Strategic Design for Energy Self-sufficiency in Historic Villages: Renewable Energy Communities and Circular Regeneration in Grecìa Salentina

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Abstract. The energy transition in rural European territories is often hindered by the structural conflict between heritage conservation and technological innovation. This study develops a systemic de-risking roadmap for establishing Renewable Energy Communities (RECs) in historic villages, utilizing a Design Science Research (DSR) approach integrated with Strategic Design and Foresight. The methodology formalizes the decision-making process by synthesizing institutional policy analysis with a comparative evaluation of radical and incremental social innovation models. The research proposes an operational roadmap structured into three strategic actions: the establishment of multidisciplinary "Transition Teams" (Cognitive Interface), the design of circular financing models to mitigate energy poverty, and the implementation of multidimensional evaluation protocols supported by Digital Twins for monitoring territorial capital. Results demonstrate that this strategic engine facilitates the transition of historic villages from passive assets toward adaptive regenerative ecosystems, effectively mediating between decarbonization mandates and the preservation of local identity. By defining the parameters for the Grecìa Salentina (Italy), the study provides a replicable roadmap that establishes the mandatory pre-implementation conditions for grounding technical infrastructures within systemic territorial coherence.

Keywords: Circular Rural Regeneration · Renewable Energy Communities · Strategic Design

1 Introduction

Rural resilience in Europe is challenged by metabolic and demographic contractions [1–3]. The RED III Directive mandates an accelerated energy transition, positioning Renewable Energy Communities (RECs) as a mechanism to decouple the built environment from carbon dependence [4]. This transition must align with New European Bauhaus (NEB) principles, reconciling sustainability with aesthetic and inclusive values to prevent the erosion of territorial identity [5–7], while leverage structured accounting systems for material cultural heritage to map territorial values [8]. This regenerative perspective is particularly relevant for terraced landscapes and rural territories, where circular economy models act as catalysts for eco-systemic recovery [9, 10].

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The transition requires engaged communities as determinant factors for system adaptability [1, 11, 12]. Within the Italian context, data reveal a persistent systemic gap in environmental performance in the Southern "Mezzogiorno", where infrastructure scarcity hampers sustainability transitions [2, 3, 13, 14]. While 55% of Italian RECs are in small municipalities, development in historic contexts is hindered by administrative complexity [15–17], requiring circular business, financial, and governance models tailored for adaptive reuse [18–20].

The limited efficacy of many energy policies in rural contexts reflects a misalignment between centralized objectives and local "daily practice". Applying "human-centered engineering", this discrepancy is identified as a "gulf of execution" where the absence of integrated planning tools prevents a coherent mapping between regulatory intent and operational reality [21, 22]. From a design-science perspective, this represents a lack of "procedural rationality", necessitating a transition toward participatory and co-evolutionary evaluation processes [23–25]. Rural resilience is defined as the capacity of territorial systems to absorb external shocks [26]. According to recent assessments, this involves recognizing the "social well-being" derived from heritage as a primary indicator of territorial health [27], necessitating foresight-driven strategies to anticipate future crises [28, 29]. In vulnerable southern contexts, identifying the socio-economic drivers of resilience is vital [2, 30]. This necessitates a human-centered approach to energy justice to ensure the transition becomes a pathway toward inclusive growth [22]. Within this framework, the circular economy functions as a restorative metabolic model [31, 32], where simultaneously the intrinsic value of cultural heritage drives human-centered adaptive reuse [18, 19]. This involves moving from abandoned assets toward active nodes in the urban metabolism. Consistent with the Faro Convention, the "heritage community" emerges as the central actor [33]. Effective implementation of these models relies on understanding best practices for adaptive reuse [34], reinterpreting the village as a circular ecosystem where "circular governance" acts as the bridge between metabolic circularity and cultural identity [1, 2, 24, 35]. Technical robustness and physical safety during adaptive transformations are further ensured by integrating optimization-based structural strengthening frameworks for historic masonry buildings [36].

