Renewable Energy Communities: Enabling Technologies and Regenerative Models for the Green and Digital Transition in the Inner Areas

Investigation Through Case Studies for the Experimentation of Living Lab in the Grecanica Area

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Abstract. This contribution addresses issues of research in Architectural Technology conducted with the laboratory ABITAlab of dArTe-Unirc, with reference to the design of devices for regenerative models based on the tool of "Renewable Energy Communities" in territories subject to marginalization and depopulation phenomena, such as the inner areas of Grecanica Area in Reggio Calabria. The aim is to envisage a transformative path of sustainable development, which can implement "mechanisms of just and equitable transition" at the local level, placing itself within the lines of support and public investment for climate neutrality, such as the Next Generation EU and the National Plan for Recovery and Resilience in Italy. We investigate the key issues of advanced sustainable project, for the design of devices and integrated innovative tools based on solar technologies (PV) for the production, storage and distribution and sharing of energy by communities settled in the inner areas (*prosumers*), helping to obtain economic and environmental benefits, towards the "climate neutrality". The model of Energy Communities, using processes of Advanced Regenerative Design, which increase the performance of the system, thanks to the integration of hybrid "zero impact" technologies, become the tool through which to trigger processes of regeneration and new quality of space and life in the inner territories, where there is a greater presence of natural resources (air, water, sun, biomass, etc.) to be used as renewable sources for energy production, but also the possibility to monitor and more easily account for the impacts of a settlement model based on "carbon free" energy production chains, with the reference community settled.

Keywords: Energy Communities · Enabling Technologies · Inner Areas

1 Introduction

The trend towards a paradigm shift in energy production, management and consumption, triggered by the gradual transition from the use of fossil sources to the prevalence of renewable resources, is the domain within which to achieve the decarbonization

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goals of the European energy system defined in the Clean Energy Package adopted in 2019 [1]. In deed, the European Union's energy policy promotes an integrated approach to environmental, climate and energy safety in order to solve also social needs [2]. Moreover, in Italy, as in all industrialized countries, buildings are assigned about 40% of total energy consumption and almost 50% of Co2 emissions. It is noteworthy that even if recent commitments rule out the worst-case emissions scenario (a global temperature rise of more than 3 °C), the transition to a net-zero GHG energy system will be costly. The problem of pollution is solved not only by limiting energy consumption and thus by using smaller amounts of energy, but also by using "clean" energy sources and, finally, by increasing the efficiency of energy transformation, that is, by using thermal and electrical energy production systems with as little loss as possible. In this sense, the solar energy produced by photovoiltaic plants (PV) is advantageous since it is currently the cheapest source of electricity. Certainly, other important advantages are related to the wide availability of energy sources and the return on investments for electricity, thanks to the payback period and the environmental friendliness (zero impact) [3]. In addition to environmental issues, the challenge also concerns the phenomenon of energy poverty, "a situation in which a household is unable to pay for the primary energy services (heating, cooling, lighting, moving, and power) needed to ensure a dignant standard of living, due to a combination of low income, high energy expenditure, and low energy efficiency in their homes" [4]. This phenomenon affects mostly the inner areas communities, which live in conditions of marginalization, caused by the lack of access to primary services (health, education, mobility) and energy sources [5]. As stated by Gaman et al. [2], in order to trigger a sustainable transformative pathways and implement "fair and equitable transition mechanisms" at the local level, it is necessary to develop an integrated sustainable development strategy, which includes the capability to adopt approaches that encourage cooperation and partnerships between the public bodies, private sector and civil society in experiences, capable to transfer knowledge and sustainable models "innovation driven" and to be accelerated by large-scale investments from sustainable policies.

In this context, the paper investigates the issue of Renewable Energy Communities (RECs) as a tool capable of responding to the environmental issues of clean and affordable energy production and the scarcity of primary services due the lack of energy provision in marginal territories, through the adoption of a method related to advanced type design for impact control and the experimentation of the Living Lab (LL) model as a demonstrator capable of implementing, managing and validating a REC. The paper is structured as follow:

- the Sect. 2 illustrates the key issues about the policies for the "green transition" and the renewable energy communities, followed by a sectoral overview at case studies of REC implemented in rural areas at the european and national levels;
- the Sect. 3 investigates the methodological approach and aspects with which architecture technology can contribute to achieve the goals of reducing impacts for climate neutrality, acting through processes and strategies of mitigation and adaptation and activating "advanced sustainable projects" for energy self-production;

– the Sect. 4 describes the preliminary findings for the experimentation of Living Lab (LL), illustrating the LL approach in european projects and key issues for the application on the Grecanica Area of Reggio Calabria;
– the Sect. 5 critically discusses the five innovative aspects for favourable conditions for an experimentation of REC in the Grecanica Area;
– in conclusion, the possibility to activate LL processes and future steps of research are discussed.

2 Key Topics of the Reference Scenario

2.1 Policies for the Green Transition

In order to accelerate the "green and digital" transition in the regions of the member countries and the achievement of the global goals for climate neutrality and sustainable development of the UN Agenda 2030, Europe has launched an "Energy Transition Strategy" to guide the transformation of the global energy sector from fossil to zero carbon by 2050 and a 55% reduction in greenhouse gas emissions by 2030 [6]. In this direction the Next Generation EU (NGEU) program operates, which has made available substantial financial resources through the Recovery and Resilience Facility (RRF), the tool through which the European Union intends to achieve the green and ecological transition of society and the environment. In July 2021, the italian Government has finally approved the National Recovery and Resilience Plan (NRRP), the package of reforms and investments launched in order to access the resources of the NGEU, which is divided into 16 components, grouped into 6 missions, including the "M2. Green Revolution and Ecological Transition" [7]. In particular, the NRRP reserves large shares to actions aimed at "Increasing the share of energy produced from Renewable Energy Sources (RES) in the system" and has identified investment lines dedicated to innovative tools and technologies for these purposes, such as the "Promotion of renewables for energy communities and self-consumption" (M2C2 – "Renewable energy, hydrogen, network and sustainable mobility"). In addition to these lines of intervention, it is also worth considering the facilities that will be available to the regions with measures of the Cohesion Policy in response to the effects of the crisis and contributing to a "green, digital and resilient economic recovery" [8]. Moreover, the areas referable to the Ecological Transition are also traceable in other trajectories, measures and actions, such as: the National Research Plan 21–27, Trajectory 5.5.2: "Climate Change, Mitigation and Adaptation", Articulation 4/8/9 [9]; the Specialization Smart National Strategy (SSNS), Regional Specialization Area "Energy" with the national priority development trajectory 5.5.4 "Intelligent and sustainable industry, energy and environment - Evolutionary and adaptive production systems for customized production - Technologies for smart grid, renewable sources and distributed generation" [10]; the 2030 Agenda with Goal 7 "Ensure access for all to affordable, reliable, sustainable and modern energy systems" and Goal 11 "Make cities and human settlements inclusive, safe, durable and sustainable" [11] and, at the local level, the National Strategy for Sustainable Development, Area "Planet", strategic choice "Ensure sustainable management of natural resources" [12]; the Regional Operational Program-ROP Calabria 21–27, Specific Objective 2 "Greener

