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D 1.2.3. Joint catalogue of EE/RES solutions needed to reach the zero-emission neighbourhood

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JOINT CATALOGUE OF EE/RES SOLUTIONS NEEDED TO REACH THE ZERO-EMISSION NEIGHBOURHOOD STANDARD 2

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JOINT CATALOGUE OF EE/RES SOLUTIONS NEEDED TO REACH THE ZERO-EMISSION NEIGHBOURHOOD STANDARD

A. INTRODUCTION

This catalogue presents a joint framework of Energy Efficiency (EE) and Renewable Energy Sources (RES) measures required to transform heritage neighbourhoods into zero CO_2 emission areas by 2050. Developed within the ZEB4ZEN project, it supports the goals of the European Green Deal and the revised Energy Performance of Buildings Directive (EPBD).

Historic urban areas face unique challenges due to architectural constraints and conservation regulations. However, tailored EE/RES strategies can significantly reduce energy demand and emissions while preserving cultural value.

The catalogue includes:

- EE/RES solutions from pilot sites,
- Technical and economic indicators (energy savings, CO_2 reduction, investment),
- A roadmap for phased implementation until 2050.

The goal is to enable partners and municipalities to systematically plan and apply effective measures, ensuring climate neutrality and improved living conditions in protected neighbourhoods.

B. ENERGY EFFICIENCY (EE) MEASURES

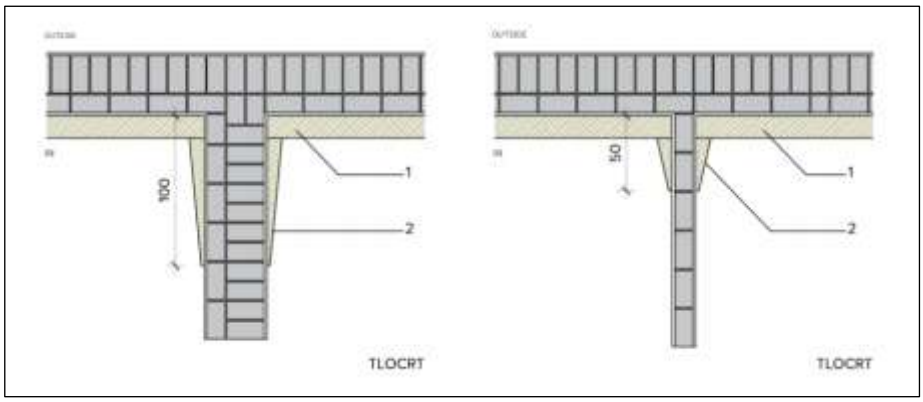
Energy efficiency measures aim to reduce the energy demand of buildings by improving their thermal performance and minimizing losses. In heritage neighbourhoods, these interventions must respect conservation rules while achieving significant energy savings.

1.1. Building Envelope Improvements

These measures target the physical structure of buildings to reduce heat loss:

- **Moisture Remediation**

Precondition for insulation. Includes drying plasters, moisture barriers, and waterproof coatings.



- **Wall Insulation**

Internal insulation preferred in heritage buildings. Materials include thermal plaster, nano coatings, and mineral wool, target U < 0.30 W/m²K. Estimated savings: up to 50% of heating demand.

Figure 1: Examples of thermal bridge solutions in cases of thermal insulation on the inside of external walls: junction of internal load-bearing wall (left) and internal partition wall (right).

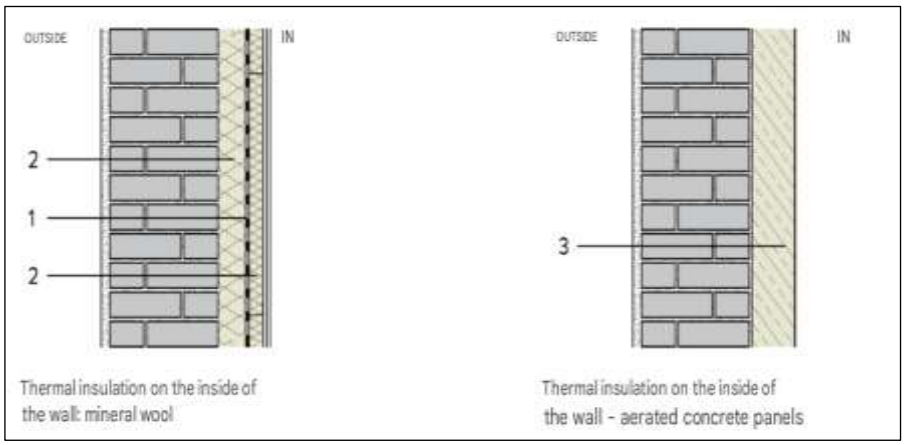


Figure 2: Examples of installing thermal insulation on the inside of exterior walls: mineral wool with a vapor barrier (left) and aerated concrete slabs (right).

