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Energy Self-Sufficiency of Smaller Rural Centers: Experimental Approaches

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Abstract: Inland areas have been affected by demographic and economic decline over the past decades. New economic models, which are more focused on a humane quality of life, encourage a revival of these territories as newer, healthier places for living. This paper focuses on minor centers, rethought as energy communities and how these can sustain themselves and become new places of living. The first part of the research critically analyzes current strategies of SECAPs (Sustainable Energy and Climate Action Plans) in smaller historic urban centers. The second part of the paper starts with the typological, morphological, and technological interscalar analysis of two case studies, testing a repeatable expeditious knowledge collection and an intervention method on them. For urban environments, the hypothesized interventions include the management of energy production from renewable sources that are compatible with the presence and value of urban and built heritage; concerning rural territories, an agro-energy park is proposed. The document aims to provide a repeatable method for planning strategic actions within SECAPs in smaller urban centers with a high historical connotation. The case studies show that energy self-sufficiency can be an opportunity to valorize the urban center while favoring environmental sustainability and local development.

Keywords: sustainable energy technologies; climate adaptation plan; urban regeneration; small towns and rural communities

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1. Introduction

The leading cause of climate change is the greenhouse effect. The energy sector accounts for about two-thirds of greenhouse gas emissions, as more than 80 percent of the world's energy consumption is still met by fossil fuels [1]. The 2030 EU strategies are mainly aimed at decarbonization, accelerating the transition from traditional fuels to renewables; energy efficiency, with actions for making buildings more efficient and constructing infrastructures, including some for sustainable mobility; and strengthening the energy market, increasing electricity interconnections and uniting the markets between member states and third world countries to foster efficient trade [2].

One of the best-known strategies is EPBD III, EU Directive 2018/844 on the energy performance of buildings, which is part of the legislative measures adopted at the European level known as the Clean Energy Package. It fixes the regulatory framework for achieving the new European 2030 energy and climate-related targets [3]. Its September 2022 update requires member states to adopt energy and climate plans with measures to at least double the annual rate of renewable energy by 2030 and the development of a sustainable, competitive, secure, and decarbonized energy system by 2050 [4].

The decarbonization process can advance at a faster pace with the deployment of renewables, but the synergies and the trade-offs between mitigation goals and the use of renewables must be better understood and integrated into climate policy [5]. The European Union's (EU) long-term climate neutrality targets require that by 2050, at least 16% of the electricity generation has its origins in collective projects and almost half of all European households must be involved in renewable energy generation, 37% of which should be engaged in collective projects [6]. More or less spontaneously in the last few years, energy communities have emerged, i.e., associations of individuals who share the benefits of producing and consuming green energy locally. In Europe, various forms of energy communities have been created according to different needs and opportunities in the area, for example, with Smart Cities' regulation. Smart Cities and communities were already defined as a priority and strategy by the previous European Horizon 2020 program and the 17 Sustainable Development Goals set by the UN and the 2030 Agenda. Energy communities are new configurations within the European electricity system. At the legislative level, they have been defined by the Directive on "Common rules for the internal market for electricity" (IEM) 2019/944 (Art.16), published in June 2019 [7]. They are legal entities based on the voluntary "network" participation of businesses, individuals, or municipal governments, whose goal is to create community-based environmental, economic, or social benefits through collective energy production. In Europe, energy communities are a rooted and widespread trend. Germany, Denmark, the Netherlands, and the UK are the European countries with the largest numbers. In Germany, there are now as many as 1700 entities; in Denmark and the Netherlands, there are over 500 active CERs.

The Covenant of Mayors is undoubtedly one of the most centered EU-level actions on this issue and can significantly counter the depopulation of these areas. This voluntary initiative has been promoted as early as 2008 by the European Commission to actively involve cities and their administrators in fighting climate change and achieving EU goals. Signatory local authorities commit to signing a Sustainable Energy Action Plan (SEAP) [8]. With the 2015 European policy (2030 Climate and Energy Package, Adaptation Strategy, and Energy Strategy), the commitment has been extended to updating the strategies according to the new goals and climate adaptation (Sustainable Energy Action Plan—SEAP) [9]. Currently, in Sicily, Italy, 145 out of 390 municipalities have signed a Covenant of Mayors [10]. Only a few have SEAPs, and a very small percentage of these have upgraded it to SECAP, even though in June 2019, the regional Department of Energy and Public Utilities [11] presented the program for the allocation of resources to Sicily's municipalities for the drafting of SECAPs. In particular, municipalities in inland areas, the farthest from major metropolitan centers, have a deficit. This fact is particularly relevant considering that Italy and Spain are the countries in Europe with the most significant number of XS municipalities (under 10,000 inhabitants) among the signatories to the Covenant of Mayors.

2. Background

The ferment towards the need for energy and climate sustainability is tangible in metropolitan cities. However, it is not yet tangible in small towns, whose size could lead to their involvement in eco-neighborhoods or energy community strategies. The most difficult contexts are inland areas, territories with semi-abandoned architectural and urban heritage, and severe depopulation. These urban centers were often founded according to defensive and territorial-control criteria. Thus, they are located in inaccessible places that are difficult to access, and their livelihood relied on the productive territory. Abandonment has resulted in further marginalization and impoverishment, both rural and urban. These scattered settlements undoubtedly lack services. Still, they are 'humane scale' places where the air is healthier, and the problems tied to humane concentration are reduced; their identity consists of ancient cultures and traditions, leading them to represent a treasure trove of knowledge and memory [12]. Still, at least the architectural and urban heritage identity features have been the object of enforced preservation, keeping the traces and original appearance of ancient historic centers of ancient dates [13]. There is still a wide presence of historical, or at least traditional, buildings and fabrics, which lacked the resources for uncontrolled building modernization.

The green economy and circular economy have restored the importance of balance with natural dynamics and resource provisioning, which were the guiding principles of the rural and survival economies [14]. Some urban centers that have kept visible historical features can be reevaluated as new energy self-sufficient territories and favorably accustomed to climate mitigation since they are often surrounded by and integrated with nature. This aligns with the principles of the Italian National Strategy for Inland Areas and aims to reverse demographic trends, maintain natural and territorial capital, and improve the resilience of these places [15,16].

Some indications for inland areas come from the Italian National Strategy for Smart Specialization (European Cohesion Policy 2014–2020 programming). The development trajectories include restoring productive activities, regenerating sustainable communities, and regaining knowledge of exploiting resources (water, energy, MSW, etc.) [17]. Regarding energy self-sufficiency from renewable sources, some actions are already outlined in the Italian National Plan for the Redevelopment of Small Municipalities referred to in Law 6 October 2017, No. 10, particularly for the energy upgrades to the public and private building stock to achieve EU targets [18].

The contribution aims to center again on the value these places can provide to the global climate resilience movement. Today, high economic commitment and technical effort are generally employed—for example, with greening actions—to restore nature in heavily urbanized contexts; yet, places such as inland areas, which are already immersed in nature, can fulfill community goals and raise the quality of life for those who want to inhabit them.

Rural depopulation would not be a limit, but rather a "potential positive opportunity", for a social reorientation due to its natural green advantages and the scarce pressure on natural resources and the environment [19]. However, declining local communities in Europe have limited capacities for long-term comprehensive policy governance responses because depopulation generates fragile communities that are very vulnerable to environmental risks and have little capacity for effective responses [20].

