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EnerCmed Project: Advancing Energy-Positive and Climate-Resilient Hinterlands through Renewable Energy Communities and Nature-Based Solutions

Jonathan Roberts[1], Augusto Bocanegra[1*], Davide Borelli[2], Elisa Fracchia[1,2], Emanuela Pallavidino[1,3], Juliana Peshku[1], and Corrado Schenone[1,2]

[1] *Department of Mechanical Engineering, Energetics, Management and Transportation (DIME), University of Genoa, Via all'Opera Pia 15/A, 16145, Genova, Italy*
[2] *Italian Centre of Excellence in Logistics, Transport and Infrastructure (CIELI), University of Genoa, Via Francesco Vivaldi 5, 16126, Genova, Italy*
[3]*Engineering Department, University of Campania "Luigi Vanvitelli", Aversa, Italy*
[*]E-mail: augusto.bocanegra@unige.it

Abstract. The EnerCmed project introduces an innovative paradigm to foster energy-positive and climate-resilient hinterlands, with a focus on marginalized neighborhoods in port cities that are exposed to energy poverty. By integrating Renewable Energy Communities (RECs) and Self-Consumption Schemes (SCSs) with Nature-Based Solutions (NBS), the project aims to demonstrate a scalable model for sustainable urban energy transitions. Supported by ten international partners across the Mediterranean region, EnerCmed moves beyond conventional energy planning by merging REC/SCS governance models with localized climate resilience strategies, ensuring that sustainability efforts directly benefit vulnerable communities. The project comprises five pilot actions located in Genoa (Italy), Valencia (Spain), Patras (Greece), Pula (Croatia), and Novigrad (Croatia). In these cities, six REC/SCS will be established in marginalized port hinterlands to engage public entities and users affected by energy poverty and climate change. The EnerCmed framework is founded on three key technical principles: 1. Energy Communities and Self-Consumption Schemes; 2. Urban Heat Island (UHI) Mitigation; 3. Energy Poverty Shielding. A defining feature of EnerCmed is its transnational Knowledge Facility Instrument (KFI), which serves as a technical and governance support mechanism. The project includes a multi-city replication program, with Larnaka, Cyprus, serving as the first metareplicator city. This initiative equips additional Mediterranean cities with the tools and methodologies needed to adopt and scale up the REC-NBS hybrid approach. Alongside the technical additions from the perspective of renewable technologies, the EnerCmed project is engaged in a fundamental activity of social value. A comprehensive communication campaign in the pilot cities aims to raise citizens' awareness of the importance of various aspects of a green transition.

1. Introduction

Over the past few decades, the Mediterranean has become one of Europe's most significant frontlines against the accelerating effects of climate change. The gradual increase in summer thermal discomfort, along with some of the heatwaves, and the continued presence of the Urban Heat Island (UHI) are hardly stressing urban systems. These pressures, however, are not uniformly distributed in urban landscapes. Some areas, particularly those on the outskirts of port cities, are picking up that burden significantly more than others, [1].
Neglected in mainstream urban development plans, these port hinterlands are characterized by a complex history of industry, disjointed planning, and social exclusion. People in such places must often struggle with substandard housing, limited access to public services, and, most of all, high energy costs they cannot afford. Often, residents have to decide between living in a comfortable, heated home and being offered a manageable bill each month**,** and this is an even starker reality elsewhere, where 'energy poverty' is a term that is ever more frequently heard, [2].
EnerCmed is attempting to tackle these overlapping issues through an integrative and territorial approach. The main aim of the project is double: on the one hand, to promote decentralized, citizen-led Renewable Energy Generation with Renewable Energy Communities (REC)/Self Consumption Schemes (SCSs), [1]; and, on the other hand to safeguard and restore ecological (and thermal) equilibrium through Nature-Based Solutions (NBS), [3]. Where RECs/SCSs provide local actors with an opportunity to engage directly in producing and distributing energy, NBS interventions, such as green roofs, tree planting, or permeable surfaces, provide instant and tangible relief from heat stress while contributing to overall environmental objectives.
However, rather than treating them as isolated tools, EnerCmed combines them into a single approach that addresses the distinctive vulnerabilities of individual neighborhoods. This is not only a technical approach, but it is also informed by the community and the combination of different institutions and local knowledge. The project aims not only to lower emissions or cut electric bills, but also to reimagine the way cities think about regeneration, recentering resilience, equity, and collective agency, [4].
In the sections that follow, the methodological framework of the project will be described, discussing what has been learned from its application to five pilot cities and drawing on early results derived from this hybrid model.