Europe and free of carbon emissions" and the S3 Calabria Region, for the trajectory "Energy and Climate - Energy Communities and technologies for smart grids and renewable sources" [13].

These references are the framework of intervention policies to support the implementation of new models of production, storage and exchange of energy from renewable sources, which employ innovative technologies and advanced devices and promote forms of decentralization and self-consumption through the so-called Renewable Energy Community (REC).

2.2 The Renewable Energy Communities

The path of regulatory adaptation in the field of renewable energy communities ended last December 15, 2021 with the Legislative Decree that definitively transposes the Renewable Energy Directive - RED II (2018/2001) and Internal Market in Electricity-IEM (2019/944) directives. This process, which began with the "Milleproroghe Decree" of February 2020, will allow the large-scale promotion of the implementation of energy communities in order to achieve the minimum target of 32% green energy as early as 2030. In distinguishing "Renewable Energy Communities" from "Renewable Energy Self-Consumers", the RED II Directive defines the former as legal entities made up of groups of individuals, local entities, companies, located in the vicinity of plants producing energy from renewable sources that on a voluntary basis come together to produce and consume clean electricity, according to the principles of self-consumption and energy self-sufficiency [14]. The purpose of REC is in fact to aggregate and account for the energy demand of a defined local community, capable of having technologies and devices for energy production from renewable sources.

The users are configured then no longer as mere "consumers", but also as "producers" of energy ("presuming" model: producing + consuming), able to cope with the issues of "energy poverty" and to operate in a participatory and collaborative way to design systems for the satisfaction of their energy demand of residential type and the management of collective structures/manufactures with social purposes. The Article 2(16) of the Renewasbles Directive defines a REC as a "legal entity: (a) which, in accordance with the applicable national law, is based on open and voluntary participation, is autonomous, and is effectively controlled by shareholders or members that are located in the proximity of the renewable energy projects that are owned and developed by that legal entity; (b) the shareolders or members of which are natural persons, SMEs or local authorities, including municipalities; (c) the primary purpose of which is to provide environmental, economic or social community benefits of its shareolders or members or for the local areas where it operates, rather than financial profits". RECs are entitled to produce, consume, store and sell renewable energy, including through renewable power purchase agreements, to share renewable energy within the community, and to access to all suitable markets [15] (Table 1). In addition, the Legislative Decree defines the increase in the power limit of plants eligible for incentive mechanisms (from 200 kW to 1 MW) and removes that of the creation of energy communities by users under the same secondary cabin.

Table 1. Comparition of energy “production/consuming” models. Source: elaboration by G. Mangano

Model	Production	Market	Transmission	Distribution	Consumer
Traditional	Few large plants	Centralised, mostly national	Based on large power lines and pipelines	Top to Bottom	Passive, only paying
Renewable Energy Communities	Many small power produces	Decentralized, ignoring boundaries	Including small-scale transmission and regional supply compensation	Both direction (sharing in the place)	Active, Partecipating in the system

The principles on which an Energy Community is based are that of “decentralization and localization of energy production”, where “the concept of self-consumption refers to the possibility of consuming on site the electricity produced by a local generation plant to meet their energy needs” [16]. In particular, the RECs organization, governance and purpose can be summarized in multiple aspetcs: generation from Renewable Energy Sources; Electrical Energy (connected to RES supply); RES supply; RES aggregation; RES sharing; RES self-consumption; E-mobility connected to RES of RECs.

Moreover, it is worthwhile to clarify the substantial difference between Citizen Energy Communities (CECs) and Renewable Energy Communities (RECs). The former’s scope is currently limited to electricity sector and is technologically neutral, while RECs are able to engage in the collective management of all energy sectors (production, consumption and selling of renewable energy, renewable gas, etc.), but limited to renewable energy technologies and the shareholders or members in RECs must be located in the proximity of the renewable energy projects that are owned and developed by the REC [17]. Both contribute to energy poverty reduction, especially in marginal or less-favored areas, and resilience to climate impacts. In fact, the production of energy at the point closest to end use and the possibility of storing and redistributing it are instrumental to the development of smart grids, that are more adaptable to the needs of the electricity system, peaks in demand, and the peculiarities of each energy source.

Therefore, it is interesting to define RECs as the result of an integration of four dimensions, which make their activation possible: a "legal" dimension, in that they are a subject defined by specific regulations; a “social” dimension, in that they constitute a new model of local governance and sharing of resources on the ground; a “political” dimension, in that it is a tool to achieve the climate goals mentioned above (New Green Deal, Ecological Transition Plan, Agenda2030, etc.); last but most decisive aspect in future developments, a “technological” dimension, as RECs take advantage of the latest storage technologies, Smart Home and Energy Box for example, for energy efficiency aspects. In fact, to support an energy community, there are many technologies that facilitate consumption monitoring and help community users save and consume energy more efficiently. These include technologies for the management and storage of energy from renewable sources, small local generation plants used by energy communities can pre-develop electrochemical storage using batteries, as lithium-ion batteries commonly do. The advantages of using such technologies are the greater utilization and better management of energy produced from renewable sources: the battery allows the excess energy produced to be stored and delivered when production is lower (e.g., at night) and reduces power peaks and imbalances due to the randomness of renewable sources, making it easier to feed into the grid electricity of energy not consumed. Smart devices for optimizing flows and energy management include the Energy Box, a device that communicates with sensors installed in the home and transmits collected data to a cloud platform that analyzes it and provides the user with suggestions for optimizing consumption. Thanks to these sensors, the user can also be informed and manage the devices in his or her home remotely via app or pc (ICT technologies) [18].