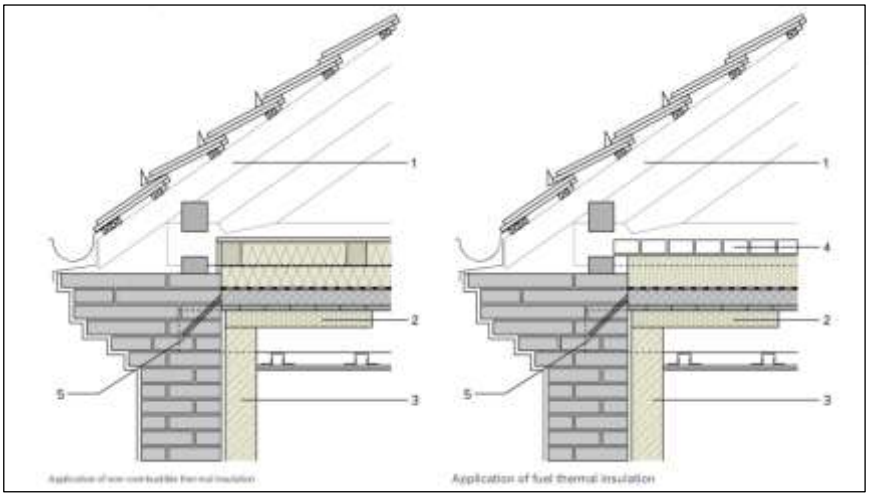


Figure 3: Thermal insulation measure of the ceiling towards the unheated attic.

- **Roof and Attic Floor Insulation**

15–20 cm mineral wool or equivalent, U < 0.25 W/m²K, include vapour control layers and ventilation gaps. Applied with minimal impact. Improves thermal comfort and reduces heat loss.

- **Basement Ceiling Insulation**

Rigid insulation ≥7 cm, U < 0.40 W/m²K. Reduces losses through unheated spaces. Requires moisture control.

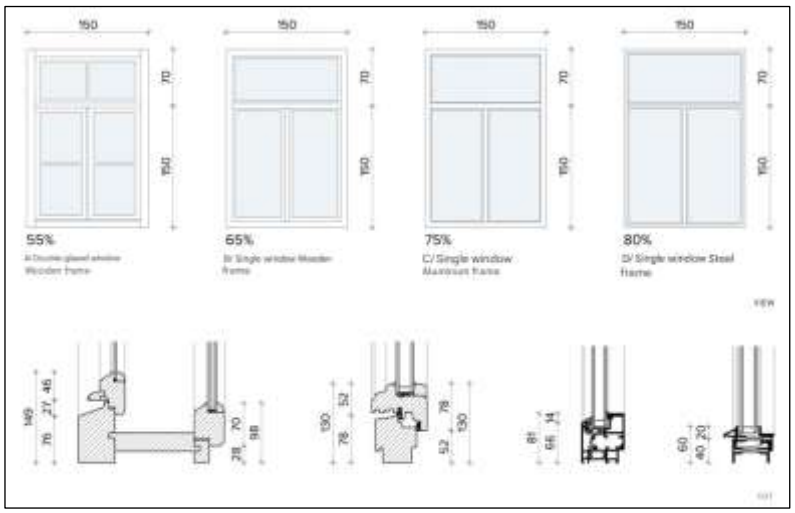


Figure 3: Relationships between window frame dimensions for different construction materials with highlighted glazing percentage (%).

- **Windows and Glazing**

Replacement with high-performance double glazing. U-value < 1.6 W/m²K. Detail to avoid thermal bridges in deep reveals.

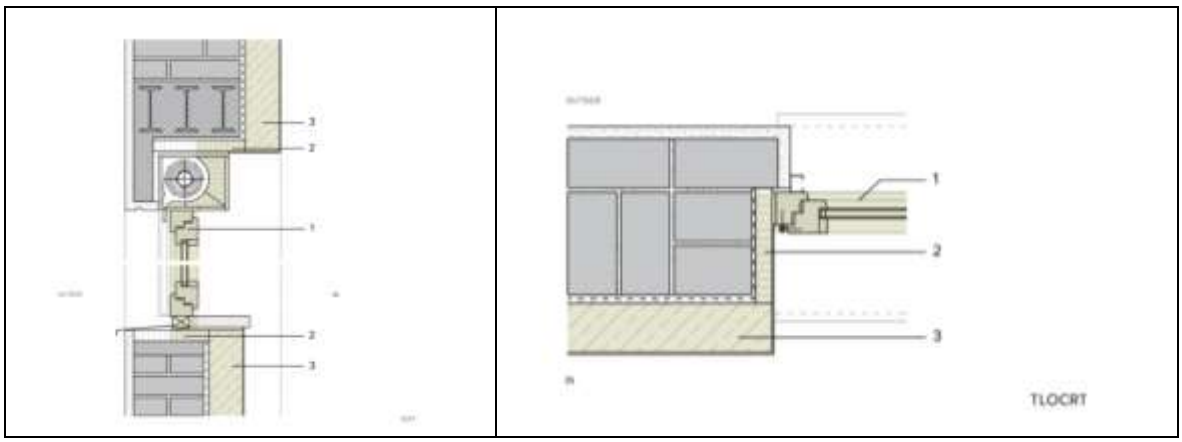


Figure 4: Properly insulated details of installing windows with insulated glass in an existing exterior wall (thermal insulation from the inside). Cross-section (left), floor plan (right).

