendly housing: Climate architecture for the Sudoe's area. Certification guidebook: Roles and procedures (Version 0.1). Fundación Estudios Calidad Edificación Asturias. https://keep.eu/api/project-attachment/56690/get_file/

[33] Flores-Abascal, I., Hernández-Cruz, P., Odriozola-Maritorena, M., Almeida, M. G., Onety, B., Nicolle, J., Allard, F., Le Dréau, J., Suárez, E., & ARCAS-consortium. (2023). A novel multicriteria methodology to assess the renovation of social buildings. *Journal of Building Engineering, 77*, 107505. https://doi.org/10.1016/j.jobe.2023.107505 (ScienceDirect, researchgate.net)

cooperatives) to collectively plan and execute the interventions, primarily through its recommendations for establishing energy communities[40]. These communities provide a formal structure for collective action and shared benefit from renewable energy systems. Through shared self-consumption mechanisms—where rooftop solar energy is distributed among the participating households—ARCAS offered a tangible economic return that grew with participation: the higher the number of involved neighbours, the greater the benefit for all[42]. This positive feedback loop, where greater participation can lead to larger systems and more widely distributed benefits, is fundamental to the success of collective renovation schemes.

Moreover, ARCAS developed legal and financial strategies and recommendations to facilitate the creation of energy communities and streamline joint funding pathways[40]. This involved defining approaches to inform basic regulations and criteria for allocating financing and subsidies, particularly for housing occupied by vulnerable groups, rather than developing standalone deployable tools[40]. This strategic focus aims to create a more enabling policy environment.

**Key contributions**: ARCAS demonstrated that coupling energy renovations with distributed renewable energy sources not only reduces energy use but also delivers quantifiable cost savings, motivating owner involvement[40]. The project confirmed that integrating an economic driver—such as shared PV benefits—can overcome common barriers in collective renovations, particularly in multi-owner buildings[40]. The economic advantages derived from shared PV systems, especially when structured within an energy community, provide a compelling incentive to address both financial hurdles and the decision-making inertia often found in such contexts. Intensive facilitation, including technical audits implicitly embedded within its certification process (involving initial status reports, project proposal reviews, and building monitoring)[42], proved vital to navigating the governance challenges of shared property contexts. The ARCAS implementation strategy emphasizes a multi-stakeholder approach involving administrations, housing management companies, professional associations, and neighborhood associations[40]. While this points to a collaborative and facilitated process, explicit details on ARCAS employing specific "co-decision support" or "professional mediation" as core tested components are not extensively documented in the provided materials. For Barrio, these findings validate the dual strategy of merging energy efficiency with community-scale renewable generation. Pilot actions involving cooperative housing can replicate this by embedding solar PV or other local energy solutions into renovation packages, advancing both decarbonisation and social engagement objectives [39]. Furthermore, ARCAS illustrates the need for a dedicated facilitation structure—an insight that Barrio's DMT and accompanying services must address in order to scale collective renovation models[40]. The ARCAS experience highlights that technical solutions are most effective when paired with robust governance and facilitation models to ensure successful implementation and scalability.

The following table summarizes the **core axes of the ARCAS SUDOE** methodology:

| AXIS | DESCRIPTION & KEY FOCUS | KEY INDICATORS (EXAMPLES) | KEY RECOMMENDATIONS FOR PUBLIC ADMINISTRATION |
|---|---|---|---|
| Energy Efficiency | Maximizing building energy performance and integration of renewables. | Primary Energy Consumption (PEC), Heat Loss Coefficient (HLC), Renewable Energy Self-Consumption Ratio (PERc/PERp). [42] | Promote policies aligned with EU goals; foster energy communities for local renewable generation.[40] |
| Energy Poverty | Addressing inability to afford adequate energy services; focus on vulnerable households. | 10% Indicator (ratio of energy expenditure to net household income). [40] | Gather reliable data on energy costs and consumption; provide temporary aid during price surges; adapt ARCAS tool to local realities.[40] |
| Air Quality / Indoor Environment Quality (IEQ) | Ensuring healthy and comfortable indoor living conditions. | Thermal comfort (temperature, humidity), acoustic comfort, CO2 levels, ventilation rates, illuminance levels. [42] | Promote technical solutions for optimal comfort (temperature, humidity, lighting, ventilation, insulation); consider occupant health as fundamental.[40] |

**Table 2 :** ARCAS SUDOE Methodology: Core Axes and Focus

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## 2.3 Data-driven cluster prioritization and outreach: the AGREE approach

AGREE (Aggregation and improved Governance for untapping Residential Energy Efficiency potential) was a Horizon 2020 project (Grant Agreement No 847068) led by the Basque Government's Housing Ministry[34],[35]. It focused on spatially and socially prioritizing renovation areas, thereby enabling municipalities to transition from isolated retrofit efforts to a cohesive, data-driven area-based strategy[36]. The leadership by a regional government signifies a strategic, top-down commitment to systemic change in urban renovation planning and execution. The project built upon prior work such as the "Guía Metodológica para la Regeneración Urbana Integrada de los barrios de la CAPV construidos en 1950-70 (IHOBE, 2019)"[37].

Its core objective was to assist local authorities in planning energy-efficiency upgrades by identifying clusters of residential buildings sharing similar deficiencies and deploying coordinated interventions across those zones [38]. The identification of "clusters with similar deficiencies" is pivotal, as it allows for the development of standardized intervention packages and the realization of economies of scale, making renovations more efficient and cost-effective than ad-hoc, building-by-building approaches.

**Methodology**: AGREE's approach integrated building-stock diagnostics—including construction age (typically 1940-1970, pre-dating thermal regulations), typology, and certified energy

[34] AGREE Project. (2019 – 2023). *Modern*. AGREE – Basque Country. https://agree-basquecountry.eu/en/modern/

[35] AGREE Project. (2019–2023). *Activating Governance to Reach Energy Efficiency (AGREE)*. Horizon 2020 Grant No. 847068. https://agree-basquecountry.eu/en/proyecto-agree/

[36] de Bruyn, S., & Warringa, G. (2023). *P9.1 – Action plans for regions where demonstration buildings belonging to civil services are located* (Deliverable SOE3/P3/E0922). ARCAS Project: New Evaluation Method for Homes of Social, Sustainable and Energy Efficient Interest – Architecture for Climate in the SUDOE Territory (Interreg Sudoe). https://keep.eu/api/project-attachment/56694/get_file/

[37] AGREE Project. (2021). *Innovative mechanisms to achieve the Agree project's goals.* https://agree-basquecountry.eu/en/los-objetivos-del-proyecto-agree-se-alcanzaran-con-mecanismos-innovadores/

[38] de Bruyn, S., & Warringa, G. (2023). *P9.1 – Action plans for regions where demonstration buildings belonging to civil services are located* (Deliverable SOE3/P3/E0922). ARCAS Project: New Evaluation Method for Homes of Social, Sustainable and Energy Efficient Interest – Architecture for Climate in the SUDOE Territory (Interreg Sudoe). https://keep.eu/api/project-attachment/56694/get_file/

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performance—with socio-economic indicators such as income levels, demographic, and energy-poverty metrics to generate composite priority-zone maps using a GIS-based Multi-Criteria Decision Analysis (MCDA) method, [39]. This sophisticated integration ensures that interventions are not only technically optimized but also socially targeted, addressing vulnerabilities and maximizing social impact alongside energy savings.

These delineated Integral Renovation Areas frequently exhibited missing elevators, inadequate thermal insulation, and inefficient heating installations, often concentrated among vulnerable populations. The housing stock from this era, as detailed by in the literature[40], is often characterized by significant degradation and vulnerability[41]. These physical deficiencies directly contribute to higher energy costs, exacerbating energy poverty, and diminishing the quality of life, particularly for susceptible groups like the elderly and low-income households. Working alongside pilot municipalities in Basauri, Donostia-San Sebastián, and Vitoria-Gasteiz, AGREE validated these clusters in situ and co-designed bespoke intervention plans grounded in local context and stakeholder input, including participatory techniques with residents and local agents. This blend of rigorous data analysis with on-the-ground validation and participatory co-design ensures that intervention plans are both technically robust and locally relevant and accepted.

