Green and Grey Transition Data Analysis for Developing Synergies in the RECs Context

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Abstract. Addressing climate change and socio-territorial inequalities requires integrated approaches that connect green and grey transitions within local development processes. In this context, Renewable Energy Communities (RECs) offer a strategic opportunity, particularly in fragile and mountain areas. This study aims to investigate how integrated data analysis can support the identification of synergies between energy systems, service provision, and local demand. The research adopts a spatially integrated approach based on the combination of socio-demographic, territorial, and energy-related datasets within a Spatial Information System (SIT). Through a collaborative and interdisciplinary process, the framework enables the interpretation and matching of multiple data layers. This paper investigates the interaction between demographic ageing, socio-spatial vulnerability, and energy transition processes in the Nort-Western Canavase, a mountain area in Piedmont (Italy) characterised by depopulation and limited accessibility to welfare and energy infrastructures. Analytical mapping and accessibility assessments are employed to identify critical areas and potential synergies. The analysis highlights the added value of integrating green (energy-related) and grey (demographic ageing and service contraction-related) dimensions. It reveals mismatches between energy supply and local demand, as well as opportunities to enhance service provision through energy initiatives. Areas characterised by high socio-territorial vulnerability emerge as priority contexts for targeted actions. The study demonstrates the potential of integrated data analysis to support decision-making in the RECs context. By fostering interdisciplinary collaboration and evidence-based insights, the proposed framework contributes to more inclusive, place-based, and synergic transition strategies.

Keywords: Homecare Services · Energy Vulnerability · Active Ageing

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1 Introduction

The transition toward low-carbon energy systems represents one of the central challenges of contemporary territorial development [1]. In recent years, particular attention has been devoted to the role of Renewable Energy Communities (RECs), increasingly framed as key instruments for fostering decentralised energy production, enhancing local resilience, and supporting the green transition. In this sense, the "green transition" is understood as a territorial process of decarbonization and energy system transformation [2] through the deployment of renewable energy infrastructure and sustainable energy policies [3]. However, in inner and rural areas, this transition unfolds within contexts characterised by structural demographic and socio-economic vulnerabilities, raising critical questions about its feasibility, inclusiveness, and long-term sustainability [4].

At the same time, many European inner regions are experiencing a parallel and equally significant process of demographic ageing and service contraction, here defined as the grey transition. In this paper, the term "grey transition" refers to the demographic transformation associated with population ageing, depopulation [5], and increasing socio-spatial vulnerability [6, 7], particularly affecting marginal and peripheral territories [8]. In such contexts, socio-assistential services are not only essential infrastructures for care provision, but also key elements shaping territorial cohesion and quality of life [9]. While the "green transition" refers to the structural transformation towards low-carbon and renewable energy systems [10], the concept of "grey transition" has been increasingly used to describe demographic ageing, shrinking labour forces, and rising dependency ratios affecting European societies [8].

Despite their coexistence, green and grey transitions are often addressed through separate policy and analytical frameworks. Energy transition strategies tend to focus on technological and infrastructural aspects, while socio-assistential systems are typically analysed within welfare and public service domains. This separation overlooks the fact that both processes are deeply interconnected at the territorial level. Demographic ageing directly influences energy demand patterns, service accessibility needs, and infrastructural pressures, while energy systems, particularly when organised through Solidarity and Renewable Energy Communities (CERS), can potentially support local welfare systems, reduce energy poverty, foster social cohesion and contribute to the provision of services in fragile contexts [11, 12].

Within this framework, the SustAge project (led by the Law Department of the University of Turin, [13]) investigates the relationship between green and grey transition, with a specific focus on the integration between energy communities and home-based socio-assistential services in rural and mountain areas. The project adopts a place-based and interdisciplinary perspective, aiming to bridge the gap between energy, social, and territorial dimensions.

The central research problem lies in the disconnection between sectoral approaches to energy transition and the socio-territorial conditions in which they are implemented. In particular, existing strategies often overlook the role of demographic dynamics and socio-assistential systems in shaping both energy needs and implementation capacity. The study is therefore guided by the hypothesis that green and grey transitions are structurally interdependent, especially in fragile rural areas. However, previous studies rarely integrate demographic vulnerability, socio-assistential accessibility, and renewable energy potential within a unified GIS-based analytical framework.

This paper focuses on the first preliminary results of the SustAge project, to demonstrate how socio-economic and energy data analysis serve as a foundational methodological step for identifying constraints and opportunities in a specific territorial context, and for supporting the development of integrated strategies of local governance that address the interdependencies between green and grey transition.