- **Sunshading Devices**

Internal blinds or low solar transmittance glazing to reduce summer heat gains. Landscape shading (trees/hedges) where consistent with heritage.

- **Indicative unit costs (€/m² of useful area, Ak):**

Envelope package (walls, roof/attic, windows, moisture): ≈ 265.6 €/m²Ak.

Result: neighbourhood-wide ~50% reduction in $Q_{h,nd}$ used for scenario modelling.

Thermal Insulation Impact

- Average reduction in heating demand: 50%
- Improved indoor comfort and health
- Lower operational costs and CO_2 emissions

Implementation Notes

- Always perform structural and moisture diagnostics first.
- All interventions must be approved by heritage authorities.
- Structural stability must be assessed before insulation.
- Integrated renovation enables access to co-financing.

Table 1: Building Envelope Improvements

Measure	Description	Unit Cost (€)	Energy Savings / Yield	CO_2 Reduction	Applicability / Notes
Moisture Remediation	Drying plasters, barriers, coatings to address rising damp.	Varies	Enables insulation	Indirect	Precondition for envelope insulation.
Wall Insulation	Internal insulation (mineral wool, thermal plaster, VIP panels); U<0.30 W/m²K.	Part of package ≈265.6 €/m²Ak	Up to 50% heating demand reduction	High	Prefer vapour-open systems, heritage approval required.
Roof/Attic Insulation	15–20 cm mineral wool or equivalent; U<0.25 W/m²K.	Incl. in package	Major reduction in heat loss	High	Vapour control layers; minimal visual impact.
Basement Ceiling Insulation	Rigid insulation ≥7 cm; U<0.40 W/m²K.	Incl. in package	Reduces losses through unheated spaces	Medium	Requires moisture control.
Windows & Glazing	High-performance double glazing; U ≤1.6 W/m²K.	Incl. in package	Lower heating/cooling loads	Medium-High	Detail installation to avoid thermal bridges.
Sunshading	Internal blinds, low-g glazing, landscape shading.	Varies	Reduced summer gains	Indirect	Ensure heritage compliance.

C. RENEWABLE ENERGY SOURCES (RES) MEASURES

RES measures aim to decarbonize the remaining energy demand by replacing fossil fuels with clean, renewable sources. In heritage neighbourhoods, these solutions must be visually and structurally compatible with protected buildings.

1.1. Photovoltaic Systems

1.1.1. On-Site Photovoltaic Systems

Two complementary variants:

Variant 1 - Visible-area avoidance: install standard PV only on roof planes hidden from public view (courtyards, inner slopes). Conservative coverage, modest self-supply gains.

- Cost: ~1,100 €/kWp
- Yield: ~1,030–1,250 kWh/kWp/year



Source: https://www.vecteezy.com/



Source: https://www.vecteezy.com/

Figure 5: Integrated photovoltaic power plant

Variant 2 - Full-roof BIPV (solar tile): building-integrated PV resembling clay tiles, enables whole-roof coverage with minimal visual impact, higher yield and self-sufficiency.

- Cost: ~5,800 €/kWp
- Yield: ~1,000 kWh/kWp/year



Source: www.invisiblesolar.it



Source: www.invisiblesolar.it

Figure 6: Invisible solar - rooftile PV

Design notes: use PV*SOL or similar for shading/orientation, map visibility in GIS, coordinate with conservation authority, integrate snow/leaf guards and fire-safe cabling.

Impact:

- Electricity self-generation
- Reduced operational emissions
- Visual compliance with heritage standards

1.1.2. Off-Site Photovoltaic Systems

Concept:

In heritage neighbourhoods where rooftop photovoltaic (PV) installations are restricted due to conservation rules, Renewable Energy Communities (RECs) offer a viable alternative for clean energy generation and collective decarbonisation. Goal ist o develop shared PV plants outside the protected core, allocate virtual shares to buildings within neighbourhood (collective self-consumption).

This model enables shared access to renewable energy, improves energy equity, and supports the zero-emission neighbourhood goal without compromising cultural heritage. Goal is to decarbonises electricity for heat pumps and services, overcomes roof constraints and promotes citizen participation.

Benefits:

- **Visual compliance**: No impact on protected facades or rooflines.
- **Scalability**: Can be expanded to include more users or technologies (e.g. batteries, EV charging).
- **Community engagement**: Encourages local participation and ownership.
- **Policy alignment**: Supports EU directives on citizen energy and collective self-consumption.

Recommendations:

- Identify suitable land near heritage zones.
- Engage local stakeholders early.
- Ensure grid compatibility and legal frameworks for energy sharing.
- Consider hybrid models combining RECs with building-level EE measures.