The project's demand-aggregation model positioned municipalities as active facilitators: once a priority cluster was confirmed, the city bundled the required deep-retrofit measures—spanning façade insulation, lift installation, and heating system upgrades—into a unified programme and executed simultaneous outreach campaigns to all property owners within the defined district. While the general approach of municipal facilitation and bundled measures is clear, specific operational details of outreach, such as "simultaneous outreach campaigns" or "neighbourhood-wide public assemblies rather than dispersed one-to-one visits" and the explicit harnessing of "peer effects," are

[39] Ministerio de Transportes, Movilidad y Agenda Urbana. (n.d.). *Guía para estrategias locales de rehabilitación urbana en el marco de la Agenda Urbana Española*. Dirección General de Agenda Urbana y Arquitectura, accessible at the link https://agree-basquecountry.eu/en/documentos/page/2/

[40] Rubio del Val, J., & Molina Costa, P. (2010). Estrategias, retos y oportunidades en la rehabilitación de los polígonos de vivienda construidos en España entre 1940 y 1980. Ciudades, (13), 15–37. Instituto Universitario de Urbanística, Universidad de Valladolid. ISBN 978-84-8448-559-9.

[41] del Valle Ramos, C., Egea Jiménez, C., & Nieto Calmaestra, J. A. (2020). *Processi di rinnovamento urbano come mitigatori di svantaggio e vulnerabilità: analisi nella città di Siviglia*. *Bollettino dell'Associazione dei geografi spagnoli*, (87). https://doi.org/10.21138/bage.2981

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not extensively detailed in the primary AGREE documentation provided. does refer to designing "Action Plans to promote community organization and articulate the information, communication, and participation of different agents".

**Key contributions**: AGREE established a replicable GIS-MCDA methodology with explicit selection criteria, empowering public authorities to proactively build renovation pipelines in coherent, high-need clusters rather than passively react to individual requests. This shift from reactive to proactive planning represents a fundamental advancement in urban management, enabling strategic resource allocation and long-term programming for systemic urban regeneration. It underscored the value of integrating technical and social filters, ensuring that clusters were prioritized not only for poor energy ratings but also for heightened social vulnerability (e.g., low-income households, elderly residents lacking elevator access). This dual focus firmly positions AGREE within a framework of energy justice and equitable urban development. The project's public-sector endorsement guaranteed a minimum aggregate project scale, unlocking economies of scale in procurement and enabling targeted subsidy alignment to bolster those clusters. Public sector leadership is instrumental in achieving the necessary scale for impactful interventions and for effectively coordinating financial support mechanisms.

### 2.3.1 Comparative Insights for Barrio: ARCAS vs. AGREE

In integrating these lessons, Barrio aims to combine the strengths of both approaches – leveraging technical drivers (like renewable energy and innovative business models) and social/spatial drivers (like vulnerability mapping and public planning) to aggregate renovations. The comparative overview below (Table 2) highlights the key methodological inputs from each initiative and illustrates how Barrio strategically synthesizes them into a unified, place-based and policy-aligned approach.

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| Factor | ARCAS SUDOE – Collective Energy Model | AGREE – Spatial Planning Model | Implications for Barrio |
|---|---|---|---|
| Aggregation Trigger | Joint renovation + collective PV ownership (energy community benefits motivate participation) | Clustering based on building needs & social vulnerability (data-driven priority areas) | Dual model: Barrio envisages a strong involvement of local authorities (to use city data, authority and outreach capacity). This involvement allows addressing both governance of owner groups and large-scale urban planning. |
| Coordination Actor | Facilitator organization for collective decisions (guides homeowner groups and sets up energy co-ops) | Municipality-driven planning and outreach (city coordinates projects in priority areas and engages owners) | Dual model: Barrio will employ a technical facilitation team (to assist building groups with decisions and energy innovations) plus strong municipal involvement (to use city data, authority and outreach capacity). This combo addresses both governance of owner groups and large-scale urban planning. |
| Main Barrier Addressed | Fragmented decision-making in multi-owner buildings; lack of financial viability for single-building projects. Also, difficulty financing renewables in small sites. | Fragmented demand and scattered interventions; lack of focus on worst-performing or vulnerable areas (inefficient allocation of resources). | Holistic barrier mitigation: Barrio's "Defragmentation Multidisciplinary Toolkit (DMT)" must tackle both governance complexity (helping organize building owners and financing, as in ARCAS) and planning gaps (helping cities target and bundle projects, as in AGREE). The approach will bridge both |

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| | | | |
|---|---|---|---|
| | | | the bottom-up and top-down challenges. |
| Key Tools | Legal & financial templates for joint PV investment; cooperative business models; energy monitoring to verify saving | GIS-based mapping of building stock and vulnerability; structured database to prioritize and track renovation area | Integrated toolkit: Barrio's digital platform will incorporate solutions for renewable energy integration and geo-referenced cluster management. This ensures both innovations are available in one package. |
| Scalability Strategy | Demonstrated replication in cities with similar housing typologies across the SUDOE region; relies on adapting the facilitator model to local cooperatives. | Provides a standardized planning method applicable to any city with data; relies on institutional capacity of municipalities to adopt the mapping approach | Upscaling in Barrio: Develop a standardized cluster-mapping and facilitation protocol that pilot cities prove out, which can then be transferred to other EU cities. Barrio will document a blueprint that tries to combine the ARCAS energy-community approach with AGREE's area-based planning so it can be used broadly. |

**Table 2.** How ARCAS SUDOE and AGREE inform Barrio's strategic choices in aggregation.

In conclusion, the EU's building renovation challenge demands not only political ambition but also novel methods of organizing action to overcome persistent fragmentation and vulnerability barriers. Strategies such as clustering buildings by shared characteristics and aggregating renovation demand have proven capable of fundamentally reshaping retrofit markets and driving up renovation rates. Learning from successful field models—including Opengela's community one-stop-shops in Bilbao, Vienna's policy-supported Smart Renovation Hub, and Wallonia's pooled procurement via the RenoWatt programme—demonstrates how municipal convening power can concentrate technical support, streamline administrative processes, and mobilize property owners at scale. By integrating

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proven innovations—ARCAS's collective photovoltaic self-consumption schemes and AGREE GIS-driven, socio-economic cluster identification—the Barrio project is forging a multifaceted, bold strategy that merges technical ingenuity, social inclusivity, and digital intelligence to defragment the entire renovation value chain. This integrated approach—aligning economies of scale, risk-sharing, and enhanced governance—is poised to accelerate retrofit rates, maximize impact per project, and ensure Europe meets its climate neutrality targets while uplifting its most vulnerable citizens.

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# 3. The Barrio approach to characterization and cluster-based renovation

The Barrio methodology is the strategic backbone of the project, enabling a shift from fragmented building retrofits to coordinated, district-level renovation strategies that are inclusive, scalable, and data-driven. It provides a structured, replicable approach for identifying priority intervention areas by integrating advanced digital diagnostics, spatial mapping, and stakeholder intelligence. At the heart of this approach are powerful data tools that transform complex spatial and performance information into actionable renovation pathways—supporting evidence-based decisions, scenario analysis, and community engagement.

Anchored in technical precision, territorial sensitivity, and digital innovation, the Barrio methodology unfolds through a robust three-step process that supports both planning and implementation. The overview of this three-step process is presented below.

### Step 1 | Comprehensive Review of Indicators for Demand Characterization

The first phase consists of a comprehensive and structured review of indicators relevant to understanding the renovation demand across various dimensions.

Rather than focusing exclusively on energy performance, this diagnostic framework acknowledges the complexity of the built environment and the multiple vulnerabilities—buildings, urban, socioeconomic —that must be addressed to enable aggregated renovation strategies.