The construction of a high-quality land development, protection, and support system has become a topic of great interest for all societies, but it still needs to be explored [21]. Especially in Italy, in urban center, the integration of renewable energy sources has struggled to take place due to the impact the technologies would have on the existing landscape. The question still arises, especially in centers with a strong historical connotation.

Sustainability assessment methods for urban centers, in general, use different approaches for assessments including LCA (life cycle cost analysis), productivity analysis, operation and maintenance optimization, indoor air quality, and other approaches; however, the existing methods are in a transition phase and the next generation will encompass all aspects of sustainability [22]. The historic urban landscape requires an additional step: landscape impact assessments. Downstream of the consolidated Historic Urban Landscape UNESCO guideline, several member states have experienced poor enforcement of building regulations by planning authorities regarding prohibited interventions in heritage areas. Amendments to national- and local-level legislation are required to integrate impact assessments for heritage projects and all initiatives in historic urban areas. The 2011 recommendation addresses the need to better integrate and frame urban heritage conservation strategies within a broader objective of sustainable development. Most member states have policies pertaining to renewable energy at the national level, which do not place special emphasis on historic urban areas [23].

The Guidelines of the Italian Ministry of Culture (2015) for the improvement of energy efficiency at cultural heritage sites address the delicate implications of an efficient use of energy in relation to the conservation and protection of historic centers and nuclei and rural architecture for landscape purposes [24]. The guidelines suggest viable solutions that pursue more explicit references to the local building tradition, as long they are within a framework of overall compositional and linguistic sobriety. Landscape constraints must be respected, with the condition that the systems are concealed and totally integrated into the built environment. In the case of using existing buildings, it is preferable to identify those of lesser value and of recent construction, and it is also suggested to identify areas for the installation of photovoltaic or solar systems on the ground, suitably identified in a defiladed position, and to carry out the interventions with the interposition, with respect to the observation points, of vegetation borders such as trees and/or hedges that are possibly accompanied and supported by wooden or metal trellises. Pertinent and service buildings may also lend themselves to accommodating micro wind farms, carefully studying their visibility in the surrounding context at various scales. An interesting proposal of the Ministry is to identify a single place outside the built-up area where the plants can be installed cumulatively by the municipality, while allowing individual users to enjoy pro quota the benefits and facilities provided by law: the so-called 'delocalised on-site exchange' provided, in application of Law 99/09, for municipalities with a population of up to 20,000 residents.

The paper reports two experimental case studies using a strategic planning approach to address the needs for climate resilience and energy self-sufficiency from renewable sources. The study focuses on two small urban centers with strong historical connotations. They are both part of the metropolitan area of Palermo but are more than 40 min away from it. They are both characterized by high and heterogeneous marginalities and disadvantages. Their location in impervious and distant places, increasingly marginalized by the infrastructure network and a lack of resources, has for a long time, together with the lack of employment, led to a progressive depopulation and, in some cases, complete abandonment. At the same time, however, they are places that still retain a high architectural and landscape quality, which are now being reviewed as primitive models of balance. Thinking of repopulating them means going back to living in sustainable places, where slow life and zero-kilometer consumption of resources persist, where the environment is still preserved in its essential features and pollution levels are contained.

This study aims to propose sustainable energy and climate actions for these marginal areas and evaluate their possible integration into historic centers. These actions aim to drive the economy of these devalued places, creating a principle of energy self-sufficiency to meet the needs of the built-up area in a vision of subsidiarity with neighboring municipalities. For these towns, energy self-sufficiency can bring a direct economic return in a short time, proving to be a fast-track system that attracts local authorities and citizens towards active management of their own resources. This is just one tile of an ideal vision, which could be implemented with simple technological designs and thematic planning solutions in cities. In addition to being scarcely invasive, they could be an opportunity for concrete development and achievement of new desirability for these places.

3. Methods

Each urban and spatial context suggests specific and tailored solutions. However, both case studies can be addressed through a needs–performance approach, starting from users' requests to identify design objectives and requirements useful for proposing solutions at various scales. Comparing the pre-identified requirements with the expected performance of design solutions allows the ex-ante assessment of projects' efficiency and effectiveness.

The first phase of the research analyzed the state of the art on sustainable energy and climate processes in Italian so-called XS municipalities (with a population below 10,000) that have joined the latest Covenant of Mayors (CoM) 2050 strategy. The study showed that this action still has a limited scope. In this research, experimenting with smaller urban centers—inland areas of the Sicilian mountainous territory—an additional effort was made concerning this method: broadening the perspective to a broader territorial context in a vision of mutual aid between municipalities. Thus, the choice of design solutions involved reflecting on the current territorial situation, considering the possibility of drawing from existing renewable energy sources (RESs) or the complementarity of potential new plants with others already in the area. Moreover, the impact of all actions on the historic and natural landscape was evaluated.

The first work phase involved interscalar context analysis, from a broader territorial to an urban and, finally, an architectural one. The spatial analysis assessed the conditions of marginality and the potential for relationships between neighboring municipalities. To lay the foundation for constructing a SECAP, the characteristics, state of use, and extent of renewable and non-renewable energy production technology solutions were analyzed.

The urban-scale analysis considered settlement principles, including environmental design choices, the city as a whole, its historic core, its relationship with the land, orography, geological formations, natural and man-made historical infrastructure, and the typology of public spaces (hierarchies, functions, and forms). At this scale, total inhabited energy consumption, produced CO_2, and toe for thermal and electrical use in the residential, tertiary, transportation, industrial, and agricultural sectors were measured for a base year.

The architectural analysis defined the high-value historical heritage and urban spaces to protect in design choices. A survey was conducted on the building units' type, morphology, technology, potential for retrofit interventions, and current performance, including historical and state of preservation analysis. These are useful for configuring suitable spaces to accommodate new design solutions. The three analyses required constantly considering urban planning instruments in force, which are helpful in landscape characterization, geology, constraint definition, and urban center zoning.

Project proposals include a preliminary study of applicable technologies. They are formulated to reduce energy and CO_2 consumption, thus achieving greater environmental sustainability, self-sufficiency, and the possibility of integrating technological solutions into the historic city. The survey of national and European best practices allowed for the identification of strategic territorial and urban actions and interventions such as climate mitigation actions at urban and architectural scales.

The premise is that the solution to energy problems cannot lie in a technological, large-scale, and invasive solution but in a mix of solutions, more tailored and, above all, tuned to the sensitivity of the historic urban and rural landscape context.

The energy and climate actions proposed here, at the architectural, urban, and sub-urban scales, are calibrated in response to the needs of the current and potential resident population. The analyses performed and the proposed actions can be preliminary for implementing a SECAP. Transversally to the technological actions here suggested, institutions are expected to perform sensitization actions with the local community, combined with energy retrofit interventions on lighting and public buildings, and with the development of agreements between public and private institutions to foster eco-sustainable systems.