The Grecìa Salentina (Apulia, Italy) is a paradigmatic case. Beyond the impact of *Xylella fastidiosa*, which devastated the olive-growing landscape, the region suffers from an erosion of identity [3, 37]. The response must integrate multi-criteria decision-making to manage trade-offs between agricultural recovery and energy transition [37], positioning the REC as a hub for energy and bio-resource circularity [38, 39]. The circular metabolism can be reinforced by valorizing local agricultural residues for renewable energy [40, 41]. In line with the Historic Urban Landscape (HUL) approach, this territory represents a "vulnerable node" where the loss of traditional agricultural metabolism necessitates a design-driven recovery of territorial capital [2, 7, 42, 43]. This study evaluates the compatibility between technological requirements and the intrinsic value of built heritage, proposing systemic nodes within the territorial metabolism [1, 39, 44, 45].

1.1 Paper Objective and Structure

The study proposes a decision-support model grounded in the convergence of Design Science Research (DSR), Strategic Design, and Foresight methodologies [23, 28, 46]. The output is a socio-technical artifact designed to mitigate the "cognitive friction" and "administrative barriers" characterizing the implementation of energy infrastructures in protected contexts [17, 21]. Strategic Design functions here as an integrative field where experts facilitate "social conversations" to ground European initiatives within local circular programs [6, 47]. Within this architecture, Strategic Design provides the "kernel theory" for integrating organizational strategy with design-led innovation [46], while Foresight acts as the protocol to ensure resilience against future shocks by integrating inbound and outbound change [28]. RECs serve as instruments for the shared management of cultural heritage [39], and for valorizing public heritage "awaiting reuse" [44]. The analysis investigates the operational translation of circular metabolic principles (RQ1), the role of energy citizenship (RQ2), the capacity of RECs to mitigate systemic risks (RQ3), and the optimal governance/financing models (RQ4). The latter is crucial as financial viability remains a primary obstacle, requiring innovative capital structures and the involvement of "heritage communities" [48–50]. This pre-implementation roadmap acknowledges the reality of social innovation in marginalized areas, where expectations often clash with structural constraints [51, 52]. By prioritizing the governance engine, the research seeks to bridge the gap between European policy goals (RED III [4], NEB [5]) and local identity [23, 53].

The document is organized as follows: Sect. 2 explores the theoretical and regulatory framework concerning rural regeneration and RECs; Sect. 3 presents the research methodology; Sect. 4 presents the results and discussion; finally, Sect. 5 outlines conclusions and future research perspectives.

2 Literature Review

2.1 Circular Metabolism and Adaptive Territorial Networks

The construction sector is a critical pressure point for environmental stability, accounting for 40% of energy consumption and 36% of greenhouse gas emissions [31]. This necessitates a transition toward circular regenerative loops that prioritize the maintenance of existing value. In the European landscape, where over 80% of the building stock predates 1990, circular regeneration is a structural necessity for territorial resilience [1]. In historic contexts, this transition requires a multi-scalar understanding of territorial capital where cultural heritage acts as a non-renewable resource [2, 18, 38]. This implies a shift toward the Circular City model, where the reuse of the built environment is a core component of territorial governance [19, 35], evolving toward a "human-centered" village model capable of regenerating both material and non-material values [24].

The historic village is re-evaluated as a vulnerable node within territorial networks, where environmental resilience can be interpreted through the lens of small-scale aggregates' ability to self-organize resources [54]. This systemic integrity is maintained through dynamic co-evolutionary processes [1, 2, 18], requiring structured transformation management [55] and rigorous methodological frameworks for heritage accounting [8]. However, reconciling modern performance with heritage constraints remains a