This diagnostic framework is designed to be both exhaustive and adaptable, drawing on the best practices from existing EU-funded projects and national initiatives (e.g., AGREE, ARCAS SUDOE, DGNB District, VEUS).

All variables have been organized under three thematic categories:

- **Buildings**: includes physical and operational characteristics of buildings such as year of construction, energy labels, accessibility features, HVAC systems, and retrofit history.

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- **Urban and Environmental Context**: captures neighbourhood-scale factors such as seismic or flood risk, mobility infrastructure, and exposure to urban heat islands.
- **Socioeconomic and Demographic Conditions**: encompasses data on income levels, unemployment, age distribution, education, homeownership, and indices of deprivation or energy poverty.

This classification allows for a shared analytical foundation across Barrio pilots. It facilitates a **common baseline** while giving each pilot the flexibility to incorporate locally relevant indicators in these proposed categories.

For each indicator category, the review captures (Table 3):

- **Relevance**: Why the indicator is essential to Barrio's objectives (e.g., targeting energy poverty, improving indoor comfort, enabling energy communities).
- **Use in Prior Methodologies**: References to past projects that successfully employed the indicator.

This step forms the conceptual and analytical foundation for Barrio's clustering engine. By unifying diverse data layers under a common interpretive framework, it ensures that the methodology is replicable, scalable, and policy-aligned.

This diagnostic foundation sets the stage for **Step 2**, where each pilot tailors and validates these indicators based on contextual needs, data conditions, and stakeholder input.

Additionally, the complete list of the indicators is reported in **ANNEX I.**

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| TOPIC | CATEGORY | RELEVANCE | USE IN PRIOR METHODOLOGIES |
|---|---|---|---|
| | | Why is it important for Barrio? | Is it used in other Project/paper for clustering or similar? |
| **Buildings** | B1.1 Energy performance | | |
| | B.2 Accessibility to the buildings | | |
| **Urban And Environmental Context:** | S.1 Vulnerability to heat waves | | |
| **Socioeconomic And Demographic Conditions** | .... | | |

**Table 3.** Structure to describe the outcome of the first methodological step

### Step 2 | Pilot-Specific Indicator Selection and Operationalization

Once the master list of indicators is established, the next step involves tailoring the framework to each pilot territory. This step ensures that the methodology is not only conceptually robust but also grounded in local feasibility and ready for implementation. Each pilot is responsible for assessing which indicators are relevant to its specific context. Key questions addressed (Table 4) include:

- **Pilot country** (Yes/No): Is the indicator relevant to the specific goals, needs and challenges of the pilot?
- **Source - Data sources and availability**[42]: Is the corresponding data available, machine readable, reliable, and up-to-date? This includes identifying accessible data repositories (e.g. municipal cadastre, EPC registries, census data, local mobility or environmental plans).
- **Measurement**: How should the indicator be operationalized for use in cluster analysis? This includes defining the data type (e.g. binary, categorical, continuous), value ranges or classes relevant for clustering, and, if applicable, thresholds or breakpoints used.

[42] availability refers not only to the existence or visualisation of data through interfaces, but also to its actual usability—i.e. whether the data can be downloaded, processed, and integrated into the clustering analysis in a technical way.

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| TOPIC | CATEGORY | RELEVANCE | USE IN PRIOR METHODOLOGIES | PILOT COUNTRY | DATABASE | MEASUREMENT |
|---|---|---|---|---|---|---|
| **Buildings** | B1.1 Energy performance | | | *Yes/No* | *Example: municipal cadastre* | *Example EPC label: G* |
| | B.2 Accessibility to the buildings | | | | | |
| **Urban And Environmenta l Context:** | S.1 Vulnerability to heat waves | | | | | |
| **Socioeconom ic And Demographic Conditions** | .... | | | | | |

**Table 4.** Structure to describe the outcome of the second methodological step

For instance, in the case of the construction period:

- **Topic**: Buildings
- **Category**: Year of Construction
- **Source**: Municipal cadastre
- **Range Definition**: <1940; 1941–1960; 1961–1980; 1981–2007

A key conceptual distinction guides this process:

- An **indicator** represents a general data concept (e.g. *accessibility*, *energy performance*, *ownership*).
- When that indicator is contextualised through a local data source, defined structure, and measurement, it becomes usable **information** (e.g. *presence of elevator: yes/no*, or *EPC label: A–G*).

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Table 5 provides illustrative examples of how the same indicator (data) can be translated into different information.

| INDICATOR (DATA) | INFORMATION LAYER 1 | INFORMATION LAYER 2 |
|---|---|---|
| **Energy performance** | Buildings with EPC rating **D or lower** | Buildings with **available EPC** |
| **Accessibility** | Buildings **without elevator** | Buildings with **no step-free access at main entrance** |
| **Employment rate** | Areas with **>20% unemployment** | Areas in **lowest quintile of employment** |
| **Flood risk** | Buildings located in **100-year flood zones** | Areas classified as **high-risk in municipal hazard plans** |
| **Income level** | Households in **bottom 20% income bracket** | Areas where **median income < regional average by ≥30%** |
| **Ownership** | Buildings in **municipal ownership** | Buildings with **>3 owners** |

**Table 5.** From data to information: illustrative examples.

This process allows not only filtering indicators by local feasibility but also effectively translating qualitative insights into structured, geo-referenced datasets ready for integration into spatial analysis and clustering. By doing so, the methodology bridges the gap between urban intelligence and operational planning, ensuring that all data is aligned with local strategies such as Sustainable Energy and Climate Action Plan- SECAPs, General Urban Plans-GUPs, and regional housing policies. With indicators now operationalized and validated at the local level, Step 3 focuses on spatializing this information into a multidimensional matrix to define actionable renovation clusters.

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### Step 3 | Development of the Multidimensional Needs Matrix and Cluster Definition

The final phase centers on the creation of a **multidimensional needs matrix**, which acts as the core analytical tool for spatial clustering.

It focuses on how the operationalised indicators are **transformed into spatial data layers**, and how these layers are combined to define renovation clusters.

This matrix enables the integration of building, urban, and socioeconomic dimensions to identify priority renovation clusters. The development of the multidimensional needs matrix, as well as the characterization of the demand for each pilot country, will be described in the following report D2.4.

When spatialised, each operationalised indicator becomes a **georeferenced layer**—a mappable unit of information that can be queried, analysed, and integrated with others. This structure follows the logic of **Geographic Information Systems (GIS)**: each category is represented as an independent spatial layer. Depending on the data resolution, these layers can operate at different territorial scales (parcel, building, block, neighbourhood, district).

Once structured and spatialised, the indicator-based layers form the foundation for a wide range of analytical operations. Each layer can be analysed on its own or in combination with others, depending on the objectives of the user. Typical uses may include:

- **Exploring overlaps or interactions** between different types of needs (e.g. social and structural).
- **Performing spatial comparisons** between areas or across time.
- **Generating composite indicators** or scoring systems by assigning relative weights to different layers, according to local priorities. (e.g. 40% weight to energy indicators, 30% to social, 30% to environmental)

The result of this process is a set of georeferenced layers that reflect spatialised renovation needs. When multiple layers are logically combined—according to defined rules—they form the basis for **renovation clusters**. These are not predefined zones, but **emergent groupings** of buildings or areas with overlapping needs and intervention potential, supported by quantitative rules:

- Minimum number of buildings or dwellings
- Geographic contiguity or proximity thresholds

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For example:

- **Cluster A**: Pre-1940 buildings, energy label D–G, no elevator, located in a flood risk zone, >50% elderly population.
- **Cluster B**: 1960s-1970s cooperative housing with flat roofs, high PV potential, and active community participation.