The method presupposes the development of scenarios and verification of the fulfillment of requirements and constraints which, in the case of the historic urban landscape, are more complex (morphological, typological, material, perceptual constraints, etc.). This required various analyses: analysis of the current urban planning tools; orography of mountain ranges; individuation of watersheds; study of the geological context, with a specific focus on orogenetic episodes; study of the territorial constitutional state; and the landscape constraints at various urban scales. For these analyses, the main source was cartography at various scales: municipality, provincial, and maps in the regional landscape plan. At the territorial scale, authorized renewable energy production plants near the studies were surveyed. At the urban scale, the size of the built environment, the construction typologies, and the building typologies were analyzed, with a specific focus on the architectural works with notable historical-architectural value.

The energy requirements of the technological systems were established through demographic analysis of the current state, analysis of the demographic trend, and analysis of energy consumption. The energy demand has been calculated by the neighborhood and economic sectors: residential, tertiary, transport, industry, and agriculture. Regarding the residential sector, the main sector in the city, the overall data provided by the Energy Department of the Sicily Region were verified for each neighborhood by crossing an estimate by number of inhabitants with one by building size. Toe and KWh consumption, as well as CO_2 production have been calculated both for thermal and electric uses.

Design phases involved programming strategic actions for energy development and urban regeneration and energy plan hypotheses. The solutions resulted from an iterative process that mainly considered two aspects: the characteristics of each urban space, marked by a specific layout and, more importantly, their infrastructural, technological, and organizational supply; and the fulfillment of energy demand.

4. SECAP: Smaller Italian Urban Centers in Line with the CoM 2050

Covenant of Mayors signatories under the latest CoM 2050 Strategy have committed to prioritizing climate action by setting medium- and long-term goals consistent with those in the Paris Agreement, with renewed ambitions for a fairer, climate-neutral Europe.

The number of XS signatories—municipalities under the population threshold of 10,000 residents—is interesting: Italy and Spain alone have 3940 XS municipalities, corresponding to 91% of the total XS signatories. The remaining 376 XS signatories are spread across 28 EU and non-EU countries, with an average percentage of less than 1 percent. In 2023, these municipalities constitute about 63 percent of the total number of signatories to the Covenant, highlighting that the Covenant is a local action supported by "small" municipalities [25]. This number of signatories makes the Covenant of Mayors for Climate and Energy the world's largest movement for local climate and energy action.

The Covenant's official website database supports advanced searches by region of origin, population, and CO_2 emission reduction target. The Italian XS signatories that have submitted a SECAP following the 2050 strategy are currently few and only located in northern Italy: Arcugnano (VI), Caraglio (CN), Colceresa (VI), Ponte di Piave (TV), and Racconigi (CN). Table 1 below clearly presents their key actions and expected CO_2 t/y savings. In bold are the actions that have the greatest impact.

Table 1. Strategic actions of SECAP in line with the 2050 strategy of smaller Italian centers.

Municipality	Date	N. Inhabitants	Strategic Actions	Reduction (CO_2 t/y)
SECAP of Colcerosa (VI) [26]	2022	5968	**Energy efficiency upgrade of residential buildings**	**2643.23**
			Energy efficiency upgrade of tertiary buildings	1109.13
			Energy efficiency upgrade of public buildings	16.90
			Installation of photovoltaic systems	519.70
			Modernization of the vehicle fleet	1713.62
			Energy efficiency upgrade of public lighting	108.18
			Urban greening	1358.6
Total expected savings				40%
SECAP of Ponte di Piave (TV) [27]	2022	8345	Electricity acquisition from renewable sources	623.00
			Energy efficiency upgrade of tertiary buildings	709.18
			Energy efficiency upgrade of residential buildings	**2356.17**
			Energy efficiency upgrade of public lighting	38.72
			Electric mobility promotion	1142.75
			Modernization of the vehicle fleet	1828.21
			Installation of private photovoltaic systems	1712.19
			Energy efficiency upgrade in industrial processes	2060.16
Total expected savings				40%
SECAP of Racconigi (CN) [28]	2022	9661	Energy efficiency upgrade of residential and tertiary buildings	746.00
			Energy efficiency upgrade of public buildings	104.00
			Energy efficiency upgrade of public lighting	80.00
			Installation of photovoltaic systems on public buildings	75.00
			Energy management of public assets	29.00
			Modernization of the vehicle fleet	2.00
			Establishment of Renewable Energy Communities	921.00
			Electric mobility promotion	**2634.00**
			Sharing mobility promotion	649.00
			Increasing sustainable mobility and bicycle and pedestrian infrastructure	107.00
			Enhancement and efficiency upgrade of public transport	284.00
Total expected savings				55.4%

Table 1. *Cont.*

Municipality	Date	N. Inhabitants	Strategic Actions	Reduction (CO_2 t/y)
SECAP of Caraglio (CN) [29]	2022	6818	Installation of photovoltaic systems on public buildings	71.61
			Solar heating installation on public buildings	8.95
			Energy efficiency upgrade of public lighting	35.80
			Energy efficiency upgrade of public buildings	53.70
			Modernization of the public vehicle fleet	8.95
			Energy efficiency upgrade of residential buildings	**3208.95**
			Energy efficiency upgrade of tertiary buildings	1814.16
			Increasing sustainable mobility and bicycle and pedestrian infrastructure	470.70
			Increase in 30 km zones in the historic center	470.70
			Modernization of private vehicle fleet	3765.61
Total expected savings				40.47%
SECAP of Arcugnano (VI) [30]	2023	7722	**Energy efficiency upgrade of residential buildings**	**3643.04**
			Energy efficiency upgrade of tertiary buildings	3479.33
			Energy efficiency upgrade of buildings for industrial use	1397.73
			Energy efficiency upgrade of public buildings	n/a
			Incentives for electric micro-mobility	294.62
			Modernization of the vehicle fleet	949.32
			Increasing sustainable mobility and bicycle and pedestrian infrastructure	458.29
			Increasing proximity shopping	425.56
			Proposals for eco-driving, carpooling, and telecommuting	523.76
			Improvement of agricultural techniques	240.00
Total expected savings				50%

The CO_2 emission reduction target set by 90 percent of the XS signatories is between 20 and 30 percent. Thus, the signatories described can be considered among the most virtuous ones, as they set an average 2030 abatement target of 40 percent of emissions following the new European Strategy. All of the municipalities surveyed aim for citizens' active involvement. The administration expects them to be willing to upgrade their homes or retrofit their vehicles to produce fewer emissions.

In some cases, the presence of photovoltaic panels is observed in the roofs of historical (yet not monumental) buildings. This phenomenon is likely to increase since the examined SECAPs report the target of a substantial rate of emission reduction by installing photovoltaic systems on building roofs. Being smaller municipalities, the center generally coincides with the historic center, which is also characterized by valuable building types and attractive monumental complexes (think of the castle of Racconigi or the Silk Mill of Caraglio). Thus, there will inevitably be an impact on the historic urban landscape. The issue is also encouraged by the Italian "Energy" Decree-Law no. 17/2022, converted into law no. 34/2022, which establishes a liberalization for installing new solar photovoltaic systems by providing the possibility to build those up to 200 kW with lighter regulations [31]. In the presence of the constraints, performing the interventions is allowed after the issuance of a permit by the competent administration according to the code in Legislative Decree No. 42 of 2004, already mentioned. According to Article 136, Paragraph 1 (c) of Legislative Decree No. 42 of 2004, the provisions also apply to "complexes of immovable property with characteristic appearance having aesthetic and traditional value, including historic centers and cores," limitedly to the installation of integrated panels in roofs. They must not be visible from outdoor public spaces and scenic viewpoints, except for roofs whose coverings are made of traditional local materials. The impact must be focused on, and it is necessary to verify that the emission abatement calculations in SECAPs consider urban planning instruments and municipal building codes while maintaining protections and limits of intervention to buildings of historical, cultural, and architectural significance.