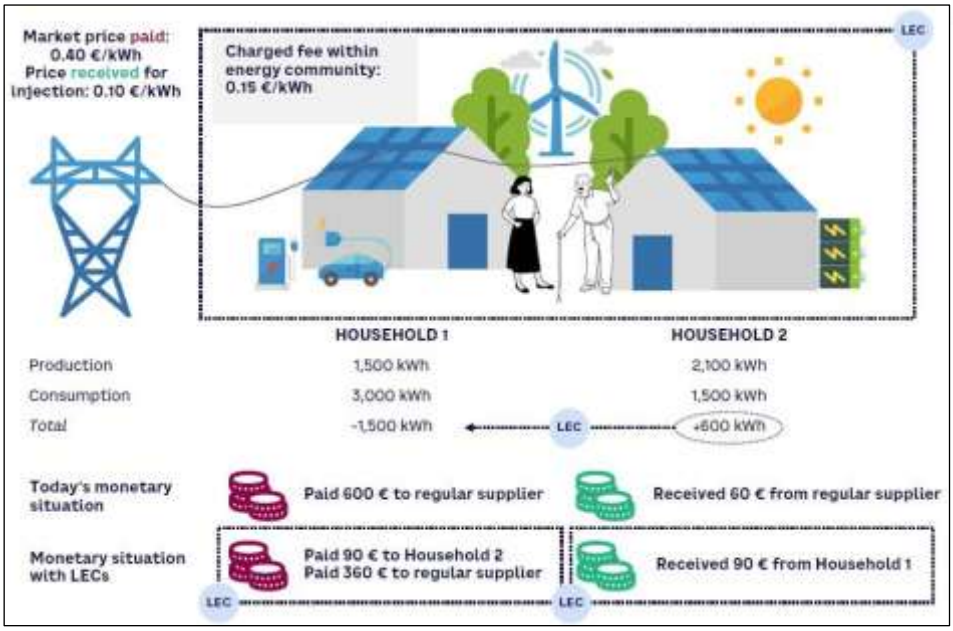
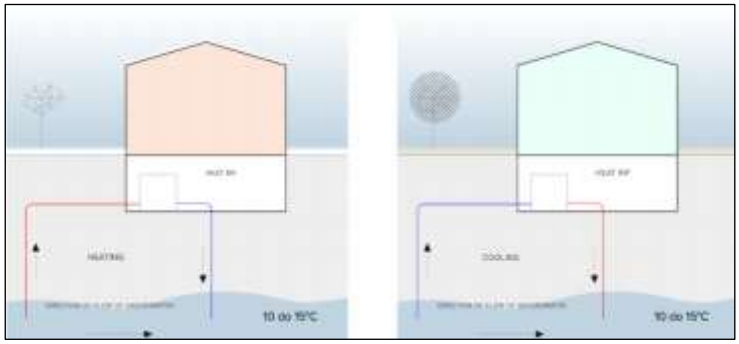


Figure 7: PV energy community – example of simple scenario electricity allocation (Source: www.adlittle.com)

Table 2: Photovoltaic Systems

Measure	Description	Unit Cost (€)	Energy Savings / Yield	CO_2 Reduction	Applicability / Notes
On-site PV Variant 1	Standard PV on hidden roof planes.	≈1,100 €/kWp	~1,030-1,250 kWh/kWp/year	High (electricity displacement)	Conservative coverage; heritage compatible.
On-site PV Variant 2 (BIPV)	Solar tile BIPV resembling clay tiles.	≈5,800 €/kWp	~1,000 kWh/kWp/year	High	Visually compatible; higher cost.
Off-site PV via Energy Communities	Shared PV plants outside core; virtual shares.	Project-dependent	Depends on allocation	High	No impact on heritage; requires community framework.

1.2. Heat Pump Systems



Concept: switch individual buildings or blocks to groundwater (open-loop) or closed-loop borehole heat pumps. Modelled SCOP ≈ 4.0 with low-temperature emitters.

Figure 8: The operating principle of a water-to-water heat pump in the case of using groundwater (heating - left, cooling - right).

Building-side works:

- HP units; hydraulic integration; DHW provision
- Boreholes or groundwater abstraction & reinjection (where permitted)
- Emitter upgrades (e.g., fan coils or enlarged radiators)

Indicative unit costs: ≈ 171.7 €/m²Ak (HP + emitters).

Impacts (after envelope package): electrification of heating, deep primary energy and CO_2 cuts; cooling co-benefit; higher electricity demand—pair with PV and green procurement.

Good for: blocks distant from DH mains; phased/owner-driven retrofits; locations with hydro-geological suitability.

Key success factors: permitting in sanitary zones; well design and maintenance (open-loop) or TRT-informed borehole design (closed-loop); grid capacity checks.