This is where the **aggregation of demand** begins to materialise: clusters are not predefined but emerge from the logical combination of needs-based layers, creating coherent intervention units. Importantly, clusters do not need to correspond to strictly contiguous areas: similar buildings facing comparable vulnerabilities may be geographically dispersed, yet still form part of the same intervention logic if addressed through coordinated planning and joint procurement.

| | Topic | Buildings | | | | | | | | | | | | | | | | | Surroundings | | | | Socioeconomic factors | | | | ... |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Characterisation | Category | B.1. Energy performance | | | | | | | | B.2. Construction year | | | | B.4. Typology | | B.3. Accessibility | | | | | | | | | | | |
| | Measurement | A | B | C | D | E | F | G | H | <1940 | 1941-1960 | 1961-1980 | 1981-2007 | Multi-family | Single-family | ... | ... | ... | | | | | | | | | |
| Clustering | Cluster 1 | | | | x | x | x | x | x | x | x | | | x | | | | | | | | | | | | | |
| | Cluster 2 | | | | x | x | x | x | x | x | | | | | x | | | | | | | | | | | | |
| | Cluster 3 | | | | | | x | x | x | x | | | | x | x | | | | | | | | | | | | |
| | Cluster 4 | | | | | | | x | x | x | | | | x | | | | | | | | | | | | | |
| | Cluster 5 | | | | | | | x | x | | | | x | x | x | | | | | | | | | | | | |

**Figure 6.** Preliminary structure to describe the outcome of the third methodological step. The figure will be updated in the next project report when the project will be completed.

# 4. From Diagnosis to Action: A Framework of Indicators for Local Adaptation

This section focuses primarily on **Step 1** of the methodology, which forms the analytical core of this deliverable. It presents the full indicator set and its methodological foundations, drawing from leading European practices and reference models.

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An introduction to **Step 2** is also provided, outlining the process by which each pilot will contextualize and validate the indicator framework. The detailed implementation and outcomes of Step 2 will be developed in the next project report, together with the applications of Step 3 in the pilot sites.

## 4.1 Key Clustering Indicators for Barrio - Focus on Step 1

This section presents a comprehensive and methodologically robust diagnostic framework that underpins the Barrio clustering engine. Developed as a foundational tool to guide large-scale, aggregated renovation strategies, particularly in vulnerable urban contexts, the framework synthesizes advanced practices drawn from leading European and regional initiatives. These include Horizon 2020 projects such as AGREE and ARCAS SUDOE, the DGNB Urban District certification methodology, and the territorial segmentation models developed in the Basque Country. The complete list of the indicators is reported in **ANNEX I.**

Barrio's approach moves beyond conventional building analysis by integrating three interdependent diagnostic dimensions: (i) building (ii) urban, environmental, and (iii) socio-demographic contexts. This integrated lens ensures that clustering processes are informed not only by architectural and technical factors, but also by spatial vulnerabilities and social needs—thereby fostering a just, effective, and replicable renovation model.

The **first analytical dimension** defines the **intrinsic and operational features of the building stock.** Indicators such as construction year, usage category, typological classification, number of storeys, and historical renovation records provide insight into the structural logic and chronological evolution of buildings. These parameters reflect long-standing construction practices and design paradigms that inform thermal behavior, structural constraints, and potential for standardization.

Leveraging the TABULA/EPISCOPE typological framework—one of the pan-European reference systems for classifying residential buildings—BARRIO categorises the built environment into coherent archetypes. This structured typology enables the identification of renovation patterns that lend

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themselves to modular and prefabricated solutions, improving efficiency and facilitating economies of scale across diverse building clusters.

Complementing these physical descriptors are indicators related to energy performance and technical system configuration. These include the condition of the building envelope, the type and efficiency of heating and cooling systems, and the official Energy Performance Certificate (EPC) classifications. These indicators are critical for assessing both the urgency and the feasibility of energy upgrades. Barrio builds on these references to guide the technical clustering of buildings with similar renovation depth and decarbonization potential.

The **second dimension** situates the building stock within its broader territorial and environmental framework. Indicators in this category include urban density, proximity to public services and transport infrastructure, planning constraints (e.g., heritage designations, zoning restrictions), exposure to natural hazards (e.g., seismic or flood risk), and climate.

These contextual parameters determine the operational feasibility and resilience of renovation strategies. For instance, buildings in compact urban areas may benefit from shared infrastructure solutions, while those in climate-sensitive zones require adaptive technologies. This spatial intelligence ensures that clusters are not only technically coherent but also contextually implementable, and aligns with urban adaptation priorities observed in the Basque Country (País Vasco; CAPV is the acronym in Spanish) CAPV model and DGNB district-level planning.

The **third and final diagnostic dimension** introduces an essential equity lens by incorporating socioeconomic and demographic indicators. These include ownership tenure, household income, age distribution, unemployment rates, educational attainment, and composite indices of energy poverty. These variables map the social landscape of the building stock, identifying contexts where renovation needs intersect with financial fragility or social exclusion.

Barrio's approach is influenced by the methodologies of projects which have demonstrated the value of targeting energy interventions based on vulnerability mapping. By identifying areas where residents are least equipped to undertake renovations independently, the framework enables targeted public

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support and incentivization strategies, reinforcing the social justice goals embedded within the EU Renovation Wave and European Green Deal.

Each indicator is defined with reference to its strategic purpose, methodological provenance, data source, spatial resolution, and measurement scale. Data inputs range from cadastral databases and EPC registries to national census data and municipal spatial plans.

Classification schemes can be binary, categorical (such as building types), or continuous (such as income levels or energy use), depending on what the clustering analysis requires.

This structured approach allows the framework to be simultaneously robust and adaptable. It supports dynamic clustering processes that are sensitive to changes in data availability, policy targets, and local implementation conditions. Clusters can thus evolve over time, reflecting new priorities or emerging vulnerabilities, without undermining the methodological integrity of the process.

Far from being a purely technical apparatus, the Barrio clustering framework operates as a high-level decision-support system. It provides a foundation for diverse operational processes, including the design of retrofit packages, stakeholder coordination, investment planning, and regulatory compliance monitoring. By revealing patterns of renovation potential and social need across a territory, it enables public and private actors to align resources and strategies with maximum efficiency.

Strategically, the methodology is fully compatible with the European Green Deal, the Renovation Wave strategy, and National Building Renovation Plans(LTRS). Its equity-oriented focus reflects the EU's just transition agenda, while its modular and interoperable architecture allows integration with digital tools such as Building Renovation Passports, Digital Twins, and GIS-based energy planning platforms.

The transparent, modular structure of the framework makes it readily transferable to regions and cities beyond Barrio's pilot sites. Indicator definitions, measurement methods, and data linkages can be adapted to national contexts while maintaining consistency with EU-level standards. Moreover, the

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framework enables multi-scalar integration, allowing renovation initiatives to scale from building level to district or metropolitan scale while maintaining analytical cohesion.

Barrio's indicator framework exemplifies how data-driven analysis can be harnessed to unlock the full potential of renovation as a catalyst for sustainable and inclusive urban transformation. It provides the analytical scaffolding to understand where renovation is most needed, where it is most viable, and where it will deliver the greatest benefits for people and the environment.As such, it is a cornerstone of the project's overarching ambition: to turn vulnerability into opportunity and to reshape Europe's building stock into a foundation for climate resilience, energy justice, and shared prosperity.

## 4.2 Insights on the Pilot-Specific Indicator Selection

Building on the master indicator framework defined in *Step 1* and available in **ANNEX I**, this second step focuses on adapting the clustering methodology to the unique realities of each pilot territory. The goal is to ensure that the selection and use of indicators are not only methodologically sound, but also grounded in local renovation needs, data availability , and stakeholder dynamics.

As described in Section 3, each pilot follows a structured and iterative process - by co-design with local stakeholders - to evaluate the **strategic relevance** of each indicator, assess the **availability and quality of data**, and define the most appropriate **measurement approach** for clustering analysis. This process is designed to maintain consistency with the overarching framework while allowing flexibility to reflect the **specific characteristics and priorities** of each local context.