Municipalities' actions primarily concern four economic sectors (residential, tertiary, industrial, and transportation). The largest share is related to the behaviors that private citizens should undertake to improve consumption efficiency and consequently reduce atmospheric emissions. This is underpinned by the public administration's essential commitment to raising public awareness of these interventions/issues through meetings, communication campaigns, and incentives. The action of information and communication aimed at citizenship helps lay the foundations for new habits of consumption and behavior. This includes education on the use of electrical and electronic appliances, care of the property's maintenance status by making it energy efficient with several simple active and passive solutions, e.g., internal relamping, automatic shut-off devices, and remote controls; replacement of heat generators and electric pumps; installation of regulation systems, adoption of construction systems capable of reducing heat loss (replacement of window frames, insulation of vertical and horizontal closures); and use of heat pumps connected to renewable energy capture systems (solar thermal panels, geothermal system, etc.). The action may receive a boost from ongoing incentive systems (heat bills, energy efficiency bonds) and tax deductions.

A good practice is the Sportello Energia (Energy Desk), created at the initiative of the Piedmont region. This desk aims to guide local property owners and condominium managers in their decision to proceed with energy upgrades. The desk staff provides information, answers doubts, and supports them in identifying incentive mechanisms, resulting in more building upgrade projects that help to achieve higher energy savings and faster returns on investments.

All the reviewed SECAPs acknowledge that the transportation sector significantly impacts the environment, leading to further sustainable transport solutions that benefit the environment, society, and the economy. The action aims to support the replacement of the car fleet with low-emission vehicles that meet the limits specified in European Regulation 715/2007. Proponents include practices for free or reserved parking spaces to encourage electric vehicle purchases (or rentals). The action provides for the placement of charging points capable of covering the urban and built-up areas. In addition, they encompass the maintenance and implementation of bicycle routes to encourage private citizens to choose slower mobility options.

One element that makes small towns in inland areas healthy is their integration into the natural green landscape. Little or almost nothing is needed to implement tree planting, except in a few parking areas.

The advantage of these areas' lower degree of urbanization and settlement principle also affects safety regarding the ability to control hydraulic hazard conditions. Greenery provides one more contribution through the waste from mowing and pruning, which is recycled along with that from agricultural production. Together with food production, this activity is among the most important in these contexts. These wastes are used in the production of energy from biogas. The latter derives from the anaerobic fermentation of agricultural plant biomass, as for the plants in Ponte di Piave and Arcugnano.

Due to being smaller centers, this action has a small global impact. So, to amplify it, some centers have decided to extend their choices by involving neighboring municipalities, forming networks with leaders, from a more long-term perspective. Indeed, if each city adopted its own SECAP, this could result in repetitive or disconnected actions among neighboring municipalities at the expense of additional resource expenditures. Small municipalities having submitted a joint SECAP with the CoM 2050 strategy include two in Italy, both in Piedmont: Sommariva Perno-Lisio-Montà (CN) and Quincinetto-Borgofranco D'Ivrea-Burolo-Lessolo-Quassolo-Chiaverano-Montalto Dora (TO). In these cases, the administrations have taken steps to redefine the municipal structure for the various activities under the initiative, identifying a responsible figure and organizing a working group capable of managing relations with the European Commission and, in general, the organization and implementation of the various activities. When drafting the SECAP, to achieve the collective goal of reducing emissions, the municipal administrations carried out an energy-environmental analysis of the territory and the activities insisting on it. They reconstructed the energy balance and realized the CO_2 baseline emission inventory (BEI). Moreover, they evaluated and indicated the potential reduction of final energy consumption and the possibility of increasing local energy production from renewable or other low-impact sources, reconstructing the possible evolutionary scenarios of the local energy system. These data are reported for each municipality and then aggregated. The actions, however, are not based on mutual help between neighboring municipalities according to a principle of subsidiarity. Instead, they share the strategy and overall goals by presenting individual and aggregated results, but the actions are specific to each municipality. The aggregation of small municipalities is a relevant first step. Thanks to this, XS municipalities can produce more substantial results within the global movement aimed at CO_2 abatement. The outcomes could be even more satisfactory if the interventions were conceived through interactions between municipalities, including the joint procurement and management of new sustainable energy and climate services (think, for example, of the continuity of mobility routes between municipalities or the possibility of surplus energy divestment between neighboring territories).

5. Case Studies of Sustainable Energy in Small Urban Centers with Strong Historical Features

The experimentation, part of the workshop "Smartness: Minor Centers as Laboratories of New Sustainable Residentiality" held in the Department of Architecture at the University of Palermo, was aimed at urban centers with strong historical connotations but were on the geographical and economic margins. Related to the theme of sustainable energy and climate adaptation, two urban centers were considered: San Mauro Castelverde and Santa Cristina Gela, both in the province of Palermo. The study aims to investigate the feasibility of implementing climate adaptation solutions and using low-impact renewable energy in a vulnerable context, such as a historic urban environment in rural areas. In the first case study, solutions with geothermal probes compatible with the subsoil characteristics, urban spaces' morphology, and architectural heritage have been identified among the many opportunities to supply energy from renewable sources [32]. In the second context, an agro-energy park is proposed, with the integration of wind power plants with micro-rotors for energy production and distribution in public buildings, a system of urban gardens to serve local populations, and a bicycle and pedestrian park, emphasizing the naturalistic values and relevant touristic and sports vocation of the place [33].

The physical resilience of these urban centers has allowed the permanence of traditional buildings, whose energy retrofit will be an improvement of their intrinsic passive-building characteristics. These buildings were constructed with an awareness of the contextual, environmental, and meteorological factors, without the aid of technical systems, which did not exist at the time or were reduced to chimneys and wood stoves. Their construction techniques aimed to protect against cold and heat with natural materials, taking advantage of exposure, sunlight, openings, and shading, wall inertia, passive ventilation, and shading.

San Mauro Castelverde, in the province of Palermo, is a municipality of 114 km^2 belonging to the territory of the Alte Madonie Mountains, in the homonymous park. It is located at 1050 m a.s.l. and about 22 km from the coast. It is on the edge of the mountainous Madonie territory; thus, it suffers from territorial marginalization in geographical and infrastructural terms. Its settlement and cultural characteristics are also partly affected by its proximity to the Nebrodi mountain range. The positional and geomorphological characteristics of San Mauro Castelverde allow for using geothermal energy to lower CO_2 emissions into the environment and achieve autonomy from the oil supply. The focus has been on designing low-enthalpy systems (geothermal fields with temperatures below 100 °C) for air conditioning, heating, and cooling of buildings intended for civil housing and services. Despite its copious initial cost, this choice can guarantee CO_2 emission abatement, high yields, and almost no perceivable landscape impacts.