The advantages that derive from the adoption of a model of energy community are certainly, on the one hand, environmental and economic (CO2 savings in energy production and incentives for prosumers), on the other hand, indirect with positive effects on the productive and economic system of the community, especially for those territories, such as inner areas, which have depopulation trends, lack of services related to energy poverty and a heritage to be regenerated. In these contexts it is possible to experiment with projects with "high rate of innovation", cohesion and promotion of knowledge, consistent with the mechanisms of "just transition", in which users are not only end users, but actively collaborate to save energy and create a circular model and collaborative economy (co-design approach), which is based on the adoption of key enabling technologies (KETs) and advanced design processes of regenerative type [19].

Although the EU legislation on RECs is of recent conception, already in the last two decades have spread in Europe some successful practices of "prosumer" communities in rural/local context, able to achieve high levels of energy self-sufficiency.

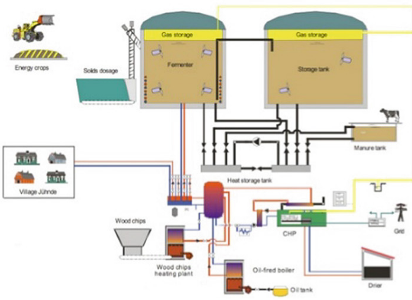
2.3 Renewable Energy Communities in Inner Areas: A Study Cases Overview

As mentioned above, although Renewable Energy Communities are instruments regulated by recent European legislation, experiments have been conducted in recent years that have become successful experiences in the field of "green" energy production with only renewable sources. In Italy, according to the last Electricity Market Report by the Politecnico of Milano [20], there could be about 20.000 REC by 2025, serving more than 1,000,000 users households and 300,00 non-domestic (public buildings – schools, municipalities, libraries…). Currently, there are 46 active RECs in Italy and it is important to notice that the 75% is located in the inner areas. Below are three national case studies located in inner territories. Since rural areas can give a substantial contribute to the goals related to climate neutrality [21] and energy transition [22], it is useful to investigate selected case studies of energy communities in rural/inner areas, at the European and national levels, summarized into "info-boxes" (Figs. 1, 2, 3 and 4):

- CS1 – Bioenergy Village of Jühnde (Ger)
- CS2 – REC Cooperative of Melpignano (Ita)
- CS3 – REC "Energy City Hall", Magliano Alpi (Ita)

– CS4 – REC “Berchidda Energy 4.0” (Ita)

Case Study 1 (CS-1). Bioenergy Village of Jühnde [23]



Location: Jühnde (Niedersachsen, Germany)

Year: 2006

Population: 989 inhabitants (up to date 31-12-2019)

Management model: Energy community of citizens’ cooperative (shareholders) with the University of Göttingen

Technology used: biogas plant for combined heat and power production (cogeneration) from liquid manure and whole plant silage of different crops and photovoltaic plant

Energy Production:
- 700 kW cogeneration
- energy for building heating= 6,500 Mwh/year
- electricity= 5000 MWh/year

Energy demand coverage:
- 70% of the energy needed to heat 145 buildings
- twice of electricity demand

Impacts:
- Switch from a consumption model based on fossil fuels to one based on the production with biomass
- 75% of the inhabitants are members of the energy community
- Quality of life of local community increased

Fig. 1. The Bioenergy plant and PV on building roofs. **Source:** IEA Bioenergy Task 37, www.100-percent.org/juehnde-germany/

As illustrated in these few study cases, the creation of RECs in inner areas, territories suffering from depopulation and aging of the population, reduces energy poverty and creates or enables new services to the population. In continuing what has been argued by Kitchen and Marsden [26] and Von Bock und Polach et al. [27], the inner areas are an optimal settings in which is favourable the promotion of models based on renewable

Case Study 2 (CS-2). REC Cooperative of Melpignano

Location: Melpignano (Lecce, Italy)	
Year: 2021	
Population: 2135 inhabitants (up to date 31-05-2021)	
Management model: Energy Community including Cooperative (Municipality with Legacoop) with the role of installing, managing, maintaining the pv systems and selling surplus energy	
Technology used: photovoltaic panels on roofs of private and public building (tot. 33 solar plants, 29 owned by cooperative)	
Energy Production: - 179.67 kW of photovoltaic systems (159.93 kW owned by the Cooperative)	
Energy demand coverage: Total satisfaction of electrical energy needs of REC households	
Impacts: - 400,000 euros of investment - Renovation of private buildings roofs - Renovation of public buildings roof	

Fig. 2. Melpignano municipality and PV installed on buildings. **Source:** www.comunirinnovabili.it/cooperativa-di-comunita-di-melpignano/

energy technologies, especially by adopting the decentralized and community based form of Energy Communities. The creation of "island" plants in rural areas not served by the electricity grid and the adaptation of existing plants according to the new energy model, also increases the resilience of territories to the impacts resulting from climate change and enables the experimentation of advanced technology in the field of production, consumption, monitoring and distribution of electricity generated from renewable sources, such as rooftop photovoltaic systems, community battery storage, residential heat pumps, electric vehicles, smart platform for energy management. These technologies can be considered either individually or integrated, hybridizing the "presuming model of buildings/structures/places in which they are considered.