The research is grounded in a place-based approach, which recognises territorial specificity as a fundamental resource for designing effective and context-sensitive interventions. This perspective is complemented by an interdisciplinary framework integrating contributions from legal studies, systemic design, economic evaluation, and electrical engineering.

The North-Western Canavese area (Piedmont, Italy) was selected as a case study for its emblematic combination of demographic fragility, territorial fragmentation, and energy potential.

The main objectives are:

- to develop a comprehensive territorial analysis integrating multiple data layers;
- to identify criticalities and latent potentials within the study area;
- to explore the interactions between energy systems and socio-assistential structures;
- to provide a robust analytical basis for future phases of the project.

The paper is structured as follows. Section 2 presents the methodological approach, outlining the integrative and interdisciplinary framework adopted to combine demographic, socio-economic, and energy-related data within a spatial analytical environment. Section 3 introduces the case study of the North-Western Canavese, highlighting its territorial, demographic, and infrastructural characteristics. Section 4 discusses the main results of the analysis, focusing on interactions between grey and green transitions and identifying patterns of synergies and mismatches. Finally, Sect. 5 provides the conclusions, summarising the key findings and outlining future research directions.

2 Methodological Approach

The study adopts a multi-disciplinary framework, based on the integration of data analyses on green and grey transition, assuming the concept of holistic territorial diagnosis [14]. This approach enables the combination of heterogeneous datasets from different sources into a coherent analytical framework [15], allowing for the identification of interdependencies across spatial, social, and technical dimensions. Rather than treating each analytical dimension separately, this approach emphasises their systemic integration [16], in line with the complexity of the case study. The proposed framework should be interpreted as an exploratory GIS-based analytical approach combining quantitative spatial indicators with a qualitative interpretation of territorial vulnerability.

The methodological approach spatially integrates heterogeneous socio-demographic, infrastructural, and energy-related datasets in order to identify territorial patterns and criticalities.

Within this framework, demographic dynamics are interpreted not merely as descriptive variables, but as drivers of territorial transformation [17], directly influencing demand for care services, mobility requirements, and energy consumption patterns. At

the same time, accessibility is conceptualised as a multi-dimensional concept, related to energy and technical systems, infrastructure provision, and service distribution [18]. It is therefore understood as a key determinant of territorial cohesion and social inclusion, particularly for vulnerable populations [19]. The integration of economic, social, and technical dimensions allows for a more comprehensive understanding of how structural ageing processes interact with energy energy systems and renewable potential, potentially mitigating territorial inequalities [20].

In this perspective, the grey transition is not only a demographic process linked to ageing, but also a spatial phenomenon [21], reshaping both the composition of the population and the accessibility of services across the territory.

Figure 1 illustrates the methodological framework adopted to integrate green and grey transition. The approach combines demographic and energy datasets through a spatial data integration layer, enabling the identification of synergies and mismatches [22] between service demand, accessibility conditions, and energy potential.

The methodological framework is structured around the convergence of two distinct but interrelated domains: the grey transition, associated with demographic dynamics and socio-assistential systems, and the green transition, related to energy systems and renewable potential. The grey transition is analysed using demographic and social data [20], including population structure, ageing patterns, and the distribution of service demand and supply, while the green transition is examined through energy-related data [23, 24], such as renewable energy potential, existing infrastructures, and energy system configurations.

These two domains are brought together within a data elaboration and integration phase, in which heterogeneous datasets are combined through spatial analysis techniques. This phase relies on the overlay and cross-referencing of demographic, service, and energy data, enabling a systemic interpretation of the territory and revealing underlying spatial patterns.

Building on this integrated dataset, the framework advances through a collaborative [25] and interdisciplinary interpretation and matching process, engaging different disciplines. In particular, the data integration enables the assessment of the alignment between energy supply and local demand, the interaction between service provision and energy potential, and the identification of areas characterised by high socio-territorial vulnerability [26, 27].This interpretative step makes it possible to detect both synergies and mismatches between systems that are typically analysed separately.

In this context, a SWOT analysis is employed as a synthetic evaluative tool to systematically identify strengths, weaknesses, opportunities, and threats emerging from the interaction between socio-demographic and energy-related dimensions.

The resulting outputs consist of a spatial classification of territorial patterns, distinguishing areas of socio-territorial fragility, areas with high renewable energy potential, areas with significant service or energy demand, as well as critical mismatch areas where demand is not adequately met by existing supply, and potential synergy areas where energy production capacity overlaps with social and service hubs. Overall, the approach enables a shift from sectoral analyses toward a relational and integrative understanding of territorial systems [14, 28], providing a robust analytical basis for the development of place-based strategies that simultaneously address environmental and social challenges.