A critical feature of **Step 2**, anticipated in chapter three, is the incorporation of **context-specific indicators**. While the core indicator set -described in Step 1- offers comparability across pilots, each partner may integrate additional variables that capture local challenges or opportunities—such as particular climatic vulnerabilities, administrative structures, or socio-economic patterns. These bespoke additions enhance the precision and local relevance of the cluster models without compromising methodological alignment at the project level. Additionally, each pilot partner acts not only as a user but also as a **co-developer** of the clustering methodology. By tailoring and

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validating the indicators, pilots contribute to refining a shared yet adaptable framework that can be scaled across diverse European regions. The outcomes of Step 2 implementation will be described in the public report *D2.4 Report on the aggregation needs matrix*. Importantly, the technical assessment is reinforced through an **inclusive validation process** involving the **D-LABs**, Barrio's participatory co-design environments. Here, preliminary indicator selections, which are based on literature research and knowledge exchange within the Consortium Partners, are reviewed and discussed with key local stakeholders—such as policy makers, property owners, aggregators, residents, and community leaders—who provide practical insights into feasibility, data interpretation, and strategic priorities. This participatory mechanism not only strengthens the credibility and quality of the clustering process, but also fosters early buy-in for implementation.

Finally, beyond the localized cluster definitions, Step 2 contributes to a broader project goal: the formulation of a **shared common cluster typology** applicable across all pilot sites. In line with the strategic objectives of the EPBD and relevant Annexes programme, this common typology places particular focus on identifying **worst-performing buildings** and **areas affected by energy poverty**, thus supporting targeted renovation efforts where they are most needed.

# Conclusions

The Barrio clustering methodology, which has been presented in this report, offers a comprehensive and forward-looking approach to overcoming the structural and operational fragmentation that continues to impede large-scale renovation efforts across Europe. By integrating multidimensional diagnostics, shared decision-making with local communities through D-LABs and S-Clusters, and scalable digital tools, it enables the transition from isolated building retrofits to coordinated, high-impact district-level renovation strategies.

Grounded in the priorities of the revised Energy Performance of Buildings Directive (EPBD), and supportive of the European Green Deal, Barrio serves as a replicable model that places energy efficiency, equity, and innovation at the heart of urban transformation. Its clustering methodology is not only methodologically robust, but also inherently inclusive—empowering municipalities, citizens, and supply-side actors to co-create renovation pathways that respond to both technical needs and socio-economic vulnerabilities.

With the analytical foundation now established, Barrio moves into its implementation phase, where the Defragmentation Multidisciplinary Toolkit (DMT) and Aggregated Prefabricated Plans (APPs) will be deployed and validated across diverse pilot territories. These forthcoming activities will demonstrate the real-world applicability of the methodology and provide critical insights for policy replication and market uptake.

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# Annex I

| Building Indicator | Why it matters for Barrio | Use | Measurement |
| --- | --- | --- | --- |
| **B.1 Building Age** | Construction age is a strong proxy for energy performance, retrofit potential, and vulnerability. Older buildings (especially pre-1960s) typically lack insulation, have outdated systems, and house socioeconomically fragile populations—making them ideal targets for early intervention and support. | Widely adopted in EU clustering methodologies (e.g., TABULA, AGREE) to identify renovation archetypes. | Typically grouped into periods (e.g., pre-1945, 1945–1970), aligned with building code changes. |

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| **B.2 Building Use** | Building function influences occupancy patterns, technical systems, and energy demands. Differentiating between residential and non-residential stock ensures tailored renovation strategies and more effective clustering. | Common in energy planning to separate typologies; residential buildings are prioritized in Barrio's pilots. | Categorical (e.g., residential, public, commercial), often from cadastre or zoning databases. |
| **B.3 Building Typology** | Typologies combine characteristics such as age, form, and construction systems, enabling standardized renovation packages across clusters. This supports prefabricated solutions and economies of scale. | Employed in AGREE, TABULA, and to define target renovation groups. | Composite classification (e.g., "post-war 5-story multifamily"), based on cadastre, surveys, and typology libraries. |

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| **B.4 Number of Floors** | Strongly linked to accessibility and retrofit complexity. Buildings with more than three floors, especially without elevators, are critical targets due to aging populations and mobility barriers. | Used in AGREE to spot apartment buildings without elevators that need both energy improvements and better accessibility. | Count of above-ground floors; categorized into low-rise (1–2), mid-rise (3–5), and high-rise (6+). ≥4 floors is a key threshold for prioritizing elevator installation. |
| **B.5 Useful Floor Area** | Indicates the scale of intervention and energy demand. Larger floor areas often imply higher renovation costs but also greater energy-saving potential. | Essential for estimating investment needs and calculating energy intensity (kWh/m²), supporting cost-benefit assessments. | Total usable m² from cadastre or permits; used directly or categorized by size (small/medium/large buildings). |
| **B.6 Number of Dwellings per Building** | Reflects building governance and renovation complexity. More dwellings typically mean shared decision-making, affecting feasibility of group renovations. | Helps distinguish single-family homes from collective housing—core to Barrio's focus on aggregated interventions. | Integer value or ranges (e.g., 1, 2–4, 5+ units). High-density buildings are more suitable for coordinated retrofitting. |

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| **B.7 Habitable Area per Person** | Proxy for overcrowding and social vulnerability. Low space per occupant signals poor living conditions, often aligning with energy poverty. | Used in diagnostic tools to identify at-risk households where renovation also improves health and comfort. | $m^2$/person, typically calculated as total dwelling area divided by registered residents. Thresholds (e.g., <15 $m^2$/person) identify critical cases. |
| **B.8 Average People per Dwelling** | Helps identify household types—important for tailoring renovation messaging and interventions (e.g., elderly vs. families). | Complements B.7 to detect underused or overcrowded housing. Relevant for social targeting and behavior-sensitive clustering. | Residents per unit (e.g., 1–2 = low, 3–4 = average, 5+ = large households). Informs cluster profiles and vulnerability scoring. |
| **B.9 Number of Rented Dwellings** | High rental rates suggest governance challenges and split incentives between landlords and tenants, requiring tailored engagement and policy tools. | Used to flag areas where renovation uptake may be hampered by tenure structures. Supports design of tenant protections and landlord incentives. | % of units rented; can be binary (owner-dominated vs rental-dominated) or continuous. Derived from property or census data. |

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| **B.10 Number of Empty Dwellings** | High vacancy signals urban decline but also renovation opportunity with fewer disruption risks. Empty units may also indicate "parked" capital, where properties are held as safe investments rather than for active use, further underlining the need for targeted regeneration | Helps prioritize under-occupied areas for regeneration and test innovative solutions with lower social friction. | % of vacant units, based on registry or census. Buildings with low occupancy may be targeted for pilot retrofits or repurposing. |
| **B.11 Cadastral Value** | Economic proxy for neighborhood wealth. Low values often correlate with degraded building stock and limited private renovation capacity. | Used to identify priority areas for public support and subsidy targeting. Key for equitable renovation planning. | Value per property or m²; normalized or categorized (low/medium/high). Enables socio-economic profiling of clusters. |

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| **B.12 Rent Value** | Rent levels reflect housing affordability and market conditions. Low-rent zones often overlap with older, under-maintained buildings and vulnerable populations—priority targets for Barrio's equitable renovation strategies. | Used to flag areas with low rental value and potential for gentrification risks. Helps identify neighborhoods needing subsidy-backed renovation. | €/month or €/m², often from local observatories or aggregated listings. Can be used as continuous data or grouped (e.g., below/above city average). |
| **B.13 Building State of Conservation** | Directly linked to rehabilitation urgency. Poor conservation signals physical vulnerability, affecting both safety and habitability. | Integrated into prioritization schemes to identify dilapidated housing requiring urgent renovation. Central to Basque and VEUS methodologies. | Categorical (e.g., Good/Average/Poor). When missing, building age or lack of past renovations may act as a proxy. |