Case Study 3 (CS-3). REC "Energy City Hall" [24]

Location: Magliano Alpi (Cuneo, Italy)

Year: 2020

Population: 2166 inhabitants (up to date 31-12-2020)

Management model: Energy Community made up of Municipality of Magliano Alpi, the Public Library, the gym, the school and n.4 residents

Technology used:
- 20Kwp photovoltaic plant on the roofs of the Town Hall
- Connection PODs for energy sharing
- Electric Vehicles (EV) recharging stations
- IoT platform for real time energy management and monitoring (Energy4Com support)

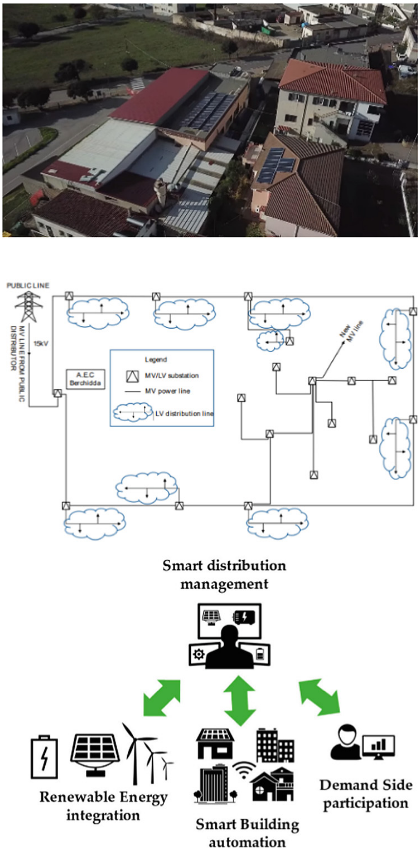
Energy Production:
- 24 MWh by photovoltaic system

Energy demand coverage: 7 households of which three municipal 3 households and 1 small handicraft enterprise

Impacts:
- Building retrofit
- Processes of local development
- Local short supply chains with a strong cognitive and technological value
- Free services for residents (EV charge, energy sharing)

Fig. 3. PV plant and energy monitoring platform. **Source:** https://cermaglianoalpi.it

Case Study 4 (CS-4). REC "Berchidda 4.0" [25]



Location: Berchidda (Sassari, Italy)

Year: 2019

Population: 2688 inhabitants (up to date 31-08-2020)

Management model: Energy Community made up citizens, Sardegna Region, Department of Engineering and Electronic University of Cagliari

Technology used:

- 200 photovoltaic plants with >1500 kWp of power
- Storage systems with a capacity of 50 kW/50kWh
- Smart Home Systems (smart box) for energy monitoring

Energy Production:

- solar energy production of about 3 GWh/year

Energy demand coverage: Local self-consumption >50%

Impacts:

- Activation of 30 pilot projects on existing pv systems for self-consumption promotion and community engagement
- 620,000 € savings (-50% public cost of energy) and 30% energy bill reduction

Fig. 4. PV panels for REC on roofs and Smart distribution manage-ment of the local energy community resources. **Source:** web search

3 The Methodological Approach: Advanced Impact Design for the Renewable Energy Communities

The enabling technologies to support the model of energy communities are part of the family of "smart" devices, aimed at production, storage, distribution and monitoring for energy efficiency and savings (such as Smart home and energy box). These technologies are configured as integrated devices to different living systems (private and public), structures and open spaces and infrastructures, becoming technological components of the "architecture in transition", whose morphology and life cycle are the result of processes of "Advanced Design" with a strong "regenerative" character from the point of view of the energy-environmental profile of high performance. As stated by C.Nava in fact, “the enabling technologies become the service devices to such “performance, they themselves adapt to the contexts in which they are called to govern the process/design to produce quality in the use, operation, configurations of urban systems and built architecture” [27]. Since climate change has become a central theme in global sustainability policies, architectural technology has begun the transition from the themes of “sustainable design” to those of “regenerative design driven by innovation”, in which the objectives of the ecological transition re-establish the relationship between design and resources (water, air, sun, materials, but also data). It is no longer sufficient to apply “restorative” design processes, which meet performance requirements in terms of energy and only reduce the environmental impacts of the building, but it is necessary to respond in an “advanced” and “regenerative” way, pursuing not the reduction of impacts, but the production of a positive impact on the environment. The shift from a “degenerative” to a “regenerative” model is to move from a model of reduced consumption to a model of “positive” production (Fig. 5).

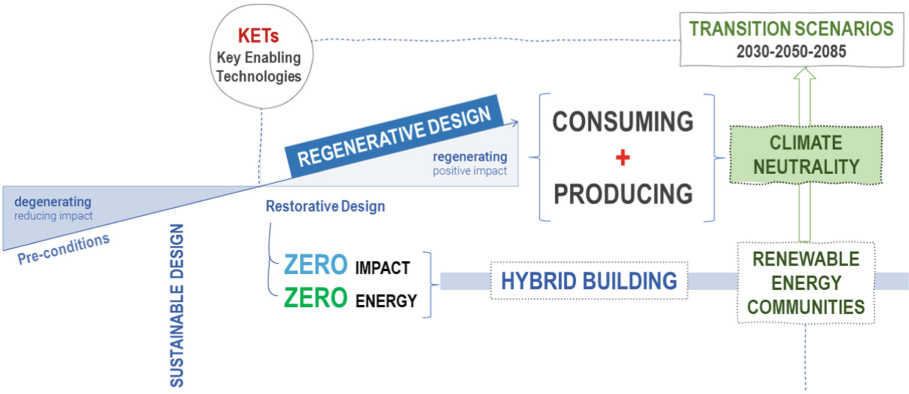


Fig. 5. Relationship between design, presuming, technologies and REC towards climate neutrality in transition scenario. Source: elaboration by G. Mangano on C. Nava’s note (Design Culture Technology Course – dArTe, 09-11-2021)

In this sense, “Impact is the way but also the gauge by which the effects of transformations in the built environment and on all social and economic scenarios are measured [and] in their assessment, impacts are not assumed as the limits of the project but rather correspond to the very resources of innovation, for each resilient transformation” (impact design).

Ecological transition and digital transition then become the caliber for the application of processes based on the availability of resources and enabling devices capable of leveraging the regenerative capacity of the same. This is a logic of distribution of “circular” type networks, based on processes of production, storage and sharing of resources and energy (smart grids, systems based on PV technologies, batteries of the latest generation, etc.), where the role of the user becomes central, no longer the final recipient but the protagonist of an iterative process of “empathy, definition, design, prototyping and testing” that can generate a positive impact on natural and human ecosystems [29].

The devices, buildings, structures will therefore have the ability not only to consume resources, but also to produce and redistribute energy. Therefore, it means developing new integrated devices by innovating existing technologies, so that these can represent not only a new hybrid model of energy production, but can also allow to act, through a project of technological and environmental type, on a new quality of open and private spaces, that make the city become a functional phenomenon expression of the relationship between its components, able to define advanced and performing spatial systems, which become "regenerative" for those territories where there is low quality of services and spaces, energy poverty and lack of networks.