2. Methodology

The methodological approach in EnerCmed is based on a transdisciplinary and multi-scalar dimension. The implementation process comprises four main stages, incorporating top-down strategic planning as well as bottom-up participatory design, as shown in Table 1.

The EnerCmed framework is founded on three key technical principles:

1. RECs/SCSs – Decentralized, citizen-driven renewable energy production and management.
2. UHI Mitigation – Deployment of NBS to enhance local climate resilience.
3. Energy Poverty Shielding – Targeted interventions in vulnerable urban districts to reduce socio-economic inequalities related to energy.

A defining feature of EnerCmed is its transnational Knowledge Facility Instrument (KFI), which serves as a technical and governance support mechanism. This collaborative structure enables partners to translate the Hinterland Renewables Communities Action Plan into real-world REC-

NBS pilot applications, ensuring consistency in methodology while allowing for context-specific adaptations in each city.

Phase	Title	Objectives	Key Activities	Expected Outcomes
Phase 1	User-Centered Design and Tailored Engagement Strategies	Foster inclusive participation and community co-design	Stakeholder mapping, workshops, participatory mapping, storytelling, and youth/elderly group consultation	Local ownership, social acceptance, and co-designed interventions
Phase 2	Financial Modeling, Contractual Structuring, and Technical Design	Develop viable, scalable, and context-specific REC models	Spatial analysis, PV feasibility, grid interaction, legal blueprints, financing models	Technically sound and economically sustainable REC prototypes
Phase 3	Activation of Six Pilot RECs/SCSs	Deploy renewable energy systems in vulnerable districts	Installation of PV systems on schools/public buildings, REC governance setup	Clean energy access, GHG reduction, and energy justice for ~345 households
Phase 4	NBS for Climate-Resilient Neighborhoods	Mitigate UHI and improve urban livability	Green roofs, bioswales, permeable pavements, urban forestry, NBS co-design	Surface cooling, biodiversity gains, enhanced climate resilience

Table 1. EnerCmed Project Phases Summary

2.1 User-Centered Design and Tailored Engagement Strategies

A necessary launching point for bringing life to an EnerCmed framework is to foster authentic and meaningful dialogue with communities. This first phase is not just about informing citizens, but also about placing them as co-creators in the development and implementation of RECs/SCSs and NBSs. It recognises that there is no monolithic 'community' that can adopt a single one-size-fits-all model for social change, as is often encouraged through top-down sustainability programmes [4].

An array of participatory instruments is employed for this purpose. These can include formal public workshops, community meetings, issue-based focus groups, and casual conversations held in schools, libraries, or community centers. These are more than simply spaces for information – they function as local knowledge exchange laboratories at work; a place where people are included in the facts, able to share their frustrations, discuss firsthand experiences of life, and help design those interventions directly. For example, in Valencia and Genoa, the recommendations of youth groups and elderly associations were used to finalize the siting of NBS installations near public areas with high foot traffic.

A key step in this phase is stakeholder mapping. This includes not just formal institutions, such as local government or utilities, but also informal networks, cultural associations, social workers, school administrators, and grassroots organizations that often prove critical in garnering trust and mobilizing participation. Particular attention is paid to capturing the perspectives of traditionally underrepresented groups, including low-income households, migrants, and tenants in social housing. Their participation is seen as crucial to ensure that interventions address real needs and do not exacerbate existing disparities.