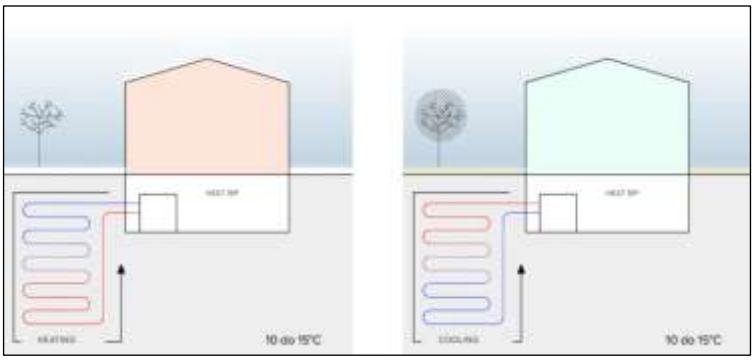


Figure 9: The operating principle of a water-to-water heat pump in the case of using ground energy (heating - left, cooling - right).

Table 3: Heat Pump Systems

Measure	Description	Unit Cost (€)	Energy Savings / Yield	CO_2 Reduction	Applicability / Notes
Groundwater/Ground-Coupled Heat Pumps	Open-loop or closed-loop boreholes; SCOP≈4.0.	≈171.7 €/m²Ak	Deep primary energy cuts; cooling co-benefit	High (depending on grid)	Check hydro-geological conditions; permits required.

1.3. District Heating Systems (Geothermal)

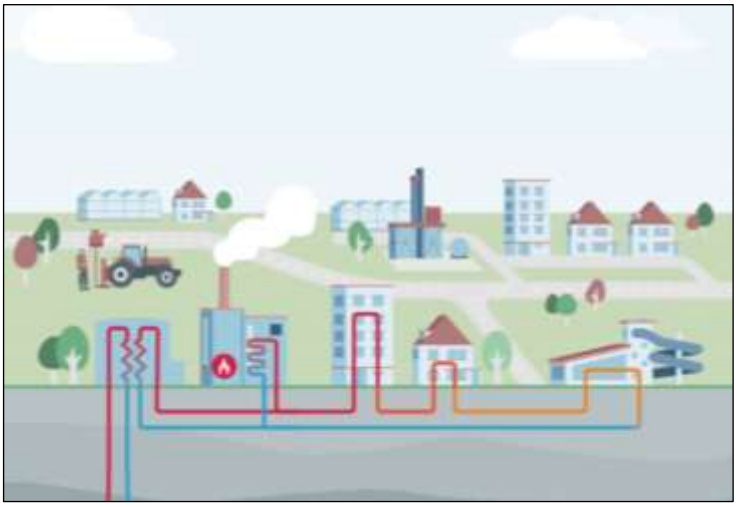


Figure 10: District Heating (source: https://www.thinkgeoenergy.com)

Concept: connect buildings to a modernised, low-temperature DH network supplied by geothermal heat (central plants) with pre-insulated distribution, substations, and emitter upgrades where needed.

Building-side works:

- Substations with heat exchangers and metering
- Internal pipework and balancing
- Radiator/fan-coil upgrades for lower supply temperatures

Indicative unit costs (building-side): ≈ 80.7 €/m²Ak (substation, internal pipework, emitters). **Impacts (after envelope package):** 100% CO_2 reduction from heating, large final energy and CO_2 reductions at neighbourhood scal, zero on-site combustion, network losses cut by modernisation.

Good for: collective renovation strategies, dense historic blocks, managed utilities, where geothermal integration to DH is feasible.

Key success factors: geothermal supply development, coordinated street-by-street works, careful phasing with envelope retrofits.

Table 4: District Heating Systems (Geothermal)

Measure	Description	Unit Cost (€)	Energy Savings / Yield	CO_2 Reduction	Applicability / Notes
Geothermal District Heating	Low-temp DH network supplied by geothermal heat.	≈80.7 €/m²Ak (building-side)	Large final energy and CO_2 reductions	Very High (near zero onsite)	Requires central supply development; phased implementation.

PUBLIC INFRASTRUCTURE

1.1. Public Lighting

Public lighting is an essential element of neighbourhood decarbonisation, improving both energy efficiency and urban quality. The catalogue assumes two main phases till 2050:



Figure 11: Exmple of Heritage Street Lighting (Source: https://veelite.ie)

Phase 1 – LED Modernisation: Replace conventional luminaires (sodium, mercury, fluorescent) with high-efficacy LED systems. Typical savings are 50–70% compared to legacy sources. Integration of basic controls (timers, photocells, dimming profiles) is recommended. LEDs also enhance colour rendering and safety.

Phase 2 – Future Retrofit after LED Lifetime: After the expected service life of current LED technology (≈15–20 years), a second retrofit is assumed.

Future systems are expected to offer:

- Higher luminous efficacy (lower W/lumen)
- Integrated smart controls as standard, including adaptive lighting, motion sensing, daylight-responsive dimming
- Connectivity to smart city platforms (traffic, security, air quality sensors)
- Obligatory regulation of operating hours and levels by policy (avoiding over-lighting)

Additional considerations:

- Heritage areas may use luminaires styled to historic aesthetics with hidden LED modules.
- Light pollution reduction (full cut-off optics, warmer CCT ≤ 2700K).
- Potential integration of PV-powered standalone poles in parks or periphery zones.