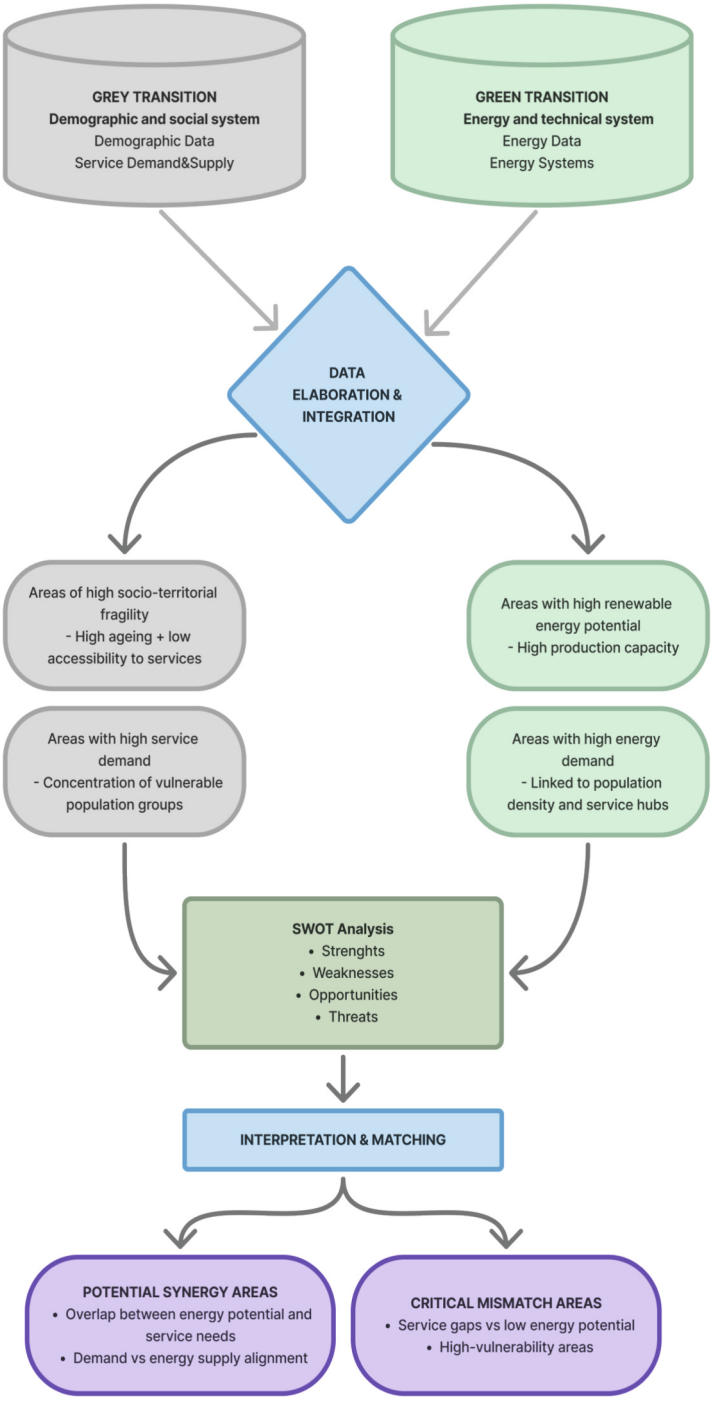

Fig. 1. Methodological framework adopted in the present research (Authors' elaboration).

3 Case Study

The North-Western Canavese represents a typical rural context, where geographical, demographic, and infrastructural conditions interact to produce complex territorial dynamics. The territory is predominantly characterised by mountain and semi-mountain areas, with numerous small municipalities distributed across valleys and upland zones. This morphology contributes to a dispersed settlement pattern, which, combined with limited transport connectivity, generates significant challenges in terms of accessibility to services and infrastructures.

From a demographic perspective, the area exhibits a pronounced ageing trend, with a high proportion of elderly population and a progressive decline in younger cohorts. This dynamic directly affects the demand for healthcare and social services, placing increasing pressure on local welfare systems. In this context, the presence of the CISS38 socio-assistential consortium [29] plays a crucial role, acting as a central coordinating body for the provision and management of social services across the territory (Fig. 2). Despite this institutional structure, the spatial distribution of services remains uneven, particularly affecting more remote and mountainous municipalities, where accessibility constraints amplify conditions of socio-territorial fragility [30].