"metabolic gap" [1, 38]. Closing this gap requires evaluating best practices in adaptive reuse to identify scalable circular governance models [34]. In the Italian context, energy efficiency must be balanced with the preservation of cultural-identity features [3, 7]. To ground these interventions without compromising structural safety, optimization-based frameworks for the strengthening of masonry buildings must be cross-referenced with energy retrofit scenarios [36]. To measure this transition, Human-Centered Indicators (HCI) are adopted to evaluate the regeneration of vulnerable heritage in terms of social and human well-being [56], ensuring that circularity integrates "beauty" and "sustainability" in line with the NEB [5]. The adaptive reuse paradigm reconfigures the historic village as a living organism [18]. By extending the life cycle of buildings, historic structures evolve from passive assets into active energy hubs [31, 44]. While reaching Nearly Zero-Energy Building (nZEB) standards in heritage contexts presents significant constraints, innovative technologies and bio-based materials allow for substantial CO_2 reductions while respecting historical integrity [31, 45, 57]. The circular metabolism of rural villages is further enhanced by the valorization of local agricultural residues for energy production [40, 41]. Empirical precedents in specific Italian contexts demonstrate that such circular interventions can transform abandoned assets, such as the former military ammunition depot in Sangano, into energy-active hubs for the community [44], provided that the overarching technological deployments are systematically integrated with nZEB adaptive reuse frameworks [31], and governance models are tailored for circular adaptive reuse [20].

2.2 Socio-technical Interfaces: Designing for "Heritage Citizenship"

The transition to decentralized energy via RECs is essentially a "social innovation" process [16]. However, social innovation often faces structural constraints in marginalized areas [51]. To mitigate this, Strategic Design must focus on the "affordance" of governance – the actual properties of the REC that determine the ease of interaction between the community and the system [21]. Citizen engagement is a dynamic process influenced by transparency and the visibility of benefits [58]. This engagement is a fundamental driver for implementing Circular City models, ensuring that regeneration strategies align with local needs [11]. Co-design acts as the operational tool, converting citizens into active "prosumers" [17, 57].

The "heritage community" [33] serves as the social engine, yet its activation requires a "neo-endogenous" development approach where local actors are supported by external networks without losing territorial sovereignty [52]. Activation is conditioned by the "governance of proximity" [59], necessitating participatory and co-evolutionary evaluation models to foster deep-rooted commitment [25]. In line with the New Leipzig Charter, social inclusion must be a structural requirement of the energy metabolism [60]. While Strategic Design and Foresight provide the operational protocols for long-term planning [24, 28], recent psychosocial research highlights that the communicative processes and behavioral drivers are fundamental for driving actual citizen involvement in RECs [61, 62]. Within this framework, the heritage community becomes the primary stakeholder in a "circular human-centered" governance, where cultural identity acts as the glue for collective action [18, 24].

2.3 Regulatory Gaps and "Systemic de-Risking" in Marginal Areas

The implementation of the RED III Directive [4] and the Italian regulatory framework (D.Lgs 199/2021 [63]; D.M. 414/2023 [64]) occurs amid regional disparities [15]. A "place-based" deficiency – applying uniform solutions to heterogeneous territories – often results in social discontent in the "Mezzogiorno" [65]. This is fueled by the "digital and energy divide" affecting inner areas [13, 66]. Addressing these disparities requires a holistic view of the circular economy supported by a clear taxonomy and mapping of existing energy community models across the European landscape [67]. Integrating the UNDRR GAR 2025 framework shifts the focus to "systemic de-risking", where energy self-sufficiency acts as insurance against cascading climate risks [26]. This is inherently linked to "energy justice" [22].

The regeneration of specific landscape features, such as terraced systems, demonstrates how circularity mitigates systemic risks while providing economic value [9, 10]. Without multi-level governance that integrates NEB and Faro principles, RECs risk technical alienation [51, 58]. The National Strategy for Inner Areas Plan (PSNAI) acknowledges this vulnerability but requires tools for "sovereign resilience" [68]. Sustainability is ultimately linked to circular well-being, where proceeds are reinvested into the maintenance of the Historic Urban Landscape [42] and monitored through multidimensional indicators [56]. Evaluating the attractiveness of these nodes remains crucial for guiding investment and identifying development potential [30]. Financial viability depends on leveraging regional funding and operational support from the Gestore dei Servizi Energetici (GSE) while managing the constraints of social innovation [48, 51, 69, 70].