The issues of "energy efficiency", "renewable energy" and "combined heat and power" (Fig. 6), become the actions addressed by advanced design processes and enabling technologies, with the aim of pursuing mitigation actions capable of acting on the causes rather than the effects of climate change.

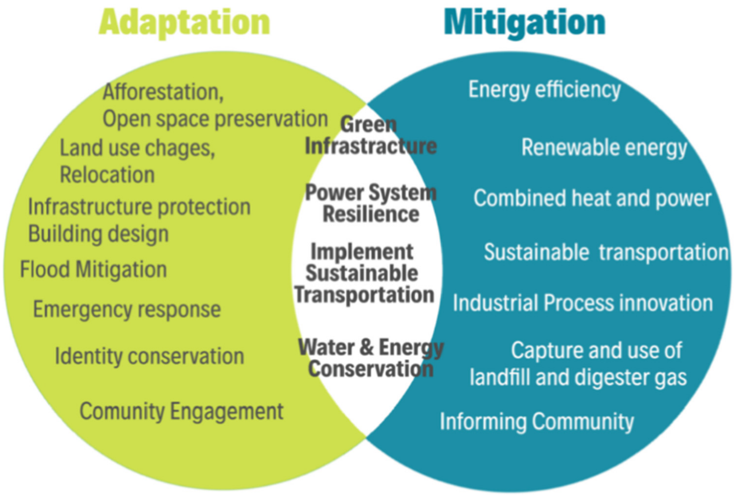


Fig. 6. Actions for Adaptation and Mitigation investigated for energy issues. Source: Climate Technology Centre & Network figure, www.ctc-n.org

The level of innovation triggered for the benefit of users/citizens, continues Nava, concerns the "control of the physical components city/building [...], in which the existing context can produce regenerative systems [...], implementing policies of circular economy, metabolism, densification, compensation, resilience, recycling, through processes of scenario 2020/30/50, for assets in energy transition (user-producer, renewable, smart grid, etc.), but also the design and process of environmental factors city-building, in which the themes of energy and hybrid systems innovate the very configuration of the project at urban and building scale. The aim is to realize climate neutral buildings/environments, that efficiently produces and consumes energy while providing high comfort and being "CO2 neutral" by passive and active systems for energy supply. The Advanced Regenerative Design, when integrating levels of monitoring and evaluation of impacts at the local level takes into account the indicators and targets of sustainable development at different scales (*micro, meso, macro*) and indicators for the accounting of resources. It is a design that provides different time scenarios in order to work on the concept of "adaptation" and "mitigation" of climate phenomena, focalized on a "performance-based approach", that "deepens the relationships that the experimental design undertakes with the physical environment, focusing the study on aspects that relate to performance attributes, referring to quantifiable parameters that can influence both the quality of the environment, when they intervene on the performance aspects of the building, and the measurement and visualization of impacts" [30].

The role of open knowledge, capacity building and co-design processes are therefore fundamental in models that include aspects of monitoring with the involvement of key players and end users together (designers, policy makers, citizens, etc.) and that identify the physical "limit" of the community of reference.

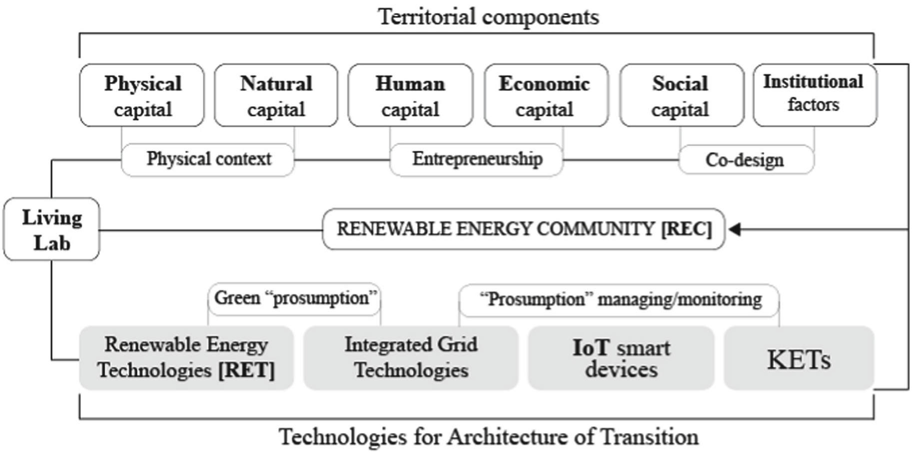


Fig. 7. Territorial components and technologies for transition as factor to trigger LL processes with REC. Source: elaboration by G.Mangano

These aspects become key levers for the development of Renewable Energy Communities with a regenerative character for the context in which they are realized, allowing also to make this model more advanced, by integrating transdisciplinary and interscalar research, knowledge, technologies and methodologies (building/neighborhood or village, citizen/community, inner areas/urban areas) (Fig. 7).

Indeed, examples of energy-efficient buildings from this point of view are many, and consumption reductions of up to 50% are easily achievable goals through applications of technological innovation. Not to mention positive energy buildings, that is, those that produce more energy than they consume. Enclosures will be made of "smart" materials, with automatic activation of control systems and management of microclimatic parameters. Each building will be interconnected to a network with which it will exchange, reversibly, energy [31].

4 Preliminary Findings for Living Lab Experimentation in Grecanica Area

The above topics are part of the research-project starting in January 2022, entitled "Advanced Impact Design and Enabling Technologies for the design and activation of "energy communities" with models, devices and prototypes for "self-production" and "assessment of impacts" from "climate change in the Mediterranean area" [32]. The objective of the research is to conceive, design and implement a device with advanced design approach, which exploits the potential of assisted and digital design and provides a phase of prototyping, verification and testing for control and technical choices, the level of efficiency, technical feasibility (and economic), at a scale of system/component of study. The prototype of this structure/system/infrastructure can be realized at a scale of 1:1 and be placed in the space under study within the area and the community identified with a path of study and scouting (territorial laboratories and co-design). It will integrate the technological devices for the station/building aimed at the production of solar energy and the devices for energy control and monitoring (consumption and impact accounting). The integrated solar and pv technologies will therefore allow to achieve adequate levels of satisfaction of energy demand, new quality of space in the areas in which it fits and new quality of life, helping to produce clean energy at "zero emissions". The research, conducted by the Center ABITAlab of the Department of Architecture and Territory will aim to implement an experiment in the territories and communities of the inner areas of the Grecanica Area of the Metropolitan City of Reggio Calabria, on the "Living Lab" model, involving local authorities, businesses, community representatives, associations and laboratories of the experimental area identified.