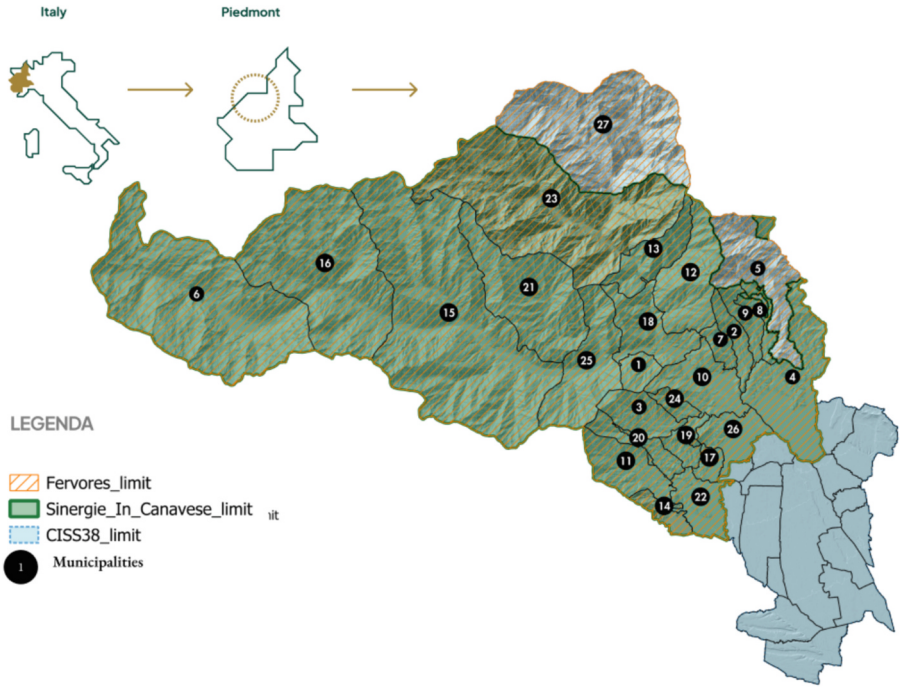

Fig. 2. North-Western Canavese area (Authors' elaboration on Geoportale Torino - Banca Dati Territoriale di Riferimento degli Enti (BDTRE), 2025).

At the same time, the territory presents relevant opportunities in the field of energy transition. It is important to highlight the presence of the Green Community *Sinergie in Canavese* [31], which promotes cooperation among municipalities to advance sustainable management, enhance energy efficiency, support green tourism, and counteract depopulation, and the Fervores CERS [32], which reflects a growing capacity to activate local resources and experiment with decentralised energy models. These initiatives highlight the potential of energy systems not only as technical infrastructures, but also as instruments for fostering territorial cohesion and supporting local communities.

Overall, the coexistence of ageing population, infrastructural constraints, and significative energy production capacity makes the North-Western Canavese a particularly relevant context for exploring the integration between green and grey transition. The interaction between demographic dynamics, service provision, and energy systems suggests the need for place-based and interdisciplinary approaches capable of addressing environmental and social challenges in a coordinated manner.

4 Results

The integration of data analyses on green and grey transition did not primarily result in a static representation of territorial conditions, but rather in a process of knowledge construction based [28] on the interaction between different disciplinary perspectives and data layers. A key outcome of this phase was the visualisation of demographic, socio-assistential, infrastructural, and energy-related data within a shared analytical environment, enabling a shift from sectoral interpretations to a systemic reading of the territory.

In this context, the collaboration between disciplines played a central role. Each domain contributed distinct datasets, interpretative frameworks, and analytical priorities, which were progressively aligned through processes of data elaboration, visualisation, and mapping. Data visualisation [33], in particular, emerged as a critical methodological tool, allowing complex and heterogeneous information to be translated into readable and comparable spatial representations. Through the development of a Spatial Information System (SIT), it became possible to highlight relationships that would remain otherwise implicit, such as the overlap between demographic vulnerability, service accessibility, and energy potential.

The data elaboration and integration phase was therefore not limited to the technical combination of datasets, but involved an interpretative process in which mapping practices supported visual outputs. Maps and visual representations functioned as boundary objects, enabling different disciplinary perspectives to converge around shared evidence and facilitating the identification of relevant analytical dimensions. Building on this SIT, the subsequent phase of interpretation and matching enabled the identification of relationships between green and grey transition, moving beyond their conventional separation. The analysis revealed how demographic ageing, service demand, and accessibility conditions interact with energy production potential, infrastructural configurations, and consumption patterns. Rather than treating these domains independently, the framework enabled explicit matching of demand and supply across social and energy systems (Fig. 3).