3 Methodology

The research adopts a Design Science Research (DSR) approach, a paradigm engineered to extend organizational capabilities by creating innovative socio-technical artifacts [23]. The study operates at the "front-end of innovation," focusing on the architectural configuration of the decision-making process rather than the empirical monitoring of existing infrastructures [28, 46]. The robustness of this approach is ensured by the recursive interaction between three cycles – relevance, rigor, and design – which establish the epistemic conditions for a replicable roadmap in fragile contexts (Fig. 1).

3.1 The Relevance Cycle: Contextualizing the "Wicked Problem"

The Relevance cycle bridges the research with the specific environment of the Grecìa Salentina. This phase serves as a diagnostic protocol to identify the requirements of the artifact.

Problem Framing: The study identifies the "metabolic friction" caused by post-ecological shocks and regulatory complexity. This justifies a circular governance model [24, 47, 56] that reintegrates abandoned biomass and marginal lands into the local energy cycle [37, 38]. The empirical feasibility of this approach is backed by recent technological assessments on the bioenergetic potential of local lignocellulosic residues and agricultural biomass [40, 41].

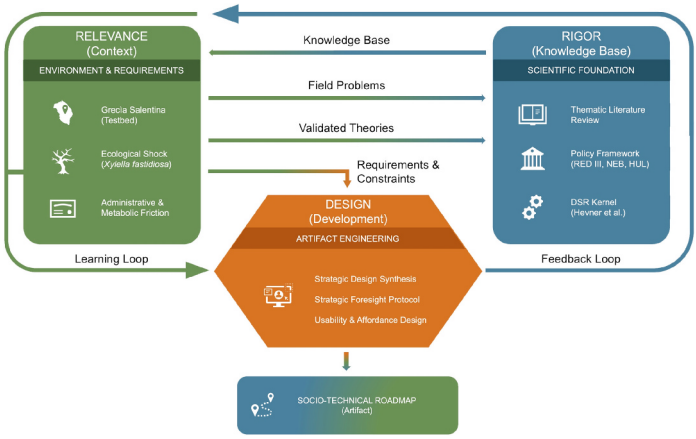

Fig. 1. Methodological framework based on DSR cycles [23] (Authors' elaboration)

Territorial Requirements: Utilizing institutional grey literature and regional policies, the research defines the socio-technical constraints [65]. The assessment of urban attractiveness in Southern contexts serves as a benchmark for identifying these requirements [30], ensuring the roadmap addresses the specificities of the "Mezzogiorno".

3.2 The Rigor Cycle: Literature as Foundation Building

The Rigor cycle provides scientific grounding through a purposive thematic review (2013–2026), structured as a "foundation building" process to justify the pre-implementation stage.

Data Collection Logic: A hybrid documentary base was synthesized by cross-referencing peer-reviewed literature (Scopus/Google Scholar) with multi-level policy frameworks, including the RED III Directive, New European Bauhaus, and UNESCO Historic Urban Landscape recommendations to ensure "convergent validity" [58]. This involves extracting best practices for the adaptive reuse of cultural heritage to identify successful circular business and governance models [20, 34]. This ensures that the roadmap's strategic actions (Sect. 4.3) are consistent with international standards of conservation and participation [58].

Strategic Scoping: The review utilized a combination of Boolean operators and keywords (e.g., "Energy Self-sufficiency", "Rural areas", "Historic Villages", "Renewable Energy Communities", "Circular Economy", "Rural Regeneration", "Place-based", "Community transition", "Energy transition", "Grecìa Salentina", "Apulia", "Regional Policy"), to capture the rapid evolution of the REC regulatory landscape and the socio-economic dynamics of heritage intrinsic value [24]. To ensure comprehensive boundary conditions, the artifact acknowledges the physical preservation of the built fabric, recognizing the role of structural strengthening frameworks for masonry buildings in ensuring long-term safety [36].