The choice of the renewable energy source followed the interscalar analysis of the characteristics of the urban center under study and the suburban landscape to determine the area's most widespread renewable energy sources. The use of photovoltaic panels was ruled out since they would impact the landscape of the historic center. Moreover, hydroelectric power would be disadvantageous since the nearest river is torrential, and the absence of reservoirs does not ensure a continuous flow of water. Moreover, the exploitation of biomass is not advisable since there is already a plant a short distance away (in Castelbuono), receiving organic MSW and pruning waste from San Mauro. After analyzing the state of law to identify landscape constraints, wind poles greater than 18 kW were ruled out. Despite being convenient, a micro-wind farm is contraindicated in the historic center due to the noise pollution caused by the rotation of the blades. The area of the historic center, almost coinciding with the entire urban center, is characterized by a multitude of courtyards suitable for geothermal installations. One more aspect is the outcrop of Numidian Flysch, a rock formation of the Sicilian Oligocene composed of argillitic sediments composed of quartzarenites, with an excellent thermal conductivity of 2.3 W/mk and an extractable power of 65–80 W/m in 1800 h [34].

The analyses (Tables 2 and 3, Figure 1) revealed that the historic center has the highest energy consumption, amounting to 2015 kWh in the heating sector alone, with CO_2 emissions to the environment of 1270 kg.

Table 2. Consumption analysis of San Mauro Castelverde (toe) (Source: Department of Energy of the Sicilian Region).

	Residential	Tertiary	Transport	Industry	Agriculture
Thermal use (toe *)	0.31	0.26	-	0.07	0.10
Electricity use (toe)	0.27	0.19	0.02	0.24	0.04
Fuel (toe)			0.71		
Total	2.21 ktoe				

* toe: ton of oil equivalent; For electricity use 1 toe = 5347.59 kWh; for fuel and thermal use 1 toe = 11,628 kWh; source: Sicilian Region Energy Department.

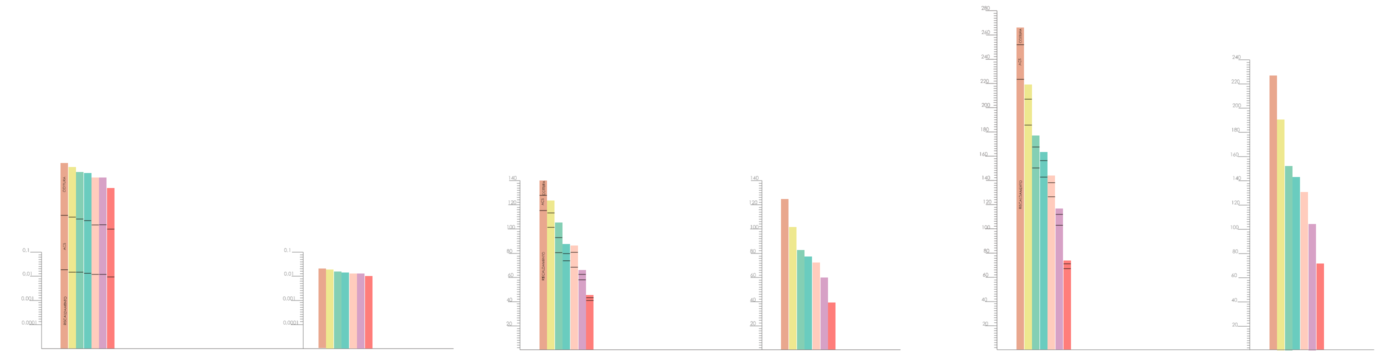
Table 3. Consumption analysis of San Mauro Castelverde (kWh) (Source: E. Nicolini).

	Residential	Tertiary	Transport	Industry	Agriculture
Thermal use (kWh)	1657.8 *1	1390.37	-	374.33	534.76
Electricity use (kWh)	3139.6 *2	2209.32	232.56	2790.72	465.12
Fuel (kWh)			3796.79		
Total	16,591.37 kWh				

*1 0.31 × 5347.59 = 1657.8 kWh; *2 0.27 × 11,628 = 3139.6 kWh; CO_2 = 16,591.37 kWh × 0.255 kg/kWh = 4230.80 CO_2 produced in the whole town.

The tables show the overall consumption, but the work was performed in detail by district and by building use. Calculations determined that to meet these needs, 149 geothermal probes with shallow exchangers of four types are needed: baskets in backyards, vertical probes along streets, loops in residences' private gardens, and vertical probes, again, outside the walls. For clarity and as an example, the calculation for the residential sector is shown below. According to the guidelines laid down by the Italian Ministry for the Environment, it is considered that to produce 1 kWh of electricity, on average, the equivalent of 2.56 kWh in the form of fossil fuels are burnt, and that approximately 0.53 kg of carbon dioxide is emitted into the air 2.56 kWh × 0.255 kg/kWh. Therefore, 0.31 × 5347.59 = 1657.8 kWh, 0.27 × 11,628 = 3139.6 kWh, giving a total of 4797.4 kWh × 0.255 kWh = 1225 kg of CO_2.

The installation of conical basket-shaped probes (Figures 2 and 3) made of polyethylene pipes attached to iron or plastic reinforcement has been hypothesized in courtyards. Their depth is set at 1.5 m for a height of 1.2 m, with a diameter of 2.4 m, at a distance of 5 m. In gardens, the choice of geothermal loops is meant to preserve trees. They are lined with plastic tubes with internal diameters between 16 and 22 mm; their embedment depth is 80 cm. The rings develop on three mutually parallel planes placed in ditch excavations. Vertical probes would be realized with foundation piles and U-shaped or spiral pipes, have a depth between 15 and 20 m, and be located in the street or outside the walls. The probes were placed throughout the neighborhoods according to the following plan.



Energy consumption (toe) for heating (left) and electricity consumption (right)

CO_2 production for heating (left) and electricity consumption (right).

Energy consumption (kWh) for heating (left) and electricity consumption (right).

Figure 1. Analysis of neighborhood consumption. The color corresponds to each neighbourhood shown in Figure 2. Images by: Arch. Maria Rosaria Cimilluca.