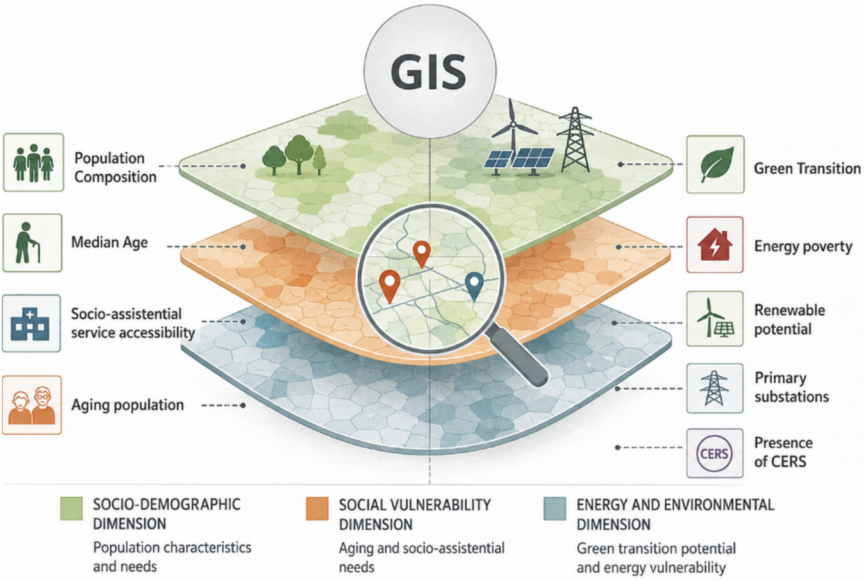

Fig. 3. Conceptual framework of the Spatial Information System (SIT) integrating grey and green transition dimensions. (Authors' elaboration, generated with AI support, OpenAI DALL·E).

The results of this matching process consisted of the identification of different types of territorial conditions, defined by the degree of alignment or misalignment between the two transitions. In particular, the analysis highlighted situations in which high levels of socio-demographic vulnerability correspond to limited service accessibility and to the fragmentation of the social fabric, reflected in instances of isolation among older populations, often associated with economic hardship and infrastructural limitations in accessing energy ('energy poverty' [34]). It also identified contexts in which energy production potential coincides with significant social demand, particularly in areas where spaces for social and healthcare interaction are already present, or where new hubs may be required to support community- and home-based care services.

At the same time, the analysis identified areas in which the overlap between energy potential and social needs suggests the possibility of integrated interventions, particularly through decentralised and community-based networks. In this sense, the results provided not only a diagnostic reading of the territory, but also an analytical foundation for linking energy transition strategies with welfare and service provision systems [23].

Overall, the results demonstrated that the added value of the proposed methodological approach lies in its capacity to connect heterogeneous data through visualisation and interdisciplinary interpretation, enabling the identification of potential synergies and critical mismatch areas between green and grey transition and supporting the development of place-based and integrated strategies.

4.1 Demographic Ageing and Socio-Assistential Services

The analysis of demographic dynamics and socio-assistential services highlighted the structural relevance of the grey transition within the study area. The territory is characterised by a markedly ageing population, with a high proportion of residents over 65 years (28.04%) and a significant imbalance between older and younger groups (309 people aged 65 or over for every 100 young people aged 0 to 14 in 2025). This demographic configuration translates into an increasing demand for healthcare, social assistance, and proximity-based services, particularly in municipalities affected by population decline and settlement dispersion (Fig. 4).