3.3 The Design Cycle: Strategic Design and Usability Interface

The core of the methodology lies in the Design cycle, where the roadmap is engineered not as a passive document, but as an "active usability interface" for territorial governance [46].

Strategic Foresight Protocol: Foresight is employed to "rehearse the future," integrating global trends with local identity [46]. This structure is grounded in the multidimensional benefits of landscape regeneration as a driver for ecosystemic and economic recovery [9, 10], transforming the roadmap into a systemic de-risking tool against the cascading risks identified in the UNDRR GAR 2025 framework [26].

Systemic Usability Engineering: The roadmap integrates principles of human-centered engineering to mitigate the "design failure" common in top-down policies through [21].

Functional Affordance: Action A (Transition Team) suggests and facilitates actionable paths for local administrators.

Signifiers and Cognitive Mapping: The roadmap guides the "heritage community", aiming to reduce the "cognitive friction" between regulatory complexity and local agency.

Strategic Feedback Loops: Action C (Digital Twin) is hypothesized as a dynamic repository of metabolic flows, leveraging digital tools and spatial data frameworks for historic building management [31, 57], while social well-being indicators are derived from human-centered monitoring models [56]. This cycle ensures that community engagement remains the primary stakeholder in governance [11, 19].

3.4 Case Study Selection and Comparative Logic

A multi-scale comparative analysis (Sect. 4.2) extracts key variables (governance, financing, participation) for roadmap replicability. The Grecìa Salentina district was selected as a critical case study (Sect. 4.1) due to the convergence of post-ecological shock conditions, geographical marginality, and institutional activism, exemplified by the European project GRowing participative models for EnErgy commuNities (GREEN) [71, 72]. This Union of Municipalities allows for testing "circular city and region models" at a sub-regional scale, where linguistic identity acts as a social glue for the "heritage community" [3, 52, 72]. The case functions as a testbed to transition from abandoned assets toward active nodes within a regenerative metabolism [32, 35], bridging theoretical premises with operational actions [2, 43, 69].

3.5 Pre-Implementation Rigor and Evaluative Boundaries

As a pre-implementation artifact, the roadmap's utility is evaluated through its internal consistency and potential to solve administrative paralysis in protected contexts [23, 50]. The absence of immediate post-operational data is a deliberate methodological boundary. The research aims to establish "epistemic prerequisites" as mandatory precursors to physical deployment, prioritizing de-risking and social consensus [28, 51]. This evaluative framework follows participatory, dynamic, and co-evolutionary models designed

to monitor the long-term impacts of circular adaptive reuse [25]. By defining structural governance and circular financial loops, the methodology provides a framework to stabilize conditions for future pilot testing [23, 26, 31].

4 Results and Discussion

4.1 Case Study: the Grecìa Salentina Context

The Union of Municipalities of Grecìa Salentina [72] represents a rural system where vernacular forms define a long-term co-evolutionary landscape [3]. The ecological shock of *Xylella fastidiosa* has converted this productive fabric into "residual capital" requiring systemic reconversion [2, 37]. This crisis necessitates a "human-centered" recovery where community engagement is the determinant factor for adaptability [58], leveraging the cultural "Grìko" identity as a catalyst for social capital regeneration [52, 72]. In this context, the Circular City model ensures that the recovery of identity coincides with economic resilience [35].

Current efforts via the GREEN Project [71], in which the Union of Municipalities of Grecìa Salentina is a strategic partner, aim to establish RECs as instruments for cohesion. However, the transition faces a "metabolic friction": integrating technology within the HUL without compromising morphological integrity [42]. The REC is designed to overcome the "gulf of execution" between regional targets and heritage constraints by adopting a "circular governance" model that reconciles ecological needs with humanistic regeneration [24].

4.2 Cross-Case Analysis and Comparative Lessons

The comparative analysis (Table 1) highlights that REC success depends on the ability to integrate heritage protection with mutualistic management [16, 49, 50]. Adaptive reuse requires specific circular business and governance models [20, 34]. Evidence suggests that social innovation in rural areas requires a "neo-endogenous" approach where local actors maintain sovereignty over resources [52].