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The engagement activities are designed to align with the rhythms and realities of each community. Sometimes, more creative methods, such as storytelling sessions or participatory mapping, help bridge gaps in technical knowledge, making the process more approachable.
By incorporating this co-design philosophy at the initial stage, EnerCmed establishes a foundation that enables long-lasting community ownership and operational sustainability. Those who have had a say in designing a solution are more likely to support its implementation, monitor its progress, and potentially roll it out in other areas of the city. This participatory design is considered not a separate element of the technical work, but rather part of the model's success and scalability.

2.2 Financial Modeling, Contractual Structuring, and Technical Design of Lighthouse RECs/SCSs
The second phase of the EnerCmed project focuses on establishing the conditions (technical and financial) for the successful development of RECs. This is essential work, as it will influence the viability, scalability, and sustainability of each pilot program. The project team takes not a linear engineering view towards implementation, but a systemic one that considers spatial constraints, load interactions, governance demands, and the risk of economic viability simultaneously, [5].
On the technical side, a full spatial analysis to locate potential places to install Renewable Energy Systems (mainly photovoltaic (PV) arrays on the rooftop) has already been carried out. These reviews go beyond simply testing for surface area. The orientation, shading, structural stability, and distance from demand nodes are all considered to maximize energy yields and facilitate integration into the local grid. Furthermore, simulations and GIS-powered mapping tools are used to cross-link building typologies with social vulnerability data, ensuring that technical deployment aligns with social priorities.
The grid connection also becomes an important issue in regions with old or weak distribution grids. The project collaborates with local Unit of Distribution and Consumption (UDCs) to analyze possible stress points, assess bi-directional flow capabilities, and explore possibilities for dynamic load balancing. Alternative models, such as microgrid islands or virtual net metering in select pilot cities (e.g., Patras, Novigrad), are being developed to address technical constraints or regulatory gaps.
At the same time, custom financial models are created to support the RECs' ability to function and provide real value to their members. It draws from models supported through the use of public and private finance, including mechanisms such as citizen finance, revolving funds, and third-party ownership. Cost effectiveness is also important: cost to participate scales with local income and how much energy the household uses (with provision of rebates or gradual entry for the most vulnerable households).
Institutionally and legally, there are significant differences between the Mediterranean EnerCmed countries. To rectify this, the project develops 'adaptable' legal 'blueprints' that take into consideration on-the-ground laws and regulations whilst maintaining open governance by default and community ownership. Such structures encompass cooperative, energy service company (ESCO), and public-private partnership approaches. In cases where there is national ambiguity regarding national regulation — as is currently the case in Spain with collective self-consumption — the project is working alongside local administrations and legal experts to co-develop provisional operating regulations.
This is the role of the KFI, a transnational technical assistance tool that helps encourage permanent collaboration among the actors. It also offers legal, methodological, and design consultation, so pilots remain coherent throughout while still being context-specific. It also serves an advisory function, allowing cities with less experience to learn from the expertise of their more

advanced partners, thereby reducing trial and error and learning curves, and preventing the repetition of mistakes.
Finally, this stage paves the way to establish RECs/SCSs that are more than just technically and legally sound, but are also equitable and financially viable. It stems from the project's broader endeavor to produce locally grounded yet transnationally relevant energy solutions for a just and inclusive energy transition.

2.3 Activation of Six Pilot RECs/SCSs
The third phase of the EnerCmed project involves the actual deployment of six RECs/SCSs in communities located in five cities from four Mediterranean countries: Genoa (Italy)[2][Fig. 1], Valencia (Spain), Patras (Greece), and the Croatian Municipalities of Pula and Novigrad. These *RECs/SCSs* are much more than proof-of-concept technologies; rather, they are functioning social–technical infrastructures designed to disrupt how we think, produce, share, and use energy at urban, so-called 'peripheries' of sustainability transitions.

Figure 1. Identification of public school buildings where PV systems could be installed in Genoa.