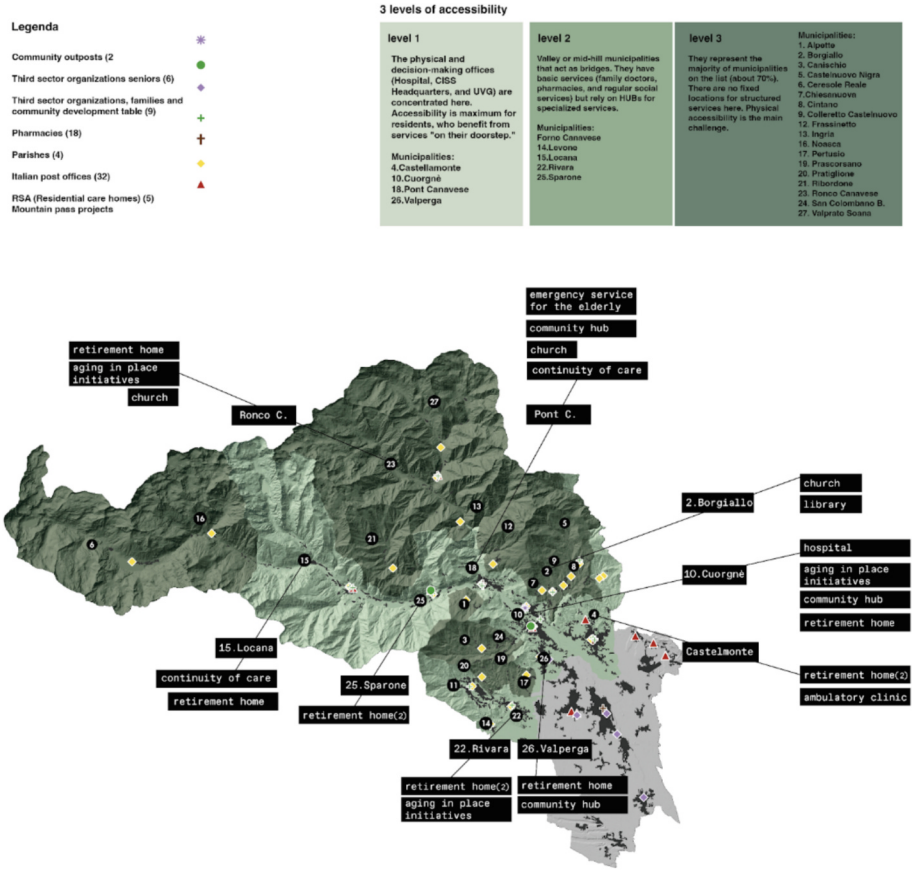

Fig. 4. Socio-Assistential System in the study area (Authors' elaboration). Cartographic sources: Geoportale Piemonte – Banca Dati Territoriale di Riferimento degli Enti (BDTRE). Data sources: CISS38, Progetto "Passi Montanti", and on-desk surveys.

The mapping of socio-assistential services, combined with accessibility analysis, revealed a multi-level and spatially uneven system of provision. Central municipalities (Cuorgnè and Castellamonte) concentrate the main service infrastructures, including

healthcare facilities and administrative functions, while intermediate areas rely on partial and often periodic services. Peripheral and mountain municipalities (Ceresole Reale, Locana and Noasca), on the other hand, are characterised by limited physical accessibility and the absence of structured service provision, relying instead on mobile, home-based, or emergency services.

Within this framework, the presence of the CISS38 socio-assistential consortium (in Cuorgnè) plays a crucial role in coordinating service provision across the territory. However, the analysis showed that institutional coordination alone is not sufficient to overcome territorial constraints related to distance, morphology, and infrastructural limitations. Accessibility emerged as a key mediating factor, shaping the effective capacity of the system to respond to demographic demand.

Through data visualisation and mapping, it was possible to highlight the misalignment between areas of higher demographic vulnerability and the spatial distribution of services, particularly in mountain areas. This confirms that the grey transition is related not only to demographic indicators, but also to service accessibility, reinforcing conditions of socio-territorial fragility [21].

Overall, the results pointed to the need for a progressive reconfiguration of service provision models toward forms of domiciliarity [35], where care and assistance are delivered closer to or directly within the living environments of the population. In contexts characterised by ageing, dispersion, and limited accessibility, domiciliary services emerge not as a complementary solution, but as a structurally necessary response to ensure continuity of care and territorial equity.

4.2 Energy System and Renewable Potential

The analysis of the energy dimension provided a complementary perspective [23] on the green transition, bringing to the forefront the issue of energy vulnerability as a key territorial condition. While the mapping of photovoltaic potential (Fig. 5), based on spatial analysis of exposure and built environment characteristics, revealed the presence of heterogeneous energy production capacities, this potential did not automatically translate into accessible or equitable energy provision [36].

The visualisation of energy data highlighted a significant misalignment between energy production potential, local demand, and service needs. Areas with higher renewable capacity are not necessarily those with higher population density or greater socio-assistential demand, resulting in asymmetries that contribute to conditions of energy vulnerability. This is particularly relevant in mountain and peripheral contexts, where infrastructural limitations, dispersed settlements, and limited accessibility can exacerbate both energy costs and service provision challenges.

In this framework, energy vulnerability [37] emerged not only as a function of income or consumption, but as a territorially embedded condition, shaped by the interaction between energy infrastructures, spatial accessibility, and socio-demographic dynamics. The integration of energy data with demographic and service-related information enabled the identification of contexts where limited access to energy resources overlaps with high social demand, reinforcing existing patterns of fragility.