Table 1 serves as the empirical base for deriving the key strategic variables – governance, financing, and participation – identified as essential for the replicability of the circular regeneration model.

Radical trajectories, such as Birse or San Giovanni a Teduccio, demonstrate that innovation lies in the collective ownership of resources [50, 59]. Specifically, the empirical dynamics of the Birse case, as investigated through the radical social innovation framework [59], illustrate how a community-led enterprise can actively build a new development trajectory by reclaiming ancient rights over natural heritage, despite deep-seated landownership concentrations and subsequent internal ideological conflicts regarding community empowerment. These models collectively demonstrate how the "intrinsic value" of heritage drives circular human-centered adaptive reuse [18]. Conversely, the incremental model prevalent in Italy reflects a municipal-led leadership that acts as a guarantor of institutional trust [53]. Cases like Melpignano or Ferla demonstrate that participation is often mediated by local authorities to facilitate access to PNRR funds

Table 1. Multi-scale comparative analysis (Authors' elaboration)

Case Study	Technological Mix & Heritage Constraint	Governance & Social Innovation Trajectory	Financing Model	Strategic Value & Heritage Integration	Ref.
Ferla (Italy)	Distributed PV (311 kW) & IoT monitoring. Constraint: Minor historic village integrity	Incremental: Municipal-led trajectory with prosumer involvement	TREPESL Project & regional funding	Education in "heritage citizenship" through collective management	[14]
Villanovaforru (Italy)	PV (44.3 kW), storage & smart meters. Constraint: Rural & historic landscape protection	Incremental: Consolidation of local resilience through institutional trust	PNRR (Mission 2, C2, I.1.2) & municipal budget	Common energy financing for proximity services	[16]
S. Giovanni a Teduccio (Italy)	55 kWp PV & 10 kWh storage. Constraint: Peripheral urban integrity	Radical: Solidarity model for combating energy poverty	Fondazione con il Sud and national public incentives	Social algorithm for inclusive well-being; regeneration of the urban-social fabric	[50]
Melpignano (Italy)	PV on historic roofs & water management. Constraint: Historic center integration	Incremental: Strengthening cohesion through a community cooperative	Local resources and PNRR (Mission 1)	Valorization of heritage as a living system (HUL)	[53]
Birse (Scotland)	Forest biomass & soil management. Constraint: Integrity of natural systems	Radical: Trajectory-creating process based on collective land ownership	Self-financing from community assets & local resources	Sovereignty over natural resources as a form of care for the common good	[59]

(*continued*)

Table 1. (*continued*)

Case Study	Technological Mix & Heritage Constraint	Governance & Social Innovation Trajectory	Financing Model	Strategic Value & Heritage Integration	Ref.
South Tyrol (Italy)	Hydroelectric & district heating. Constraint: Alpine landscape conservation	Incremental / Historical: Evolution of centuries-old mutualistic patterns	Social capital of cooperatives & energy sales	Energy self-sufficiency as a pillar of cultural identity	[67]
San Severo (Italy)	Onshore wind farm. Constraint: Landscape integration	Incremental: Active civic participation model	Civic crowdfunding: investment open to residents	Democratization of energy; shared productive infrastructure	[70]

[14, 53]. When expanding this perspective to the macro-regional level, the historical evolution of mutualistic patterns – such as those historically observed in alpine cooperative networks [70] – further confirms that regional long-term energy self-sufficiency can act as a structural pillar of local identity, reinforcing the broader taxonomies and mapping criteria established for European energy communities [67]. This confirms that the transition must be framed as a pathway toward energy justice, ensuring benefit distribution among vulnerable populations [22].

4.3 The Strategic Design Roadmap: Operationalizing the "Human-Centered" Interface

The proposed roadmap (Fig. 2) translates the RED III Directive [4] and New European Bauhaus [5] into an operational framework.