Every REC/SCS is considered a local, citizen-led renewable energy production and community-based consumption ecosystem. The technological backbone of these communities *is* solar PV installations, mainly mounted on public buildings, schools, and social housing; for example, in *Figure 1,* two public schools were identified as the target for the Genoa pilot action. The plants are not only designed for optimal energy production, but also to coincide with local end-use consumption and the position of the built environment.
The districts chosen for these pilots were not selected at random. Sandwiched between low household incomes, thermally inefficient housing stock, and a lack of institutional support, these communities are experiencing energy vulnerability. By focusing on these contexts, the RECs/SCSs aim to deliver tangible benefits in both environmental and social spheres. Based on rough estimates of energy production and simulation models, the combined systems are expected to produce approximately 278 MWh per annum. This translates into an estimated annual decrease of around 160 tons of CO_2 emissions—a significant step towards urban decarbonization objectives.
From a community standpoint, the RECs are developed to benefit 345 households, a population that may not have had access to clean energy programs in the past. City governance models differ but are underpinned by a commitment to transparency, inclusiveness, and collective value. Take

Genoa, where the REC is run as a public-cooperative hybrid involving the city council and city residents. In Patras, the school buildings knit the community together and demonstrate how saving energy leads to investment in education and public facilities.
In addition to these direct technical roles, the pilot RECs, Fig. 2, also function as "lighthouse projects"—real-world examples intended to educate and catalyze deployment elsewhere. Their value extends beyond the kilowatt-hours they generate; they are sources of institutional learning, catalysts of capacity, and wellsprings of social cohesion. By showing that energy justice may be technically and community feasible, these RECs help transform how urban resilience and citizen empowerment can be integrated into Mediterranean climate transition strategies.

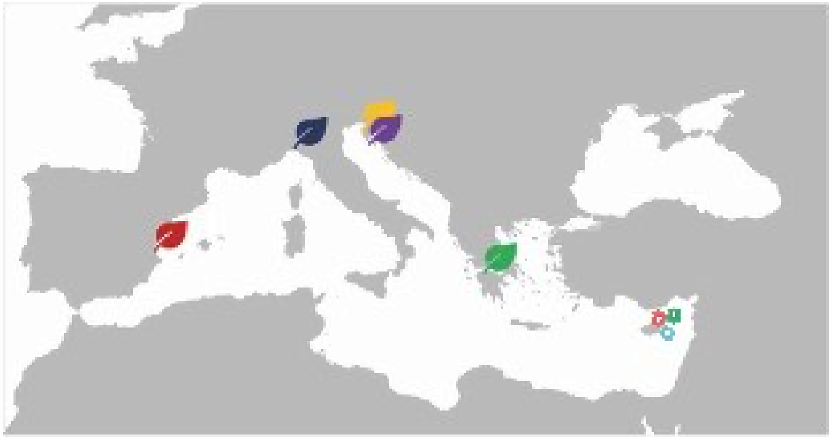

Figure 2. Map of the Pilots (Valencia, Genoa, Pula, Novigrad, and Patras) with Larnaka as Meta-Replicator

2.4 Nature-Based Solutions for Climate-Resilient Neighborhoods
Concurrently with the implementation of RECs/SCSs, the EnerCmed project introduces an NBS special-purpose cluster to foster local climate resilience at the small area level. These kinds of ecological interventions are not add-ons but essential to the dual strategy of the project, acting as devices that help adapt to those environments while increasing the social and physical liveability of such fragile areas.
A range of NBS typologies is piloted in the pilot cities, chosen based on in-depth bioclimatic analysis and spatial diagnostics. This might include public buildings topped with green roofs, the space between residential blocks covered by vegetated plots, bioswales for directing storm runoff, and highly reflective surfaces to minimize heat absorption from pavements and facades. Urban forestry programs—as varied as trees along streets and the rehabilitation of neglected open spaces—also provide shade, cool, and help re-establish ecosystems. Flash flood-prone areas are also ideal locations for installing permeable paving, which can prevent long-term damage to infrastructure and promote sustainable drainage and groundwater recharge.
Endpoint assemblies, relating to each NBS intervention location and configuration, are defined based on microclimatic simulations and thermal mapping results. In Genoa[6], for instance, a priority was to identify sectors with poorer building stock and less air replenishment, where the impact would be more effective in deteriorating surface temperatures and atmospheric temperature. In Valencia, NBS are interconnected with public infrastructure and mobility corridors, enabling them to deliver environmental and recreational services. The generation of green corridors around the REC facilities is not only enhancing energy targets through the

reduction of cooling demand, but also reclaiming marginal lands for the creation of a collective urban commons.