Table 5: Public Lightning

Measure	Description	Unit Cost (€)	Energy Savings / Yield	CO_2 Reduction	Applicability / Notes
Phase 1 - LED Modernisation	Replace legacy luminaires with high-efficacy LEDs.	Varies	50-70% vs. legacy	High	Add basic controls; heritage-style fixtures where needed.
Phase 2 - Advanced Smart Lighting	Future LEDs with adaptive controls, smart integration.	Future cost reduction expected	Higher efficacy; smart dimming	Additional cuts	Smart city integration, obligatory regulation.

1.2. Sustainable Mobility



Figure 12: Sustainable Mobility (Source: www.vecteezy.com)

Neighbourhood-scale mobility measures reduce emissions, improve accessibility, and protect heritage values.

Core interventions include:

Traffic demand management: Establish low-emission or car-restricted zones, promote walking and cycling infrastructure.
Electrification of transport: Provide EV charging stations (preferably at perimeters or parking hubs), ensure compatibility with grid upgrades, and apply heritage-sensitive furniture design.
Shared and micro-mobility: Bike-sharing, e-scooters, and small electric shuttle buses for internal circulation.
Public transport integration: Link neighbourhood with wider regional transport hubs, ensure schedules and stops favour sustainable travel.
Accessibility and inclusivity: Ensure barrier-free design for elderly and disabled residents.
Pilot pedestrianisation schemes: Introduce visual markers or temporary barriers to test car-free weekends or holidays.
Delivery zoning: Define time windows for freight and service vehicles (e.g., early morning), with a preference for low-emission or electric vans.
Materials and surfaces: Use comfortable, non-slip pavements compatible with protected architecture.

Infrastructure for cycling and walking: Bicycle stands, benches, drinking fountains, low-intensity (warm-tone) pedestrian lighting, and wayfinding signage.
Mobility information systems: Digital kiosks or apps showing walking routes, available transport options, and arrival times.
Cultural and spatial activation: Guided tours, street performances, and cultural interventions that reinforce non-motorised mobility.
Green edges and pocket parks at the perimeter of historic cores, serving as rest areas and access points for micro-mobility.

Table 6: Sustainable Mobility

Measure	Description	Unit Cost (€)	Energy Savings / Yield	CO_2 Reduction	Applicability / Notes
Traffic Demand Management	Low-emission or car-free zones; promote walking/cycling.	Policy-driven	Indirect (reduced car use)	High	Align with UNESCO guidelines.
Electrification of Transport	EV charging stations, preferably at perimeter hubs.	Varies	Depends on uptake	Medium-High	Ensure grid readiness; heritage-sensitive design.
Shared & Micro-Mobility	Bike-sharing, e-scooters, electric shuttles.	Varies	Modal shift	Medium	Requires governance & infrastructure.
Public Transport Integration	Connect neighbourhood to regional PT hubs.	Varies	Reduced private car dependence	Medium	Coordinate with operators.
Accessibility & Inclusivity	Barrier-free design, safe crossings, inclusive access.	Varies	Social benefits	Indirect	Elderly and disabled access.
Delivery Zoning	Time windows, low-emission vehicles.	Varies	Reduced congestion	Medium	Restrict freight times; incentivise clean vans.

D. PHASING AND GOVERNANCE

Achieving zero CO_2 emissions in heritage neighbourhoods requires more than technical solutions, it demands a strategic, phased, and governance-driven approach. This section outlines a generalized methodology that can be adapted to different urban contexts, ensuring that interventions are systematic, data-informed, and policy-aligned.

1.1. Baseline Assessment and Existing Conditions

Before any intervention, a thorough analysis of the current state is essential. This forms the foundation for all future planning and decision-making.

Data Collection

Gather available documentation: cadastral maps, building registries, energy bills, renovation records, and conservation status, EPC`s data.

Energy Mapping

Identify:

- Types of energy carriers used (e.g. gas, electricity, biomass),
- Distribution of heating systems,
- Share of heated vs. unheated spaces.

Building Use Analysis

Determine:

- Which buildings are in active use,
- Which are vacant or underutilized,
- Functional typologies (residential, public, mixed-use).

Condition Assessment and Categorization

Evaluate structural integrity, envelope condition, moisture presence, and categorize buildings by:

- Renovation urgency,
- Technical feasibility,
- Heritage sensitivity.

Digitalization of Data

Use tools like QGIS, 3D modelling, or BIM to visualize:

- Energy flows,
- Building typologies,
- Intervention zones.

1.2. Technical and Economic Feasibility Analysis

Once the baseline is established, the next step is to identify optimal EE/RES measures tailored to the local context.

Measure Selection

Based on building typology and heritage constraints, select:

- Envelope upgrades (insulation, glazing),
- Heating system replacements (heat pumps, district heating),
- Renewable energy options (PV, REC participation).

