WP1 – Scoping and methodological approach
T1.4 Integrated methodological framework and KPIs Updates

Deliverable 1.2 – Indicators and methodological framework

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AUTHOR(S)	ORGANISATION
Saghar Hosseinalizadeh	Department of Engineering, The University of Palermo
Emilio Sessa	Department of Engineering, The University of Palermo
Maurizio Cellura	Department of Engineering, The University of Palermo, Centre for Sustainability and Ecological Transition
Francesco Guarino	Department of Engineering, The University of Palermo, Centre for Sustainability and Ecological Transition
Henna Hukari	VTT Technical Research Centre of Finland Ltd
Sonia Longo	Department of Engineering, The University of Palermo, Centre for Sustainability and Ecological Transition
Clemens Mayer	Joanneum Research

Rakesh Ramesh	VTT Technical Research Centre of Finland Ltd
Francesco Reda	VTT Technical Research Centre of Finland Ltd
Hassam ur Rehman	VTT Technical Research Centre of Finland Ltd
Daniele Ronsivalle	Department of Architecture, The University of Palermo, Centre for Sustainability and Ecological Transition
Sebastian Seebauer	Joanneum Research
Andreas Tuerk	Joanneum Research

Abstract

This deliverable presents the integrated methodological framework and KPIs developed within the RESPED project to support the implementation of Positive Energy Districts (PEDs) through a novel combination of Territorial Acupuncture (TA) and Co-Creation (CC). The report is structured in two complementary sections. Section A introduces the conceptual and operational architecture of the TA-CC framework, which positions targeted spatial interventions — termed "acupoints" - as catalysts for energy transition across urban and territorial scales. Drawing on integrated urban, climate, and energy analysis, the framework maps high-potential nodes for decentralized or optimized energy interventions, while embedding participatory Co-Creation processes to ensure stakeholder engagement, contextual relevance, and social legitimacy throughout. Section B proposes a structured set of 28 KPIs organized under four thematic pillars, resilience (10 indicators), energy poverty (10 indicators), carbon neutrality (3 indicators), and circularity (5 indicators), specifically selected for their capacity to evaluate the systemic performance of PEDs and to characterize acupoints in terms of their energy, environmental, and urban attributes. Together, these two sections establish a transparent, scalable, and replicable basis for translating territorial analysis into performance-driven urban energy strategies aligned with European climate and sustainability objectives.

Keywords

Co-creation, Territorial Acupuncture, Energy transition, Positive Energy Districts (PEDs), Integrated Urban Energy Planning, Key Performance Indicators

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EXECUTIVE SUMMARY

Global urban policy is increasingly shaped by the imperative of climate neutrality; yet with the urban population projected to reach 68% by 2050, systemic challenges such as pollution and energy insecurity remain insufficiently addressed, owing largely to a persistent reliance on legacy planning models. These outdated paradigms demonstrate a limited capacity to navigate the complex socio-economic interdependencies between cities and their surrounding territories. In response, this study introduces an innovative structural framework aimed at fostering deeper integration across socio-technical and political institutions, thereby transforming theoretical sustainability objectives into operational, scalable realities.

Section A presents the conceptual architecture of the study, grounded in the operational synergy between TA and CC. Together, these approaches establish a multi-scalar framework that balances top-down analytical precision with bottom-up social inclusivity. The methodology commences with a comprehensive data-gathering phase designed to decode the territorial fabric and inhabitant needs, laying the groundwork for integrated urban, climate, and energy simulations. Through the systematic identification of key spatial, environmental, and social indicators, the study maps the territory to locate "acupoints", high-potential intervention nodes capable of catalyzing energy transitions across entire neighborhoods. These nodes serve as the primary reference points for determining technical interventions, such as the establishment of decentralized energy communities or the optimization of centralized plants, each tailored to the localized metabolic characteristics of the territory. The participatory Co-Creation component further aligns technical outputs with place-specific knowledge, directly addressing challenges of stakeholder ownership and contextual relevance. By defining the scope of indicators at the outset, the research ensures a transparent and standardized process that translates technical energy efficiency measures into tangible instruments for broader social and territorial resilience.

Section B proposes a comprehensive set of KPIs specifically selected for their relevance to the implementation and evaluation of Positive Energy Districts (PEDs), as well as their capacity to define acupoints in terms of the energy, environmental, and urban characteristics of the territory. Organized under four thematic pillars, resilience, energy poverty, carbon neutrality, and circularity, these indicators function as diagnostic tools to assess the systemic impact of proposed interventions. Specifically, ten indicators address the resilience of PEDs, ten examine the multidimensional issue of energy poverty, three evaluate progress toward carbon neutrality, and five pertain to circularity. Collectively, this indicator framework provides a structured and replicable basis for translating territorial analysis into actionable, performance-driven urban energy strategies.

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SECTION A: ACRONYMS AND TERMS

Acronym	Full name
TA	Territorial Acupuncture
PED	Positive Energy District
CC	Co-Creation
CG	Co-Governance
UA	Urban Acupuncture
BBA	Building Block Approach
SDG	Sustainable Development Goal
EPBD	Energy Performance of Buildings Directive
RS	Remote Sensing
TIA	Territorial Impact Assessment
JRC	Joint Research Centre
LUISA	Land-Use based Integrated Sustainability Assessment
RHOMOLO	Regional Holistic Model
RED	Renewable Energy Directive
TEN-T	Trans-European Transport Network
SCP	Safety and Coordination Plan
CP	Comprehensive Planning
UPBR	Urban Planning and Building Regulations
RES	Renewable Energy Sources
EGD	European Green Deal
LIFE	L'Instrument Financier pour l'Environnement

RFNBO	Renewable Fuels of Non-Biological Origin
SME	Small and Medium-Sized Enterprise
TSO	Transmission System Operators
DSO	Distribution System Operators

SECTION B: KPIs ACRONYM GLOSSARY BY DOMAIN

Acronym	Full name
Resilience	
TAD / Thermal Autonomy	Robustness Threshold Duration / Thermal Autonomy
IoF	Impact of Failure
CS	Collapse Speed
RT	Recovery Time
DoD	Degree of Disturbance
IOD	Indoor Overheating Degree
WBGT	Wet-bulb Globe Temperature
CCA	Climate Change Amplification Factor
IAT	Islanded Autonomy Time / Grid Independence Duration
EUE	Expected Unserved Energy
CLC	Critical Load Coverage (related metric within EUE, not counted among the 28 KPIs)
Energy Poverty	
IKH	Inability to Keep Home Adequately Warm / Cool
AEBR	Arrears on Energy Bills Rate
EES / 2M	Energy Expenditure Share / Twice-the-Median Rule
HEP / LILEE	Hidden Energy Poverty / Low Income Low Energy
ITAR	Indoor Temperature Adequacy Rate (Cold / Hot)
BEPVH	Building Energy Performance of Vulnerable Households

HECS	Household Energy Cost Savings due to PED
IVHPED	Inclusion of Vulnerable Households in PED
BEE / EPC	Building Energy Efficiency / Energy Performance Certificate
AAL / EEPF	Accessibility to Affordable Living / Exposure to Energy Price Fluctuations
Carbon Neutrality	
CNI	Climate Neutrality Indicator (Operational)
CNE	Climate Neutrality Embodied (Life-Cycle)
NEET	Net-Zero Energy Trade-off
Circularity	
WRS/WRR	Waste Recycling Share / Waste Recovery Rate
CDWRR	Construction & Demolition Waste Recovery Rate
REU	Renewable Energy Usage
SSI	Service Sharing Indicator
FARI	Functional Areas Recovered Indicator

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Section A. Methodological Framework for Implementing Co-Creation Roadmap on Territorial Acupuncture

1. Territorial Acupuncture: From Emergent Practice to Co-Governed Strategy in Urban Planning and Energy Transition

1.1. Introduction to Co-Creation and Co-Governance of Territorial Acupuncture

This chapter provides a comprehensive overview of co-creating Territorial Acupuncture (TA) as an innovative methodology for transforming urban areas into PEDs. It emphasizes the policy and societal significance of this approach in advancing systemic change and supporting the mainstreaming of the energy transition.

Section 1.3 discusses the importance of adopting TA in urban and regional initiatives. Section 1.4 explores the benefits and potential of incorporating TA to support the energy transition. It then examines existing resources, including global agendas and EU regulations, related to co-creating the energy transition. Finally, the chapter concludes by outlining the steps for mainstreaming TA in strategic planning processes.

1.2. The Evolution of Territorial Acupuncture: Key Steps from Emergence to Acceleration

In recent decades, the world has witnessed a significant increase in population migration to large metropolitan areas, and this urban share is projected to rise to 68% by 2050 [1]. Numerous studies support this trend, highlighting the growing challenges cities face in accommodating their inhabitants. This extreme challenge is exemplified in the study by Leone et al. (2023), which states that urban areas are increasingly burdened by the unprecedented consequences of pollution and the climate crisis — already evident in the emergence of new epidemics and pandemics, food and energy crises, and extreme weather events [2]. Simultaneously, the persistent use of urban planning models rooted in 19th-century principles presents significant obstacles to addressing the complexities of contemporary urban transformation. These legacy models lack the flexibility and responsiveness needed to cope with rapid shifts and often neglect the interconnected socio-economic and energy systems that extend across entire territories, including inland areas beyond the urban core.

The convergence of interconnected socio-economic challenges and unequal access to energy resources underscores the urgent need for an innovative and integrated methodological framework. Such a framework should be capable of addressing these complex issues holistically across entire territories, fostering synergistic solutions. In response to this need,Leone et al. (2023) propose TA, a novel framework that reconceptualizes the city as the core locus of social vitality and development. This approach focuses on revitalizing existing urban centers to catalyze transformations across broader territorial systems—including energy infrastructure, settlement patterns, socio-economic organization, and community practices [2].

Rooted in earlier theoretical frameworks, this approach derives its theory from synthesizing elements of biourbanism, emerged around 2010, urban acupuncture, and energy community design. It conceptualizes the territory as a living, interdependent organism, through carefully targeted interventions—such as the establishment of interconnected energy communities, as well as infrastructures, services, buildings, and the population as integrated components in order to, generate systemic benefits, much like traditional Chinese acupuncture activates healing by stimulating specific points on the human body [2].

Building upon these foundations, the theory evolved into the concept of TA, which promotes spatial transformation through small-scale, rapid, and cost-effective interventions, aiming to stimulate broader

urban regeneration. All the mentioned theories derive from placemaking approaches and the important role of place. They aim to reinvent public spaces as places of community, but with a focus on energy optimization at territorial scale.

1.3. The Importance of Territorial Acupuncture in Urban Planning Initiatives

Given that TA stems from spatial changes in urban systems driven by territorial energy transitions, it is crucial to determine the most appropriate areas for optimal energy allocation [2]. As it is also emphasized in the same study that, the city is identified as a hyper-complex and interconnected system whose internal dynamics and those of its surroundings (territory) influence each other in a non-linear manner. Accordingly, this makes it difficult to analyse different parts individually. Conversely, urban and territorial management is regarded as a key factor contributing to the crisis, as ineffective governance has created significant misalignment among the main stakeholders. Although the TA could serve as a viable solution for identifying gaps within these issues, the absence of a coherent structure and comprehensive processes to monitor all aspects of territorial development highlights the need for deeper insights. On a broader scale, the Co-Creation (CC) process within the framework of TA can support multi-scalar participation, interaction, and collaboration with citizens, while simultaneously ensuring political representation of public officials, stakeholders, and academic institutions. Accordingly, as Sillak (2022) highlighted CC is conceived as emerging governance strategy that occurs to define common problems and design and implement innovative solutions by engaging multiple actors [3,4].

Since TA envisages spots with positive energy and make implementing place of energy communities more prominent in defining cities with carbon neutral and energy efficiency, addressing the issue of strategic energy planning and its implementation are fundamental for all the urban regions. However, as stated in the study by Sillak (2022) and Ryszawska et al. (2021), CC in the energy sector has been insufficiently conceptualized in a structured methodological manner and lacks the proper empirical studies for energy implementation and energy transition projects [3,5]. Accordingly, the results indicate that CC together with Co-Governance (CG) strategy for renewable energy transitions can be divided into collaborative process, institutional design and leadership, outputs and outcomes and antecedent conditions. To specify in detail, firstly, effective collaboration hinges on aligning expectations, fostering mutual learning, assessing progress, and adapting roles across sectors. Secondly, CC efforts may be structured through a municipality-led initiative or managed by a dedicated network organization—each path shaping the energy transition in distinct ways. Thirdly, CC yields more than just strategic plans or policies; it can foster enduring partnerships, joint ventures, institutional evolution, and greater public trust in the transition process. Lastly, the success of CC is deeply shaped by pre-existing factors such as natural resource availability, industrial strengths, policy frameworks, civic capacity, and a history of cross-sector collaboration.

Effective climate communication strategies within the energy transition depend on fostering inclusion, mutual learning, and strong relationships (Gray et al., 2024). Such an approach empowers communities to take ownership of the visioning process, allowing co-created designs to integrate local knowledge and respond to specific contexts. It also demands flexibility, ongoing dialogue, and active efforts to ensure that every voice is heard [6].

1.4. The Added Value of Incorporating Territorial Acupuncture in Support of Energy Transition

The adoption of TA as an innovative urban and regional planning approach offers a strategic framework for the phased development of energy district networks across broader territories. This method enables targeted, localized interventions that gradually reshape energy infrastructure and foster community resilience. Through this approach, the transition from a centralized, fossil-fuel-driven urban energy model to a decentralized, renewable-based system becomes not only possible but effectively guided.

TA facilitates the reprogramming and reconnection of diverse territorial zones, shifting away from the dominance of urban cores and encouraging energy self-sufficiency at the district level. According to Leone et al. (2023), TA can effectively contribute to addressing a variety of challenges across three primary domains:

1. Energy-Related Issues

- Energy crises and instability
- Environmental degradation caused by energy markets
- Rising demand for heating and electricity

2. Climate Crisis & Environmental Challenge

- Development and revitalization of informal or slum districts
- Breakdown of services in large metropolitan areas
- Climate Crisis
- Limited access to essential services across rural and urban areas
-
-

3. Urban and Territorial Planning

- The decline of centralized urban hubs and spatial imbalances
- Metropolitan Areas Overpopulation
- Depopulation of Inland Areas
- Crisis of the Space Modulation
- Shortage of Labour Supply
- Population Aging in Inland Areas
- Social Issues
- Speculation in Housing Market [2]

Given these multifaceted applications, CC and CG are essential for maximizing the impact of TA. These collaborative approaches promote inclusive stakeholder engagement, leverage local knowledge, and ensure shared responsibility, leading to more equitable, resilient, and sustainable development outcomes. Accordingly, CC and CG support sustainable development of TA in some specific ways:

- **Enhanced Problem Definition and Solution Design**

CC, which involves the collaborative efforts of public and private sector entities alongside citizens, ensures that interventions are appropriately aligned with the unique needs and characteristics of the targeted region [7] (van Elk & Regal, 2023). Through the involvement of a wide array of stakeholders, such as local residents, businesses, and community organizations, CC processes enable the identification of subtle insights into local challenges and opportunities that might otherwise be overlooked in top-down approaches. This results in solutions that are both more pertinent and effective [8] (Ansell et al., 2024).

To examine the effects of the energy transition of energy communities in the pursuit of carbon neutrality in urban areas, CC can help pinpoint specific sectors where focused interventions—such as

enhancing public transportation or promoting energy-efficient buildings—would yield the most substantial benefits [2] (Leone et al., 2023). Politically designed CC platforms serve as valuable tools for fostering multi-stakeholder engagement, ensuring that a diverse range of viewpoints are incorporated into the design of TA initiatives [7]. (van Elk & Regal, 2023).

- **Improved Resource Mobilization and Implementation**

CG, which emphasizes shared decision-making and responsibility, enhances the legitimacy and sustainability of TA projects [4]. (Ansell & Torfing, 2021)When stakeholders are actively involved in governing the implementation of interventions, they are more likely to contribute resources, expertise, and social capital to support their success. This collaborative approach also fosters a sense of ownership and accountability, increasing the likelihood that interventions will be maintained and expanded over time [8]. Moreover, CC and CG can help navigate potential conflicts and trade-offs between different interests, ensuring that TA's initiatives are implemented in a fair and equitable manner [9].

- **Fostering Innovation and Systemic Change**

By bringing together diverse perspectives and expertise, co-creation stimulates innovation in the design and implementation of TA. This can lead to the development of novel solutions that are more effective and adaptable to changing circumstances [10]. Furthermore, CG facilitates the scaling up and replication of successful interventions by creating a supportive policy environment and fostering collaboration among different levels of government and sectors. For example, the principles of goal-orientation, interactivity, and pluralism are crucial for effective climate change governance [11]. (Schmidt et al., 2024)

1.5. Global Agendas, Programs and EU Policies Enabling Territorial Acupuncture

The TA approach is embedded within a multilevel policy framework spanning global, European, and local strategies that promote sustainable urban development and the energy transition. At the global level, the UN Sustainable Development Goals [12] and the New Urban Agenda support inclusive, energy-efficient, and resilient cities through place-based and participatory planning. At the European level, initiatives such as the European Green Deal [13], the Renovation Wave [14], and the Energy Performance of Buildings Directive [15] provide strategic and regulatory support for localized interventions, while EU funding programmes enable their implementation through collaborative and data-driven projects. Within this framework, the assessment process is a key instrument for aligning local interventions with broader strategic objectives. It supports strategic analysis and decision-making by identifying high-impact areas through location-specific evaluations of energy demand, land use, urban morphology, mobility patterns, and environmental risks. Geospatial analysis, supported by GIS, remote sensing, and environmental diagnostics, allows the identification of targeted sites where small-scale actions—such as building retrofitting, public space regeneration, or renewable energy installations—can generate wider social and spatial benefits.

At the European level, this process is reinforced by policy-driven analytical support. The Knowledge Centre for Territorial Policies, established in 2016 by the Joint Research Centre (JRC) and the Directorate-General for Regional and Urban Policy, acts as a central reference point for territorial development. It supports evidence-based policymaking through integrated datasets, analytical models, and scenario-building tools, enabling comprehensive assessments of regional and urban dynamics. A key contribution is the Territorial Reference Scenario, which combines socioeconomic data, spatial infrastructure information, and existing EU policies to serve as a benchmark for evaluating alternative policy options [16].

In the context of territorial assessment, it is essential to conduct a comprehensive geospatial analysis at the regional scale before implementing energy transition measures. This broader spatial analysis enables the systematic identification of environmental constraints and regulatory conditions, including territorial and landscape plans, hydrogeological risks, land-use regulations, protected and Natura 2000

areas, cultural heritage constraints, fire-prone zones, and areas unsuitable for renewable energy systems. Satellite-based data further support this process by providing information on geomorphology, vegetation, hydrography, accessibility, and environmental sensitivities, ensuring an integrated and robust territorial knowledge base.

1.6. Mainstreaming Energy Transition into Integrated Planning Process

Integrating energy planning into spatial planning requires a comprehensive approach. As highlighted in an IN-PLAN report [17], (Höftberger et al., 2024), incorporating energy potentials is challenging and demands a broader perspective and a solid implementation plan for effective integration into a territory's development plan of a territory.

The report identifies three key dimensions of integrated spatial planning: vertical, horizontal, and territorial integration. This three-layered approach stresses the need for coordination among organizations at the local, governance, and territorial levels, aligning long-term planning with sustainability and growth objectives. Vertical integration ensures policies and plans are aligned, preventing conflicts and redundancies while fostering cohesive development strategies. Horizontal integration promotes collaboration across policy areas within municipalities, essential for achieving climate neutrality through the integration of climate adaptation, sustainable mobility, and renewable energy. By considering social and economic factors, spatial planning seeks sustainable development that balances growth, environmental protection, and social equity. Collaboration among municipalities enables them to address shared challenges, optimize resources, and implement regional strategies beyond individual boundaries. This enhances the effectiveness of spatial planning, fostering a strategic vision for territorial growth aligned with sustainability goals. The Commission's approach highlights multi-level governance and stakeholder coordination, involving relevant actors at all levels and ensuring active citizen participation.