However, NBS [Fig. 3] has a role to play that goes beyond the aspects of technique within EnerCmed. These interventions are conceived as being visibly situated within the lives of residents in their daily environments, providing leisure, interaction, and knowledge with respect to sustainability. Flung Seedlets: planting, tending, and watching the place fosters achievable community involvement, as participants share in accountability for the overall stewardship of that community during the planting, tending, and watching phases.

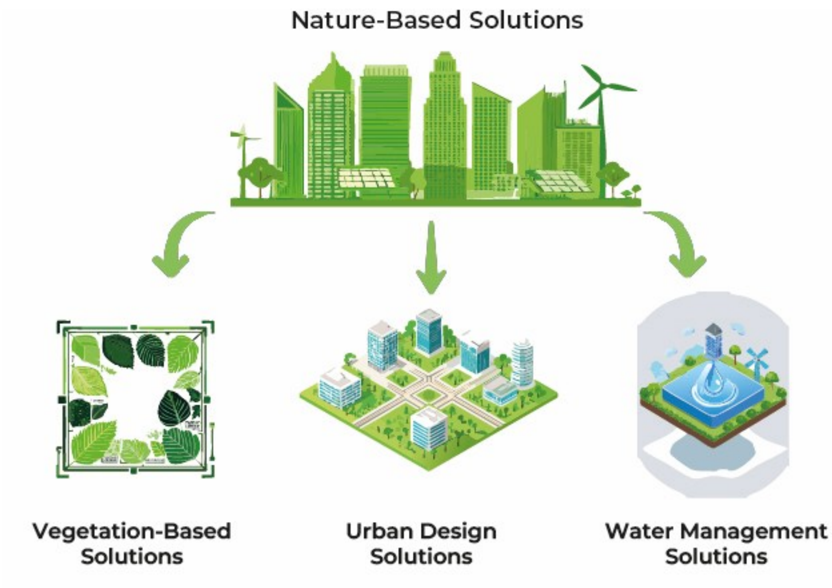

Figure 3. Nature-based solution (NBS) concept

From a systems point of view, NBS integration addresses several urban challenges simultaneously: it breaks the hardness of the urban environment, boosts biodiversity, improves air and water quality, and mitigates the intensity of UHI effects [7]. In this manner, it reduces energy use directly and specifically (in summer cooling) in a way that complements the RECs. This coupling effect demonstrates the central innovation of the EnerCmed approach: that energy and climate resilience are not two separate goals pursued in parallel, but two dimensions of the same transition process that strengthen each other.

3. Discussion

3.1 Social-Ecological Impacts

Preliminary findings from the EnerCmed pilot sites offer positive insights into the combined benefits of RECs and NBS. The combination of these two elements seems to have a 'compounding' effect, increasing the positive effects within the natural and social realm in a way that is more than a simple arithmetical sum.

From an environmental perspective, post-project information validates that a decrease in temperature can be measured on the surface, especially in sites with dense application of vegetative measures. Thermal observations in Valencia and Genoa showed cooler surface temperatures and temperature drops of up to 3–4°C in newly created green corridors and