Simulation and Modelling

Estimate:

- Energy savings (kWh/year),
- CO_2 emission reductions (t/year),
- Investment costs (€/m^2 or €/building),
- Payback periods and OPEX savings.

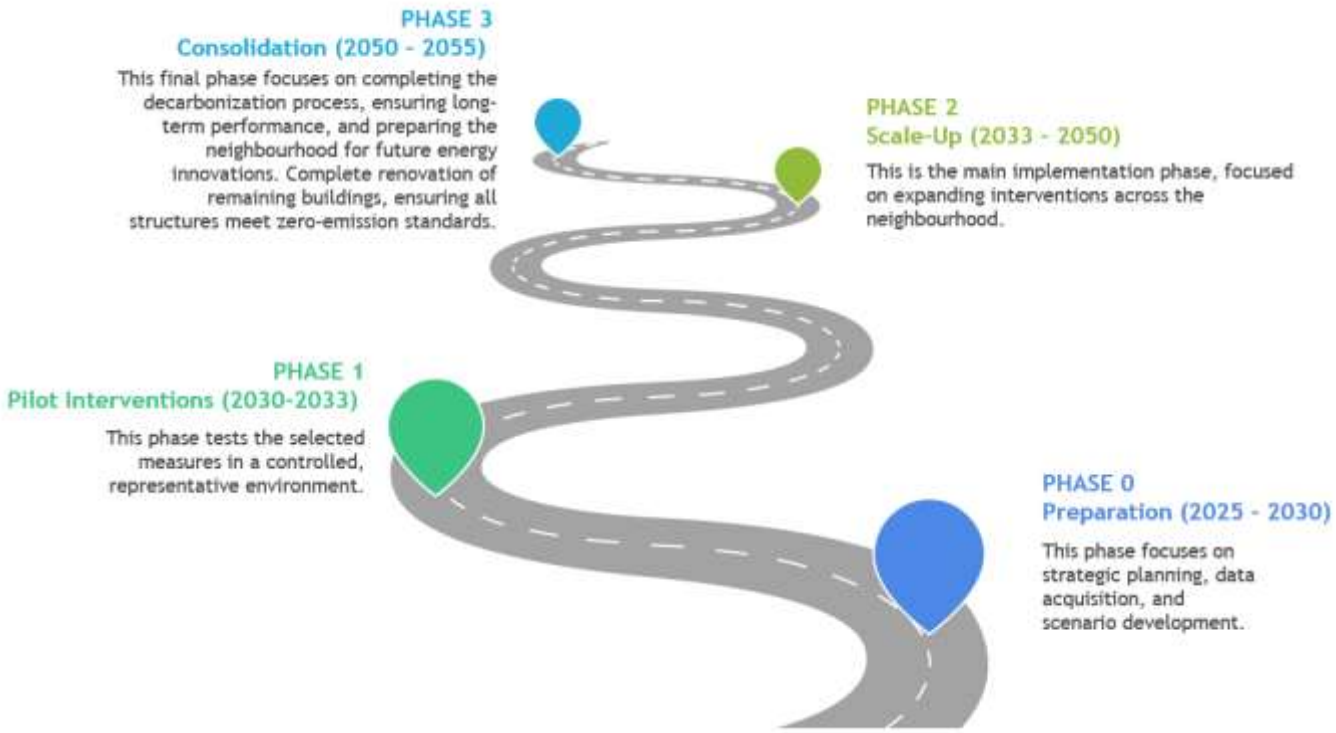
Prioritization Criteria

Rank buildings or blocks based on:

- Energy intensity,
- Current condition,
- Renovation feasibility,
- Social impact (e.g. schools, public buildings),
- Synergies with other urban plans.

1.3. Strategic Decarbonisation Roadmap

A phased implementation ensures manageable investment cycles, stakeholder engagement, and continuous learning. The following structure outlines a strategic and scalable approach to decarbonizing heritage neighbourhoods:



PHASE 0

Conduct a comprehensive baseline assessment of the neighbourhood, including:

- Energy carriers and consumption patterns,
- Building usage (active, vacant, underutilized),
- Structural condition and conservation status,
- Categorization of buildings by renovation potential and urgency.
- Identify and map technical and economic constraints.
- Select optimal EE/RES measures based on feasibility and heritage compatibility.
- Engage key stakeholders: municipalities, heritage authorities, residents, utilities.
- Secure funding sources and define the governance model.

Digitize all spatial and energy data using tools like QGIS, enabling:

- Scenario modelling,
- Visual planning,
- Cumulative impact tracking.

Develop a Decarbonization Roadmap Plan, outlining:

- Target milestones,

- Phasing logic (e.g. by blocks, priority zones),
- Expected outcomes.

PHASE 1

Select 1-3 building clusters or blocks for pilot renovation and prepare full technical documentation, including:

- Project documentation and Energy audits,
- Architectural and structural plans,
- Heritage compliance reports,
- Obtain all necessary permits and approvals.