The Commission advocates for the use of diverse funding sources to enhance resource availability, facilitating the implementation of large-scale, impactful spatial development projects. Figure 1 illustrates the diagram of the integrated planning process.

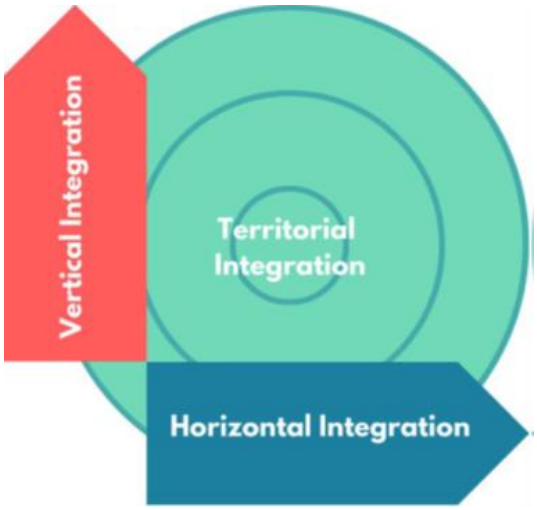


Figure 5. Diagram of Integrated Planning [17]

1.6.1. The Integrated Planning Process for Energy Transition of a Territory

Incorporating energy planning into a territory's strategic planning requires several key steps throughout the stages of preparation, development, and implementation (including monitoring). These steps are

further clarified to enhance understanding of the process. Figure 2 presents a concise overview of all five phases of the Integrated Planning Process of the Territory.

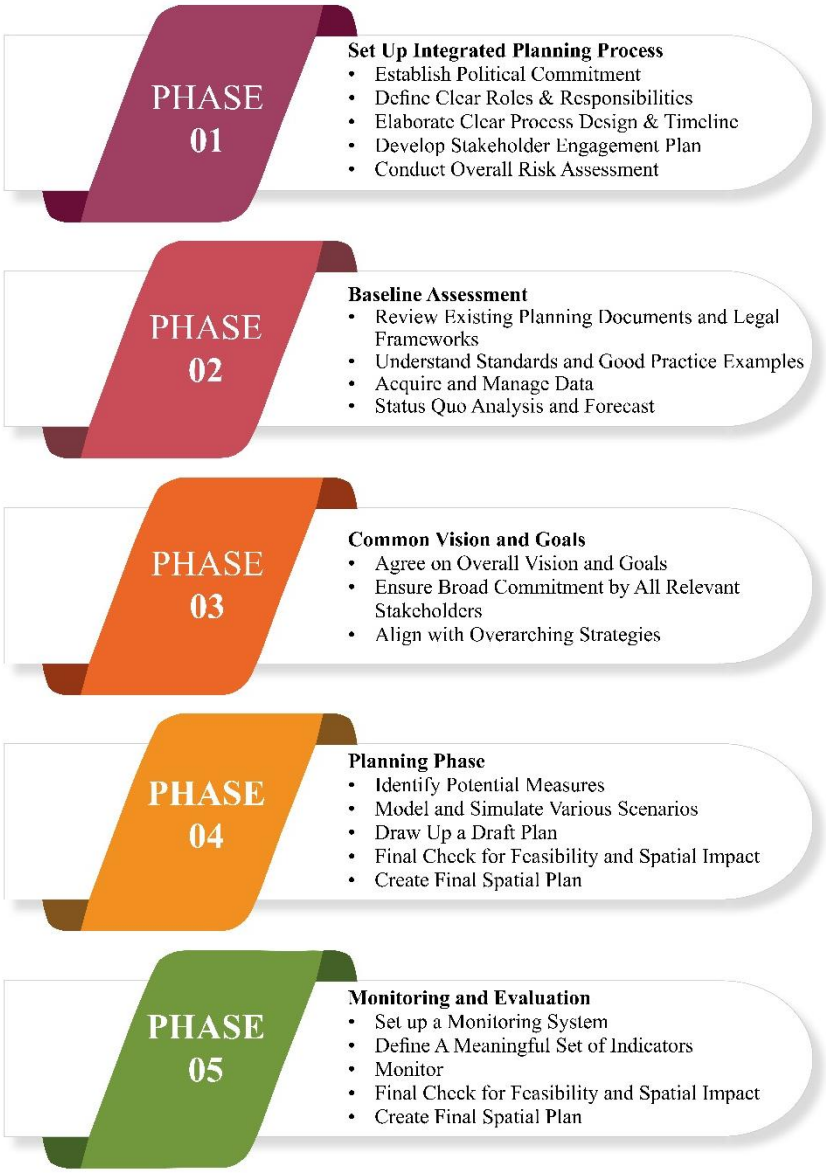


Figure 6. Integrated Planning Process of the Territory [17]

To further illustrate the process, the Integrated Planning Process is divided into five phases, as outlined below. All these phases should be followed to ensure the integration of climate-neutral and sustainable approaches—covering energy, mobility, and climate adaptation—into the strategic plan of a territory, as they collectively provide comprehensive and aligned information.

Phase 1: Set Up Integrated Planning Process

At this phase, it is essential to clearly define the goals, timeline, and stakeholders to be involved. Input from experts across various sectors should be incorporated, and cross-departmental collaboration is

typically necessary. Effective stakeholder coordination at this stage is crucial to ensure the successful progression of the integrated planning process. Here there are some questions to be addressed:

Q1: How can political commitment to the plan be established?
Q2: Who is leading the planning process and are additional partners needed for its establishment?
Q3: What is the timeline for the planning process including work packages, milestones and final delivery of the product?
Q4: Which stakeholders should be involved in the integrated process?at what stages and in which formats should their participation occur?
Q5: Are there any risks to timely implementation of the process? How will progress be monitored and controlled?

The output of this phase will include:

- Established political commitment
- Clear roles and responsibilities in process management
- Clear process design and timeline
- Comprehensive vertical and horizontal stakeholder engagement plan
- Risk assessment

Phase 2: Baseline Assessment

In the initial phase of spatial planning, it is crucial to review existing policies, planning documents, and the legal framework, as well as to assess the availability, accessibility, and management of spatial data. This includes identifying what data is already available, what additional data is needed, and how it can be effectively accessed and managed. Examining international, national, and regional best practice examples can also provide valuable guidance and inspiration.

This foundational stage should include an analysis of the insights the data offers regarding the status and potential future development of the area. These steps are essential for informing the decision-making process and shaping clear visions and objectives for land use planning in the next phase.

Key questions to address in Phase 2 include:

Q1: Which existing planning documents and legal frameworks must be considered?
Q2: Which (international) best-practice examples can be used to guide and inspire our work?
Q3: What (spatial) data is currently available, what additional data is required, and how can it be accessed and managed?
Q4: What relevant insights can the data provide regarding the current condition of the area and its potential future development?

The output of this phase will include:

- Review of existing planning documents, strategic plans, current measures, planning guidelines and legal instruments.
- Understanding of contemporary standards and good practice examples in the field.
- Data acquisition and data management plan.
- Status quo analysis and forecast.

Phase 3: Define Vision and Goals

While the baseline assessment helps a municipality or region to understand the current context and conditions, establishing a clear vision and well-defined goals is essential to guide the planning process. These goals should align with existing strategies, planning documents, and broader policy objectives to ensure consistency and coherence.

Equally important is securing broad support and fostering a shared understanding of the vision among all stakeholders. This helps build commitment and ensures the planning process reflects diverse interests and perspectives. Active stakeholder engagement at this stage is key. Questions to address at phase 3 include:

Q1: What challenges should integrated spatial planning aim to address?
Q2: What is the long-term vision for the municipality or region in tackling these issues?
Q3: What specific and measurable objectives should be achieved?
Q4: How can all relevant stakeholders be engaged and aligned with the defined vision and goals?
Q5: Are these goals consistent with the targets outlined in overarching (inter/national) strategies?

The output of phase 3 will include:
- Agreement on overall vision and goals.
- Broad commitment to vision and goals by all relevant stakeholders.
- Alignment of goals with overarching strategies.

Phase 4: Planning Phase

After identifying local issues and confirming the goals with stakeholders, the next phase involves developing spatial scenarios and conducting modelling. Based on these insights, specific activities and measures will be defined to support the drafting of the spatial plan. By analysing the overlap of various thematic indicators, it becomes possible to recognize both positive and negative interactions within spatial configurations. The objective is to establish a sound, spatially informed foundation for decision-making, which will guide the creation of a viable draft plan and ultimately lead to the publication of the final version. Necessary question to be addressed in phase 4 of integrated planning process are:

Q1: Which measures can be introduced to ensure the defined goals are met?
Q2: Which of these goals are effective and which of them are the most effective among others?
Q3: How can these measures be integrated into an effective, coherent action plan?
Q4: Is this plan feasible and effective?
Q5: How can the plan be finalized and the support of all relevant stakeholders be secured? ?

The output of phase 4 will include:
- Identification of Potential measures.
- Modelling and simulation of Various scenarios.
- Preparation of a draft plan.
- Final check for feasibility and spatial impact
- Creation and agreement on a formal draft plan .

Phase 5: Monitoring and Evaluation

Monitoring and evaluation are critical tools supporting public authorities in implementing and improving integrated spatial development after the plan has been adopted. It allows the project team to assess whether the intended progress has been made and whether corrections are necessary. The

monitoring takes part in parallel to the implementation of the plan and has the main purpose of identifying potential issues ahead of time to take corrective action. Accordingly, phase 5 provides guidance and highlights some key concepts and elements for developing and making use of a systematic monitoring system suitable for integrated spatial development. Questions to be addressed at phase 5 encompass:

Q1: How can the implementation of the plan be monitored? Which actors are involved in overseeing this phase?

Q2: Which aspects must be taken into account to design a meaningful and effective set of indicators?

Q3: What happens after the adoption of the plan?

Q4: How can monitoring results be communicated and who should be addressed?

The output of phase 5 will include:

- A monitoring framework has been established.
- A set of indicators as the basis for monitoring has been developed.
- Monitoring is periodically carried out and results are summarised.
- Monitoring results are communicated to relevant stakeholders and utilised.

This chapter explored the innovative concept of energy transition through the lens of Territorial Acupuncture (TA), a framework recently examined by a group of researchers who simultaneously link urban regeneration with energy interventions [2].

Accordingly, the study of TA requires a dual layer of assessment and information gathering. On one hand, addressing both energy-related and spatial data at a territorial scale is inherently complex and requires the collaboration and coordination of multiple stakeholders and responsible parties. On the other hand, the intricacies of urban energy systems at a macro scale—especially within urban environments characterized by undefined or fragmented spatial relationships—a holistic and co-creative approach becomes essential. Such an approach helps to integrate diverse data sources and bring together the people necessary to guide the territorial assessment process effectively.

The current literature increasingly highlights the relevance of TA in urban planning, emphasizing how the integration of renewable energy considerations into spatial and strategic planning not only adds value but also strengthens the potential for implementing energy, mobility, and broader sustainability initiatives within urban development frameworks.

Overall, this chapter provides a foundational understanding of TA and its role in strategic planning. The next chapter will further develop this discussion by tracing the theoretical roots of TA, examining antecedent frameworks such as biourbanism and urban acupuncture (UA), and considering the role of place-making in small-scale interventions.

2. From Urban to Territorial Acupuncture: Transforming Territorial Energy through Placemaking

This chapter addresses the key concepts and theoretical foundations from that have shaped the evolution of TA. It begins by examining the theories of UA and biourbanism as the foundational framework of the TA approach. This is followed by an exploration of the placemaking concept, which closely aligns with the principles of UA. The chapter then discusses how TA is derived from these ideas and outlines its overarching aims and focus. It concludes with a summary and a brief overview of Chapter 2, highlighting its connection to Chapter 3.

2.1. Theories of Urban Acupuncture: Exploring the Foundational Concepts Behind Territorial Acupuncture

Emerging in the final decade of the 20th century, UA has evolved into a theoretical framework centred on small-scale interventions within the urban fabric, targeting strategic points capable of triggering broader urban transformation.

This theory draws its essence from the metaphor of traditional Chinese medicine, where needles are strategically inserted into specific points of the body to stimulate energy flow and promote healing. Similarly, UA concentrates on low-cost, small-scale interventions aimed at improving urban and social conditions. By revitalizing targeted areas of the city, these interventions support and enhance broader urban planning strategies.

The UA's practices often emerge as a valuable tool for fostering innovative forms of participation in urban transformation processes. The concept refers to projects characterized by a high degree of reversibility [18]. UA introduces the idea of reshaping urban fabric through targeted technical actions, framed within broader urban regeneration strategies. Highlighting its catalytic role in the urban environment, studies by Zagora & Šamić (2021) and Del Marmol (2022) describe UA interventions as having long-lasting effects, not only within the targeted area but also in enhancing the function and vitality of surrounding spaces, when properly implemented [18,19]. Similarly, Apostolou (2015) describes UA as a regenerative approach that helps restore urban balance by identifying and acting upon strategic points within the city, with lasting impacts on both social dynamics and urban morphology [20].

Lerner (2014) views the advantages of UA through political and economic lenses. In addition to emphasizing its ability to deliver immediate improvements to the urban environment, hehighlightsUA's potential to bypass lengthy decision-making processes and economic barriers by asserting the point that *"lack of resources is no longer an excuse not to act"* and warning that "the idea that action should be taken only after finding all the answers and accordingly, warns that *"the idea that action should be taken only after finding all the answers and resources is a sure recipe for paralysis"* [21].

2.2. Role of Placemaking in Identification of TA Approach

The intellectual lineage of placemaking can be traced to the critical works of Jane Jacobs, Kevin Lynch, and William Whyte, who, during the 1960s, challenged the dominant paradigm of automobile-centered urban development Their ideas introduced a human-scale vision of urban life, advocating for cities as spaces shaped by social interactions, spontaneity, and community identity. Placemaking emerged from this critique as a practical and philosophical method for transforming public spaces through inclusive, site-specific strategies that enhance social well-being and foster a sense of belonging [22].

UA, a term popularized by Lerner (2014), shares conceptual ground with placemaking by focusing on small-scale, highly localized interventions that act as catalysts for broader urban transformation [21]. Rubió et al., (2008) highlights how these subtle, yet strategic, interventions—such as the insertion of green infrastructure or community spaces—can revitalize neglected areas and enhance the overall quality of urban life. These approaches emphasize minimal physical intervention with maximal social and environmental impact, positioning place as not only a geographic unit but a socio-cultural construct essential to urban vitality [23].

Scannell & Gifford, (2010) tripartite model emphasizes that place attachment bolsters community cohesion, encourages civic engagement, and contributes to mental well-being—foundational dimensions that are central to socially grounded energy transition strategies [24]. Devine-Wright, (2013) advances this argument by demonstrating that place attachment is a key determinant of to public acceptance of renewable infrastructure [25]. Likewise, van Veelen & Haggett (2017) reveal profound

emotional relationship with landscape—including perceptions of the site's *"feel of the soul"*— play a crucial role in shaping community support for energy Initiatives [26].

Energy transition strategies require territorial transformations—whether through renewable infrastructure, decentralized grids, or community energy systems—yet these changes must not be spatially abstract or imposed. Instead, they must be rooted in the lived experience and identity of place. According to Delgado-Jiménez (2024), spatial occupation in support of energy transition must reflect the relationship between people and their environment. Places are where abstract policies meet the everyday realities of communities. Hence, placemaking is not peripheral concern but central to energy transition—it humanizes it [27].

Contemporary definitions of placemaking vary, encompassing goals from economic revitalization to cultural preservation. However, a shared feature is the emphasis on inclusive processes and collaborative governance. Placemaking is inherently participatory, often beginning with the smallest unit—the individual or local community—and scaling upward to affect broader spatial dynamics. Wyckoff et al. (2015) Drawing on the principles advanced by the Project for Public Spaces, Wyckoff (2014) and Wyckoff et al. (2015) emphasize that effective placemaking enhances the collective value of space by actively engaging its users in processes of design and transformation [28, 29]. This participatory ethos aligns closely with the concept of co-creation, a process that requires early and continuous collaboration between professionals and community members.

As framed by Manzini (2015), placemaking operates within the "high involvement" quadrant of participatory design, where the transformation of place is inseparable from the empowerment of its people [30]. Sanders & Stappers (2008) define co-creation as a mutual, designer–non-designer process that unfolds within what Lee (2008) calls a *"realm of collaboration."* The quality and authenticity of this collaboration directly affect the success of placemaking initiatives, especially when these are linked to complex transformations such as the energy transition [31, 32].

Considering global sustainability commitments—such as the United Nations Framework Convention on Climate Change and the Agenda 2030 for Sustainable Development—the European Union has issued directives aimed at accelerating the green transition. These policies go beyond environmental protection; they actively shape the development trajectories of urban and rural areas alike. However, for these goals to materialize meaningfully at the local scale, they must be translated into spatial practices that reinforce the cultural identity, livability, and resilience of place. Guidelines, handbooks, and participatory planning tools are therefore necessary to empower local authorities and citizens to navigate these changes together.

In this regard, Delgado-Jiménez (2024) offers a comprehensive framework for integrating placemaking into energy transition initiatives. Their model is structured around four thematic groups of principles [27]:

Group 1: Foundational Concepts

1. **The Community is the Expert:** Effective projects are rooted in local knowledge and active citizen involvement.
2. **Create a Place, Not Just a Design:** Planning should integrate real-life usage and local values into spatial interventions.
3. **Seek Local Partners:** Collaboration with community-based organizations strengthens ownership and longevity.
4. **Overcoming Constraints:** Address regulatory fragmentation and diverse territorial contexts with adaptive strategies.

Group 2: Planning and Engagement Techniques

5. **Develop a Shared Vision:** Engage diverse stakeholders in shaping a collective direction for transition and sustainability.

6. **Observe Before Acting:** Pay close attention to local conditions and scale-specific characteristics before implementing change.

Group 3: From Vision to Action

7. **Form Supports Function:** Policy and design must reflect and support the multifunctionality of space.
8. **Strategic Placement of Amenities:** Leverage public infrastructure to foster interaction and enhance accessibility.
9. **Lighter, Quicker, Cheaper:** Use small-scale interventions with low costs and high visibility to build momentum.

Group 4: Implementation

10. **Resourcefulness Over Resources:** Empower communities to contribute ideas, labor, and networks, reducing financial burdens while enhancing engagement.

These principles stress that the energy transition is not merely a technological or policy challenge—it is a spatial and social transformation. The intersection of energy systems with place-based practices like placemaking and UA represents a powerful opportunity: to reimagine cities and regions not only as carbon-neutral, but also as inclusive, vibrant, and resilient environments. When small, strategic interventions are guided by community values and linked to broader territorial planning, they can create ripple effects—both socially and ecologically—across the urban fabric.

2.3. From Urban to Territorial Acupuncture: Driving Energetic Transitions in the Urban Landscape

TA builds upon the conceptual foundation of UA, expanding its principles from the scale of individual neighbourhood or city block to that of entire region or territorial system. While UA, inspired by traditional Chinese medicine, focuses on small-scale, precise interventions—targeting *"pressure points"* in the urban fabric to stimulate broader systemic transformation—TA extends this logic to a more complex and integrated landscape. In this model, the territory is regarded as a single, dynamic organism. Just as acupuncture can trigger healing throughout the body via focused insertions, localized interventions—particularly the implementation of interconnected energy communities—can catalyze positive social, environmental, and economic effects across the entire region. The aim of this approach is to address and recalibrate the interconnected energy, social, and environmental dynamics within the territory. It contributes to the broader transition toward carbon neutrality by proposing localized solutions that scale in impact without requiring invasive, large-scale redevelopment. The analytical phase of the process plays a crucial role in this transformation. It synthesizes a wide range of data collected during preliminary research stages, helping to identify critical areas of intervention and potential misalignments within the system. Through the use of visual tools such as charts, thematic maps, lists, and spatial catalogues, a structured framework for understanding the territory is developed.