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| **B.14 Designation for Renovation** | Captures existing institutional priorities. Buildings already marked for intervention can be clustered to align or contrast with current plans. | Used to reinforce clusters already under public regeneration programs, or to highlight overlooked zones. | Binary (designated or not), often derived from municipal maps or planning tools. |
| **B.15 Fire Safety Retrofit Needed** | Key for integrated renovation: absence of fire safety features raises life-risk, especially in older mid-rise buildings. | Supports safety-inclusive clustering; identifies areas requiring concurrent energy and safety upgrades. | Yes/No flag based on code compliance. Proxies include building age and height; ideally from inspection data. |
| **B.16 Urgent Structural Interventions Needed** | Signals critical risk. Buildings flagged for urgent repairs must be prioritized to prevent collapse or evacuation. | Acts as a 'knock-out' variable—top-priority clusters often revolve around these cases. | Binary, based on technical inspections or official declarations (e.g., buildings marked as unsafe or at risk of collapse). |
| **B.17 Elevator Presence** | Essential for aging populations. Absence of lifts in 4+ story buildings creates accessibility challenges. | Used in Barrio and AGREE to define 'walk-up' clusters needing vertical access retrofitting. | Yes/No or proxy based on height and construction period. Some cadastres include elevator data explicitly. |

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| **B.18 Entrance Accessibility (Barrier-Free Entry)** | Reflects inclusivity and universal design. Step-free entry is vital for elderly and disabled residents. | Supports accessibility audits and neighborhood-wide ramp retrofits. Important for social sustainability. | Binary (compliant/not). Audits or visual surveys required; often inferred from typology or year built. |
| **B.19 Construction System / Envelope Type** | Influences thermal performance and seismic resilience. Material and form guide suitable retrofit techniques. | Used to group buildings with similar renovation needs (e.g., solid brick walls needing insulation). | Categorical (e.g., masonry, concrete). Often simplified via typology libraries like TABULA. |
| **B.20 Insulation Type/Presence** | Directly affects energy performance. Lack of insulation is a key retrofit target and energy poverty driver. | Used in EPC-based vulnerability mapping to identify thermally deficient clusters. | Binary or detailed (internal, external, cavity fill). Derived from EPCs or inferred from year built. |
| **B.21 Final Energy Consumption** | Measures actual energy use and helps identify inefficient, high-consumption buildings—critical for decarbonization. | Core variable in clustering buildings by performance level. Used in EPCs and GIS mapping. | kWh/m²/year, often from EPCs. Used as continuous or banded variables in analysis. |

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| **B.22 Final Energy Demand** | Shows theoretical heating/cooling needs under standard use—key to diagnosing hidden energy poverty. | Clusters buildings by intrinsic efficiency, regardless of user behavior. Highlights thermal weakness. | kWh/m²/year, modeled from EPCs or simulations. Used alongside consumption to detect under-heating. |
| **B.23 Energy Label (Certification)** | A compact, interpretable indicator of building energy performance. Easy to communicate and benchmark. | Used in most clustering frameworks to rank or qualify buildings for renovation. | Ordinal scale (A to G). Mapped directly from EPCs; often transformed to numeric scores or thresholds. |
| **B.24 Building Envelope Efficiency** | Differentiates envelope-driven inefficiency from system-related issues. Critical to targeting insulation/window retrofits. | Applied in high-resolution cluster analysis, often using composite or derived indicators. | Composite metrics (U-values, W/m²K, etc.) or categorical classes based on code compliance or EPCs. |
| **B.25 Energy Cost** | Translates energy use into financial burden, linking performance to affordability—vital for addressing energy poverty. | Combined with income data to highlight vulnerable populations; used in Energy Vulnerability Index approaches. | €/year or €/m²/year, derived from consumption and tariff. May be expressed as % of household income. |

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| **B.26 Heating Systems** | Heating systems determine comfort, energy use, and carbon impact. Their type and efficiency are critical for targeting energy upgrades and reducing emissions. | Used to group buildings by system type and identify areas needing modernization or electrification. | Categorical (e.g., gas boiler, district heating, electric). May be binary (has an efficient system or not). |
| **B.27 Cooling Systems** | Cooling presence reflects both energy needs and climate vulnerability. Lack of AC suggests heat risk and low resilience. | Included in clustering to differentiate high-comfort vs. overheating-risk buildings. Key in heat adaptation. | Binary or categorical (e.g., none, split unit, central HVAC). |
| **B.28 DHW Systems** | Hot water systems influence energy use and retrofit potential. Electric DHW increases operational costs, while solar DHW reduces them. | Used to identify areas for DHW upgrades or solar integration opportunities. | Categorical (e.g., electric, gas, solar thermal). May be grouped by efficiency or renewable integration. |

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| **B.29 Gas Pipeline Connection** | Indicates energy infrastructure. Buildings off-grid face higher energy costs and may require alternative retrofit paths. | Clusters buildings with or without gas access to tailor renovation approaches (e.g., electrification, district heating). | Binary (connected or not). |
| **B.30 Households without Adequate Comfort** | Captures energy poverty and lives discomfort. Essential for socially just renovation strategies. | Used to locate areas with high discomfort levels and prioritize them for integrated renovation. | % of households unable to maintain comfort (from surveys or proxies). |
| **B.31 Dwellings without WC (or Bath)** | A strong indicator of extreme housing deprivation. Directly tied to health, dignity, and urgent habitability improvements. | Flags the most deprived clusters for immediate basic infrastructure upgrades. | Binary or % of homes lacking indoor sanitation. |
| **B.32 Buildings without a Garage** | Garage absence reflects older building design and may relate to property value and mobility patterns. | Supports broader quality-of-life assessments or retrofit potential for ground-floor repurposing. | Binary (garage present or not). |

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| **B.33 Mechanical Ventilation Availability** | Influences indoor air quality and heat resilience. Lack of ventilation contributes to discomfort and health risks. | Used to highlight poorly ventilated buildings, relevant for summer adaptation and post-COVID design. | Binary (Y/N) or based on floor plan characteristics. |
| **B.34 Natural Lighting Adequacy** | Affects well-being, energy use (lighting), and building habitability. Poor lighting is common in substandard housing. | Helps identify poorly designed or overcrowded buildings requiring interior upgrades. | % of rooms with daylight access or binary adequacy per dwelling. |
| **B.35 Façade Recently Retrofitted** | Indicates previous investment. Helps avoid redundancy and understand renovation readiness. | Differentiates fully degraded clusters from those with partial improvements. Guides strategic targeting. | Binary (yes/no within the last 10 years) and / or year of facade renovation |

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| **B.36 Scale of the stability of the structure** | Indicates technical priorities and legal and safety compliance. Buildings that fail inspection pose safety risks and must be prioritized. | Applied in post-disaster reconstruction programmes (e.g. JICA–Central Java, 2006 earthquake) where structural stability inspections determined eligibility for reconstruction funding. The indicator was used as a safety compliance filter, ensuring that only buildings passing minimum stability thresholds could continue construction. Similar approaches are adopted in EU seismic risk assessments and urban regeneration schemes | Ordinal – expressed on a graded scale (e.g. safe / minor damage / major damage / unsafe), allowing prioritisation of buildings according to increasing levels of structural risk. |

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| **B.37 Scale of the type of building envelope** | Indicates recent investment in the building envelope, which affects thermal performance and prevents redundant work. While B.16/B.36 are about structural safety (life-critical, legal compliance). B.37 is about energy and functional performance of the *building envelope*. It's not about safety but about renovation sequencing and avoiding waste (don't redo façades that were recently refurbished). | Used to differentiate clusters that are fully degraded from those with partial improvements, helping to guide strategic targeting. | Binary (yes/no within the last 10 years). |

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| **B.38 Occupant Satisfaction (Humidity, Ventilation)- IEQ Perception** | Captures broader aspects of indoor environmental quality. The indoor quality influences investment prioritization and design of healthy upgrades. | Used to differentiate clusters that are fully uncomfortable from those with partial improvements, helping to guide strategic targeting. | % of household satisfaction (from surveys or proxies). |