Implement EE/RES measures and monitor:

- Energy performance,
- CO_2 reductions,
- User satisfaction.

Evaluate results and refine methodologies for scale-up.

PHASE 2

Renovate additional blocks every 2-3 years, following:

- Priority-based scheduling (e.g. worst-performing buildings),
- Spatial logic (e.g. contiguous blocks for infrastructure efficiency).
- Apply lessons learned from pilot phase to improve cost-effectiveness and execution.

Integrate buildings into district-level systems, such as:

- Geothermal networks,
- Renewable Energy Communities (RECs),
- Shared heat pump clusters.
- Maintain continuous monitoring and stakeholder feedback loops.

PHASE 3:

- **Conduct fine-tuning of installed systems, including:**
  - Optimization of heat pump operations,
  - Calibration of PV and RES systems,
  - Adjustment of control systems for occupant comfort and efficiency.
- **Perform a post-implementation audit to identify:**
  - Residual inefficiencies,
  - Gaps in coverage or performance,
  - Opportunities for further improvement.
- Establish long-term maintenance protocols, including:

- Scheduled inspections,
- Performance monitoring,
- Resident feedback mechanisms.

- **Integrate future-ready technologies**, anticipating the evolution of energy systems:
  - **Battery storage systems** to enhance self-consumption and grid flexibility,
  - **Smart infrastructure** (IoT sensors, building automation, predictive maintenance),
  - **Vehicle-to-grid (V2G)** capabilities for electric mobility integration.
- Update the digital planning environment (e.g. QGIS, BIM) to reflect final conditions and enable:
  - Ongoing monitoring,
  - Public transparency,
  - Replication in other neighbourhoods.
- Prepare a final impact report summarizing:
  - Total energy savings,
  - CO_2 reductions,
  - Investment outcomes,
  - KPI`s,
  - Lessons learned and recommendations for future projects.

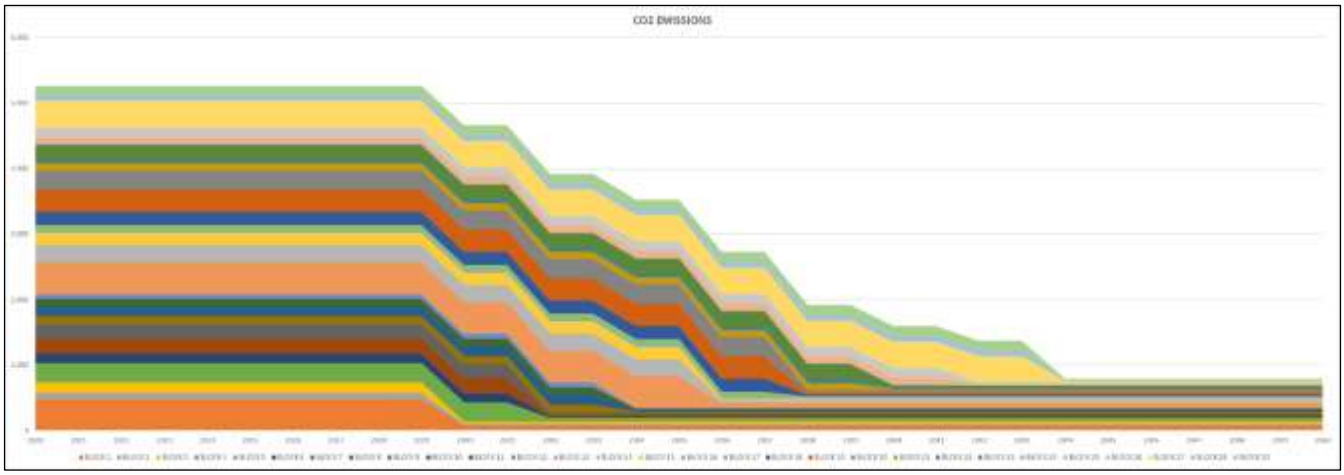


Figure 13: Example of Decarbonisation Impact - Baseline (2020 - 2030) and Phased CO_2 Emissions Reduction by Blocks (2030-2050)

Table 7: Phasing and Governance

Measure	Description	Unit Cost (€)	Energy Savings / Yield	CO_2 Reduction	Applicability / Notes
Baseline Assessment	Collect data: maps, registries, energy bills, conservation status.	Study cost	Foundation for planning	Indirect	Digitise in GIS.
Technical & Economic Feasibility	Identify optimal EE/RES measures; model scenarios.	Study cost	Identifies best options	Indirect	MCDA and LCC analysis.
Strategic Phasing Plan	Phased implementation: pilots, scale-up, consolidation.	Project-dependent	Progressive decarbonisation	High	2-3 year waves; coordinated works.
Governance & Financing	Stakeholder map, PMO, financing blend, ESCO models.	Admin	Enables delivery	Indirect	Align with EU funds.
Monitoring & Verification	KPIs, metering, dashboards, IPMVP protocols.	Low (permanent)	Ensures persistence	Indirect	Annual reporting.