The application of TA demands a multi-dimensional analysis of various spatial and social parameters. These include the configuration of the urban fabric, population density, the historical development of urban settlements, the distribution of green and blue infrastructure, existing energy systems, the availability and potential of renewable energy sources, climate adaptation policies, mobility and transport networks, demographic patterns, service accessibility, and the community's willingness to embrace change. Each of these factors contributes to a nuanced understanding of the local context and helps ensure that proposed interventions are both effective and sensitive to place-specific dynamics.

Importantly, the methodology seeks to promote carbon neutrality in densely inhabited regions without resorting to disruptive overhauls of existing urban structures. At the same time, it aims to address the longstanding imbalance between large metropolitan centers and smaller towns by enabling a more equitable and distributed model of development. To develop this methodology, two distinct but complementary theoretical perspectives were combined: the micro-scale insights of UA and the systemic vision of energy district planning. These approaches were not simply juxtaposed but carefully

integrated and reimagined to support a new, holistic framework for territorial transformation—one that leverages the precision of localized interventions within a broader strategic vision.

By synthesizing these two strands—UA and TA—this framework positions itself as a tool for sustainable transition, capable of responding to the environmental challenges of our time while enhancing the liveability, resilience, and functionality of both cities and regions.

This chapter begined by outlining the key theoretical foundations of TA and examining UA as a tool for small-scale urban interventions. UA presents a practical approach to enhancing urban greenery through precise assessments and analyses of the built environment. These interventions aim to improve spatial functionality by embedding ecological value into existing structures. While UA focuses on localized transformation, TA extends the discussion by emphasizing the broader impact of energy community interventions in strengthening the identity and purpose of a place. Within this framework, placemaking emerges as a supportive strategy, bridging UA's site-specific actions with TA's goal of fostering functional recognition, collective identity and redefinition of urban spaces.

3. Co-Creation in Action for Territorial Acupuncture

This chapter shifts from the theoretical foundations of TA to its practical application by positioning CC process as a central component of the territorial intervention process. Given the cross-sectoral and participatory nature of TA, where academic, technical, and political expertise converge, the chapter frames CC Through the BB model, providing a clear and operational structure to organize activities. This framework facilitates the identification of sites with potential for transformation into Community Energy Hubs or PEDs, ensuring that stakeholder engagement contributes to the long-term viability and spatial relevance of renewable-energy interventions within broader place-making strategies.

3.1. Steps in Implementing Territorial Acupuncture Approach

As stated by Leone et al. (2023), the TA approach employs a technically driven, top-down methodology to map territorial contexts and identify strategic intervention points - similar to acupuncture needles- where initiatives such as energy communities or centralized energy systems can be implemented to generate benefits for the surrounding areas. The decision between these two solutions depends on the specific characteristics of the targeted district (the acupoint) [2].

For instance, if the selected acupoint corresponds to an undeveloped, abandoned area located away from residential centers, it is more likely to be suited for hosting an energy generation facility that serves a broader region. The type of intervention recommended ultimately depends on the local context and needs of each area. Among the available options, the PED model—an advanced form of energy community—is currently regarded as the most effective and efficient solution. Figure 3 shows how the phases of Territorial Acupuncture function, following the framework proposed by Leone et al. (2023).Given the synergy between five steps of TA and the CC process, this section focuses on outlining the TA framework itself. The following section will then introduce a proposed CC process tailored to TA and the broader energy transition.

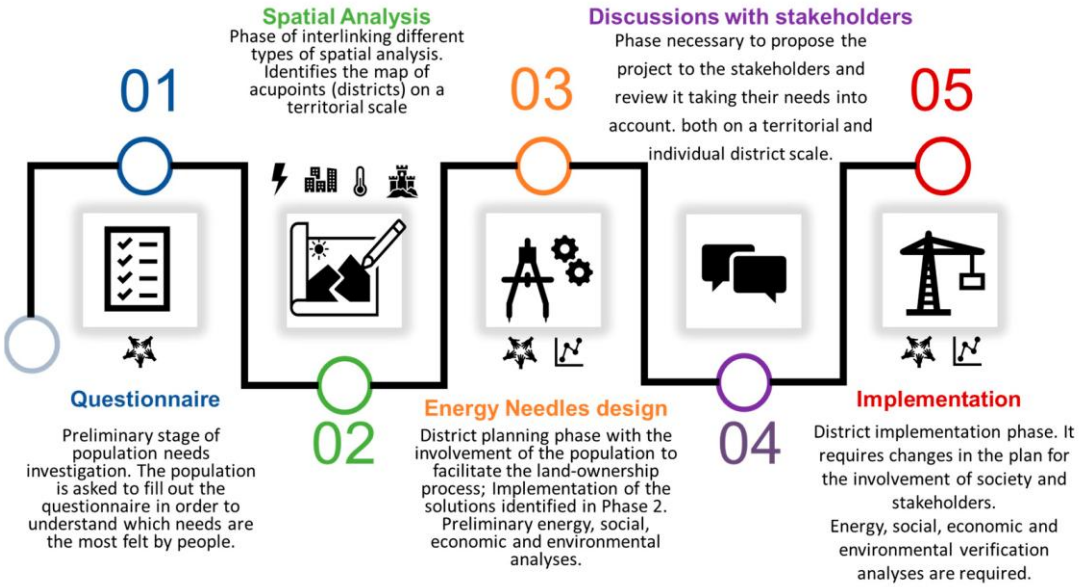


Figure 7. Functioning of the Phases in Territorial Acupuncture [2]

To effectively implement the TA approach, five strategic steps must be followed.

1. The initial stage involves engaging the local population through a structured questionnaire. This preliminary consultation is essential for identifying the community's key needs and priorities, which will inform and guide the subsequent phases of the project.
2. The second phase of the TA process involves conducting a comprehensive spatial analysis of the territory through a multidisciplinary approach. The objective is to develop an intervention map at the territorial scale, identifying key nodes where targeted actions will be implemented. This mapping serves as a foundational tool for planning modifications and adaptations at the district level and, over time, across the broader territory.
   Completing this level of analysis is essential to ensure that all relevant factors—such as infrastructure, environment, landscape, urban dynamics, and others—are considered. The following analyses must therefore be carried out:
   - Energy analysis of the entire territory
   - Compound analysis
   - Infrastructure analysis
   - Isochrone identification in 45-min drive of the main point of attraction
   - Historical and landscape analysis to identify constrains and risks
   - Land value analysis
   - Analysis of equipment distribution in the territory
   - Analysis of the distribution of brownfield sites and abandoned lands on the territory.

   In this phase, individual analyses are conducted separately and then integrated, either through expert consultation or by overlaying the results. This method enables the development of a comprehensive map identifying specific districts as intervention points. As a result, both the appropriate types of interventions for each district and a corresponding implementation timeline can be effectively defined.
3. The third stage involves zooming in from the territorial scale to focus on the district level, refining the previously developed map to design specific "acupuncture needle" intervention points. This shift allows for a targeted approach to improving energy efficiency at both the district and neighbourhood scales. These acupoint locations may take the form of energy communitiesor support zones for energy infrastructure, like solar or wind power plants.

At this stage, aligning the design of intervention areas with the needs and expectations of local residents is crucial. Doing so fosters a sense of ownership and belonging, while also helping to prevent future neglect or abandonment of these spaces. Additionally, preliminary analyses and simulations must be conducted to assess the district's energy demand, estimate the output of selected technologies, and evaluate the overall effectiveness of the proposed interventions.

4. The fourth stage involves clear communication and open dialogue with all stakeholders involved in the project. This step is essential for reaching consensus on the actions to be taken at both the district and territorial scales. During this phase—focused on verifying decisions and refining the plan—minor adjustments may be made to ensure alignment with stakeholder input and evolving project needs.
5. The final phase involves the implementation of the PED, including the construction and activation of all planned infrastructure and facilities. Concurrently, verification analyses will be conducted to assess the performance, effectiveness, and efficiency of the adopted solutions. Ultimately, the PEDs will be integrated according to the timeline and strategy established during the initial spatial analysis phase.

3.2. Framing Territorial Acupuncture Steps into Co-Creation Roadmap

Establishing a robust framework for integrating CC into the TA process requires aligning collaborative activities with the specific steps of TA implementation. To streamline this integration, a BB approach is adopted, breaking down each phase of CC into manageable, functional layers that support TA execution and facilitate the energy transition. Figure 4 illustrates the synergistic framework of CC applied to the context of the TA framework.

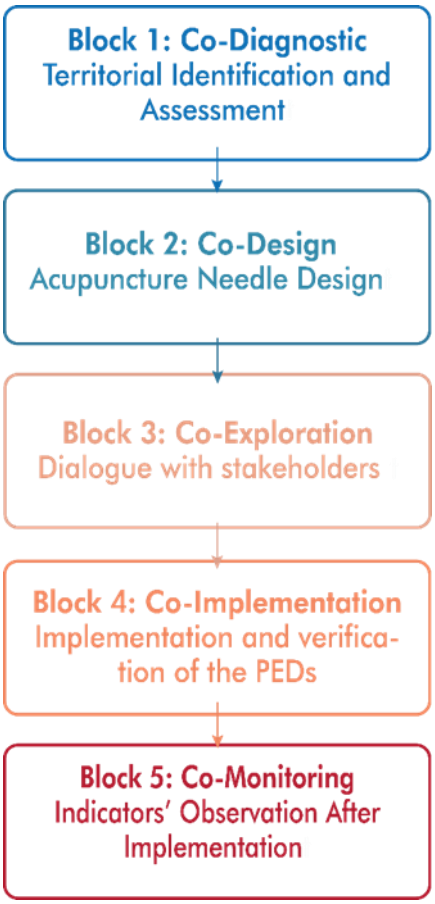


Figure 4. Co-Creation process Framework for Territorial Acupuncture

This framework emphasizes synergy between the Co-Creation process and the structured stages of TA. Each building block corresponds to a distinct phase of Co-Creation, providing a structured methodology for engaging stakeholders, analysing territories, and implementing sustainable energy solutions. The following blocks outline the key phases of this approach:

Block 1: Co-Diagnosis – Territorial Identification and Assessment

This initial phase focuses on understanding the unique characteristics and needs of a given territory. Activities include distributing questionnaires to gather qualitative data and conducting spatial analyses to map existing conditions. The goal is to assess infrastructure, environmental assets, landscape features, and urban dynamics in order to identify opportunities for targeted interventions.

Block 2: Co-Design – Acupuncture Needle Design

This phase involves a preliminary study of the selected intervention area (referred to as the "acupoint"), with a focus on community energy solutions and PEDs. It includes multi-criteria spatial analysis, defining a collective vision, and developing future scenarios for the acupoint. The aim is to create a clear and context-sensitive strategy for transformation.

Block 3: Co-Exploration – Dialogue with Stakeholders

Building upon the co-design phase, this stage deepens engagement through stakeholder workshops. Participants refine the shared vision using technical and spatial evaluations, assess potential implementation challenges, and collaboratively shape the roadmap for action. It is a critical point for aligning stakeholder interests with project goals.

Block 4: Co-Implementation – PEDs Implementation and Verification

Here, the framework moves into action. Solutions developed during earlier phases are implemented, and their alignment with the envisioned outcomes is analysed. This phase includes feasibility assessments, resource allocation, and early-stage monitoring to ensure the strategies are on track.

Block 5: Co-Monitoring – Post-Implementation Indicators and Evaluation

In the final phase, a set of performance indicators is defined and monitored to evaluate the impact of the implemented solutions. This includes tracking environmental, social, and technical metrics to assess effectiveness and inform future iterations of the TA process.

This chapter concludes by reviewing the operational steps of TA and aligning them with the co-creation process within the TA framework. Accordingly, part of the chapter focuses on outlining the procedural structure of TA. Following this, the Building Block approach is introduced, presenting five core blocks of co-creation. A general overview of what each block entails is provided here, while a more detailed explanation of each block and its specific steps will be discussed in the next chapter.

Figure 5 illustrates the comprehensive roadmap of CC on TA, detailing its sequential steps and the structured workshops associated with each action block. The roadmap is developed in alignment with the BBA logic and offers an overarching view of the CC framework for TA. Detailed descriptions of each action block, including their respective steps and planned activities, are provided in Chapter 4, Section 4.1.

CO-CREATION ROADMAP FOR TERRITORIAL ACUPUNCTURE

The co-creation process in Territorial Acupuncture supports multi-scalar collaboration with citizens, officials, stakeholders, and academics as a strategy for advancing renewable energy transitions.



BLOCK 1 : CO-DIAGNOSTICIAN
Territorial Identification and Assessment

Step 1.1: System Definition
- Define the Territorial Scale (Nation, Region or City)

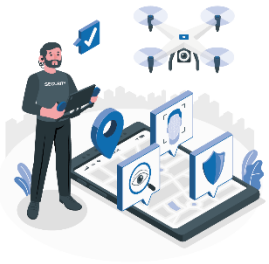
Step 1.2: Stakeholders' Identification
- Identification of Stakeholders at Territorial Scale
- Baseline context assessment
- Mapping stakeholders for 1st stage of engagement

Step 1.3: Analysing Socio-Economic and Political Status
- Understand local needs and barriers via the questionnaire
- Political Revision of the Territory
- Analysis socio-economic status of citizens at Territorial Scale
- Economic Developments of a Territory and Its Aspects

Output: Territorial Acupoints Map & Development Priorities
- Elaborating Scenarios for Acupoints (Intervention Areas)
- Generate All acupoints at territorial level
- Define Potential Scenarios and Narratives
- Assess the territorial framework and initiatives

Step 1.4: Diagnosis of Green-Blue Elements of the Territory & Potential Risks
- Multidisciplinary Territorial Analyses
- Defining Natural Capital and land values and constrains
- Analysis of all energy spots including communities energy or PEDs

W01 W02



BLOCK 2 : CO-DESIGN
Acupuncture Needle Design

Step 2.1: Co-Design Requirements for the Selected District
- Preliminary Analysis at District/Community Scale
- Define study area at Community Energy or PEDs
- Data Collection the areas with the needs of the population

Step 2.2: District Multicriterial Evaluation
- Multidisciplinary Territorial Analyses
- Defining Natural Capital, Land Values and Constrains
- Analysis of All Energy Spots including Communities Energy or PEDs

Output: Scenario-Driven PED Development Plan
- Digital Twins of PEDs for Simulating and Modeling Future Scenarios
- Simulate Results of the District's Assessment

Step 2.3: District Scenario Building
- Elaborating Results for Simulation and Modeling
- PEDs Scenarios and Possible Solutions
- Strategic District Planning Agenda for Energy Transition
- Assess Municipal Frameworks, Constrains and Risks for Implementing PEDs



BLOCK 3 : CO-EXPLORATION
Dialogue with Stakeholders

Step 3.1: Acupoint Development Vision
- Co-elaboration of SWOT Analysis and Diagnosis of Acupoint for PEDs Deployment
- Mapping City Department and Primary Stakeholders
- Co-design 2050 PEDs' Vision Application

Step 3.2: Discussion Session with Stakeholders
- Project insights and data for improved strategies
- Verification of the choices and concentration of the plan at district and territorial scale
- Participation, Discussion and Debate on PEDs Scenarios
- Project insights and data for improved strategies
- Define Structured Version of the Project Aspects for Future Scenarios

Output: District Planning Modification
- Slight Modification to the Plan after stakeholders Discussion

W03 W04



BLOCK 4 : CO-IMPLEMENTATION
Implementation & Verification of PEDs

Step 4.2: Co-Implementation of Solutions for PEDs
- Discuss Maintenance Requirements and Scalability Potential
- Incorporating the Energy Scenarios into Furniture Design
- Obtain Feedback from both Users and Local Officials
- Deployment and Evaluation in Public Spaces
- Developing Physical Prototypes following the Design Process

Step 4.1: Feasibility Analysis
- Estimating Cost, Efforts, and Community Impacts
- Aligning PEDs Implementation with the Project Vision and Feasibility Results
- Budget Definition based on Steps of the Projects

W05



BLOCK 5 : CO-MONITORING
Indicators' Observation After Implementation

- Define All the Indicators to be Improved through Project Completion
- Define Metrics to Assess Impacts of Each Indicator on Project
- Connect indicators to SDGs

Co-Development

Replicate and generalize the results of the project on another case studies



Figure 5. Co-Creation Roadmap for Territorial Acupuncture

4 Monitoring and Evaluating the Co-Creation Process of Territorial Acupuncture

This chapter explores the implementation of the Building Block Approach of CC for TA, as defined in the previous section. It outlines the steps required to operationalize each block and details the process for executing them effectively.

As previously described, each block will be presented individually. The chapter will discuss the relevant steps (sub-blocks), key aspects, and procedures to be followed in a step-by-step manner. Each block will conclude with a description of its expected output.

Additionally, for each block, a corresponding workshop will be introduced. The objectives, methodology, and involved stakeholders of each workshop will be detailed, taking into account the specific functionality of the respective block.

4.1. Building Blocks of Co-Creation

Block 1: Co-Diagnosis – Territorial Identification and Assessment

As the first step in the co-creation process, this phase provides essential information about the territorial scale of intervention and includes two important components of the Territorial Assessment. First, it involves collecting data through questionnaires distributed to individuals. Additionally, it conducts a spatial multi-criteria analysis of the entire territory. *Territorial Identification & Assessment* contains following steps:

- **Step 1.1:** ***System definition***

  At this stage, it is important to determine the territorial scale of focus. We need to identify the appropriate scale of intervention at the territory—whether it should focus on the, national, regional, city or the district level.
- **Step 1.2:** ***Stakeholder's Identification***

  Following with indication of territorial scale, there is a mandate to define all the stakeholders at first stage of engagement involved at territorial assessment.
- **Step 1.3:** ***Analysing Socio-economic and Political Status***

  This step outlines anapproach that involves citizens to gain insights into their needs and the changes they envision for their immediate environment. As part of this proposed process, a selected group would collect individual responses through a questionnaire.
- **Step 1.4:** ***Diagnosis of Green-Blue Elements of the Territory & Potential Risks***

  A multidisciplinary territorial analysis is conducted, combining geospatial assessments with the evaluation of physical, environmental, and regulatory constraints.
- **Output:** ***Territorial Acupoints Map***

  This block results in a Territorial Acupoints Map that highlights key intervention areas and potential sites throughout the territory, serving as a foundation for scenario development in the following phase.

Workshop 1: ***Bringing Citizens to the Table – Involving citizens to identify needs in territorial transformation***

- **Objective:** The main objectives of this workshop at territorial scale are the following:
  - Collect insights on community needs and aspirations for local improvements.
  - Share first multi-criteria assumptions and results to identify jointly Acupoints (key intervention points) in the territory.
- **Methodology:** The analysis is conducted by:
  - Involving citizens in questionnaires, workshops, and participatory board games.

  - Sharing and discussing insights from multi-criteria spatial analysis to establish a foundation for further elaboration.
- **Engaged Stakeholders:** The main groups of stakeholders to be involved at this scale of analysis are:
  - Municipalities
  - Professionals, and experts, including urban planners, environmental engineers, geologists, and academic staff, and
  - Citizens

During the first workshop, participants would respond to questions designed to understand how they perceive and talk about renewable energy, and what ideas or experiences they can share to support local energy solutions.The full set of questions, presented in a simplified format to engage citizens and encourage their involvement in the project, is provided in Table 1.