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| **B.39 Availability of documentation/Digital Building Logbook (DBL) /facility management - FM compatibility** | Identifies clusters suitable for "data-rich" digital twin pilots. | Widely applied in digital twin and BIM-based renovation projects where the availability of building documentation determines the feasibility of data-rich modelling. For example: EU Horizon 2020 project BIM-SPEED used the completeness of existing documentation (architectural drawings, energy certificates, O&M data) as a precondition for selecting pilot buildings suitable for digital twin creation. | Binary (present/not present). |

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| | | In several national digital twin initiatives (e.g., UK National Digital Twin Programme), building clusters were prioritised based on the availability of legacy datasets and FM records, since missing documentation significantly increases modelling costs and complexity. | |
| **B.40 Availability of technical building inspection** | Captures useful information to obtain aids (e.g. for Spain). | Required as precondition for accessing public subsidies (e.g. energy-efficient retrofit funds) in Spain. The ITE—mandatory for buildings over 45–50 years—is used to verify structural safety and preservation as an eligibility filter. | Binary (yes/not). |

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| **B.41 Average Renovation Cost per Square Meter** | Provides benchmark for costs, assesses affordability. It also acknowledges past investments and helps recognize experience and readiness. | It is used to separate newly targeted areas from previously renovated zones. | Binary (included the date of the last intervention). |
| **B.42 Reserve of land/plots for social housing** | Aligns renovation interventions with areas where social housing may expand. Helps ensure coherence with future housing strategies. | Used to prioritize renovation clusters in proximity to future or planned social housing developments, enhancing long-term urban planning. | Mapped availability of reserved plots in local/regional plans. Binary or categorical (reserved / not reserved / planned). |
| **B.43 Photovoltaic potential** | Indicates potential for renewable energy production. Supports integration of energy communities and self-consumption schemes. | Supports the identification of buildings or districts suitable for PV installations under Barrio. | GIS layer with PV potential index (kWh/m2/year or similar), categorized into low/medium/high potential. |

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| **B.45 Installation recently retrofitted** | Shows previous investment in HVAC systems, which is crucial for assessing the need for upgrades. | It identifies buildings that have already made partial energy efficiency improvements, guiding the focus toward other necessary interventions. | Binary (yes/no within the last 10 years). |
| **B.46 Manager of the building** | Indicates the presence of a building manager simplifies governance and decision-making for group renovations. | It is used to identify buildings that are easier to engage and can serve as key contacts for project implementation. | Binary (present/not present). |

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| **B47 locations of transformer stations with capability to connect new production facilities eg. PV and electrical car charging stations.** | Transformer stations are the nodes that determine whether building clusters can integrate renewable energy generation (e.g. rooftop PV) and new loads (e.g. electric vehicle charging). Their capacity and proximity affect both the *technical feasibility* and *cost-effectiveness* of district-level renovation strategies. Clusters near well-dimensioned transformer stations can support prosumer models and local energy communities, while those in constrained areas may face grid bottlenecks that limit uptake of clean technologies. | Helps prioritise clusters where integrated renovation can go beyond building envelopes to include *energy system upgrades*. Supports planning of renewable integration, storage, and EV infrastructure | Expressed as categorical (e.g. *sufficient / limited / constrained capacity*) or continuous (kVA available). Data sourced from grid operators and municipal energy plans. |

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| Urban Indicator | Why it matters for BARRIO | Use | Measurement |
|---|---|---|---|
| **U.1 Delimited area in previous renovation interventions** | Leverages previous public or private investment and planning efforts. Reduces time and cost of new interventions. | Used to map synergy with past renovation actions for clustering or project continuity. | GIS shapefiles or maps of pre-designated intervention zones. Binary (inside/outside past renovation area). |
| **U.2 Vulnerable neighbourhood** | Facilitates social equity in renovation planning. Ensures support reaches those most in need. | Used to prioritize intervention in areas eligible for public support or suffering from energy poverty. | Index of vulnerability (composite or EPC-based) at the census tract or neighborhood scale. |
| **U.3 Seismic risk** | Identifies structural vulnerability that can act as a trigger for integrated renovation (energy + safety). | Supports clustering of buildings needing both structural and energy upgrades. | Seismic hazard zones classified by national standards (e.g., low/medium/high risk). |

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| **U.4 Flooding risk** | Highlights areas at high risk of flooding. Can drive resilient renovation approaches. | Used to assess whether adaptation/resilience measures should be included in building retrofits. | Categorical flood risk maps (1-in-100-year risk, 1-in-500-year risk, etc.). |
| **U.5 Heat waves vulnerability** | Identifies buildings or neighborhoods at greater risk of overheating, especially during climate events. | Used for prioritizing passive cooling strategies and health-related interventions. | Thermal comfort risk or urban heat island intensity maps (low/medium/high). |

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| **U.6 Access to public services** | Access to essential public services (healthcare, education, administrative services) is a key component of urban quality of life and social inclusion. Integrating this indicator helps identify areas where improving building conditions could be part of a broader regeneration effort. | To prioritize clusters where improved energy performance could also enhance access to critical community infrastructure, especially in underserved neighborhoods. | Proximity analysis in GIS (e.g., service within 500m or 10-minute walk). |

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| **U.7 Access to public open spaces** | Open spaces contribute to urban cooling, public health, and resident satisfaction. Clustering renovations in areas with limited green space can be paired with complementary greening strategies. | Used to assess liveability and identify co-benefits of renovation projects. | GIS-based coverage area analysis (e.g., access within 300m to parks). |
| **U.8 Access to public transportation** | Good transport links are essential for mobility, especially for vulnerable populations. They also support climate objectives by reducing reliance on private cars. | Supports clustering in transit-accessible zones, aligning renovation with sustainable mobility. | Distance to nearest bus/tram/metro stop; number of connections. |

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| **U.9 Mobility infrastructure** | Upgraded mobility infrastructure (e.g., walkable paths, cycling routes) enhances safety and access. Retrofitting in these areas supports cohesive district transformation. | To align renovation areas with mobility planning and improve overall connectivity. | Availability and condition of bike lanes, pedestrian paths (urban audit). |
| **U.10 Existing DH/DC** | District Heating or Cooling infrastructure can be leveraged for greater energy efficiency. Renovations can be synchronized with system upgrades or connections. | To identify zones with shared infrastructure that support group renovation strategies. | Mapped availability of DH/DC infrastructure (utility datasets). |

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| **U.11 Density of commercial services / Vacant business premises** | Helps assess the economic vitality and attractiveness of an area. Higher vacancy may indicate urban decline; lower density may reduce renovation incentives. | Useful for urban regeneration clustering; identifying commercial-residential synergies. | Percentage of vacant commercial premises in the area; local urban registries. |
| **U.12 Commuting time** | Influences urban quality of life and dependency on transportation. Long commutes may signal urban sprawl or lack of services. | Supports clustering of transport-dependent zones for renovation co-benefits (e.g., integrated mobility and energy upgrades). | Share of population commuting >30 minutes daily; census or mobility surveys. |
| **U.13 Urban perception: Complaints about poor communication** | Reveals subjective barriers to accessibility, potentially influencing renovation willingness. | Supports demand-side clustering based on perceived accessibility deficits. | Survey-based perception indicators; % of respondents indicating poor transport links. |

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| **U.14 Urban perception: Complaints about urban environment** | Identifies areas with poor perceived quality of life, potentially reducing housing value and interest in investment. | Targeting areas needing environmental and aesthetic improvements. | Survey responses on urban dissatisfaction; typically expressed in % of population. |
| **U.15 Urban perception: Complaints about pollution and measurements of air quality** | Perception of pollution correlates with environmental risks and discomfort. | Supports clustering of areas needing air quality improvement. | Surveyed % of residents dissatisfied with pollution levels; environmental perception indices. |
| **U.16 Urban perception: Complaints about poor cleanliness** | Impacts perceived livability and willingness to invest in area renewal. | Identifying areas where environmental quality interventions should complement renovation. | % of residents reporting cleanliness dissatisfaction; urban survey data. |