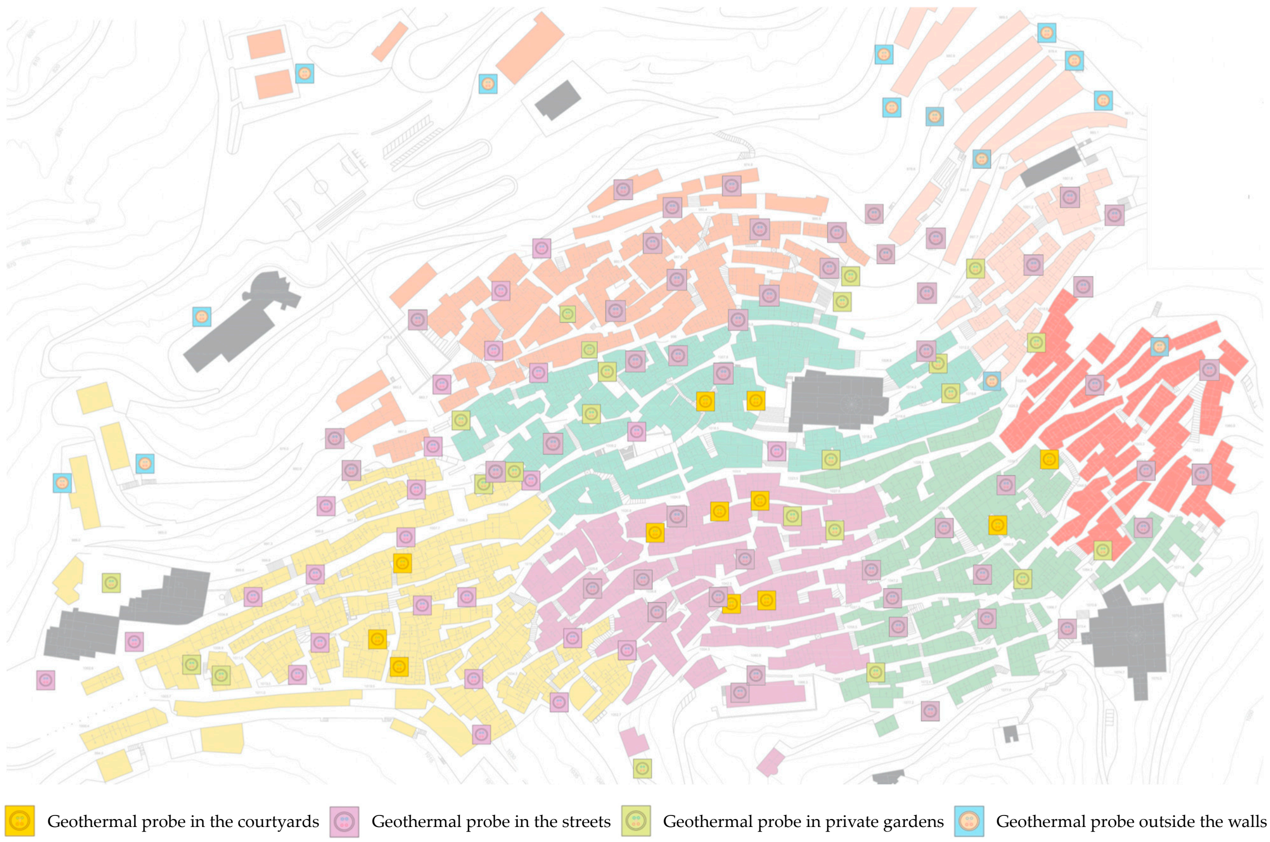


Figure 2. Geothermal probe placement hypothesis in the urban center. Images by: Arch. Maria Rosaria Cimilluca.

Serra district	**245 inhabitants**	Color yellow indicated on the plan of Figure 2						
Building type	**Ground floor use**	**Construction technique**	**Floors**		**Probe classification**	**Kwh produced for heating/refreshing**	**n° probe**	**Kwh produced per district**
Terraced housing	Abandoned local	Mixed-structure buildings	2–3 elevations		Ring probes	15 kWh	5 × 15	75 kWh
Palaces and buildings	Abandoned local	Plastered stone masonry	2–4 elevations		Basket-shaped probes	15 kWh	3 × 15	45 kWh
New buildings	Garages	Reinforced concrete	2–3 elevations		Vertical probes	15 kWh	3 × 15	45 kWh
Terraced housing	Garages	Mixed-structure buildings	2–4 elevations		Vertical probes	15 kWh	14 × 15	210 kWh

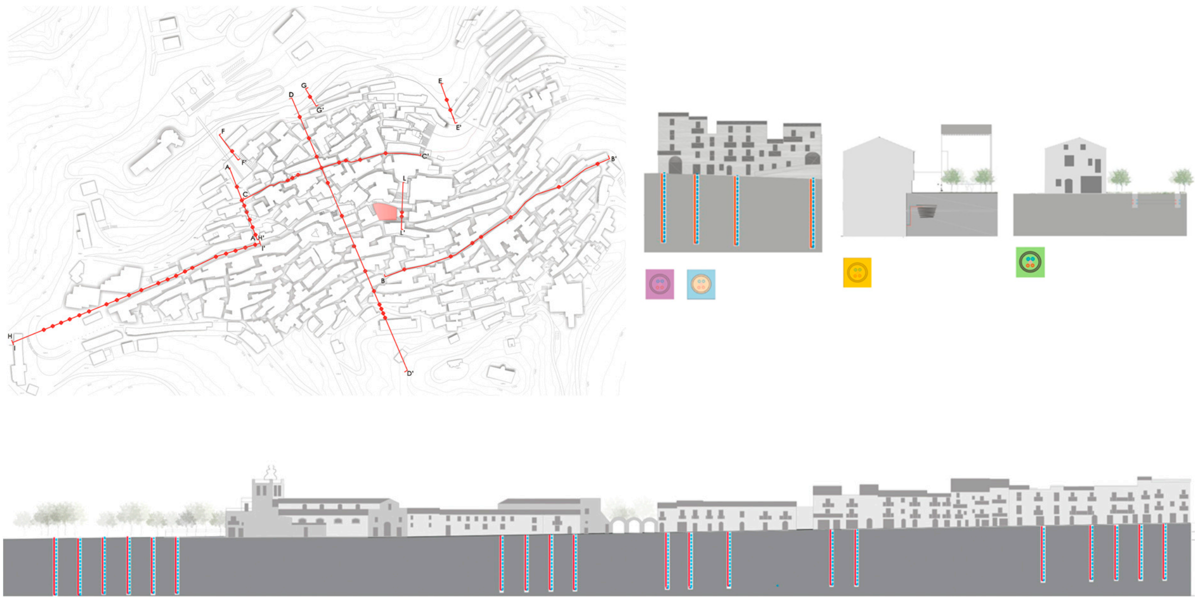


Figure 3. Probe type selection according to building type and calculation of KWh produced. Images by: Arch. Maria Rosaria Cimilluca.

Neighborhood consumption analysis was performed regarding thermal and electric uses for residential, agriculture, service, transportation, and industry sectors. The total consumption is 1.97 toe (1 toe = 11,628 KWh for fuels and 1 toe = 5247.59 KWh for electricity consumption). Considering the standard emission factor, the amount of CO_2 released into the environment expressed in kilograms is 1270.53 kgCO_2 in the heating sector alone. Based on the analysis, the sector that consumes the most is the residential one, especially for heating. Building profiles of some streets with associated geothermal probes were drawn to highlight the relationship between excavation and the built environment. This was followed by a study of the various shallow geometric probes available in the market, with their types, applications, materials, power, and depth of deployment. Ground floors or basement floors, such as cellars or current technical rooms, were identified as places for system components, such as manifolds, with at least a minimum volume of 30 m^3.

After identifying the probe network's placement in the historic center's urban spaces, energy efficiency upgrades to the city hall building were explored (Figure 4). The hypothesis of one more low-enthalpy geothermal system was formulated, involving the installation of probes in the square before the building and a geothermal heat pump inside the building to power the fan coils.

The facility has a traditional thermal system with an oil-fired power supply and thermal output of 110 kW; it was proposed to replace it with a system with 16 vertical probes 12 m deep to meet the energy consumption and needs for heating and cooling. The hypothesized air-conditioning system mainly consists of one to several water-to-water heat pump units and hydraulic circuits with vertical heat-exchange probes. A room in the basement was chosen to place the heat pump and various collectors; a total of 12 vertical recessed fan coils are to be placed as terminals in the various rooms on the aboveground levels.