Table 1. Checklist of Community Information on Energy Transition and Its Relevance to Territorial Acupuncture

Community Questions on Energy and Urban Improvements (Territorial Acupuncture & Energy Transition)				
Questions	**Yes**	**Partially/Not Sure**	**No**	**Comment(s)**
1. Are there efforts in your community to make better use of existing spaces rather than building outwards into natural areas?				
2. Have you noticed any small projects (like pocket parks, green roofs, solar panels, or shared spaces) that help reduce energy use or improve comfort in your neighbourhood?				
3. Are new buildings or renovations using clean energy (like solar panels or heat pumps) or being designed to save energy?				
4. Are there places where the community can produce and share energy locally, such as solar cooperatives or neighbourhood energy groups?				
5. Do you know if there are any plans or projects in your area that make use of sunlight or wind to produce electricity?				
6. Have you noticed any changes in how homes or buildings are heated or powered in your area, such as new equipment, energy-saving devices, or other improvements?				
7. To your knowledge, do local plans consider that different homes may have different heating or cooling needs?				

8. Have you seen anything in your area that helps reduce heat in outdoor spaces, such as trees, shaded areas, or water features?				
9. Have you seen any improvements in your neighborhood's public areas, like adding shade, trees, or better drainage, to make them nicer and easier to use in hot or rainy weather?				
10. Do you know if anything has been done in your area to help people walk or bike more easily, or to improve buses and shared vehicles?				
11. Are parking spaces or car-dominated areas being redesigned to support greener uses (like mobility hubs, bike lanes, or green spaces)?				
12. Do you feel there are enough charging stations or facilities for electric vehicles in your area?				
13. Are local green areas or natural corridors being improved or connected to help plants, animals, and cooler air move through the city?				
14. Are energy and mobility changes planned in a way that respects local culture, history, and identity?				
15. Do you think these small, targeted improvements (urban acupuncture) help create stronger connections between people, places, and clean energy solutions?				

Workshop 2: ***Data to Action Talk– Territorial Analysis and Acupoints' Identification***

- **Objective:** The main objective of the second workshop at territorial level and as the output level are:
    - Create a second iteration and unified map of Acupoints within the whole territory.
- **Methodology:** The analysis is carried out by summarizing the solutions generated from the socio-economic and environmental assessments.
- **Engaged Stakeholders:** The main group of stakeholders to be involved at this scale of analysis are:
    - Technical staffs including professionals, and experts—as urban planners, environmental engineers, geologists, and academic staff.

As part of the second round of technical workshops and based on the findings from the spatial analysis of the territory, Table 2 presents a follow-up technical checklistdesignedto collect input from stakeholders.

Table 2. Technical Checklist of Activities for Territorial Acupuncture [17]

Spatial Planning	Yes	Partially	No	Comment(s)
Compact Settlement Structures				
Is the plan prioritising inner over outer settlement development?				
Is the plan pushing for re-densification within existing settlement areas to achieve an adequate building density?				
Is the plan controlling the density of settlement structures, e.g. by defining minimum and maximum permissible development densities?				
Is the plan implementing mixed land uses and promoting diversity of uses?				
Is the plan aligning spatial development with existing infrastructure or future infrastructure developments (e.g. public transport, district heating network)?				
What measures or considerations should be included to ensure development supports a compact and efficient settlement pattern?				
Renewable Energy Generation and Building Energy Performance	**Yes**	**Partially**	**No**	**Comment(s)**
Managing Energy Demand				
Does the plan promote energy-efficient building practices that reduce operational energy demand and support long-term sustainability?				
Does the plan support the local production and consumption of renewable energy, e.g. through energy communities?				
What strategies should be prioritized to enhance building energy performance while encouraging local renewable energy generation?				
Harnessing Energy Potentials and Ensuring Efficient Supply				

Does the plan mandate standards for energy performance of buildings or for the use of renewable energies?				
Does the plan identify local renewable energy potentials?				
Does the plan designate prioritised areas for renewable energy generation?				
Is the existing grid infrastructure (electricity and heat) sufficient to accommodate future energy demand and supply?				
What strategies should the plan adopt to maximize local renewable energy resources and maintain an efficient and reliable energy supply?				
Heating and Cooling Planning				
Does the plan consider heating & cooling demand and supply in a spatially differentiated way?				
What measures should be included to balance heating and cooling needs across the territory in a sustainable way?				
Climate Adaptation	**Yes**	**Partially**	**No**	**Comment(s)**
Addressing (Urban) Heat				
Does the plan consider fresh and cold air corridors?				
Does the plan map out urban heat islands and/or use other data to identify areas vulnerable to climate change?				
Does the plan consider measures for the climate-resilient transformation of public space?				
Does the plan set up regulations for climate-resilient buildings?				
What additional approaches could help the plan manage urban heat while improving the resilience and comfort of city areas?				
Disaster Risk Management				
Does the plan consider measures to prepare urban spaces for heavy rainfalls?				

If you are located at the coast, does the plan consider measures for mitigating risks of flooding and erosion?				
If you are located on a river or in a mountainous area, does the plan consider measures for mitigating risks of flooding, landslides and/or avalanches?				
If you live in areas with heavy snow or very cold winters, are there any measures in your area to reduce risks from snow, ice, frozen rivers, or winter storms?				
If you live in a windy or low-lying area, are there any measures in your neighborhood to reduce risks from strong winds, storms, or flooding, such as barriers, improved drainage, or reinforced buildings?				
Do you consider any other risk relevant for your case?				
Supporting Biodiversity				
Does the plan set measures to protect existing and provide new habitats for a diverse flora and fauna?				
Does the plan take into account measures to connect existing natural habitats?				
Does the plan consider measures to adapt existing ecosystems to changing climatic conditions?				
What additional measures could help the plan safeguard and strengthen biodiversity while responding to climate change?				
Sustainable Mobility	**Yes**	**Partially**	**No**	**Comment(s)**
Does the plan consider the hierarchical A-S-I approach (Avoid – Shift – Improve) in your planning?				
Does the plan include both passenger transportation and urban freight aspects in your planning?				
Does your mobility plan consider the different needs of the local population as well as other groups (for example commuters or tourists)?				

What measures could the plan include to encourage more sustainable travel patterns using the Avoid–Shift–Improve framework?				
Reorganization of Streets				
Does the plan take into account the various street functions and categories of your area to transparently justify mobility planning decisions?				
Does the plan set measures to reduce or reorganise parking spaces or streetscapes?				
Does the plan consider traffic calming measures to improve safety and quality in public spaces?				
What measures could help the plan optimize street use while enhancing both mobility and the public realm?				
Strengthen Sustainable Transport Offers				
Does the plan consider the needs of active mobility modes such as pedestrians and cyclists?				
Does the plan consider mobility measures in the early stages of new development areas and workplaces to foster new mobility behaviours?				
Does the plan consider new mobility solutions like vehicle sharing or implementing mobility hubs?				
What additional measures could help the plan strengthen sustainable transport offers and promote active and shared mobility?				
Promotion of Eco-friendly Propulsion Technologies				
Does the plan set up regulations or measures to reduce fossil-fuel based vehicle usage?				
Does the plan address the infrastructure needs for electric vehicles?				
What strategies could help the plan support eco-friendly propulsion technologies while meeting the mobility needs of the area?				

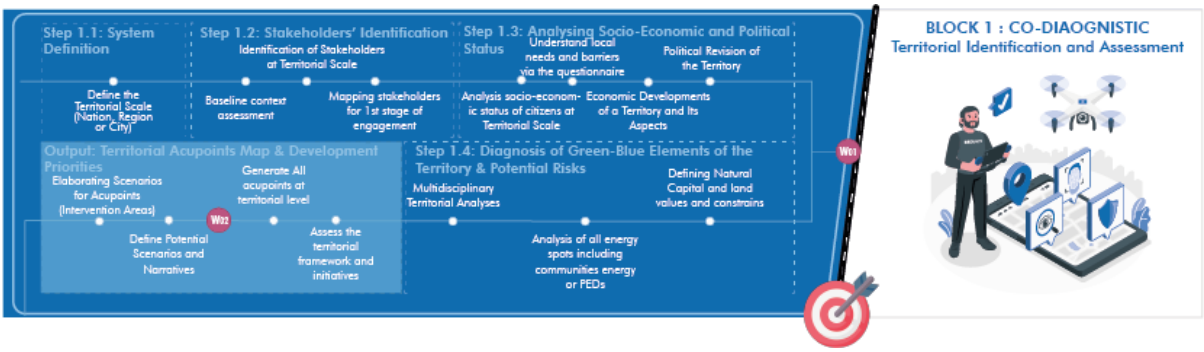


Figure 6. Aspects of *"Territorial Identification & Assessment"* and Its Outcomes

Block 2: Co-Design – Acupuncture Needle Design

This block represents a more focused level of intervention at the district or neighbourhood scale, aiming to identify key hotspots such as Community Energy initiatives or Positive Energy Districts (PEDs). It follows the identification of territorial acupoints and requires a concentrated analysis of a selected area within one of those acupoints. At this stage, all assessments and evaluations should be conducted specifically at the neighbourhood or district level. *Acupuncture Needle Design* contains following steps:

- **Step 2.1:** ***Co-Design Requirements for the Selected Districts***
  This step is related to define an intervention area at zoom in scale which it needs to be a community energy, PED or any other relatives. This step should be followed with preliminary district-level analysis based on citizens' needs.
- **Step 2.2:** ***District Multicriterial Evaluation***
  This step delivers information through a spatial multi-criteria analysis of districts, encompassing environmental and energy assessments of the entire community.
- **Step 2.3:** ***District Scenario Building***
  At this level of analysis, the District Scenario Building involves developing a strategic district planning agenda, including PED solutions and scenarios, which will be integrated into simulations and modelling for further discussion of the district development plan.

  Output: ***Scenario-Driven PED Development Plan***
  The outcome of this block is a Scenario-Based PED Development Plan, which incorporates the simulation and modelling of previous technical analyses and advances the creation of digital twins for PEDs to produce detailed, multi-layered representations of the city.

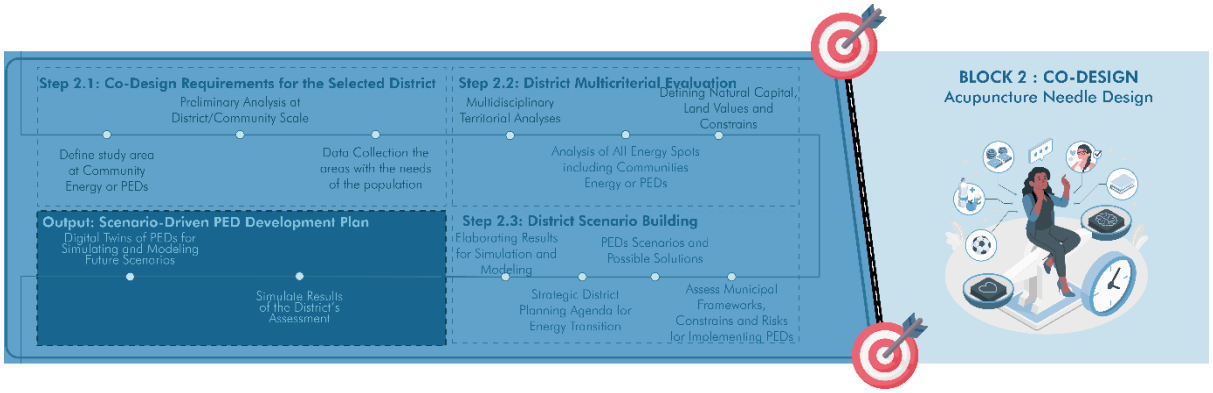


Figure 7. Aspects of *"Acupuncture Needle Design"* and Its Outcomes

Block 3: *Co-Exploration – Dialogue with Stakeholders*

This block, which is complimentary steps with Co-Design phase, follows a precise description with all the stakeholders involved in the process. This is one of important part following with the design phase. Dialogue with Stakeholders is a complementary step to the co-design of the certain acupoint and includes the following phases:

- **Step 3.1:** ***Acupoint Development Vision***
  Following with consolidating the results of the territorial assessment into a final model and defining a vision for the co-design of the acupoint to be presented at the stakeholders' meeting.
- **Step 3.2:** ***Discussion Session with Stakeholders***
  Participating in stakeholder workshops to present project insights and strategies, verify key decisions, and discuss the focus and future directions of the plan.

- **Output:** ***District Planning Modification***
  The outcome of this block is a Revised District Plan, reflecting adjustments made in response to stakeholder input and collaborative discussions.

Workshop 3: ***A Technical Perspective on Simulating PEDs with Targeted Acupoint Focus – Second Roundtable with citizens, Policy Makers and Stakeholders***

- **Objective:** The main objectives of the third workshop at neighbourhood level are:
  - Review the existing status and strategic direction of acupoint development plan (Intervention site)
  - Develop jointly priority criteria for the multi criteria analysis.
- **Methodology:** The analysis is conducted through:
  - Disseminate simulation outcomes from Digital Twins and connect urban planning strategies with organizational and governance dimensions.
  - Develop jointly priority criteria for the multi criteria analysis.
- **Potential Stakeholders:** The main group of stakeholders to be involved at this scale of analysis are:
  - Municipalities, Technical staffs including professionals, and experts, academic staff, local communities

Workshop 4: ***Co-Design Lab: Shaping the Future through Shared Models***

- **Objective**
  - Establish the project vision and strategic options through stakeholder meetings.
  - Finalizing the priority list for the PED design interventions based on multi criteria assessment.
- **Methodology:** The analysis is conducted through:
  - Delivering a comprehensive presentation of technical and simulation-based results from prior stages.
- **Engaged Stakeholders:** The main group of stakeholders to be involved at this scale of analysis are:
  - Policymakers, Municipality together with technical staffs including professionals, and experts, academic staff, investors, community-based association and local communities.

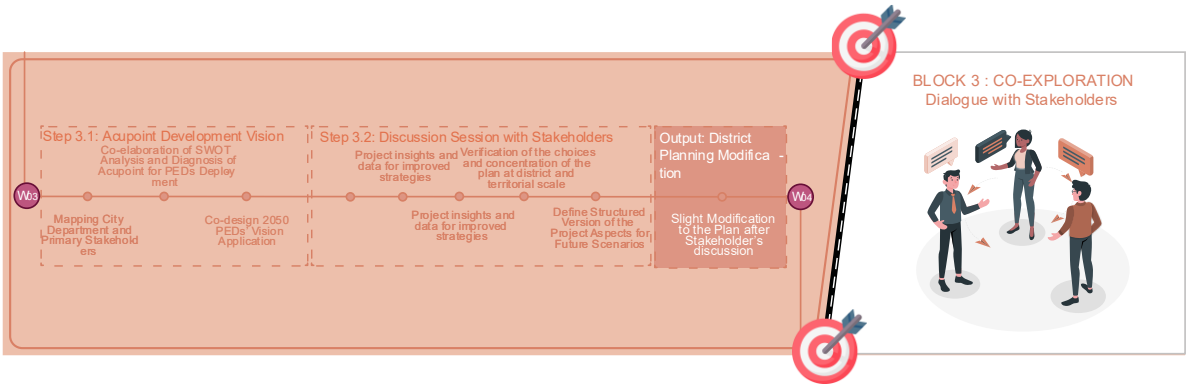


Figure 8. Aspects of *"Dialogue with Stakeholders"* and Its Outcomes

Block 4: *Co-Implementation – Implementation and Verification of PEDs*

This section outlines the implementation of all proposed solutions and the evaluation of their feasibility. A physical prototype for deploying PEDs in local areas will be assessed, and the specific requirements and strategies for scaling up will be discussed with legal authorities and local communities. Implementation and verification of PEDs contain following steps:

- **Step 4.1:** ***Feasibility Analysis***
  Managing the project according to the established vision, with a focus on implementing solutions and assessing financial and technical feasibility.
- **Step 4.2:** ***Co-Implementation of Solutions for PEDs***
  Creating prototypes based on the design process while assessing their scalability and to understand feedback from local citizens and officials.

This block consolidates the outcomes of all multi-criteria analyses and provides strategic direction for the project's implementation and future development.

Workshop 5: *From Vision to Action: Feasibility and Implementation Dialogue*

- **Objective**
  - To evaluate the feasibility and execution potential of the project in relation to the initial vision.
  - To assess the viability of implemented solutions by analysing expected results, projected costs, resource needs, and timelines.
- **Methodology:** The analysis is conducted through:
  - Through the presentation of results derived from the analysis of the project plan and established timeline.
- **Engaged Stakeholders:** The main group of stakeholders to be involved at this scale of analysis are:
  - Municipalities, Community-based associations, developers, landowners, Professionals and experts, Energy Providers

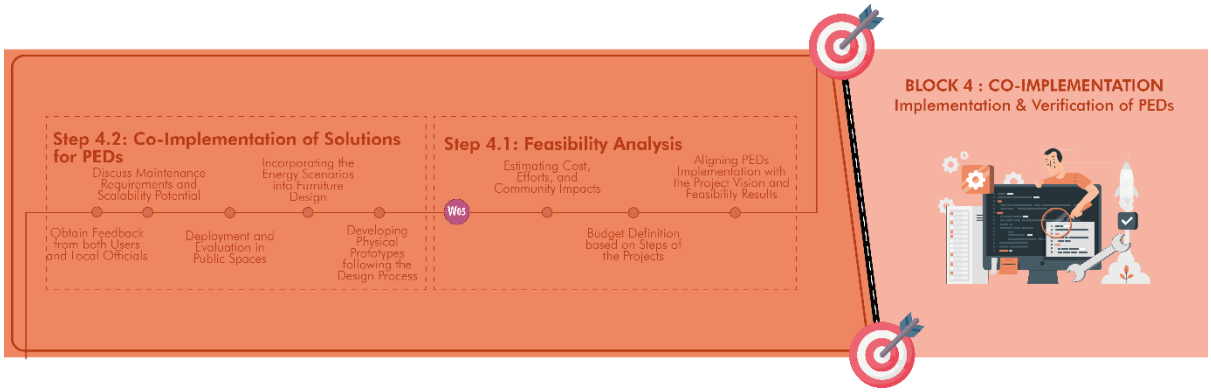


Figure 9. Aspects of *"Implementation & Verification of PEDs"* and Its Outcomes

Block 5: *Co-Monitoring – Indicators' Observation After Implementation*

This step in the CC process addresses all relevant indicators that can be achieved throughout the process. These indicators will be monitored and aligned with the corresponding Sustainable Development Goals (SDGs).

- **Step 5.1:** ***Indicator's Observation after Implementation***

  This step encompasses listing all indicators identified after implementing the solutions and linking them to relevant SDGs to understand which aspects of sustainable development are addressed, along with the metrics used for their evaluation.

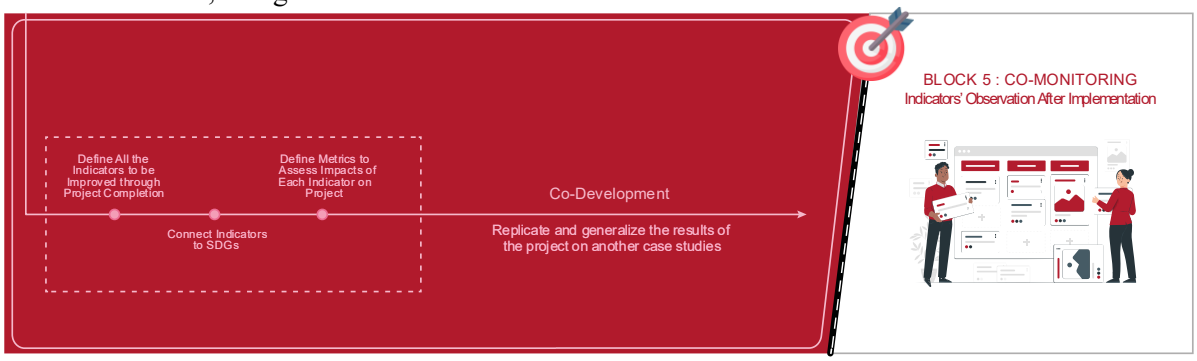


Figure 10. Co-Monitoring the Indicators for Co-Creation Process

Overall workshops conducted during the CC roadmap have been listed in Table 3, outlining the objectives of each workshop, the methodology used, and the stakeholders involved.