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| **U.17 Urban perception: Complaints about poor green areas** | Lack of green space affects thermal comfort, biodiversity, and mental health. | Targets renovation strategies that integrate urban greening and open space planning. | % of the population expressing dissatisfaction; urban quality reports or resident surveys. |
| **U.18 Urban perception: Complaints about vandalism** | High perceived insecurity may hinder stakeholder engagement in renovation. | Guide social and physical regeneration efforts for higher uptake. | % of residents reporting vandalism concerns; citizen security surveys. |
| **U.19 Infrastructure capacity (electricity grid)** | Determines feasibility of electrification, integration of heat pumps, and PV systems. | Clustering based on grid readiness; avoids overloading weak infrastructure. | Grid capacity maps; connection load data from DSOs or regional utilities. |

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| **U.20 Brownfield land** | Identifying brownfield land is important for prioritizing urban regeneration and infill development as part of renovation strategies, especially where land availability is constrained. | Used to cluster renovation efforts around areas with redevelopment potential and maximize spatial synergies. | Identified from land use databases or DGNB criteria; measured as areas marked for reuse or "degradated areas" rehabilitation. |
| **U.21 Existing policies/incentives** | Helps align BARRIO strategies with ongoing public programs and funding opportunities that can amplify project impact. | Used to target areas where support for prefabrication, energy efficiency, or social housing is already active. | Qualitative review of regulatory frameworks, funding ordinances, and program coverage. |

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| **U.22 Construction noise/dust sensitivity zones** | Important for planning non-invasive interventions, especially in areas with vulnerable populations or sensitive functions (e.g. hospitals, schools). | Used to prioritize prefabrication or low-disruption methods in sensitive areas. | Mapped from municipal noise plans or DGNB district criteria. |
| **U.23 Noise level** | High noise levels are linked to reduced comfort and health issues; retrofits can help mitigate acoustic discomfort alongside thermal benefits. | Used to guide façade and window upgrades to deliver dual energy-acoustic benefits. | Measured in decibels from city environmental noise maps. |
| **U.24 Areas of housing need** | Helps identify neighborhoods facing acute housing shortages, which can be addressed through renovation and repurposing. | Used to target interventions in line with social equity and housing provision goals. | Derived from ANHA or equivalent indices; interpreted as high-need zones for affordable or upgraded housing stock. |

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| **U25 Electric car charging points** | The availability of EV charging points is a key enabler for electrified mobility and for linking building renovation to broader decarbonisation goals. In cluster planning, the presence (or absence) of charging points signals both infrastructure readiness and community accessibility. Integrating charging into renovation packages can create synergies with PV generation, storage, and demand response, making clusters more attractive for investment and for participation in local energy | Supports the identification of clusters where renovation can be combined with sustainable mobility measures. Highlights gaps in charging coverage that could be addressed through CEP+ models, ensuring equity in access to EV infrastructure across neighbourhoods. | Mapping of public and semi-public charging stations (slow/fast) per area or per 1,000 inhabitants. Expressed as continuous (number of charging points) or categorical (low / medium / high coverage). Data from municipal mobility plans, energy agencies, or national EV charging registries. |

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| Social Indicator | Why it matters for Barrio | Use | Measurement |
|---|---|---|---|
| **S.1 Unemployment rate** | Serves as a proxy for social vulnerability and economic stress. High unemployment may correlate with higher risk of energy poverty and lower capacity to co-finance renovation. | To identify socially vulnerable areas and target subsidized renovation schemes or technical support. | Percentage of unemployed residents at census-tract or neighborhood level (e.g. >10%, >20%, etc.). |

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| **S.2 Income** | Directly affects ability to invest in energy renovation. Low-income areas may require higher levels of public support. | Used to prioritize low-income zones for targeted financial support and inclusion in area-based renovation programs. | Average or median income per household or individual, categorized in brackets (e.g. <€15,000, €15,000–25,000, >€25,000). |
| **S.3 Age of the population** | Helps identify areas with elderly residents who may require accessibility upgrades or have limited capacity to initiate renovations. | Supports targeting of clusters for age-friendly renovations (e.g., elevators, thermal comfort, remote monitoring). | Population percentage by age brackets (e.g. >65 years, <15 years). |
| **S.4 Density of population** | Determines the intensity of intervention required and potential for economies of scale. High-density areas offer greater renovation impact per euro invested. | To prioritize dense urban clusters for efficient group retrofits. | Residents per square kilometer or per building block. |

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| **S.5 Main dwellings** | Permanent residence status indicates long-term occupancy, which aligns with stable investment horizons and increased willingness to renovate. | To focus efforts on primary residences where benefits of renovation will be realized continuously. | Share of dwellings classified as primary residence (%). |
| **S.6 Dwelling ownership** | Ownership structure affects decision-making processes and renovation feasibility. Owned dwellings typically offer better prospects for long-term investment. | Used to understand governance constraints and assess feasibility for collective action. | Percentage of owner-occupied vs. rental housing per zone. |

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| **S.7 Educational level** | Low educational attainment can be correlated with energy poverty and limited access to renovation programs. Understanding this helps target outreach and simplify communication strategies. | Identify areas with potential communication or capacity barriers; tailor awareness and education campaigns for renovation. | Percentage of population with primary, secondary, and tertiary education (based on census or regional statistics). |
| **S.8 Population of foreign origin** | High shares of foreign-origin populations may indicate cultural and linguistic barriers, lower income, and less access to support systems. | Enable inclusive planning and culturally sensitive renovation outreach strategies. | Percentage of residents with foreign nationality or foreign-born residents (from census or municipal databases). |

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| **S.9 Economic dependency ratio** | A high ratio of dependents to the working-age population suggests economic vulnerability and limited ability to invest in renovations. | Helps prioritize public funding or subsidies and identify socially fragile clusters. | Ratio of non-working (0–14, 65+) to working-age (15–64) population. |
| **S.10 Deprivation rate** | Indicates multidimensional poverty and helps define priority areas for socially equitable renovation strategies. | Inform social clustering and eligibility for targeted aid and incentives. | Composite index including income, employment, education, and housing deprivation scores. |
| **S.11 Social welfare subsidies/social assistance** | Highlights socioeconomically vulnerable households likely in need of subsidized renovation. | Support planning of public renovation programs and targeted aggregation efforts. | Percentage of households receiving social assistance; data from social services or municipal databases. |

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| **S.12 Household typology - % single-parent households** | Single-parent households may face higher financial and logistical barriers to renovation. | Support vulnerability-based clustering and inform social support mechanisms. | Percentage of single-parent households among total households. |
| **S.13 Household typology - % of households with 1 or 2 single persons over 65 years of age** | Elderly residents often have reduced income and mobility, impacting ability to manage or afford renovation. | Inform accessibility-focused retrofitting and identify needs for facilitation or home adaptation. | Percentage of elderly single-person or two-person households. |
| **S.14 Gender distribution – % of women** | Gender-sensitive approaches are increasingly relevant in ensuring inclusive renovations and equitable policy design. | Enable gender-informed planning, especially in socially vulnerable areas. | Percentage of female residents by area (census or local statistics). |

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| **S.15 Population residing in the dwelling for more than 25 years** | Long-term residency indicates stability and potential higher engagement in renovation initiatives. | Identify engaged communities and tailor long-term support strategies. | Percentage of residents by years of occupancy (from census or housing registries). |
| **S.16 Resident Willingness to Renovate** | High willingness indicates potential for aggregation and smoother implementation of collective renovations. | Gauge likelihood of uptake and inform outreach and engagement strategies. | Survey data on willingness to participate in renovation or join collective schemes. |
| **S.17 Energy communities** | Existing or planned energy communities suggest high engagement and infrastructure for collective renovation. | Support energy-sharing schemes and collective self-consumption integrated with renovation. | Presence or proximity of registered energy communities (regional energy agency or OSS databases). |

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