The Living Lab aims to be a "demonstrator" with the goal of facilitating the transfer of scientific innovations into applications through the provision of facilities and expertise qualified largely within applied research pathways. As argued by Teixeira A.J.S. et al. [33], "the Living Lab is not just a repository of technologies. It is essentially an interactive environment in order to facilitate the research, development, integration, validation and evaluation of multimodal, adaptability and user monitoring technologies, new modes of interaction and new services supported". It means searching for new research paradigms, which intends to increase the understanding of problem statemens; explore and evaluate new ideas and concepts; confront the new ideas and concepts with users' value model; triggering iterative processes for experimentation; more accurate results in reliable producats and services; scale-up concepts and contribution to bring scientific results and innovation to the citizens (Fig. 8).

The "Living Lab" approach is that of "user-centered research" and ecosystems of Open Innovation, which involve public and private entities in multi-actor partnerships (co-design) and territorial impact. In this sense, important Living Lab pilot cases for the design, implementation and management of energy communities can be found, for example, in the "Smart Energy Living Lab" project, developed by Enerbrain with the Energy Center of the Polytechnic University of Turin [34] which aims to develop a digital platform for the optimized management of multiple energy communities, understood as constituent elements of a functional Smart District for the implementation of territorial policies aimed at carbon neutrality with solutions aimed at increasing the energy efficiency of buildings, decreasing the needs of users and increasing the use of

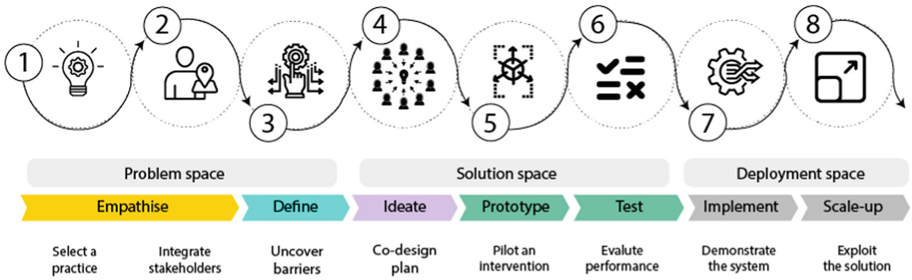


Fig. 8. Living Lab integrated approach. Source: G. Mangano's elaboration on Mastelic, 2019

self-generated energy from renewable plants. At the European level, it is interesting to point out the project "LEC-Civic energy future: sustainable Local Energy Communities" (Interreg-IPA CBC EU-Axis "Environment and Energy"), led by Montenegro, Italy and Albania, whose objective is contribute to improving energy efficiency and renewable energy usage through the development of a "local community of active energy consumers", which cooperates with municipalities, by promoting local actions inspired by switching to "energy presuming" model. Within the framework of Smart Specialization Strategy (S3) of Portugal, it is worth mentioning the "Culatra 2030 - Sustainable Energy Community" initiative, a living lab for the sustainable energy transition, a real-life laboratory for green transition, aimed at the transformation of all structures on the island into energy self-sufficient systems, through new technologies implemented. The community "produces energy exclusively from renewable sources, use electric mobility, decarbonise its fishing industry and acquire sustainable habits and living practices" [35]. Based on the framework described above, the pilot experiences illustrated and the methodological approach adopted in the ABITAlab research, it is possibile to integrate these research experimental trajectories for the Grecanica Area with the National and Regional Strategy of Inner Areas and the Framework Programme Agreement already ongoing. The experimentation will be conducted in order to trigger advanced regenerative processes and the opportunity to contribute to the objectives for climate neutrality to 2050, starting from those territories that constitutes about 80% of the territory of the Calabria region and are inhabited by over 60% of the population of Calabria. In particular, the "Grecanica" Area is the second pilot area for the implementation of the National Strategy of Inner Areas in Calabria (after Reventino-Savuto).

The Grecanica Area includes a wide territory in the eastern part of Metropolitan City of Reggio Calabria and includes eleven municipalities in the Project Area, with four additional municipalities added for the Strategy Area. The area surveyed is inhabited by 18,821 people out of the total 551,380 in the Metropolitan City of Reggio Calabria. In the last forty years have suffered the loss of over 40% of the resident population and marginalization phenomena (Fig. 9).

These factors have caused the almost total abandonment of entire inner centers, affected by both events of hydrogeological instability that led to the construction of a new town far from the places of "historical foundation" (see the case of Roghudi), and the lack of adequate connections with the metropolitan area of Reggio Calabria and coastal centers, where they are provided the essential services of health and education.