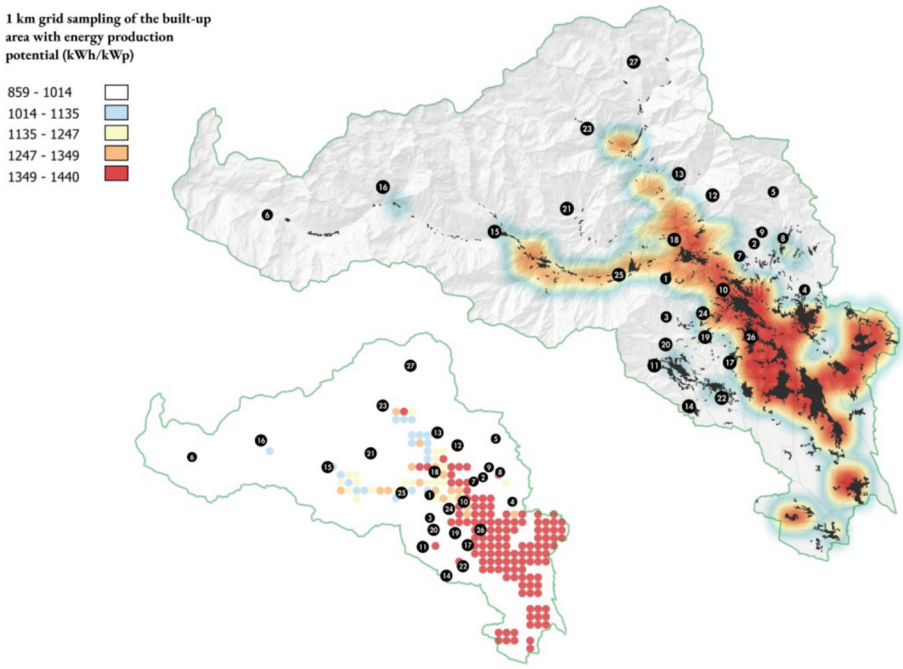

Fig. 5. Energy photovoltaic potential in the focus area (Authors' elaboration).

The presence of emerging initiatives such as the Fervores CERS suggested a potential pathway for addressing these challenges through decentralised and community-based energy systems. However, the analysis also revealed a significant gap between the conceptual potential of RECs and their current implementation. In particular, the development of these initiatives appears to be constrained by regulatory complexity, administrative delays, and the relatively recent activation of the supporting legislative framework. As a result, RECs have so far been only partially able to develop projects with tangible social impact, especially in relation to supporting vulnerable populations and socio-assistential services.

This limitation highlighted a broader issue in the current energy transition framework, where technical and regulatory advancements are not yet fully aligned with social and territorial needs. In the absence of targeted strategies, the risk is that renewable energy systems remain disconnected from local welfare systems, failing to address energy vulnerability in a structural way.

Overall, the results showed that the green transition, when analysed in isolation, tends to emphasize production potential while underestimating issues of accessibility, distribution, and social impact. The integration between green transition and grey transition is therefore essential to reframe energy systems as infrastructures with both environmental and social functions [24], capable of contributing to the reduction of territorial inequalities and the support of care systems [21], particularly in fragile and mountain areas.

4.3 SWOT Analysis Results

The SWOT analysis identifies territorial potentialities and critical vulnerabilities requiring strategic intervention. The findings concerning the energy dimension, demographic dynamics, and socio-assistential services are summarized in a matrix organized by three macro-themes:

- Territory dimension
- Socio-assistential services
- Energy dimension

To enable a more detailed analysis, each macro-theme was subdivided into specific sub-themes:

- Territory dimension: morphology, governance, population, mobility, and services.
- Socio-assistential services: aging and social needs, access, organizational structure and social relations.
- Energy dimension: general framework, production and consumption potential.

Each sub-theme revealed multiple strengths, weaknesses, opportunities, and threats. The data integrated into this matrix derived from a cross-analysis of energy, demographics, and social services, further enriched by three interviews with key stakeholders: Fervores CERS, the Green Community *Sinergie in Canavese* and CISS 38.

This integration of quantitative and qualitative data allowed a comprehensive comparison between desk analysis results and stakeholder insights.

The merged dataset reveals a complex and heterogeneous system characterized by strong interdependencies between territory, service provision, and energy potential. From a governance perspective, the presence of multi-actor cooperation (CERS Fervores, CISS 38, Green Community) represents a key enabling condition for integrated territorial development. However, this potential is constrained by administrative fragmentation and regulatory instability, which limit the scalability of coordinated interventions. However, the region suffered from morphological fragmentation, low population density, and an aging index far exceeding the regional average. Such conditions render service distribution uneven, particularly as travel times for public transit increased more sharply than for private vehicles as travel distance increases. While the CERS could act as a territorial aggregator and together with other key stakeholders could facilitate access to multi-level funding (EU, national, regional), administrative fragmentation and unstable planning instruments remained significant threats.