Table 3. Workshops' Table at Every Stage of Co-Creation Procedure

Block Name	Workshop	Objective	Methodology	Stakeholders

Block 1: ***Bringing Citizens to the Table – Involving citizens to identify needs in territorial transformation***	WS 01: Bringing Citizens to the Table – Involving citizens to identify needs in territorial transformation	• Collect insights on community needs and aspirations for local improvements • Share first multi-criteria assumptions and results to identify jointly Acupoints (key intervention points) in the territory.	• By involving citizens in questionnaires, workshops, and participatory board games. • Share and discuss insights from multi-criteria spatial analysis to establish a foundation for further elaboration.	Municipalities, professionals, and experts—including urban planners, environmental engineers, geologists, and academic staff and Citizens
	WS 02: Data to Action Talk– Territorial Analysis and Acupoints' Identification	• Create a second iteration and unified map of Acupoints within the whole territory	• By synthesizing the collected solutions derived from socio-economic and environmental analyses.	Technical staffs including professionals, and experts—as urban planners, environmental engineers, geologists, and academic staff.
Block 3: ***Dialogue with Stakeholders***	WS 03: A Technical Perspective on Simulating PEDs with Targeted Acupoint Focus – Second Roundtable with citizens, Policy Makers and Stakeholders	• Review the existing status and strategic direction of acupoint development plan (Intervention site) • Develop jointly priority criteria for the multi criteria analysis	• Disseminate simulation outcomes from Digital Twins and connect urban planning strategies with organizational and governance dimensions. • Polls and determination of numerical weights lists for different criteria.	Policymakers, Municipality together with technical staffs including professionals, and experts, academic staff, investors, community-based association and local communities
	WS 04: Co-Design Lab: Shaping the Future through Shared Models	• Establish the project vision and strategic options through stakeholder meetings. • Finalizing the priority list for the PED design interventions based on multi criteria assessment.	• Delivering a comprehensive presentation of technical and simulation-based results from prior stages.	

Block 4: *Implementation and Verification of PEDs*	WS 05: From Vision to Action: Feasibility and Implementation Dialogue	• To evaluate the feasibility and execution potential of the project in relation to the initial vision. • To assess the viability of implemented solutions by analysing expected results, projected costs, resource needs, and timelines.	• Through the presentation of results derived from the analysis of the project plan and established timeline	Municipalities, Community-based associations, developers, landowners, Professionals and experts, Energy Providers

Section B. RESPED Indicators Tables

Analytical overview of the RESPED Indicator tables

The RESPED indicator framework comprises 28 key performance indicators (KPIs) structured across four complementary domains: Resilience, Energy Poverty, Carbon Neutrality, and Circularity. Together, they are designed to operationalise the multi-dimensional assessment of Positive Energy Districts (PEDs) and Positive Energy Buildings (PEBs) across spatial scales ranging from individual buildings to the district level. The framework combines quantitative performance metrics grounded in thermodynamic and energy system modelling with socio-economic and material flow indicators, enabling an integrated pre-feasibility appraisal of district-scale energy transitions, despite it does not provide per-se any specific logic or rationale to aggregate them.

A defining structural feature of the framework is its multi-scale architecture. Most indicators are explicitly formulated at building level and then aggregated (through area-weighting, occupancy-weighting, or distributional statistics) at block (PEB) and district (PED) scales. This scalar coherence is essential for RESPED's multi-scale pre-feasibility pipeline, where indicators computed at finer resolution must propagate consistently to support decision-making at the district and municipal levels. Several indicators, notably IAT (1.9) and IKH (2.1), are only meaningful at the district scale, reflecting phenomena that are intrinsically collective rather than reducible to individual buildings.

1. **Resilience Domain (10 indicators)**

The ten resilience KPIs focus on thermal and electrical energy supply continuity under disruption. The first six indicators (1.1–1.6) form a coherent set describing the full arc of a disruption event: how long a building resists thermal degradation (Thermal Autonomy, 1.1), how severely indoor conditions deteriorate (IoF, 1.2), how fast the collapse occurs (CS, 1.3), how quickly the system recovers after restoration (RT, 1.4), the overall magnitude of disturbance relative to baseline (DoD, 1.5), and the cumulative overheating burden in warm climates (IOD, 1.6). These six indicators are closely aligned with the Building Thermal Resilience Framework (BTRF) developed by Homaei & Hamdy (2021) and extended by Rehman et al. (2024).

WBGT (1.7) shifts the perspective from building physics to occupant heat stress, combining radiant and humidity-adjusted temperature to assess survivability conditions, a critical consideration for southern European climates including the Italian living labs. CCA (1.8) introduces a forward-looking dimension, quantifying whether the building envelope amplifies or attenuates climate change-induced warming trends; a CCA below 1.0 indicates that the structure shields occupants from future thermal intensification. At the district scale, IAT (1.9) and EUE (1.10) capture the collective ability of PED-scale energy systems to sustain critical loads during islanded operation, directly linking distributed generation, battery storage, and demand flexibility to district resilience.

2. **Energy Poverty Domain (10 indicators)**

The energy poverty domain is constructed around the official EU monitoring framework while extending it to the building and district scales required for RESPED. IKH (2.1) and AEBR (2.2) are the two primary Eurostat EU-SILC indicators and provide the reference baseline against which intervention impacts are measured. EES/2M (2.3) adds the income-normalised expenditure dimension, flagging households whose energy cost burden exceeds twice the national median (the standard EPAH operationalisation of affordability-based poverty).

A notable strength of the framework is the explicit inclusion of hidden energy poverty (HEP/LILEE, 2.4), which captures households that suppress consumption to avoid unaffordable bills. This phenomenon is systematically underdetected by expenditure-based indicators and is particularly relevant in Southern Europe where mild climates allow households to under-heat without triggering obvious distress signals. ITAR (2.5) operationalises the direct health dimension, translating minimum

temperature thresholds into an occupancy-weighted adequacy rate that bridges the Energy Poverty and Resilience domains. Indicators 2.6 and 2.9 both address building energy performance, with 2.6 specifically targeting the stock occupied by vulnerable households (recognising that structural building inefficiency, rather than household behaviour, is the primary driver of energy poverty in the Mediterranean context).

The final three indicators (2.7–2.10) assess the distributional outcomes of PED implementation itself: cost savings accruing to households, the inclusivity of PED governance structures, and the risk of energy price volatility exposure. These forward-looking indicators are essential for ensuring that the transition to positive energy does not generate exclusionary dynamics — a risk flagged in the RESPED project framework.

3. Carbon Neutrality Domain (3 indicators)

The carbon neutrality domain is intentionally compact, comprising three indicators that together cover the full carbon accounting scope required for a credible neutrality claim. CNI (3.1) captures operational emissions on an annual net balance basis (Scope 1 + 2), which is the minimum required for PED designation. CNE (3.2) extends this to a whole-life perspective by annualising embodied emissions (materials, construction, replacement, and end-of-life) over a 50-year reference period, consistent with an LCA approach and aligned with the emerging literature on zero-emission neighbourhoods. NEET (3.3) explicitly addresses the trade-off between energy neutrality and carbon neutrality: a building can be net-zero in energy terms while remaining a net carbon emitter if the grid carbon intensity or the embodied carbon of renewable systems is high. This distinction is critical for RESPED's decision-support layer, where pathways must be evaluated both on energy balance and on carbon performance.

4. Circularity Domain (5 indicators)

The circularity domain extends the framework beyond operational energy performance to address material flows, waste, and access-based urban systems. WRS/WRR (4.1) and CDWRR (4.2) capture the waste recovery performance of the district for urban solid waste and construction/demolition waste respectively — two streams that are closely coupled in renovation-led PED transitions. REU (4.3) is positioned within the circularity domain because renewable energy self-production and sharing within a Renewable Energy Community (REC) constitute a form of local resource circulation, reducing dependence on fossil imports. The 2030 national target of 63.4% renewable electricity set in the final Italian PNIEC (2024) provides a concrete calibration anchor.

SSI (4.4) and FARI (4.5) are the most innovative indicators in the framework, extending circularity logic to urban mobility and spatial reuse. SSI quantifies the uptake of shared services (carpooling, shared appliances, e-scooters), which reduce per-capita resource consumption without requiring individual ownership. FARI measures the recovery of vacant, degraded, or post-industrial land for ecological, social, or service functions — a circularity metric applied to the urban fabric itself. Together, these two indicators position RESPED within a broader conception of circular urbanism that goes beyond material recycling rates.

5. Data requirements and scale limitations

Indicators 2.1, 2.2, and 2.3 are derived from household survey data (EU-SILC) and are not directly computable at building level; their finest meaningful resolution is the block or district. Conversely, indicators 1.1–1.6 require either monitored indoor temperature time-series or high-resolution building energy simulation outputs, which may not be available in early-stage pre-feasibility assessments. The framework accommodates this through scale-specific formula variants and the use of proxy or simulated data, but data availability should be flagged as a key uncertainty input in the decision-support layer.

6. vi. Benchmark calibration

Benchmarks provided in the indicator sheets are drawn from the peer-reviewed literature and EU policy targets. They represent reference ranges, not universal thresholds: performance targets must be calibrated to the specific climate zone, building stock typology, and socio-economic context of each

living lab. Southern Italian conditions (mild winters, severe summer overheating, high energy poverty rates) imply materially different benchmark values than Central European contexts, particularly for ITAR, WBGT, IOD, and the energy poverty prevalence indicators.

1. Resilience

1.1 Robustness Threshold Duration/Thermal Autonomy

KPs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	***District Level (PED)***
Robustness Threshold Duration/ Thermal Autonomy	(hours)	Thermal mass, passive design, insulation, heating/cooling systems etc.	x	x	x

KPI Description

This KPI measures the duration that a building's indoor temperature can be maintained within the robustness thresholds following an energy supply disruption or extreme weather event, i.e. above the lower threshold in cold conditions and below the upper threshold in hot conditions. The lower threshold is set at 18 °C, the minimum indoor temperature recommended by the WHO Housing and Health Guidelines (2018). Since the building operates in free-running mode during the disruption, the upper threshold is derived from the adaptive thermal comfort model of EN 16798-1:2019 as a function of the running mean outdoor temperature (Category III upper limit). The metric quantifies how long passive thermal measures can sustain livable conditions without active heating/cooling.

KPI Formula

- **Building Level:** Duration = t_end - t_start (when temperature crosses threshold)
- **Block level (PEB):** Average duration across all buildings, occupancy-weighted
- **District level (PED):** Average duration across all buildings in the district, occupancy-weighted

References	Benchmark or numerical ranges
Kesik T., "Thermal Resilience" (guide; defines thermal autonomy and percent of hours in 18–25 °C band, basis for passive habitability thresholds), Rehman H. et al., "Energy Flexibility and towards Resilience in New and Old Residential Buildings" Energies 2023 (discusses resilience indicators based on how long indoor temperature is maintained after outage) World Health Organization (2018). WHO Housing and Health Guidelines. Geneva: WHO. ISBN 978-92-4-155037-6. CEN (2019). EN 16798-1:2019, Energy performance of buildings. Ventilation for buildings. Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. Module M1.	**Higher (> 24 hours) the better**

1.2 Impact of Failure (IoF)

KPs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	***District Level (PED)***
Impact of Failure (IoF)	°C (or K)	Building envelope (insulation, airtightness, thermal mass), passive design strategies, heating/cooling systems, thermal storage	x	x	x

KPI Description

Impact of Failure (IoF) represents the minimum performance (e.g., minimum indoor temperature) that the building reaches during a power outage or heating/cooling system failure, indicating how far the system falls from its pre-disturbance condition. In thermal terms, IoF is expressed as the difference between the pre-event indoor temperature and the minimum (or maximum for overheating) indoor temperature reached during the outage; This metric is related to the amplitude of event (AoE), which captures only the total temperature drop from the starting condition to the minimum temperature

KPI Formula

- **Building Level:**

$$\boldsymbol{IoF} = (\boldsymbol{P_{ST}} - \boldsymbol{P_{RT}}) + (\boldsymbol{P_{RT}} - \boldsymbol{P_{min}})$$

_ST is the pre-event indoor setpoint temperature, P_RT is the robustness threshold (e.g. 18 °C), and P_min is the minimum indoor temperature during the outage;

- **Block level (PEB):** Area-weighted mean of building-level IoF across all buildings in the block, accounting for thermal heterogeneity.
- **District level (PED):** Area-weighted mean of building-level IoF across all buildings in the district.

References	Benchmark or numerical ranges
Rehman, H.u.; Nik, V.M. https://cris.vtt.fi/ws/portalfiles/portal/105776155/buildings-14-02821_1_.pdf) Towards resilient building performance: definitions, frameworks, and metrics Shabnam Homaei, 2022, ISBN: 978-82-326-6814-4 Handle: https://hdl.handle.net/11250/3000436	a higher IoF indicates a more severe thermal disturbance and poorer resilience

1.3 Collapse speed (CS)

KPs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	***District Level (PED)***
Collapse speed (CS)	°C/h (or K/h)	-	x	x	x

KPI Description

Collapse speed (CS) represents how quickly a building's indoor conditions fall from the initial set temperature to the point where they are no longer comfortable during a power or system failure; lower CS means the building cools (or heats up) more slowly and is therefore more resilient. For heating failures, CS describes the rate of temperature drop, while for cooling failures a lower absolute value of CS indicates slower overheating and better resilience in hot seasons

KPI Formula

- **Building Level:**

$$\boldsymbol{CS = ((P_ST - P_RT) + (P_RT - P_min))/(t_2 - t_0)}$$

where P_{ST} is the indoor setpoint temperature at the start of the event, P_{RT} is the robustness threshold, $P_{\min}$ is the minimum indoor temperature reached during the outage, t_0 is the time of heating/cooling system failure, and t_2 is the time when $P_{\min}$ is reached.

- **Block level (PEB): occupancy- or area-weighted mean CS across all buildings.**
- **District level (PED): occupancy- or area-weighted mean CS across all buildings.**

References	Benchmark or numerical ranges
Rehman et al. (2024). "Towards Extensive Definition and Planning of Energy Resilience in Buildings in Cold Climate." Buildings 14(5) Crawley et al. (IEA Annex 80, 2022). "Resilient Cooling of Buildings.	A lower CS (smaller °C/h, or smaller absolute value in cooling failure) indicates a slower collapse and higher thermal resilience

1.4. Recovery Time (RT)

KPs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	***District Level (PED)***
Recovery Time (RT)	hours (h)	Heating/cooling systems capacity, building envelope efficiency, thermal mass, system redundancy, energy storage (BESS/PCM)	x	x	x

KPI Description

Recovery Time (RT) is the duration required for the building's indoor temperature to return to the target setpoint (e.g., 21.5°C) after power supply restoration following a heating/cooling system outage. Shorter RT indicates faster recovery and higher resilience. A similar KPI is Recovery Speed (RS) = rate of temperature return (°C/h); higher RS indicates superior system capacity and control performance

KPI Formula

- **Building Level:**

$$\boldsymbol{RT = t_{normal} - t_{power_restored}}$$

, where $t_{power_restored}$ is when power is restored and t_{normal} is when indoor temperature first returns to setpoint

- **Block level (PEB):**
- Occupancy-weighted mean RT across all buildings
- **District level (PED):**

References	Benchmark or numerical ranges
H. Rehman, et al., "Towards Extensive Definition and Planning of Energy Resilience in Buildings in Cold Climate," Buildings, vol. 14, no. 5, p. 2821, 2024. S. Homaei and R. Hamdy, "Building thermal resilience framework (BTRF): A novel indicator-based approach to assess the post-extreme event performance of buildings," Frontiers in Built Environment, vol. 7, 2021.	Shorter RT indicates faster recovery and higher resilience.

1.5 Degree of disturbance (DoD)

KPs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	***District Level (PED)***
Degree of Disturbance (DoD)	**dimensionless (normalized)**	**Building envelope, HVAC system reliability, energy storage, backup power, PCM thermal storage**	x	x	x

KPI Description

Degree of Disturbance (DoD) quantifies the severity and duration of performance degradation during a disruption relative to normal baseline conditions. Higher DoD → larger and/or longer disturbance → worse resilience. Parameter can be average indoor operative temperature, baseline energy use, PMV, CO_2 levels, etc.

KPI Formula

- **Building Level:**

$$DoD = \frac{Parameter_{disruption} - Parameter_{reference}}{Parameter_{reference}} * \frac{t_{disruption}}{t_{reference}}$$

where:

- $Parameter_{disruption}$ = measured parameter during outage
- $Parameter_{reference}$ = normal baseline
- $t_{disruption}$ = duration of disturbance (h)
- $t_{reference}$ = normal baseline period (h)

- **Block level (PEB):** Area/occupancy-weighted mean DoD
- **District level (PED):**

References	Benchmark or numerical ranges
H. Rehman, et al., "Towards Extensive Definition and Planning of Energy Resilience in Buildings in Cold Climate," Buildings, vol. 14, no. 5, p. 2821, 2024. S. Homaei and R. Hamdy, "Building thermal resilience framework (BTRF): A novel indicator-based approach to assess the post-extreme event performance of buildings," Frontiers in Built Environment, vol. 7, 2021	Higher DoD → larger and/or longer disturbance → worse resilience.

1.6 Indoor Overheating Degree (IOD)

KPs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	***District Level (PED)***
Indoor Overheating Degree (IOD)	°C (degree-hours normalized)	Ventilative cooling, solar shading, thermal mass, night purging, PCM, reflective surfaces	x	x	x

KPI Description

IOD quantifies both the intensity and frequency of indoor overheating across all occupied zones of a dwelling. It is a single number combining how often (duration) and by how much (°C above comfort) a building overheats; higher IOD = worse overheating / lower thermal resilience.

KPI Formula

- **Building Level:**

$$IOD = \frac{\sum_{z=1}^{Z} \sum_{i=1}^{N_{occ(z)}} \left[\left(T_{in,o,z,i} - T_{comf,z,i} \right)^{+} \bullet t_{i,z} \right]}{\sum_{z=1}^{Z} \sum_{i=1}^{N_{occ}} t_{i,z}]}$$

→ total degree-hours of overheating

→ total occupied hours (summed over all zones).

z = zone counter, Z = total zones
i = occupied timestep (hour), $N_{occ}(z)$ = occupied hours in zone z
$T_{max,i,z}$ = max operative temp in zone z, timestep i
$T_{comf,i,z}$ = comfort threshold
$t_{i,z}$ = occupied duration timestep (typically 1h)

- **Block level (PEB):** Weighted average IOD across buildings.
- **District level (PED): TBD**

References	Benchmark or numerical ranges
Attia et al., "Comparison of overheating risk in nearly zero energy dwelling based on three different overheating calculation methods," in Proc. BS 2021, Bruges, Belgium, 2021. A. Sengupta et al., "Thermal resilience to overheating assessment," E3S Web of Conferences, vol. 396, 2023	higher IOD = worse overheating / lower thermal resilience..

1.7 Wet-bulb Globe Temperature (WBGT)

KPs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	***District Level (PED)***
Wet-bulb Globe Temperature (WBGT)	**°C**	**Ventilation, solar shading, thermal mass, evaporative cooling, radiant cooling panels, PCM**	x	x	x

KPI Description

WBGT measures environmental heat stress on humans, combining humidity/air temperature (70%) and radiant heat (30%); higher WBGT indicates greater combined heat load and reduced thermal resilience. Related KPI: Discomfort Index (DI) combines temperature and humidity to directly assess occupant thermal discomfort

KPI Formula

- **Building Level:**

$$\boldsymbol{WBGT = 0.7T_w + 0.3T_g}$$

where:

- T_w = wet-bulb temperature (°C) [70% weightage: humidity + air temp]
- T_g = globe temperature (°C) [30% weightage: radiant heat]

- **Block level (PEB):** Mean WBGT across occupied zones during heat events.
- **District level (PED):**

References	Benchmark or numerical ranges
ISO 7243:2017, "Ergonomics of the thermal environment—Assessment of heat stress using the WBGT index," Int. Org. Standardization, 2017. A. Sengupta et al., "Thermal resilience to overheating assessment," in Proc. E3S Web Conf., vol. 396, 2023.	The limit values range from WBGT = 33 °C for heat-acclimatized persons with resting activities and fall to WBGT = 20 °C for non-heat-acclimatized persons with heavy physical work. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2022GH000701 ..