Sicily is characterized by a scorching summer climate with an asymmetry of solar irradiance and temperatures from March to October. Thus, the extensive use of heat pumps with low-enthalpy geothermal energy as a thermal source can help drastically reduce greenhouse gas emissions produced by air conditioning systems in building structures. Soil is a great energy resource, as it keeps higher average temperatures than average air temperatures in winter while doing the opposite in the summer. Under these conditions and heat pumps being cooled and heated by water instead of air, the resulting efficiency can provide an economically and environmentally valid alternative to combustion-based heating and air conditioning systems.

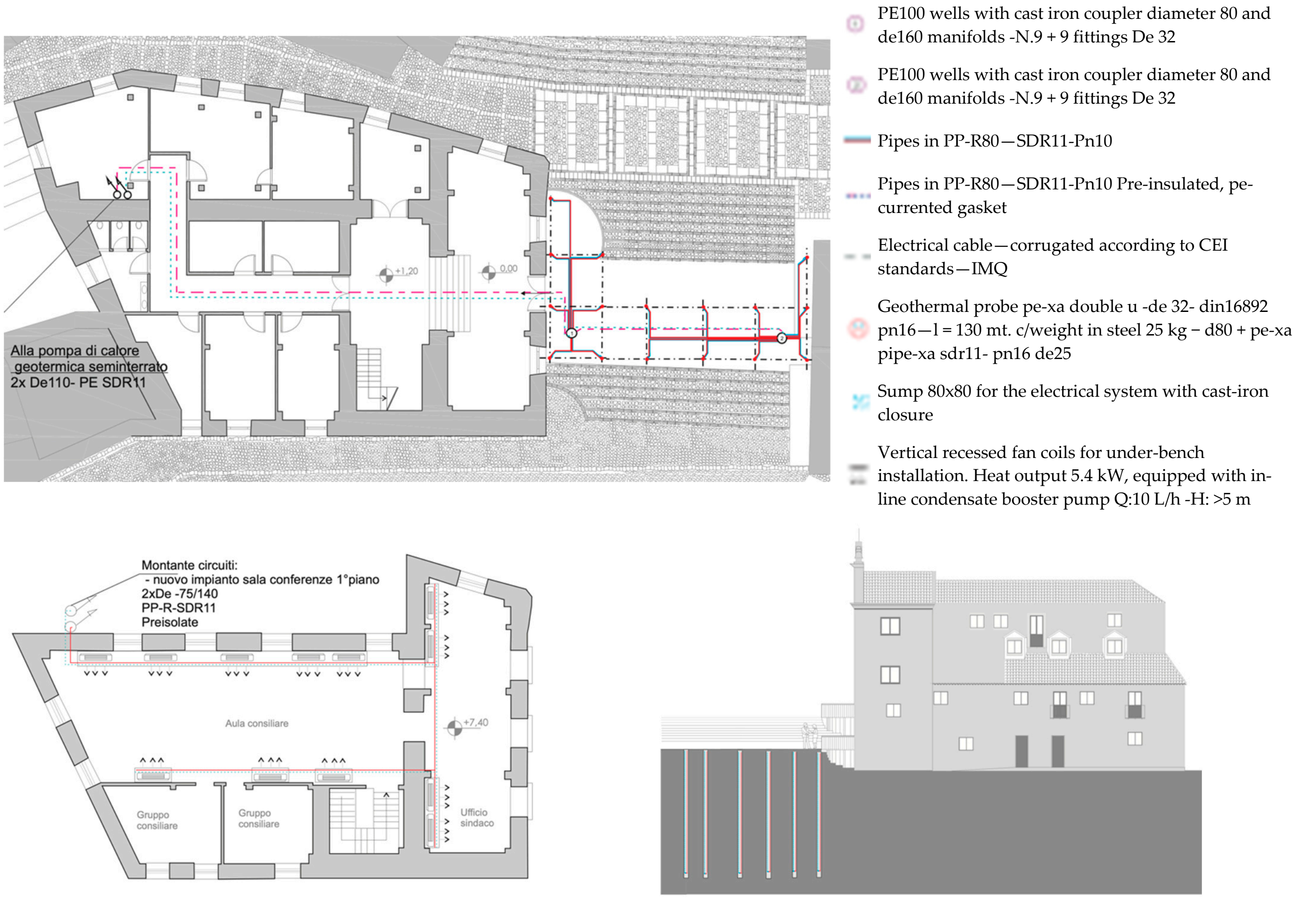


Figure 4. Example of the installation of a geothermal system in a historic building, the Municipal Palace of San Mauro Castelverde. Ground floor plan, first floor plan, and elevation. Images made by: Arch. Maria Rosaria Cimilluca.

Santa Cristina Gela is a small municipality founded in the late 17th century. It is located 25 km from Palermo and now covers 38 km^2. Located in the hilly inland areas behind Palermo, it is among the inland areas that have suffered a gradual abandonment of the countryside toward a major attractor. Demographic movements in the municipality mark a steady demographic decline, especially during the 30 years between 1951 and 1981. It seems the trend has been the opposite in the last few years. The historic core of the township has a valuable eighteenth-century build heritage, which would require an overall redevelopment and valorization project with a focus on cultural tourism. Indeed, urban planning tools identify it as an area to be protected. In addition, the surrounding area is characterized by several geographic peculiarities. Indeed, the municipality belongs to both the Oreto Valley and the protected area of Lake Piana degli Albanesi. They are both notable watersheds devoted to enhancing agricultural resources and with high scenic value. The strategic plan hypothesis of energy self-sufficiency (Figure 5) results from a field analysis showing that Santa Cristina Gela is a windy area with predominant winds from the northwest and southwest with an average speed of 8.20 m/s. The idea involves a new smart grid infrastructure for managing and distributing electricity and advanced metering systems to constantly monitor energy consumption. The hypothesized interventions include upgrading the energy efficiency of the public lighting systems by replacing lighting fixtures with latest-generation LED devices, providing network optimization systems with smart on/off controls, and reconnecting the urban and agricultural areas through urban gardens. The urban garden can also trigger other circular resource reuse actions, such as composting organic waste and reusing rainwater for irrigation.

Figure 5. Energy development and urban redevelopment: strategic action planning. Images by: Arch. Angelo Alabiso.

To meet the energy needs of the entire municipality, estimated to be around 1650 MWh now, an "agro-energy" urban park was hypothesized (Figure 6). It houses a mini-wind farm consisting of 100 vertical-axis blades 8 m high with a power rating of 6 kW and, therefore, a total instantaneous power of 600 kW capable of producing 1140 MWh per year. Its internal park is divided into areas dedicated to typical local crops (almond, citrus, and olive groves). Despite their high performance and constant blade rotation, horizontal-axis wind turbines (mega-wind turbines with a capacity of about 3 MWh, mini-wind turbines with a capacity of 2 kW to 20 kW, and micro-wind turbines with a capacity of 0.5 KW to 2 KW) can impact the landscape both visually and sonically. Therefore, their installation away from urban centers is recommended. Therefore, this type of turbine was ruled out due to the excessive size of the machines (heights between 20 m and 100 m and shovel diameters from 10 m to 50 m) and the risks involved in their inclusion in a natural setting like the case study, which is particularly rich in protected bird species. Vertical-axis wind turbines (mini-wind turbines with power from 2 KW to 10 KW, micro-wind turbines with power from 0.5 KW to 2 KW) do not need to be oriented toward the wind and have low noise levels. Moreover, energy is produced where it is consumed, and thanks to their small dimensions (height from 4 m to 8 m and diameter from 2 to 3 m), they could be integrated into the natural landscape.