bioswales. This thermal delay not only provides for immediate gains in comfort but also results in system-level energy savings, particularly in buildings neighboring NBS installations.
There have also been visible results in the monitoring of energy. In REC-activated districts, average electricity consumption during peak summer hours has declined slightly but significantly [8]. This reflects enhanced solar self-consumption, as well as the cooling impact of adjacent NBS components, which mitigated the need for air-conditioning systems. The confluence of such paired efficiency gains further supports the logic for integrating energy generation with climate-adaptive design.
Equally noteworthy is the social impact. At the level of the pilot cities, there were strong signals of awareness raising and a positive attitude towards sustainability as a policy framework, through structured local engagement (e.g., open days, school-based activities, local assemblies). Each pilot city organised open days with the local population to disseminate the EnerCmed project message, illustrate the technologies, benefits, and regulatory framework, and to dispel any doubts citizens might have. This also made it possible to collect impressions and feedback for a better communication approach. Results from the survey feedback indicate an increase in the sense of community identity, interest in energy issues, and willingness to participate in local transition initiatives. In Valencia, a symbol of social inclusion and urban improvement in the minds of residents was the installation of shaded public seating areas as part of the NBS strategy.
In several instances, households led by women and younger residents were involved in leading co-design sessions or awareness-raising campaigns. Their participation challenged the project narrative and introduced new subjectivities into local decision-making arenas. This aligns with the broader EnerCmed vision, which views the energy transition as not only a technological transformation but also a social process, [9].
In short, the social-ecological co-benefits documented to date provide evidence that the EnerCmed model may represent a viable approach to climate action, whether of the military kind or not, that is both technically cost-effective and socially responsive. The results reflect a growing understanding that resilience is not simply about infrastructure, but about inclusion, trust, and the joint ability to influence change.

3.2 Technical Feasibility and Governance

Indeed, the operationalization of RECs/SCSs in the EnerCmed context has involved navigating a complex set of technical, regulatory, and administrative challenges [4]. These are not trivial obstacles but rather go to the heart of how transitions play out in diverse regional and national settings.
One of the major obstacles is the legal restrictions on shared self-consumption. In most participating countries, current regulations limit the geographic range over which renewable power can be shared among consumers. This is especially the case in compact urban areas, where public buildings that can be equipped with PV systems are often far away from energy-vulnerable social households. In Genoa, it partnered with the local authority, operating within the legal and regulatory framework, while still aiming to reach the target population with the community energy model.
Financial viability is another major issue. The cost of solar installations and the structuring of governance can be front-loaded, which can be a barrier for cities with limited budgets or where the private sector is wary of innovative models with social components. To overcome this, EnerCmed has experimented with various fine-tuned financing schemes, including local cooperatives' financial schemes, public revolving funds, and collaborations with Ethical Finance institutions. Municipal authorities in Patras (one of the participating pilots) have secured co-

financing from a regional development agency to cover initial installation costs, with the long-term energy savings being reinvested in the schools.
The complexity of structuring legal entities to operate on the REC market varies significantly between countries. Although some countries provide clear rules for establishing energy communities, the legal frameworks in others remain fragmented or not well-established. A level of legal engineering based on the cases opened and constant public regulator dialogue has become required. The KFI, as a transnational facility, has been instrumental in this respect. It also offers modular governance templates, legal advice, and cross-case, comparative analysis to enable each pilot to be responsive locally while being coherent with the overall project strategy.
Each city has notably followed a governance model that corresponded to its institutional culture and local specificity. In Pula, the REC/SCS is designed as a cooperative that reinvests energy revenue back into the local community through a participatory budgeting system, which identifies local needs, such as public lighting, youth services, or green infrastructure. It increases local control and transparency. By contrast, the model applied in the city of Patras is one of public-institutional integration. By integrating the REC into school and public housing authority operations, the city ensures administrative stability and scales the impact to include educational achievements.
Early experiences, such as these, underscore the importance of ensuring that ongoing RECs possess the flexibility and intelligence to design governance models tailored to their specific context. Instead of prescribing a single institutional building plan, EnerCmed focuses on flexibilizing design, characterized by an ongoing dialogue with stakeholders and guided by policy feedback. This ability to customize while preserving values—equity, transparency, and sustainability—is just one of the critical enablers of the project's success and replicability.