1.8 Climate Change Amplification factor (CCA)

KPs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	***District Level (PED)***
Climate Change Amplification factor (CCA)	dimensionless	High thermal mass, low U-value envelope, solar shading, window-to-wall ratio optimization, night ventilation, PCM thermal storage	x	x	x

KPI Description

Climate Change Amplification (CCA) quantifies how buildings amplify or shield internal temperatures from climate change-induced outdoor warming. Example: if outdoor temperature rises +3°C under future climate but indoor only rises +2°C, CCA_mean = 0.67 (67% shielding = good performance).

KPI Formula

- **Building Level:**

$$C_{T_{mean}} = \frac{\delta T^{internal}_{mean}}{\delta T^{external}_{mean}}$$

$$C_{T_{max}} = \frac{\delta T^{internal}_{max}}{\delta T^{external}_{max}}$$

where:

- $\delta T_{ext,\ mean}$ = change in mean outdoor summer t[illegible]en reference climate (1961-1990) and future climate (2050s)
- $\delta T_{int,\ mean}$ = change in mean indoor summer temperature for same periods/building

- **Block level (PEB):** Area-weighted mean CCA across all buildings in block/district
- **District level (PED): TBD**

References	Benchmark or numerical ranges
R. S. McLeod and C. J. Hopfe, "Changes in internal temperatures within the built environment as a response to a changing climate," Building Services Eng. Research Technol., vol. 31, no. 1, pp. 83-99, 2010.	CCA > 1.0 = building amplifies climate signal (vulnerable, poor resilience); CCA < 1.0 = building shields climate signal (resilient).

1.9 Islanded Autonomy Time (IAT)/ Grid Independence Duration

KPs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	***District Level (PED)***
Islanded Autonomy Time (IAT)/ Grid Independence Duration	hours (h)	Distributed energy resources (PV, wind, CHP), battery energy storage systems (BESS), thermal storage (PCM, hot water), demand response, microgrid	x	x	x

KPI Description

Islanded Autonomy Time (IAT) measures how long a Positive Energy District (PED) can sustain a target share of its critical load using only local resources (no main grid connection), starting from a given initial storage state. IAT = earliest time the system can no longer operate within defined resilience constraints minus initial time of islanded

KPI Formula

- **Building Level:**
- **Block level (PEB):**
  - **District level (PED):** $IAT = t_{constraint} - t_0$

where:

t_0 = initial time of islanded operation (grid disconnection)

$t_{constraint}$ = earliest time when any resilience constraint is violated:

Critical load coverage drops below target

State of charge (SoC) of BESS drops below minimum threshold

Indoor temperature exceeds survivability limits across >X% of buildings

- Voltage/frequency stability limits violated

References	Benchmark or numerical ranges
K. Sayed, M. M. Elsayed, A. M. Mohamed, and A. Eid, "Key performance indicators for resiliency assessment in islanded microgrids," Renewable and Sustainable Energy Reviews, vol. 225, 116135, Jan. 2026.	Larger IAT (hours) = better district-scale survivability in islanded/microgrid mode.

1.10 Expected Unserved Energy (EUE)

KPs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	***District Level (PED)***
Expected Unserved Energy (EUE)	kWh (electrical) or kWh_th (thermal)	Distributed generation (PV, CHP, wind), BESS, demand response, microgrid controls, backup generators	x	x	x

KPI Description

Unserved Energy (UE) quantifies the total district demand unmet during a single outage event (formula below). Expected Unserved Energy (EUE) is its expected value over the set of disruption scenarios considered, EUE = Σ_s (p_s · UE_s), where p_s is the probability of disruption scenario s. Related KPI: Critical Load Coverage (CLC) = portion of district's critical demand (emergency lighting, health loads, ICT) served during outage;

KPI Formula

$$UE = \int_{t_0}^{t_0+T_{out}} [P_{demand}(t) - P_{served}(t)]^{+} dt$$

where:

$P_{demand}(t)$ [kW] = total district electrical (or thermal) demand at time t

$P_{served}(t)$ [kW] = demand actually supplied at t (grid + RES + storage)

$[x]^{+} = \max(x, 0)$ = positive part (only unmet demand counted)

t_0 = disturbance start, t_{out} = disturbance end

- **Building Level:**
- **Block level (PEB):**
- **District level (PED):**
-

References	Benchmark or numerical ranges
https://cse.cigre.org/cse-n027/c5-beyond-expected-values-evolving-metrics-for-resource-adequacy-assessment.html	• EUE = 0 (perfect supply) → high resilience; higher EUE → worse resilience CLC = 1 → all critical loads covered (excellent resilience).

2. Energy Poverty

2.1 Inability to Keep Home Adequately Warm

KPs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	***District Level (PED)***
Inability to Keep Home Adequately Warm	% of population / households			x	x

KPI Description

Share of households unable to afford adequate thermal comfort (heating or cooling). This is a core EU-SILC indicator and directly reflects deprivation. The Inability to Keep Home Adequately Warm/Cool (IKH) indicator measures the self-reported share of households that cannot maintain adequate thermal comfort in their homes due to financial or structural reasons. It is a primary official Eurostat energy poverty indicator included in EU-SILC. The indicator captures the subjective experience of energy poverty: households that report being unable to keep their home warm in winter and/or cool in summer despite needing to. It is widely used across EU Member States as a proxy for energy poverty prevalence and is directly referenced in the EU Energy Poverty Recommendation C(2023) 2407 as one of the core mandatory indicators.

KPI Formula

- **Building Level:** Not applicable at individual building level; collected through household survey.
- **Block level (PEB):** IKH_block (%) = (Households reporting inability to keep home warm OR cool) / (Total surveyed households in block) × 100.
- **District level (PED): IKH_district (%) =** Share of district households reporting IKH; disaggregated by season (winter/summer), tenure, and household vulnerability.

References	Benchmark or numerical ranges
European Commission, EU Energy Poverty Recommendation, C(2023) 2407 final.	EU-27 average IKH (warm): ~7–8% of population (Eurostat SILC 2022).
Eurostat EU-SILC, ILC_MDES01 — Inability to keep home adequately warm; ILC_MDES02 — inability to keep home adequately cool.	Italy: ~14–16% IKH_warm; Southern Italy significantly higher.
Energy Efficiency Directive (EED) 2023/1791/EU, Art. 22.	Czech Republic: ~6–8% IKH_warm.
Social Climate Fund Regulation, COM(2021) 568 final.	Austria: ~3–4% IKH_warm.

2.2 Arrears on Energy Bills Rate (AEBR)

KPIs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	**KPI name**
Arrears on Energy Bills Rate (AEBR)	% of households; EUR arrears amount			x	Arrears on Energy Bills Rate (AEBR)

KPI Description

The Arrears on Energy Bills Rate (AEBR) measures the proportion of households that have been unable to pay their energy bills on time and have accumulated arrears. It is one of the two primary official EU energy poverty indicators used by Eurostat and referenced across EU policy frameworks.

AEBR is derived from the Eurostat EU-SILC survey (Statistics on Income and Living Conditions), question HS050: 'Can your household afford to keep its home adequately warm / cool?' and 'Has the household been in arrears on utility bills in the past 12 months?'. The indicator directly captures financial inability to access adequate energy services.

KPI Formula

Building Level: Not applicable (individual household data, not building-level metric).

Block level (PEB): AEBR_block (%) = (Number of households with energy bill arrears in the past 12 months) / (Total households in block) × 100.

District level (PED): AEBR_district (%) = (Households with arrears) / (Total households in district) × 100. Disaggregated by tenure type (owner, renter), household size, and income quintile.

References	Benchmark or numerical ranges
Eurostat (2026). *Arrears on utility bills – EU-SILC survey* [Online data code: ilc_mdes07]. European Commission. Data extracted on 28 August 2026. https://ec.europa.eu/eurostat/databrowser/view/ilc_mdes07/default/table Energy Poverty Advisory Hub (2024). *National indicator – Arrears on utility bills*. European Commission. https://energy-poverty.ec.europa.eu/modules/custom/epah_indicator/pdfs/Arrears_on_utility_bills_EPAH_indicators_June24.pdf Eurostat. *EU statistics on income and living conditions (EU-SILC) methodology – economic strain*. Statistics Explained. https://ec.europa.eu/eurostat/statistics-explained/index.php/EU_statistics_on_income_and_living_conditions_(EU-SILC)_methodology_-_economic_strain	EU-27 average: **7.0%** of the population in arrears on utility bills (Eurostat EU-SILC 2025), essentially flat since 2022 (6.9%) but with wide dispersion — from **Bulgaria 17.2%** down to **Finland and Slovenia below 3%**. Italy: **5.9%** in 2025, up from a 2023 low of 4.1%; regional EU-SILC data show markedly higher rates in the Mezzogiorno than the national average. Czechia: **2.4%** in 2025. Arrears remained low through the 2022 energy price shock; the shock is instead visible in the thermal-discomfort indicator, which more than doubled from 2.9% (2022) to 6.1% (2023). Austria: **4.7%** in 2025, roughly double the pre-crisis level of 2.6% (2022) — the national baseline against which the Graz Living Lab is assessed.

2.3 Energy Expenditure Share (EES) / 2M Rule

KPIs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	***District Level (PED)***
Energy Expenditure Share (EES) / 2M Rule	% of household net income	Energy metering, smart meters, billing data	x	x	x

KPI Description

The Energy Expenditure Share (EES) — commonly referred to as the '2M Rule' or 'twice-the-median' indicator — measures the proportion of a household's net disposable income spent on energy. A household is considered energy poor when its energy expenditure share exceeds twice the national median energy expenditure share. This indicator is the primary energy poverty indicator referenced in the EU's Energy Poverty Advisory Hub (EPAH) and is grounded in Eurostat household budget survey data. It captures affordability from the income side and is applicable from building to district scale when combined with census and income data.

KPI Formula

Building Level: EES(%) = (Annual energy expenditure [EUR]) / (Annual net household income [EUR]) × 100. A household is energy poor if EES > 2 × national median EES.
Block level (PEB): Share of households in the block with EES > 2M threshold (%)
District level (PED): Share of households in the district with EES > 2M threshold (%)

- **Block level (PEB):**
- **District level (PED): TBD**

References	Benchmark or numerical ranges
European Commission, EU Energy Poverty Recommendation, C(2023) 2407 final, Brussels, 2023. Eurostat, Household Budget Survey (HBS), 2010, 2015, 2020. Energy Efficiency Directive (EED), Directive 2023/1791/EU, Art. 22, Official Journal of the EU, 2023. Energy Poverty Advisory Hub (EPAH) — Indicator Library: https://www.energypoverty.eu/indicators	Household is considered energy poor if EES > twice the national median energy expenditure share (2M rule). EU target: significant reduction in energy poor households by 2030 (EED Art. 22). Typical national median EES in EU: 5–9% of net income.

2.4 Hidden Energy Poverty (HEP)

KPIs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	***District Level (PED)***
Hidden energy poverty	% of households; kWh/m²/year	Smart meters, building energy certificates (EPC), income records	x	x	x
KPI Description The Low Income Low Energy (LILEE) indicator — also referred to as the Hidden Energy Poverty indicator — identifies households that spend abnormally low amounts on energy not because of energy efficiency but because they cannot afford adequate energy services (under-consumption / self-restriction). A household is classified as LILEE when its income is below 60% of the national median AND its energy consumption is below 50% of the national median. This indicator reveals households that suppress consumption to avoid unaffordable bills, a phenomenon extensively documented in Austria and other EU Member States.					
KPI Formula Building Level: LILEE flag = 1 if: net household income < 60% national median AND energy consumption (kWh/m²/year) < 50% national median energy use. Proportion of flagged households per building (%). Block level (PEB): Share of LILEE households within the block (%). District level (PED): Share of LILEE households within the district (%), disaggregated by building type and tenure					
References			**Benchmark or numerical ranges**		
European Commission, EU Energy Poverty Recommendation, C(2023) 2407 final. Eisfeld, K. & Seebauer, S. (2022). The energy austerity pitfall. Energy Research & Social Science, 84, 102427. Seebauer, S., Friesenecker, M., Eisfeld, K. (2019). Integrating climate and social housing policies to alleviate energy poverty. Energy Sources B, 14(7-9), 304-326. Energy Efficiency Directive (EED) 2023/1791/EU, Art. 22. Eurostat SILC (Statistics on Income and Living Conditions), annual data.			LILEE threshold: income < 60% national median AND energy use < 50% national median. Eisfeld & Seebauer (2022) found ~10–15% of Austrian households may be in hidden energy poverty.		

2.5 Indoor Temperature Adequacy Rate (ITAR) — Cold / Hot

KPIs Domain	**Carbon Neutrality**	**Energy Poverty**	**Resilience**		**Circularity**
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	**KPI name**
Indoor Temperature Adequacy Rate (ITAR) — Cold / Hot	% of occupied hours with adequate temperature; °C	Indoor temperature sensors, smart meters, occupancy sensors	x	x	Indoor Temperature Adequacy Rate (ITAR) — Cold / Hot

KPI Description

The Indoor Temperature Adequacy Rate (ITAR) measures the proportion of occupied hours during which indoor temperatures remain within the adequate thermal comfort range defined by WHO and EU standards: 18–25°C in winter (minimum 18°C; minimum 20°C for vulnerable groups), and below 26°C in summer.

Energy poverty is directly manifested as inadequate indoor temperatures — households that cannot afford sufficient heating/cooling and thus live in thermally inadequate conditions. WHO classifies indoor temperatures below 18°C as a health risk. The indicator directly links energy affordability to living conditions and health outcomes. In RESPED, this indicator bridges the Energy Poverty and Resilience KPI domains, as it is also relevant for stress-testing building performance under disruption scenarios.

KPI Formula

Building Level: ITAR_cold (%) = (Hours with T_indoor ≥ 18°C during winter occupancy) / (Total winter occupied hours) × 100. ITAR_hot (%) = (Hours with T_indoor ≤ 26°C during summer occupancy) / (Total summer occupied hours) × 100.
Block level (PEB): Area-weighted mean ITAR_cold and ITAR_hot across all residential units.
District level (PED): Aggregate ITAR_cold and ITAR_hot for district; share of dwellings below threshold (%).

References	**Benchmark or numerical ranges**
WHO Housing and Health Guidelines, World Health Organization, 2018. ISBN 978-92-4-155037-6. Energy Performance of Buildings Directive (EPBD), Directive 2024/1275/EU, Annex I, Official Journal of the EU. European Commission, EU Energy Poverty Recommendation, C(2023) 2407 final. EN ISO 7730:2005, Ergonomics of the thermal environment — Analytical determination of thermal comfort. Rehman, H.u. et al. (2023). Energy Flexibility and towards Resilience in New and Old Residential Houses in Cold Climates. Energies, 16, 5506.	WHO minimum: T_indoor ≥ 18°C for general population; ≥ 20°C for elderly, children, and chronically ill. ITAR_cold = 100%: all occupied hours meet minimum temperature — no cold-related energy poverty. ITAR_hot < 95%: indicates overheating risk, relevant for southern European climates (Italy Living Labs).

2.6 Building energy performance of vulnerable households

KPIs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	**KPI name**
Building energy performance of vulnerable households	kWh/m²·year (final energy consumption); optional: EPC class (A–G)	Building envelope (insulation, windows), HVAC systems, ventilation, smart controls, renewable integration (PV, heat pumps)	x	x	Building energy performance of vulnerable households

KPI Description

This KPI measures the final energy consumption intensity of residential buildings occupied by energy-poor or vulnerable households, expressed as energy use per square meter of heated floor area. It captures the structural drivers of energy poverty, distinguishing them from behavioral or income-related causes.

Within the EU, energy poverty is strongly linked to inefficient building stock, with a large share of dwellings exhibiting poor thermal performance and high energy demand . Low-income households are disproportionately affected, as they are more likely to live in poorly insulated buildings and lack the financial capacity to invest in renovations.

KPI Formula
Building Level: Energy intensity = Annual final energy consumption (kWh/year) / heated floor area (m²)
Block level (PEB): Area-weighted mean energy intensity across buildings
District level (PED): Σ final energy consumption (district) / Σ heated floor area

References	Benchmark or numerical ranges
Energy Performance of Buildings Directive (EPBD), Directive (EU) 2024/1275 *Energy performance certificates (Articles 19–21, Annex V) and independent control systems (Article 27, Annex VI)"* Directive (EU) 2024/1275 — EUR-Lex · Commission guidance, EPC annex (Arts. 19–21, Annex V)	**Indicative benchmarks (not set by the EPBD). The EPC class correspondence below is illustrative only, since class boundaries are defined at national level.** **Very efficient (PEB / nearly zero-energy buildings) :**< 50 kWh/m²·year **Good performance:** 50 to 100 kWh/m²·year **Moderate:** 100 to 200 kWh/m²·year **Poor (energy poverty risk zone):** > 200 kWh/m²·year **EPC classification** A - very efficient (~ <50 kWh/m2 year) B to C – efficient (~50 – 100) D to E – moderate (~100 - 200) F to G - inefficient (~200 - 300) -> high risk of energy poverty

2.7 Household Energy Cost Savings due to PED

KPIs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	**KPI name**
Household Energy Cost Savings due to PED	€/household·year; % reduction compared to baseline	Local renewable energy systems (PV, PVT), heat pumps, district energy systems, energy storage, smart energy management	x	x	x

KPI Description

This KPI quantifies the reduction in annual household energy costs resulting from PED implementation, capturing the direct economic benefit of improved energy efficiency, local renewable generation, and optimized energy use.
Energy costs are a central dimension of energy poverty, and reducing them is one of the most effective mechanisms for alleviation. In RESPED, this corresponds to the "energy cost" impact pathway, where PEDs reduce dependence on external energy markets and stabilize energy expenses.
PEDs can lower costs through:

- On-site renewable energy production (reducing purchased energy)
- Increased energy efficiency (lower consumption)
- Smart energy management and flexibility (optimizing energy use and timing)

This KPI is also strongly linked to resilience, as lower exposure to energy price volatility enhances household stability during crises, such as price shocks or supply disruption

KPI Formula

Building Level: Energy cost savings = Baseline annual energy cost – post-PED energy cost
Block level (PEB): Average savings across households
District level (PED): Mean or median savings across all households in PED

References	Benchmark or numerical ranges
RESPED Deliverable 1.1 Energy Efficiency Directive (EU) 2023/1791 European Commission, Social Climate Fund Regulation (EU) 2023	≥30% reduction → strong positive impact 10–30% → moderate impact <10% → limited impact

2.8 Inclusion of Vulnerable Households in PED

KPIs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	**KPI name**
Inclusion of Vulnerable Households in PED	Percentage (%) of households		x	x	x
KPI Description This KPI measures the extent to which energy-poor or low-income households are included in PED developments, addressing the social dimension of energy poverty and ensuring equitable access to benefits. RESPED highlights that PEDs may unintentionally exclude vulnerable groups, especially when implemented in new developments targeting higher-income populations . Therefore, inclusion is a critical success factor for a just energy transition.					
KPI Formula Number of vulnerable households in PED / total households in PED × 100.					
References			**Benchmark or numerical ranges**		
Social Climate Fund Regulation (EU) 2023 European Commission, Energy Poverty Recommendation C(2023) 2407			<10% → low inclusion (risk of exclusion) 10–30% → moderate inclusion 30% → strong inclusion		

2.9 Building Energy Efficiency (Energy Performance of Building)

KPIs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	**KPI name**
Building Energy Efficiency (Energy Performance of Building)	kWh per m² per year (kWh/m²·year) or Energy Performance Certificate (EPC class: A to G) Primary energy demand (kWh/m²·year)		x	x	x

KPI Description
Building energy efficiency measures the amount of energy required to provide adequate indoor conditions such as heating, cooling, lighting, and appliance use. It is one of the main structural drivers of energy poverty, because inefficient buildings require significantly more energy to maintain comfort. Overall energy performance of the building includes insulation airtightness and heating cooling systems. The quality of the building envelope and energy systems affects household energy needs and is therefore a structural factor that strongly influences energy poverty especially in low income housing.