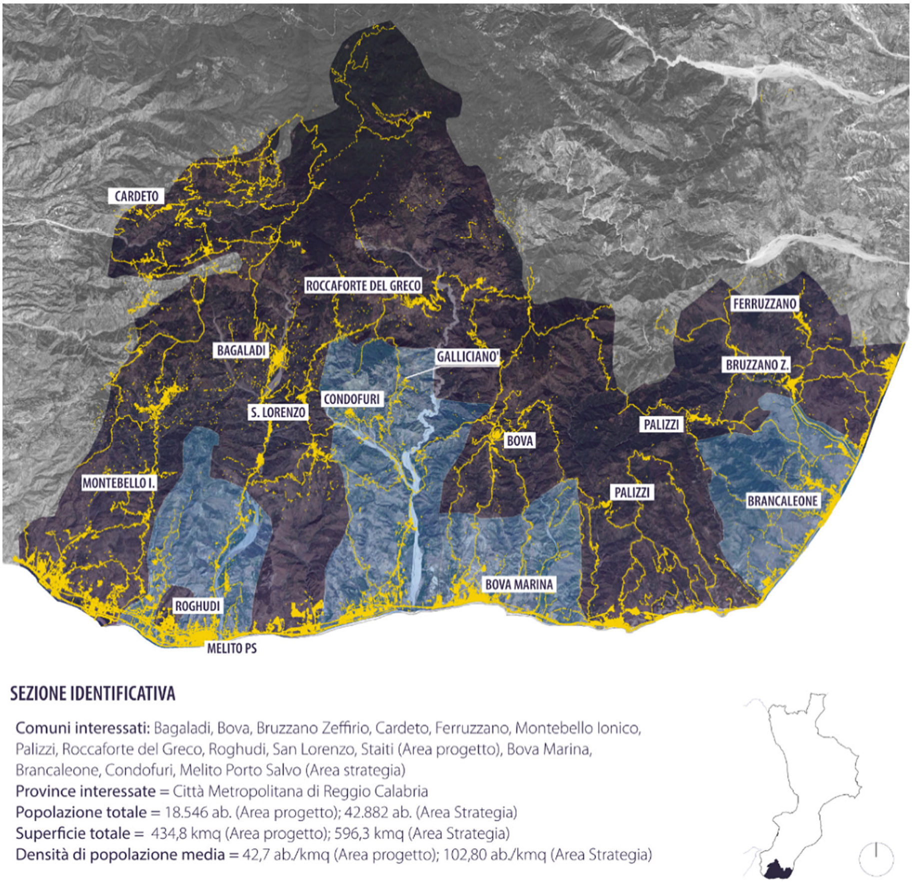


Fig. 9. Grecanica Area Identifying map. In light blue: the municipalities inside the Strategy Area. In purple: the municipalities in the Project Area. Source: Data processing for G. Mangano's phd thesis, 2019

In response to these conditions, the "Grecanica" Area Strategy has focused on the adjustment of rural infrastructure to ensure access to resources (water, electricity) by farms in areas not yet served by adequate networks. The Area Strategy includes, in fact, lines of action dedicated to the experimentation of "new models and tools for the production and use of energy produced from renewable sources" [36]. At this point of the research, on the basis of the identifying scenario for the Pilot Area "Grecanica" [37], a preliminary survey is carried out for the candidacy of three "inner" settlements that possess favorable characteristics for the activation of an energy community, from the point of view of location, solar radiation and performance potential of installable PV systems.

This analysis is carried out by means of the open access tool made by the Join Research Center of the European Union "PhotoVoltaic GIS" (PVGIS) [38], which returns the calculation for the power generation potential for different photovoltaic technologies and configurations and solar radiation and temperature, as monthly averages or daily profiles in complete time series (annual, monthly, daily), calibrated by the European Solar Test Installation (ESTI) photovoiltaic calibration laboratory and accredited by ISO17025.

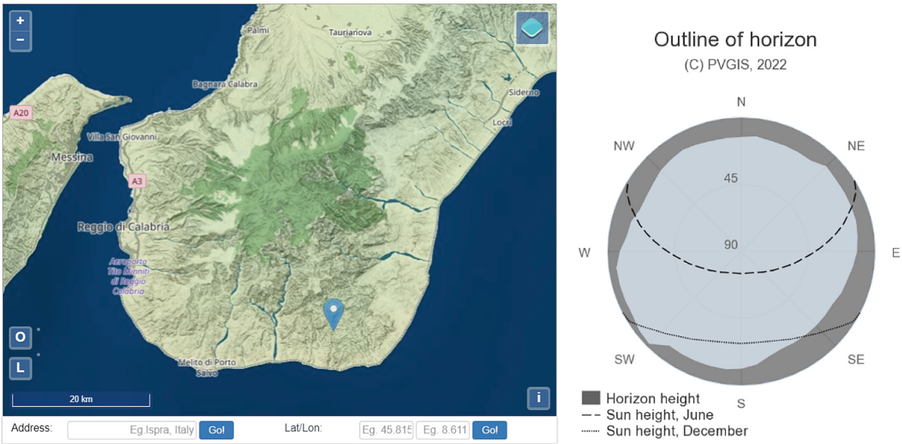


Fig. 10. Outline of horizon, localized in Palizzi (RC). Source: PVGIS (2022)

Simulations were performed on the municipalities of Cardeto, Condofuri, and Palizzi, using the PVGIS-SARAH2 database, crystalline silicon PV technology, with installed PV [kWp] = 1, system power loss (average) of 14% and fix-angle 35°.

The results show that among the three candidate municipalities for the experimentation of a REC (Table 2), from the point of view of the performance of grid-connected PV, Palizzi has an annual PV energy production potential of 1631.26 kWh and flat irradiation of 1979.47 kWh/m^2, with higher values than Cardeto (1424.95 kWh–1839.72 kWh/m^2) and Condofuri (1516.9 kWh–1952.61 kWh/m^2), due to its location and exposure more favourable to the performance of photovoltaic panels (Figs. 10, 11 and 12). In addition, the municipality of Palizzi, located in climate band C, is the one of the three municipalities that has the lowest number of degree-days. Therefore, already in this preliminary investigation phase, it is possible to state that, from an environmental point of view, it possesses conditions that make heating less necessary. In energy terms, this translates into lower energy requirements, an important factor in the dimensioning of renewable energy production systems.

Table 2 is also useful to give a comparison between the data related to demographic size of the municipalities and the presence or absence of policies and investments (past and ongoing) on renewable energy sources. Palizzi municipality is divided into two settlements: one coastal, with higher presence of services (roads, schools, commercial) and one inner (at 680 m. of altitude), with the presence of historical architectural heritage (16th century), in process of depopulating.

These preliminary findings at this stage of research make the municipality of Palizzi as favourable territory and community for triggering a LL process for the creation and the management of a REC.