Action A – The Transition Team (Cognitive Interface): This unit is intended to function as a technical bridge for participatory co-design, potentially reducing the "cognitive friction" deriving from administrative complexity and regulatory burden [21, 42]. By aligning with NEB initiatives and HUL criteria, it identifies specific investment sectors where heritage and energy synergy is highest [6, 19].

Action B – Civic Crowdfunding (Circular Financial Loop): This action integrates public grants with digital crowdfunding to support "procedural justice" [22, 48]. Retaining added value locally is essential to fund the restoration of heritage assets like dry-stone walls within compromised agricultural and terraced contexts [3, 9]. Aligning with UNDRR GAR 2025 [26], this action proposes to treat community investment as an experimental asset to mitigate energy poverty while preserving cultural identity [2, 39].

Action C – Digital Twin Monitoring (Strategic Evaluation Feedback): This tool evaluates "territorial capital quality" through participatory, dynamic, and co-evolutionary

protocols [25, 28]. It transforms data into "strategic intelligence" [57], monitoring the impact on the intrinsic value of heritage and the well-being of the population [27, 56]. This ensures the REC is treated as an "active adaptive reuse project" capable of responding to post-ecological shocks [31, 37, 44].

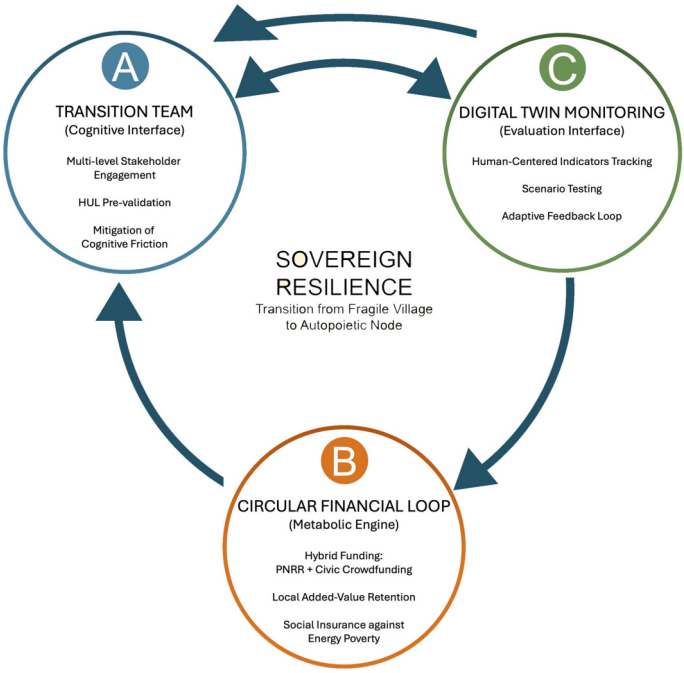

Fig. 2. Strategic Design framework for circular rural regeneration an integrated de-risking engine (Authors' elaboration)

4.4 Design Architecture for Territorial Resilience: A Systemic Synthesis

The innovation of the proposed roadmap lies in its architectural configuration as a potential multi-layer de-risking engine for fragile heritage contexts. By leveraging community engagement as the primary driver, the roadmap transforms urban regeneration into a shared management of common goods [11].

Administrative De-risking (Action A): It aims to address the conflict between conservation and innovation [45, 55]. By establishing a multidisciplinary Transition Team, the roadmap seeks to neutralize the risk of "veto-players" (e.g., *Soprintendenze*) through early-stage co-design, it hypothesizes a transition from a bureaucratic "wicked problem" into a process of human-centered engineering [12, 21], where the Faro Convention [33] and HUL criteria [42] are not constraints but design parameters. It seeks to ensure that circular governance reduces the risk of failure in top-down initiatives by fostering local consensus [24]. This pre-validation phase is intended to reduce the "time-to-market" of

energy communities in areas under landscape protection, where delays often lead to the loss of funding [17, 64, 69].