KPI Formula

- **Building Level:**

Energy Use Intensity (EUI): Annual final energy consumption / Floor area
Units: kWh/m²·year
Where energy includes heating, cooling, domestic hot water, electricity
Data requirements: Measured or simulated energy consumption, Floor area (gross or heated area), building characteristics (insulation, systems)

- **Block level (PEB):**

District level (PED): TBD

References	Benchmark or numerical ranges
Energy Performance of Buildings Directive (EPBD) EU Energy Poverty Observatory (EPOV)	**Very efficient (PEB / nearly zero-energy buildings) :**< 50 kWh/m²·year **Good performance:** 50 to 100 kWh/m²·year **Moderate:** 100 to 200 kWh/m²·year **Poor (energy poverty risk zone):** 200 kWh/m²·year **EPC classification** A - very efficient (~ <50 kWh/m2 year) B to C – efficient (~50 – 100) D to E – moderate (~100 - 200 F to G - inefficient (~200 - 300) -> high risk of energy poverty

2.10. Accessibility to Affordable living (Exposure to Energy Price fluctuations)

<table>
<tr><th>KPIs Domain</th><th>Carbon Neutrality</th><th>Energy Poverty</th><th colspan="2">Resilience</th><th>Circularity</th></tr>
<tr><td>KPI name</td><td>Unit of Measure</td><td>Technology</td><td>Building</td><td>Block level (PEB)</td><td>KPI name</td></tr>
<tr><td>Accessibility to Affordable living (Exposure to Energy Price fluctuations)</td><td>Percentage of households with adequate access (%)</td><td></td><td>x</td><td>x</td><td>x</td></tr>
<tr><td colspan="6">KPI Description
Accessibility of PED benefits for low income and vulnerable households; Indicates risk of exclusion gentrification or uneven benefit distribution.</td></tr>
<tr><td colspan="6">KPI Formula
• Building Level:
Accessibility Rate:
AR = (Number of households with adequate energy access / Total households) × 100
• Block level (PEB):
District level (PED): TBD</td></tr>
<tr><td colspan="4">References</td><td colspan="2">Benchmark or numerical ranges</td></tr>
<tr><td colspan="4">EU Energy Poverty Observatory (EPOV)
European Commission (Social Climate Fund definition)
Bouzarovski (energy poverty research)
Hearn et al. (2021, 2022)
IEA (2014) energy poverty insights
Derkenbaeva et al. (2022) on PEDs</td><td colspan="2">• Low burden: < 5 percent
• Moderate: 5 to 10 percent
• Energy poverty risk: 10 percent
Severe energy poverty: 15 to 20 percent</td></tr>
</table>

3. Carbon Neutrality

3.1 Climate Neutrality Indicator (CNI)

KPIs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	**KPI name**
Climate Neutrality Indicator	kg CO_2eq / m²·year kg CO_2eq / capita·year Total annual emissions (kg CO_2eq/year)	Meter, bills	x	x	x

KPI Description

Climate Neutrality Indicator (CN) quantifies the annual operational greenhouse gas emissions associated with energy use in buildings or districts, including Scope 1 (direct emissions) and Scope 2 (indirect emissions from purchased energy).
In the literature, climate neutrality at building/district scale is consistently defined as achieving:

$$Net\ zero\ CO_2 (or\ GHG) emissions\ on\ an\ annual\ basis.$$

In particular, a PED is considered carbon neutral when:

$$CN\ =\ 0\ \rightarrow\ no\ net\ operational\ emissions$$

This corresponds to annual net-zero emissions balance, typically achieved through:

- energy efficiency
- renewable energy generation

energy system integration

KPI Formula

- **Building Level:**

Basic formulation (operational emissions intensity)

$$CN\ =\ \frac{Annual\ operational\ emissions}{reference\ unit}$$

Where:

$$CN\ =\ \frac{kg\ CO^2eq}{m^2\cdot year}$$

$$or$$

$$CN\ =\ \frac{kg\ CO^2eq}{capita\cdot year}$$

Emission-based formula

$$CN\ =\ E_{operational}$$

$$E_{operational}\ =\ total\ annual\ GHG\ emissions\ from\ energy\ use$$

Includes:

$$Scope\ 1\ \rightarrow\ on-site\ combustion$$

$$Scope\ 2\ \rightarrow\ purchased\ electricity\ /\ heat$$

Balance-based formulation (climate neutrality condition)

$$CN\ =\ E_{import}\ -\ E_{export}$$

Where:

$$E_{import}\ =\ emissions\ associated\ with\ imported\ energy$$

$$E_{export}\ =\ avoided\ emissions\ from\ exported\ renewable\ energy$$

The neutrality condition is:

$$CN\ =\ 0\ \rightarrow\ climate\ neutral$$

$$CN\ >\ 0\ \rightarrow\ net\ emitter$$

$$CN\ <\ 0\ \rightarrow\ climate\ positive$$

Levelized Cost of Electricity formulation (for energy-producing systems)

$$LCOE = \frac{Total\ Costs}{Cumulatively\ Generated\ Energy}$$

Where:

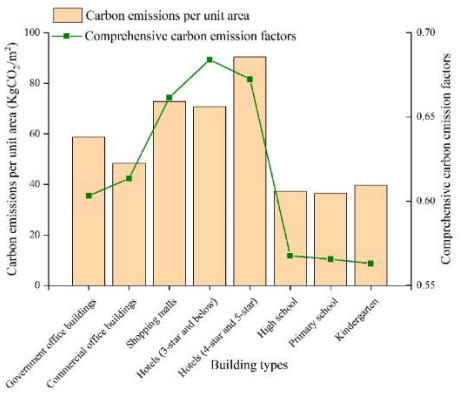
$$Total\ Costs = total\ discounted\ project\ costs$$
$$Cumulatively\ Generated\ Energy = total\ electricity\ produced\ over\ the\ life\ cycle$$

Replacement-based formulation

$$NR(i) = rounded\ up\left(\frac{ReqSL}{ESL(i) - 1}\right)$$

Where:

$$NR(i) = number\ of\ replacements\ of\ component\ i$$
$$ReqSL = required\ service\ life$$
$$ESL(i) = estimated\ service\ life\ of\ component\ i$$

References	Benchmark or numerical ranges
Guarino, F., et al. (2023). Renovation assessment of building districts. Energy & Buildings, 296, 113414. DOI: 10.1016/j.enbuild.2023.113414 Villa, G., et al. (2025). Life cycle cost assessment of a PED. Energy & Buildings, 347, 116299. Sassenou, L.-N., et al. (2024). Methodologies for PED design. Building and Environment, 260, 111667. Rehman, H., et al. (2022). Positive energy buildings analysis. Energy & Buildings, 262, 111991. Kertsmik, K.-A., et al. (2025). Zero-emission neighbourhood feasibility. Building and Environment, 278, 113004. Abouebeid, S., et al. (2026). PED optimization modelling. Energy & Buildings, 352, 116783. Giacomelli, M., et al. (2025). Climate neutrality and urban planning. Sustainable Cities and Society, 130, 106570. Xiaoping Li, Yitong Li et al. (2023) Research on the Carbon Emission Baselines for Different Types of Public Buildings in a Northern Cold Areas City of China Buildings 2023, 13(5), 1108;https://doi.org/10.3390/buildings13051108	The core benchmark is: $CN = 0 \rightarrow climate\ neutrality\ target$  After https://doi.org/10.3390/buildings13051108

3.2. Climate Neutrality Embodied (CNE)

KPIs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	**KPI name**
Climate Neutrality Embodied	kg CO_2eq / m²·year kg CO_2eq / capita·year Total annual emissions (kg CO_2eq/year)	Meter, bills	x	x	x

KPI Description

Defined as the whole-life carbon emissions, Climate Neutrality Embodied (CNE) quantifies the **total greenhouse gas emissions over the full life cycle of a building or district**, including operational emissions (Scope 1 + Scope 2) and embodied emissions (materials, construction, replacement, end-of-life). These are expressed on an annualized basis over the system lifetime (typically 50 years)- Despite often literature defines sufficient the operational-only emission, this methodology would need a life-cycle-assessment perspective.

KPI Formula

- **Building Level:**

Basic formulation (annualized life-cycle emissions)

$$CNE = \frac{GWP_{total}}{Lifetime}$$

Where:

$$GWP_{total} = total\ life-cycle\ greenhouse\ gas\ emissions\ (kg\ CO^2eq)$$
$$Lifetime = reference\ period\ (typically\ 50\ years)$$

Expanded formulation

$$CNE = \frac{(GWP_{operational} + GWP_{embodied})}{Lifetime}$$

Where:

$$GWP_operational = emissions\ from\ energy\ use\ (Scope\ 1 + 2)$$
$$GWP_{embodied} = emissionfrom\ usage, emissions\ from\ materials, construction, maintenance, replacements, end-of-life$$

Balance-based formulation (extended neutrality condition

$$CNE = E_{operational} + E_{embodied} - E_{offset}$$

Where in this case:

$$E_offset = avoided\ emissions\ (renewables, sequestration, etc.)$$

The neutrality conditions in the case of Embodied emission accountability are:

$$CNE = 0 \rightarrow full\ life-cycle\ climate\ neutrality$$
$$CNE > 0 \rightarrow net\ life-cycle\ emissions$$

$$CNE < 0 \rightarrow climate\ positive\ (rarely\ achieved\ and\ not\ consistently\ defined)$$

References	Benchmark or numerical ranges
Di Pilla, L., et al. (2025). Fostering the energy transition in a neighbourhood perspective: towards Positive Energy Districts' application for a university case study. *Energy Reports*, 13, 5628–5652. Kertsmik, K.-A., et al. (2025). The feasibility of zero-emission neighbourhood renovation of apartment buildings in a cold climate. *Building and Environment*, 278, 113004. Skandalos, N., et al. (2025). Decarbonizing operational emissions in urban neighborhoods with the integration of rooftop photovoltaics and green infrastructure under current and future climate conditions. *Energy & Buildings*, 329, 115306.	Benchmark: $CNE = 0 \rightarrow full\ life-cycle\ climate\ neutrality$ After: Ulpiani et al https://doi.org/10.1016/j.scs.2026.107164

Brozovsky, J., et al. (2025). A comparative analysis of climate friendly neighbourhoods in China and Norway: Insights on approaches, practices and policies from four case studies. *Energy & Buildings*, 335, 115569. Sessa, E., et al. (2025). Climate neutral cities in the landscape of sustainability, climate justice, and decarbonization: a literature review. *Energy Reports*, 14, 3657–3672. Giacomelli, M., et al. (2025). Climate neutrality and urban planning: A state of the art from literature and the European cities. *Sustainable Cities and Society*, 130, 106570. Ulpiani et al. (2025) Do ambitious cities value collaboration in climate action? Insights from the f irst group of cities pursuing climate neutrality Cities 162 (2025) 105945	

3.3. Net-Zero Energy Trade-off (NEET)

KPIs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	**KPI name**
Net-Zero Energy Trade-off (NEET)	t CO_2eq / year kg CO_2eq / m²·year kg CO_2eq / capita·year	Meter, bills	x	x	x

KPI Description

Defined as the balance between operative emissions as avoided t CO_2eq, Net-Zero Energy Trade-off (NEET) quantifies the net balance between operational emissions and the avoided emissions enabled by renewable energy generation and energy exchange, typically at building, neighbourhood, or district scale.

Net-zero energy performance does not automatically imply net-zero carbon performance, and vice versa, in fact, some studies explicitly show that the pathway toward net-zero energy imports, renewable surplus, and carbon neutrality involves structural trade-offs between energy balance, operational emissions reduction, embodied emissions, and local context. In other words, it expresses the tension between energy neutrality and avoided operational CO_2eq emissions, usually annualized and assessed within defined system boundaries.

- $NEET = 0 \rightarrow avoided\ operational\ emissions\ fully\ offset\ operational\ emissions$
- $NEET > 0 \rightarrow net\ operational\ benefit\ /\ net\ avoided\ emissions$

$$NEET < 0 \rightarrow operational\ emissions\ exceed\ avoided\ emissions$$

KPI Formula

- **Building/District Level:**

Basic formulation (avoided operational emissions balance)

$$NEET = E_{avoided} - E_{operational}$$

$$E_{avoided} = avoided\ operational\ emissions\ due\ to\ renewable\ generation/export$$

$$E_{operational} = operational\ emissions\ from\ imported\ or\ consumed\ energy$$

Using this formulation implies mitigation of operational emissions through on-site or off-site renewables and the use of "avoided" GHG emissions within or beyond the system boundary.

Net-balance formulation

$$NEET = CO_2eq_{import} - CO_2eq_{export}$$

Where:

$$CO_2eq_{import} = emissions\ associated\ with\ imported\ energy$$

$$CO_2eq_{export} = avoided\ emissions\ associated\ with\ exported\ renewable\ energy$$

Trade-off formulation

$$NEET = f\ (energy\ balance, renewable\ generation, carbon\ intensity, boundary\ conditions)$$

Where the indicator depends on:

- $annual\ energy\ imports/exports$
- $grid\ carbon\ intensity$
- $on-site\ renewable\ generation$
- $system\ boundary$
- $inclusion\ or\ exclusion\ of\ embodied\ impacts$

References	Benchmark or numerical ranges
Wang, Y., Zhang, C., Rezgui, Y., Ghoroghi, A., Luo, Z., Li, Y., Zhao, T. (2026). From buildings to district: A systematic review of life cycle assessment approaches for energy system planning and optimization. *Building and Environment*, 295, 114441. DOI: 10.1016/j.buildenv.2026.114441	Benchmark: [Benchmark values and source to be provided by the KPI author]

Kertsmik, K.-A., Kalamees, T., Hallik, J., Arumägi, E. (2025). The feasibility of zero-emission neighbourhood renovation of apartment buildings in a cold climate. *Building and Environment*, 278, 113004. DOI: 10.1016/j.buildenv.2025.113004 Bruck, A., Díaz Ruano, S., Auer, H. (2022). One piece of the puzzle towards 100 Positive Energy Districts (PEDs) across Europe by 2025: An open-source approach to unveil favourable locations of PV-based PEDs from a techno-economic perspective. *Energy*, 254, 124152. DOI: 10.1016/j.energy.2022.124152 Abouebeid, S., Enerbäck, J., Malakhatka, E., Strömberg, A.-B., Sindelar, D., Mazidi, M., Sridha, A., Wallbaum, H., Thuvander, L. (2026). Urban building energy modelling and multi-objective optimization for PED transition in an existing neighbourhood in Sweden. *Energy & Buildings*, 352, 116783. DOI: 10.1016/j.enbuild.2025.116783 Guarino, F., Rincione, R., Mateu, C., Teixidó, M., Cabeza, L. F., Cellura, M. (2023). Renovation assessment of building districts: Case studies and implications to the positive energy districts definition. *Energy & Buildings*, 296, 113414. DOI: 10.1016/j.enbuild.2023.113414	• $NEET = 0 \rightarrow$ *avoided operational emissions fully* • $NEET > 0 \rightarrow$ *net operational benefit / net avoided emissions* • $NEET < 0 \rightarrow$ *operational emissions exceed avoide*

4. Circularity

4.1 Waste Recycling Share (WRS)/Waste Recovery Rate (WRR)

KPIs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	**KPI name**
Waste Recycling Share (WRS)/Waste Recovery Rate (WRR)	Percentage of SUW recycled or recovered (%) Dimensionless share (0–1) Ton/year recycled or recovered SUW	Meter, bills	*x*		*x*

KPI Description
Waste Recycling Share (WRS), also referred to as Waste Recovery Rate (WRR), quantifies the share of Solid Urban Waste (SUW) that is recycled, recovered, or separately valorized over a full year relative to the total SUW generated in the same period. It is used to assess the extent to which the urban waste system shifts waste away from landfill and low-value disposal toward circular recovery pathways and measure as % of recycled Solid Urban Waste (SUW) over a whole year.

KPI Formula

- **Building/District Level:**

Basic formulation (Waste Recycling Share)

$$WRS = \frac{M_{recycled}}{M_{SUW}, total}$$

Where:

- $M_{recycled} = annual\ mass\ of\ SUW\ recycled\ or\ materially\ recovered\ from\ a\ building\ or\ a\ district$
- $M_{SUW,total} = total\ annual\ mass\ of\ SUW\ generated\ from\ a\ building\ or\ a\ district$

Percentage formulation

$$WRS(\%) = \left(\frac{M_{recycled}}{M_{SUW}, total}\right) \times 100$$

Where:

$$WRS(\%) = annual\ percentage\ of\ recycled\ or\ recovered\ SUW$$
$$Trade - off\ formulation$$

- Low circularity condition: WRS < 0.20
- Intermediate circularity condition: 0.20 ≤ WRS < 0.50
- High circularity condition: WRS ≥ 0.50

Complementary recovery formulation

$$WRR = \frac{M_{recovered}}{M_{SUW}, total}$$

Where:

$M_recovered$
$= annual\ mass\ of\ SUW\ diverted\ from\ disposal\ toward\ recycling, composting, anaerobic\ digestion, or\ equivale$

Residual waste formulation

$$Residual\ Share\ =\ 1\ -\ WRS$$

Where:

Residual Share expresses the fraction of SUW that remains unrecycled and is typically landfilled, incinerated without material recovery, or otherwise not valorized.

References	Benchmark or numerical ranges
Xu, Y., Xu, X., Wen, L., & Wang, Y. (2025). *Extending from reutilization to by-product service: A life-cycle environmental, economic, and risk assessment of heavy metal-containing hazardous waste recycling*. **Waste Management, 203**, 114898. DOI: https://doi.org/10.1016/j.wasman.2025.114898 Slorach, P. C., Jeswani, H. K., Cuéllar-Franca, R., & Azapagic, A. (2019). *Energy demand and carbon footprint of treating household food waste compared to its prevention*. **Energy Procedia, 161**, 17–23. DOI: https://doi.org/10.1016/j.egypro.2019.02.070 Patel, N., Kök, A., Zwickl-Bernhard, S., Kranzl, L., & Auer, H. (2026). *District heating supply optimization under positive energy district targets: A waste-heat dominated case study*. **Sustainable Cities and Society, 140**, 107220. DOI: https://doi.org/10.1016/j.scs.2026.107220 Li, Y., Lv, M., Li, R., & Liu, Z. (2022). *Life cycle assessment of melting reduction treatment for iron and steel waste slag: A case study in Tangshan, China*. **Resources, Conservation & Recycling Advances, 15**, 200108. DOI: https://doi.org/10.1016/j.rcradv.2022.200108	Benchmark: One paper reports an EU policy benchmark of **65% recycling of municipal waste by 2030**. Another shows that, in the UK case for household food waste, only **10%** was separately collected for treatment routes such as anaerobic digestion or in-vessel composting, indicating a low recovery share for that waste stream. Other benchmarks (ttps://doi.org/10.1016/j.egypro.2019.02.070) **WRS < 10–20%** → very low recovery performance This is consistent with the UK household food waste example, where only 10% was separately collected for valorization routes. **WRS = 20–50%** → intermediate recovery performance **WRS ≥ 50%** → high recovery performance Approaching strong circularity performance. **WRS ≈ 65%** → policy-aligned high benchmark This corresponds to the EU municipal waste recycling target cited by Slorach et al. (2019).