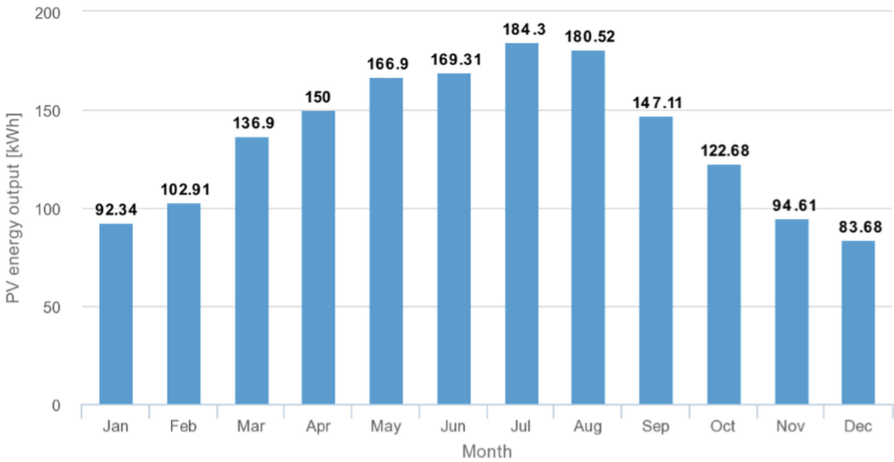


Fig. 11. Monthly energy output from fix-angle PV system in Palizzi. Source: PVGIS (2022)

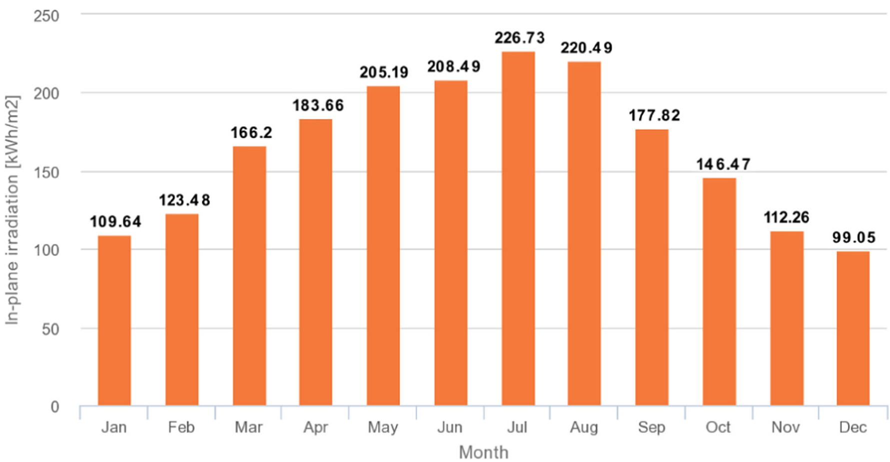


Fig. 12. Monthly in-plane irradiation for fixed angle in Palizzi. Source: PVGIS (2022)

5 Discussion of Innovative Aspects for the Experimentation in the Inner Areas

The recognition of the value of ecosystem services in Ecological Transition policies has once again highlighted the importance of energy production through renewable sources. The experimentation of development models of Energy Communities in Inner Areas opens to processes of territorial, technological and social innovation in the direction of smart communities (SDG 11 of Agenda 2030), equipped with technologies for smart grid and the exploitation of renewable sources (SDG 7). Therefore, it is possible to identify some specific factors that make it advantageous to start the model of energy communities

Table 2. Comparison of three inner according to population, REC and RES ongoing or past investments, climatic zone and yearly energy output and irradiation in the three inner areas candidate for REC. Source: elaboration by G. Mangano

	CARDETO	**CONDOFURI**	**PALIZZI**
Population (n. inhabitants)	1,591	4,656	2,017
Ongoing REC or green policies (Yes/ No)	No	No	No
Past investments on RES	Yes (ROP 2007–2013 – Axes I/II)	No	No
Climatic Zone	D	C	C
Degree-days	2,033	1,323	**1,205**
Monthly energy output from fix-angle PV (kWh)	1424.95	1516.9	**1631.26**
Monthly in-plane irradiation for fixed angle (kWh/m^2)	1839.72	1952.61	**1979.47**

in inner areas in order to make these territories self-sufficient from the energy point of view and trigger processes of sustainable development:

1. *Climatic and environmental factors*. The inner areas and their villages have a favorable location in terms of availability of resources, exposure, natural capital to be used in sustainable energy production chains;
2. *Defined settlement pattern*. In inner areas it is easier to identify the scale of intervention not only from a demographic point of view (villages and settlements of less than 5000 inhabitants), but also from the point of view of accounting for the energy needs of the community of reference;
3. *Absence or low efficiency of primary services*. Inner areas are identified by their dependence on urban centers for the provision of essential services (health, education, mobility) and energy supply. Breaking this dependence would allow communities to reach levels of self-production and self-sufficiency, such as to trigger new development processes and thus combat the phenomenon of energy poverty. In particular, energy poverty is a central issue in regions such as Southern Italy, where almost 1/5 of households live in energy poverty [39];
4. *Scalability of interventions*. In inner areas it is possible to act with projects at different scales (object/manufactured, structure/building, network/landscape), thanks to the great availability of territorial capital and architectural heritage to regenerate;
5. *Public policy investments*. As discussed in more detail in Sect. 2, community planning in the period 2021–2027, thanks also to the role of the National Strategy for Inner Areas, which is being implemented throughout Italy, will invest large amounts of money in the development of energy communities and smart grid technologies with renewable sources in municipalities identified as Inner Areas and the energy efficiency of the existing housing stock.

6 Conclusions and Future Steps

The reduction of the dependency between the location of resources and the places of production reverses the role and the relationship between cities, urban areas and marginal and inner areas: there are contexts which possess an underutilized environmental heritage and capital of natural resources, capable to be enhanced by using innovative technologies for energy production and energy saving, in order to increase both the "margins" of self-sufficiency of socio-productive systems from the energy market, and to trigger local development processes through the grafting of new energy and economic supply chains, through the involvement of new professional experts in the field of energy and smart grid and in land management (emerging co-communities) and local communities [40]. On the basis of these considerations, which coincide with the state of the art study phase, the next steps of the research will concern the planning of the activities preliminary to the start-up of the Living Lab phase in the internal municipality of the Grecanica Area for the experimentation of a Renewable Energy Community. The LL, as an open innovation environment that brings together public subjects, enterprises, universities, research centres and citizens' associations), will be structured as an "enabling" place for experimentation and co-creation with stakeholders to

– a REC management (production and consumption) model;
– a protocol for the monitoring and management of functional aspects (services) related to RES technologies;
– a validation system, enabling its application in a pilot community, with the possibility of scale-up within the same municipality or co-territory.

To this aim, scouting activities with the administrators and communities of the candidate municipalities for the experimentation of the LL REC and the involvement, from the initial phases, of market players with experience in the KETs and green technologies sector will prove propaedeutic.

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- the theoretical and experimental discussion of TREnD (Transition with Resilience for Evolutionary Development) research project, which has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement No. 823952;

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