From a socio-assistential perspective, the expansion of the over-65 population increased healthcare demand, placing additional pressure on waiting lists and caregiver availability. The territory is characterized by a shortage of general practitioners; furthermore, 70% of the municipalities lack primary healthcare facilities. Initiatives like “Passi Montani” have addressed these gaps, while the upcoming “Prossimità” project aims to provide further reinforcement. There was a significant perceptual gap: social workers were often perceived as obstacles rather than support systems, unlike local administrators, who were individuals with whom the population directly expressed their care and assistance needs. Regarding energy, the primary weakness was the operational delay of Fervores CERS, alongside limited production potential in restricted zones. On the other

hand, strengths included the involvement of 10 new CER participants and the alignment between high-production areas and the largest town, such as Castellamonte. Currently, the most significant threat is the regulatory burden and bureaucracy imposed by the GSE.Overall, the SWOT synthesis suggests that the three domains cannot be interpreted independently, as they co-produce a unified framework of socio-territorial vulnerability. In this sense, territorial fragility, social demand pressure, and energy transition dynamics emerge as mutually reinforcing processes.

5 Conclusions

This paper has explored the relationship between green and grey transitions in rural areas through an integrated and place-based analytical framework, focusing on the North-Western Canavese area as an exploratory case study. The work represents a first step in investigating the interaction between demographic ageing, service contraction, and renewable energy potential within the ongoing SustAge project. While the results presented here are still preliminary, they provide the basis for further methodological developments and future operational applications that will be explored in the next phases of the project. The results confirmed the initial hypothesis that these transitions are not independent processes, but rather structurally interconnected dynamics that jointly shape territorial development.

The application of a multi-layered and interdisciplinary framework demonstrated the value of combining demographic, socio-assistential, infrastructural, and energy-related data within a shared analytical environment. This approach enabled a shift from sectoral interpretations to a systemic understanding of the territory, allowing identification of both synergies and mismatches between social demand, service accessibility, and energy potential. The use of a SWOT analysis provided a necessary bridge between hard data and field interviews, helping to contextualize territorial conditions within the larger framework of external opportunities and threats.From the perspective of the grey transition, the findings highlighted how demographic ageing is not only a demographic trend but a spatially embedded process, strongly influenced by territorial morphology, accessibility conditions, and service distribution. In the North-Western Canavese, some inequalities in access to socio-assistential services emerged, particularly in peripheral and mountain municipalities, where fragmented settlement patterns and infrastructural constraints limit the effectiveness of existing welfare systems. In this context, domiciliary and proximity-based care models emerged as a structurally necessary response to ensure continuity of care and territorial equity.

At the same time, the analysis of the green transition revealed that renewable energy potential, although present and in some cases significant, is unevenly distributed and not inherently aligned with local demand or socio-assistential needs. The results showed that energy systems, when considered in isolation, risk reinforcing existing territorial disparities, as areas with higher production potential do not necessarily correspond to areas of higher vulnerability or service demand. Energy vulnerability therefore emerged as a territorially embedded condition, shaped by the interaction between infrastructure, accessibility, and socio-demographic dynamics.

A key contribution of this study lies in the identification of spatial configurations in which overlaps between energy potential and social demand suggest opportunities

for integrated interventions. In particular, the presence of local initiatives such as RECs indicates a promising pathway for linking decentralised energy production with welfare systems and service provision. However, the current gap between the theoretical potential of these initiatives and their practical implementation highlights the need for more coherent regulatory, institutional, and governance frameworks.

Overall, the results suggested that addressing green and grey transitions requires moving beyond sectoral approaches toward integrated, place-based strategies that consider energy systems not only as technical infrastructures, but also as social infrastructures capable of supporting care, reducing inequalities, and enhancing territorial cohesion.

From a methodological perspective, the study demonstrated the central role of data visualisation and mapping as tools for integrating heterogeneous datasets and supporting interdisciplinary dialogue. Visual representations function as boundary objects, enabling different disciplinary perspectives to converge and facilitating the construction of shared knowledge.

Finally, this research represents a first step within the broader SustAge project. Future developments will focus on translating the identified synergies into operational strategies, exploring governance models, and testing pilot interventions aimed at integrating energy communities with socio-assistential services. Further research is also needed to refine the analytical framework, set a range of measurable indicators, and assess the replicability of the approach in other inner and rural contexts.

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Declaration of AI Usage. During the preparation of this manuscript, we used artificial intelligence-based tools to support language refinement, grammar and style improvement, and English editing. All outputs generated by these tools were critically reviewed, edited and approved by the author, who take full responsibility for the final content and language quality.

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