3.3 Transnational Replication
One of the highest strategic values of EnerCmed consists in its potential to go beyond the local and enhance mutual learning between a network of Mediterranean cities. The project is not envisioned as a set of isolated pilot actions, but as a coordinated transnational experiment in the uptake, scaling up, and institutionalization of integrated energy and climate solutions in different sociopolitical settings. This is particularly important in a region characterized by similar climatic conditions yet considerable governance and infrastructure differences.
The City of Larnaka in Cyprus is the first replication site where EnerCmed will be adapted to a new, local urban and institutional context. Based on this technical understanding and practice materials from the pilot cities, Larnaka has begun outlining its own REC-NBS strategy. What stands out is not just the transfer of technology or policy tools, but equally an insistence on "contextualisation": that successful replication requires more than copy-paste solutions. Cultural norms, management structures, or even land tenure arrangements can influence how quickly a REC or an NBS intervention gains traction.
To foster this, the project has developed a comprehensive range of knowledge transfer architecture. Digital platforms store technical manuals, design blueprints, and legal guidelines, while biennale expositions bring practitioners together to exchange experiences in real-time. Much of this training consists of peer-review elements, where partners question each other's tactics and point out potential risks, and compare notes about what they have learned in the field. Not only does this format expedite mutual learning, but it also establishes trust between cities facing the same struggles.
The comparison that emerges from this networked approach has already begun to yield important observations. For instance, in Spain, legal frameworks for collective energy

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management are a bottleneck [10], while in the northern part of Croatia, partnerships between municipalities and regional energy agencies have been successfully used to operationalize RECs more easily. In Italy, NBS have been mainstreamed into national climate policy, which can serve as a model for cities in countries that still consider the approach experimental.

It is these transversal results that are reported and updated as a “living compendium” of replication “pathways”, feeding back into the process to support subsequent cities in their replication of the model. This document is intended for use anywhere in the world, in any medium, at any scale, for any purpose – there is no one-size-fits-all solution. The approach describes flexible sequences of action and comes with lists of risk considerations to navigate, checklists of policy approaches, life-cycle packages, and more. This resource is complemented by a mentoring component, through which new partners can be matched (as appropriate) with pilot cities that share similar characteristics and receive support tailored to their needs.

In the long run, this transnational dimension situates EnerCmed not just as a project, but as a platform—a replicable apparatus for energy-climate co-innovation grounded in genuine urban life, yet susceptible to change. As the climate emergency escalates and the call for local, fair energy transitions becomes louder, this kind of platform could also be key to turning isolated good practices into systemic ones across the board.

4. Conclusions

In this paper, an innovative framework designed by the EnerCmed project is presented to promote energy-positive and climate-resilient urban hinterlands. Additionally, it is shown how the combined application of RECs and NBS contributes to addressing energy poverty, mitigating the UHI effect, and enhancing the resilience of disadvantaged communities in five Mediterranean cities.

In EnerCmed, a challenging new paradigm of urban transformation is outlined, which redefines the energy transition as an aspect of socio-ecological possibility, rather than a technical problem. Fundamentally, it is a two-pronged mission of promoting climate resilience through ecological design and providing energy justice through community-owned renewable systems. The integration of a REC/SCS with an NBS can provide an agile and flexible structure able to cope with these cross-cutting crises: urban overheating, energy poverty, and social exclusion.

The results seen in the five pilot cities show that it can bring real benefits on several scales. From lower greenhouse gas emissions and thermal comfort benefits to stronger community connections and citizen empowerment, the benefits are measurable and transformative. More significantly still, these benefits are not limited to individual interventions but flow from a systemic, participatory approach that centers on residents in planning, governing, and caring for the system.

In a forward-looking manner, EnerCmed is also presented as not only a set of pilots but also an approach that can be replicated, as well as a policy-relevant knowledge base. The transnational nature of the project provides a comparative perspective for developing best practices and anticipating barriers to implementation. Further work will develop better indicators to compare environmental and social outcomes more robustly, to look into the role of digital energy platforms in managing distributed generation and the embedded commercial and financial systems the EU are currently working on to standardise the measurement of energy performance and assessment, to integrate EnerCmed’s hybrid model with ongoing EU developments such as the Renovation Wave, the New European Bauhaus and the Fit for 55 package, and UE Green Deal [11].

With cities around the Mediterranean struggling with the combined effects of climate instability and social dislocation, the call for context-sensitive, integrative, and equitable approaches could not be more timely. EnerCmed not only provides a vision of what such policies could entail but also a rational, tested method to achieve them.

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