S score	Basis
	Observed low-performance reference Slorach et al. (2019): ~10% separate for UK household food waste.
	Analytical interpolation between low empirical case and EU benchmark.
	Analytical midpoint for transition-ph systems.
	Analytical interpolation approaching aligned performance.

	P90	0.65		EU municipal waste recycling target cited in Slorach et al. (2019): 65% by 2030.	
			Reference basis: Slorach, P. C., Jeswani, H. K., Cuéllar-Franca, R., & Azapagic, A. (2019). Energy demand and carbon footprint of treating household food waste compared to its prevention. Energy Procedia, 161, 17–23. https://doi.org/10.1016/j.egypro.2019.02.070		

4.2 Construction & demolition waste recovery rate (%)

KPIs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	**KPI name**
Construction & demolition waste recovery rate (%) CDWRR	Percentage (%) Dimensionless ratio (0–1)	NA	x	x	x

KPI Description

The Construction & Demolition Waste Recovery Rate (CDWRR) quantifies the percentage of construction and demolition waste (CDW) that is reused, recycled, or otherwise valorised, instead of being sent to landfill.

It captures the circularity performance of the construction sector, reflecting how effectively material loops are closed across upstream (construction) and downstream (demolition) phases.

Lower CDWRR indicates a linear waste system with high landfill dependency, while higher values indicate circular economy integration and resource efficiency.

KPI Formula

- **Building Level:**

$$CDWRR = \frac{M_{recovered}}{M_{total}}$$

Where:

- $M_{recovered} = mass\ of\ CDW\ reused, recycled, or\ valorised$
- $M_{total} = total\ CDW\ generated$

Percentage formulation

$$CDWRR\ (\%) = \left(\frac{M_{recovered}}{M_{total}}\right) \times 100$$

Complementary landfill indicator

$$Landfill\ Share = 1 - CDWRR$$

Material-specific formulation (optional)

$$\mathrm{CDWRR_i} = \frac{\mathrm{M_{recovered,i}}}{\mathrm{M_{total,i}}}$$

Where:

$$i = specific\ material\ stream\ (concrete, metals, wood, gypsum, etc.)$$

References	Benchmark or numerical ranges
Heuer, C., Jung, V., Kamp, C., Brell-Cokcan, S. (2025). Deconstruction system for the reuse of concrete building parts in circular automated construction. *Journal of Building Engineering*, 114, 113952. DOI: https://doi.org/10.1016/j.jobe.2025.113952 Gao, Y., Yiu, T. W., Shen, X., Tam, V. W. Y. (2025). Life cycle insights into construction and demolition waste management: Past, present and emerging futures. *Journal of Building Engineering*, 111, 113441. DOI: https://doi.org/10.1016/j.jobe.2025.113441	Benchmark: Observed ranges • Global recovery variability: → 7% – 90% depending on region • Landfill share: → ~35% of CDW still landfilled globally • Recoverable potential: → up to 75% of CDW has recoverable value Benchmark (further)

Liu, Y., Loo, B. P. Y. (2025). Circular economy application in construction: An evaluation framework. *Journal of Building Engineering*, 111, 113306. DOI: https://doi.org/10.1016/j.jobe.2025.113306 Antunes, A., et al. (2024). Reducing the environmental impact of the end-of-life of buildings. *Journal of Building Engineering*, 82, 108197. DOI: https://doi.org/10.1016/j.jobe.2024.108197 Soto-Paz, J., et al. (2023).	• Low performance: CDWRR < 0.30 → Linear system, landfill dominant • Medium performance: 0.30 ≤ CDWRR ≤ 0.70 → Transitional system • High performance: CDWRR > 0.70 → Circular economy aligned Reference: The circular economy in the construction and demolition waste sector. *Journal of Building Engineering*, 78, 107724. DOI: https://doi.org/10.1016/j.jobe.2023.107724

4.3 Renewable Energy Usage (REU)

KPIs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	**KPI name**
Renewable Energy Usage (REU)	Percentage of renewable energy used (%) Dimensionless ratio (0–1) kWh/year or MWh/year of renewable energy used	Meter, bills	x	x	x

KPI Description

Renewable Energy Usage (REU) quantifies the share of total energy used that is supplied from renewable sources, whether self-produced on-site or on-site within the district/community or purchased from external suppliers with certified Guarantees of Origin (GO). It is intended to capture the degree to which fossil-based energy is replaced by renewable electricity and, where relevant, other renewable energy carriers within the defined assessment boundary.

REU is central to Plus Energy Buildings (PEBs), Positive Energy Districts (PEDs), and Renewable Energy Communities (RECs), all of which depend on balancing energy demand with local renewable generation and, in many cases, reducing dependence on imported non-renewable energy.

KPI Formula

- **Building/District Level:**

Basic formulation (final energy basis)

$$REU = \frac{E_{RE}, used}{E_{total}, used}$$

Where:

- $\boldsymbol{E_RE, used} = renewable\ energy\ actually\ used\ within\ the\ system\ boundary$
- $\boldsymbol{E_total, used} = total\ energy\ used\ within\ the\ same\ boundary\ and\ period$

This is the most direct formulation when the goal is to express the percentage of energy use that is renewable. It is consistent with the logic of comparing energy load and renewable generation/load coverage used in PEB assessment.

Self-produced renewable usage formulation

$$REU_{self} = \frac{E_{RE}, self - consumed}{E_{total}, used}$$

Where:

$$E_{RE}, self - consumed = renewable\ energy\ generated\ locally\ and\ consumed\ locally$$

This reflects the "load cover factor" or "self-generation" logic, and the key question is how much of the demand is covered by on-site renewable production.

Purchased certified renewable formulation

$$REU_{cert} = \frac{E_{RE}, purchased, GO}{E_{total}, used}$$

Where:

$$E_{RE}, purchased, GO = externally\ supplied\ renewable\ energy\ covered\ by\ valid\ Guarantees\ of\ Origin$$

.

Composite formulation

$$REU_{total} = \frac{(E_{RE}, self - consumed + E_{RE}, shared + E_{RE}, purchased, GO)}{E_{total}, used}$$

Where:

$$E_{RE}, shared = renewable\ energy\ shared\ within\ a\ REC/PED)/community\ boundary$$

This is the most suitable formulation for district and community applications, especially where energy sharing and collective renewable production are part of the system design. Assessment frameworks for Italian Renewable Energy Communities are likewise built around production, consumption, total demand and internal energy sharing.

References	Benchmark or numerical ranges
Bruck, A., Diaz Ruano, S., Auer, H. (2022).ùDOI: https://doi.org/10.1016/j.enbuild.2022.112493 Zhu, Y., Salvalai, G., Zangheri, P. (2025). https://doi.org/10.1016/j.enbuild.2025.116404 Hawila, A. A. W., Pernetti, R., Pozza, C., Belleri, A. (2022). https://doi.org/10.1016/j.enbuild.2022.112069 Ahrens Kayayan, V., Cabral, D., Israelsson, K., Gustafsson, M. (2025).: https://doi.org/10.1016/j.enbuild.2025.115471 Pahlavan, H. M., Nord, N. (2026). *Scenario-based analysis of energy retrofit strategies and their impacts on building energy demand using a validated multi-building energy model: A university campus case study*. *Energy & Buildings, 354*, 116956. DOI: https://doi.org/10.1016/j.enbuild.2026.116956 Cai, S., Gou, Z. (2024). *Transitioning positive energy buildings towards positive energy communities: Leveraging performance indicators for site planning assessments*. *Energy & Buildings, 325*, 114976. DOI: https://doi.org/10.1016/j.enbuild.2024.114976 Abouebeid, S., Enerbäck, J., Malakhatka, E., Strömberg, A.-B., Sindelar, D., Mazidi, M., Sridha, A., Wallbaum, H., Thuvander, L. (2026). *Urban building energy modelling and multi-objective optimization for PED transition in an existing neighbourhood in Sweden*. *Energy & Buildings, 352*, 116783. DOI: https://doi.org/10.1016/j.enbuild.2025.116783	Thresholds: Low renewable use condition: REU < 0.30 Intermediate renewable use condition: 0.30 ≤ REU < 0.63 High renewable use condition: REU ≥ 0.63 i.e., according to the final Italian PNIEC submitted to the European Commission on 1 July 2024 (Ministero dell'Ambiente e della Sicurezza Energetica), Italy aims to cover 63.4% of gross final electricity consumption with renewable energy by 2030. This target can be used as a national-level policy reference. Zhu, Y., Salvalai, G., Zangheri

4.4 Service Sharing Indicator (SSI)

KPIs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	**KPI name**
Service Sharing Indicator (SSI)	Users per capita Accesses per m² Dimensionless index (0–1)	Meter, bills	x	x	x

KPI Description

The Service Sharing Indicator (SSI) quantifies the level of utilization of shared (non-owned) services within a district or urban system, such as carpooling, shared micromobility (e-scooters), communal laundry, and other access-based services. It reflects:

- the intensity of participation in shared services
- the degree of transition from ownership-based to access-based consumption
- the real accessibility and uptake of shared infrastructures

Higher SSI indicates stronger adoption of sharing economy practices and higher system efficiency in resource utilization.

KPI Formula

- Building Level:

Basic formulation

$$SSI = \frac{N_{users}}{N_{population}}$$

Where:

- $N_{users} = number\ of\ people\ accessing\ shared\ services$
- $N_{population} = total\ population$

Self-Spatial density formulation (suited for district)

$$SSI = \frac{N_{access}}{A}$$

Where:

- $N_{access} = number\ of\ service\ accesses\ (per\ time\ unit)$
- $A = area\ (m^2 or\ km^2)$

Hybrid formulation

$$SSI = \left(\frac{N_{access}}{N_{population}}\right) \times Availability_{factor}$$

Where:

- $Availability_factor = degree\ of\ service\ availability\ (0-1)$

Composite formulation

$$REU_{total} = \frac{(E_{RE}, self-consumed + E_{RE}, shared + E_{RE}, purchased, GO)}{E_{total}, used}$$

Where:

$$E_{RE}, shared = renewable\ energy\ shared\ within\ a\ REC/PED)/community\ boundary$$

This is the most suitable formulation for district and community applications, especially where energy sharing and collective renewable production are part of the system design. Assessment frameworks for Italian Renewable Energy Communities are likewise built around production, consumption, total demand and internal energy sharing.

References	Benchmark or numerical ranges

McQueen, M., Clifton, K.J. (2022) *Assessing the perception of E-scooters as a practical and equitable first-mile/last-mile solution* Journal: Transportation Research Part A DOI: 10.1016/j.tra.2022.09.021 Talandier, M., Duroudier, S., André-Poyaud, I., Chardonnel, S., Ployon, E. (2024) *The territorial impacts of BlaBlaCar carpooling: Between metropolitan polarization, intermediate cities' structuration, and rural services* Journal: Journal of Transport Geography DOI: 10.1016/j.jtrangeo.2024.104041 Wasserbaur, R., Sakao, T., Ljunggren Söderman, M., Plepys, A., Dalhammar, C. (2020) *What if everyone becomes a sharer? A quantification of the environmental impact of access-based consumption for household laundry activities* Journal: Resources, Conservation & Recycling DOI: 10.1016/j.resconrec.2020.104780 Jordan-Cuebas, F., Krogmann, U. (2026) *Laundry energy consumption in multistory buildings: Technology versus laundering practices* Journal: Journal of Building Engineering DOI: 10.1016/j.jobe.2026.115189	SSI (0–1 normalized) Reference: *What if everyone becomes a sharer? A quantification of the environmental impact of access-based consumption for household laundry activities* Journal: Resources, Conservation & Recycling DOI: 10.1016/j.resconrec.2020.104780 Low Sharing (Underdeveloped System) SSI < 0.30 Interpretation: • Ownership-based consumption dominates • Low service availability or adoption • High resource inefficiency Evidence basis: • Underutilized appliances and low sharing uptake Moderate Sharing (Transition Phase) 0.30 ≤ SSI < 0.60 Interpretation: • Mixed ownership + sharing • Early-stage sharing economy • Typical current European urban condition Evidence basis: • Spatial variability and partial adoption patterns High Sharing (Optimized System) SSI ≥ 0.60 Interpretation: • Strong sharing economy integration • High utilization of assets • Reduced environmental footprint Evidence basis: Significant efficiency gains and emission reductions from sharing

4.5. Functional Areas Recovered Indicator (FARI)

KPIs Domain	Carbon Neutrality	Energy Poverty	Resilience		Circularity
KPI name	**Unit of Measure**	***Technology***	***Building***	***Block level (PEB)***	**KPI name**
Functional Areas Recovered Indicator (FARI)	Dimensionless ratio (0–1) Percentage of recovered functional area (%) Recovered m² / total useful m² Recovered m³ / total useful m³	Meter, bills	x	x	x

KPI Description

The Functional Areas Recovered Indicator (FARI) quantifies the share of the total useful surface area or volume of exploited spaces that has been recovered and brought back to functionality. It measures the extent to which underused, vacant, abandoned, post-industrial, interstitial, or degraded spaces are reactivated for usable ecological, social, cultural, or service functions. Higher FARI indicates a stronger recovery of latent urban capacity (the recovery of small vacant lands, urban novel ecosystems, blue-green infrastructure, and temporary reuse of post-industrial areas,) and a greater reintegration of previously non-performing areas into the urban system.

KPI Formula

- **Building/District level:**

Basic formulation (surfaced-based)

$$FARI = \frac{A_{recovered,functional}}{A_{total,useful}}$$

Where:

$$A_{recovered}, functional = useful\ surface\ area\ recovered\ and\ returned\ to\ functionality$$
$$A_{total}, useful = total\ useful\ exploited\ surface\ area\ within\ the\ assessment\ boundary$$

Self-Spatial density formulation (suited for district)

$$SSI = \frac{N_{access}}{A}$$

Where:

- $N_{access} = number\ of\ service\ accesses\ (per\ time\ unit)$
- $A = area\ (m^2 or\ km^2)$

Percentage formulation

$$FAPI\ (\%) = \left(\frac{A_{recovered,functional}}{A_{total,useful}}\right) \times 100$$

Where:

- $Availability_factor = degree\ of\ service\ availability\ (0-1)$

Volume-based formulation

$$FAPI_v = \frac{V_{recovered}, functional}{V_{total}, useful}$$

Where:

$$V_{recovered}, functional = recovered\ useful\ volume\ returned\ to\ functionality$$
$$V_{total}, useful = total\ useful\ exploited\ volume$$

This formulation is appropriate when the recovered spaces are volumetric rather than planar, for example in buildings, under-bridge areas, industrial halls, or multi-level reused sites.

Typology-specific formulation

$$FAPI_i = \frac{A_{recovered,i}}{A_{total,useful}}$$

Where:
i may refer to:

- ecological function
- social/recreational function
- mobility/service function
- cultural/temporary use function
- climate adaptation function

References	Benchmark or numerical ranges
Pineda-Pinto, M., Collier, M., Cooper, C., O'Donnell, M., Nulty, F., Rodriguez Castaneda, N. (2024). *Exploring urban novel ecosystems: Understandings, insights and recommendations for future research and practice*. *Futures, 164*, 103487. DOI: https://doi.org/10.1016/j.futures.2024.103487 Naghibi, M. (2025). *Greening the gaps: Small vacant lands as catalysts for urban well-being and resilience*. *Societal Impacts, 6*, 100144. DOI: https://doi.org/10.1016/j.socimp.2025.100144 García Sanchez, F., Govindarajulu, D. (2023). *Integrating blue-green infrastructure in urban planning for climate adaptation: Lessons from Chennai and Kochi, India*. *Land Use Policy, 124*, 106455. DOI: https://doi.org/10.1016/j.landusepol.2022.106455 Marian-Potra, A.-C., Caizer, A. D., Popa, N., Ile, A. L., Ancuța, C. (2026). *Pop-up urbanism in post-industrial landscapes within the European capital of culture program: Can it foster processes of creative placemaking? Cities, 170*, 106670. DOI: https://doi.org/10.1016/j.cities.2025.106670	Benchmarks • Low recovery condition: **FARI < 0.10**Only a small share of latent area has been restored to function. • Moderate recovery condition: **0.10 ≤ FARI < 0.30** A meaningful but partial recovery of functional areas is occurring. • High recovery condition: **FARI ≥ 0.30** A substantial portion of previously non-performing area has been brought back into urban function.

Conclusion

The following conclusion synthesizes the two primary sections of the RESPED project report, detailing the innovative methodological framework and the performance-driven evaluation metrics designed to accelerate the implementation of PEDs.

The first section of this study introduces an innovative conceptual and operational architecture that combines TA with CC to transform traditional urban planning paradigms. Modern cities face unprecedented challenges from the climate crisis and energy insecurity, yet many still rely on legacy planning models from the 19th century that lack the flexibility to navigate complex socio-economic interdependencies. In response, the TA approach reconceptualizes the city as a living organism where small-scale, surgical interventions act as catalysts for systemic change across broader territorial systems. By identifying *"acupoints"*, high-potential nodes for decentralized energy interventions, planners can generate widespread environmental and social benefits without requiring disruptive overhauls of existing urban structures. Social legitimacy is as vital as technical efficiency, which is why the framework integrates a robust CC and CG strategy. This participatory approach ensures that a diverse range of stakeholders, including citizens, public officials, and academic institutions, are active partners in defining problems and designing solutions. By empowering communities to take ownership of the transition, co-created designs can integrate local knowledge and respond to specific territorial contexts, fostering public trust and long-term institutional evolution. This collaborative process effectively navigates potential conflicts and enhances the overall sustainability of the interventions.

The methodology is operationalized through a five-phase integrated planning process that spans from initial baseline assessments to long-term monitoring and evaluation. This process begins with comprehensive data gathering to decode the territorial fabric and continues through multi-criteria spatial analysis using GIS and RS to identify the most effective acupoints. These analytical tools allow for the systematic identification of environmental constraints and regulatory conditions, ensuring that technical energy measures, such as building retrofitting or renewable energy installations, are tailored to the localized metabolic characteristics of the region.

The second section of the report provides the diagnostic tools necessary to measure the success of these territorial interventions through a structured set of 28 KPIs. These indicators are organized under four thematic pillars: resilience, energy poverty, carbon neutrality, and circularity, establishing a replicable basis for translating complex territorial analysis into actionable energy strategies. By employing these standardized metrics, the framework ensures that the transition to climate neutrality is both transparent and performance-driven, aligning local actions with broader European climate objectives. Resilience is a core priority of the framework, with ten specific indicators designed to evaluate the systemic performance and robustness of Positive Energy Districts. These metrics go beyond simple energy efficiency to assess factors like thermal autonomy and the ability of a district to maintain functionality during disturbances or failures. Similarly, the framework places a heavy emphasis on social equity through ten energy poverty indicators. These tools allow planners to measure energy expenditure shares and the inclusion of vulnerable households, ensuring that the energy transition does not exacerbate existing social imbalances but instead promotes affordable living for all residents. The final two pillars, carbon neutrality and circularity, provide the technical roadmap for environmental sustainability. Carbon neutrality indicators track progress toward operational and life-cycle net-zero goals, while circularity metrics evaluate waste recycling rates and the recovery of functional urban areas. Together, these indicators function as diagnostic tools that allow for the continuous verification of the performance and effectiveness of adopted solutions. By combining the strategic spatial precision of Territorial Acupuncture with the measurable impact of this KPI framework, the RESPED roadmap

offers a comprehensive model for fostering inclusive, vibrant, and resilient carbon-neutral territories across Europe.

The RESPED roadmap demonstrates that the energy transition is not merely a technological challenge but a profound spatial and social transformation. By leveraging geospatial analysis, supported by GIS and remote sensing, planners can identify high-impact areas with high precision while aligning local actions with broader European objectives like the European Green Deal and the Renovation Wave. Through the strategic use of TA and CC, cities and regions can evolve into environments that are not only carbon-neutral but also inclusive, vibrant, and resilient. This report provides the necessary instruments for local authorities and communities to navigate these changes together, ensuring that small-scale, high-impact actions generate lasting positive effects across the entire urban fabric.

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