Financial and Metabolic De-risking (Action B): Community investment serves as "social insurance" against energy poverty [26, 49]. By integrating grants (e.g., PNRR) [64, 69] with crowdfunding, the roadmap attempts to solve the "place-based deficiency", proposing a financial metabolism that could prevent the "draining of value", aiming for "sovereign resilience" [52, 54, 65], where the economic surplus is recycled into the maintenance of the territorial capital [2, 7].

Adaptive and Foresight De-risking (Action C): It is intended to prevent "identity erosion" via feedback loops and Digital Twin technology [18, 28, 29]. This enables the REC to function as an adaptive socio-technical system capable of absorbing ecological shocks through simulated diagnostic scenarios [1, 50], incorporating active citizen engagement into its long-term evolution [58], monitored through Human-Centered Indicators [56]. The use of Digital Twins allows for "scenario-testing", helping the heritage community to visualize the impact of energy infrastructures before they are built, thus increasing social acceptance [57, 58].

4.5 Critical Evaluation of the Pre-implementation Roadmap

As a pre-implementation artifact, the proposed roadmap requires a balanced assessment of its potential utility and inherent limitations.

Potential Strengths (Pros): The primary hypothesized advantage is the reduction of "cognitive friction" through a structured governance interface [21]. By providing a clear roadmap before physical deployment, local administrations can coordinate the NEB pillars (inclusion, aesthetics, sustainability) [5] with the New Leipzig Charter's focus on the common good [60], justifying the human-centered approach as the core requirement for resilient system design [58, 65].

Challenges and Limitations (Cons): Effectiveness remains linked to the "social activation capacity" of the community, which may be limited in marginalized areas [51, 61, 62]. Metrics currently serve as predictive hypotheses requiring validation through longitudinal pilot testing [23].

Ultimately, while the roadmap does not claim to solve all the systemic issues of inner areas, it aims to provide a replicable operational method to potentially ensure that the energy transition is a regenerative process tailored to the specific metabolic needs of heritage-rich territories [2, 3, 7, 27, 37, 56].

5 Conclusions

The persistent marginalization of inner areas necessitates a paradigm shift from passive preservation toward proactive, circular regeneration. This research establishes a methodological bridge between European energy ambitions and the granular constraints of historic rural contexts. Adopting a Design Science Research approach, the work confirms that the viability of RECs in fragile territories depends on the architectural configuration of governance models rather than technological endowment alone [23, 24].

Addressing RQ1 and RQ2, the research demonstrates that circular metabolism functions as a socio-technical transition where community energy practices serve as primary procedural assets [2, 11, 16]. The proposed roadmap narrows the gap between policy targets and the operational reality of marginalized landscapes, identifying administrative complexity and regulatory barriers as the primary obstructions to local agency [2, 24]. To address RQ3 and RQ4, the research proposes a synthesis of three integrated de-risking mechanisms: a multidisciplinary Transition Team to navigate regulatory hurdles [1, 6]; a circular financial loop to retain economic value within the heritage community [48, 49]; and a Digital Twin-based monitoring system to safeguard historical integrity and track human-centered well-being [25, 31, 56, 57]. This tripartite structure provides a strategic response to the structural and financial constraints of social innovation in marginal territories [51, 52]. Furthermore, the Strategic Foresight protocol allows local administrations to anticipate future trajectories and absorb external shocks through an adaptive socio-technical artifact [28, 29]. This approach shifts de-risking from a purely financial dimension to a socio-epistemic one, where the usability of governance is a prerequisite for success.

While the pre-implementation scope constitutes a methodological boundary, the architecture provides a replicable protocol for both national (PSNAI [68]) and international (RED III, NEB [4, 5]) frameworks. The Grecìa Salentina case study serves as a scalable model for Mediterranean "vulnerable nodes", where RECs mitigate environmental shocks by transforming residual capital into multidimensional value [19, 37, 42, 56]. Ultimately, if validated through future longitudinal testing, this roadmap offers a pathway for fragile villages to evolve toward "sovereign resilience", where resource autonomy and cultural persistence converge into a unified trajectory of territorial regeneration.

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