In Italy, oil-fired thermal power plants emit an average of 0.65–0.85 $kgCO_2$ into the atmosphere to produce one electric kWh. The emission reduction associated with using wind power can be estimated as follows: CO_2 (t) = 0.3 × A × h × 860/1000. Where 0.3 is a constant that depends on the intermittent nature of wind, availability of wind turbines, and energy losses; h is the number of hours of operation per year (order of magnitude: 7000–8000 h); and A is the estimated theoretical power output (in MWh). Thus, for example, a 1 kW turbine, operating for 8000 h/year, reduces CO_2 production by 20 t/year. The park itself could meet almost all the needs of the municipality if combined with resource-friendly consumption and an energy-efficient regime and, at the same time, contribute to a decrease of 12,000 tons of CO_2/year. In addition, it could complement the ongoing work of a nearby hydroelectric power plant (Agghiastro locality in the municipality of Santa Cristina Gela) without interference. The plant exploits a net energy jump of about 240 m with a maximum flow rate of 1100 L per second, thus producing 2.5 MWh. It already powers several grid municipalities.

In conclusion, the project envisions upgrading and integrating the existing axis by connecting the town center, the new agro-energy park, and the lake through pedestrian–cycling tracks and redesigning the route of a former railway line integrated into the park also as a pedestrian–cycling track.

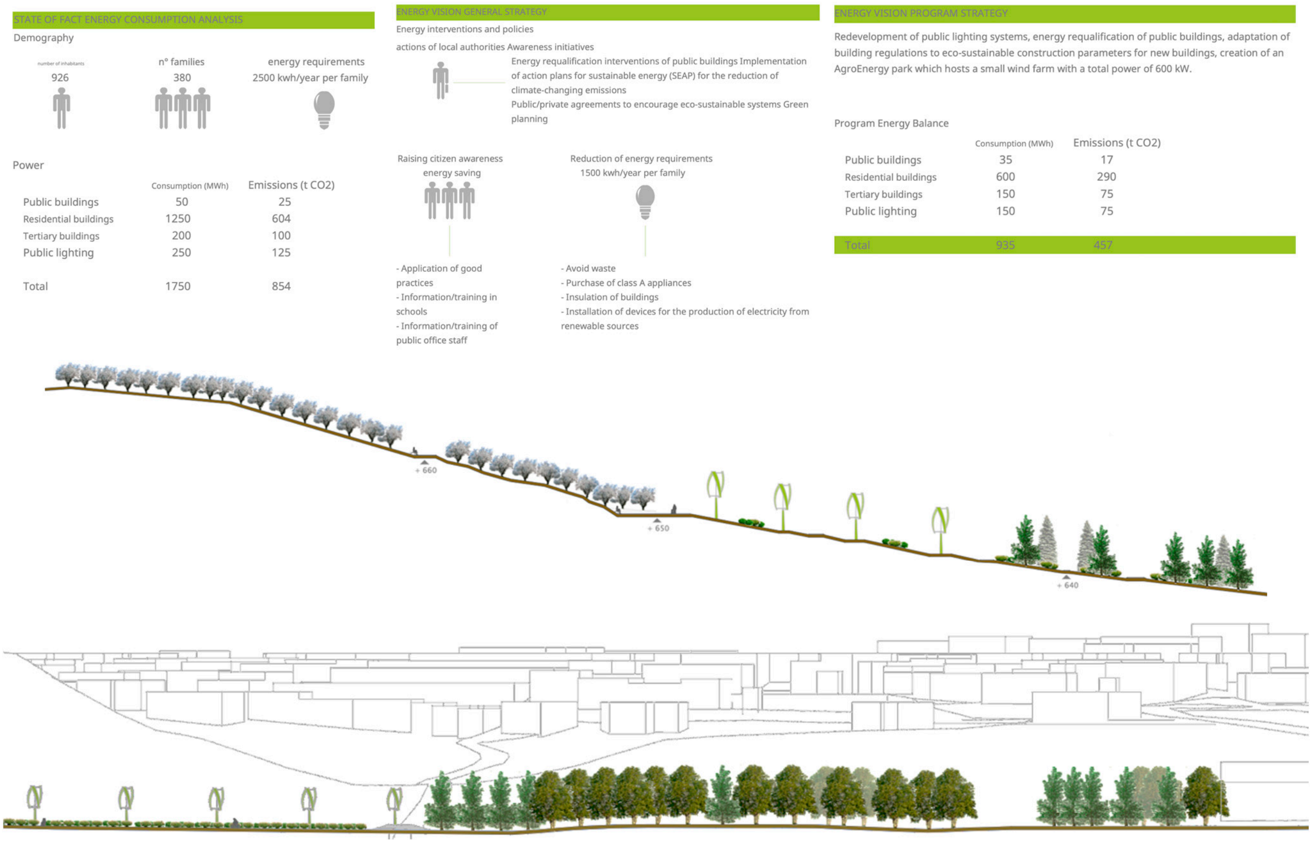


Figure 6. Consumption analysis, energy vision, and planned energy balance. Agro-energy park project, sections. Images made by Arch. Angelo Alabiso.

6. Considerations and Conclusions

This paper provides a preliminary analysis of actions to draft a SECAP in two historic urban settings characterized by territorial marginality.

One of the most emerging and least-addressed issues in the literature in these urban contexts is the risk of implementing single, unconnected punctual actions, benefiting only some points in the urbanized area without an overall macro-scale reasoning. The contribution recalls this aspect and is meant to support architects, planners, and local government administrations in proposing technological design solutions involving the whole housing community, also in agreement with the surrounding areas, precisely in the logic of sustainable energy communities, aiming at a SECAP. This paper can be useful to inform administrations, especially in inland areas, so that they can rethink their territories as energy communities and achieve self-sufficiency. The limited size of these centers favors the sense of community; with little effort, the active management of energy resources can be a promising solution to fight energy poverty while co-creating sustainable systems suitable for the community's needs. Thus, adjacent municipalities could develop by constructing an energy network to sustain two or more cities through a system of technologies integrated into periurban areas, which are often not valorized. For example, the "Agro-Energy Park" described here can be an opportunity for the regeneration of an area in a state of abandonment; at the same time, it turns into a place for sustainable production. It preserves and extends cultivated areas and realizes an integrated system of mini/micro-wind energy production, sized to produce most of the energy demand of the park and the municipality itself.

The advantages of these actions in small municipalities are, first and foremost, the enhancement of an original vocation for sustainability; the implementation of design solutions with an overall vision, as these territories are less vast and complex than metropolitan contexts; and the possibility of achieving effectiveness and benefits quickly. In addition, tactical actions aimed at energy efficiency, such as those designed here, could be opportunities for concrete development and the conferring of new desirability, as well as having a trailing effect on other initiatives.

Spatial proximity is essential and reveals the need for place-based approaches to developing energy communities. This aspect is underscored by the National Plan for Recovery and Resilience (NRRP): an instrument that outlines the objectives, reforms, and investments that Italy aims at, thanks to Next Generation EU funds to mitigate the economic and social impact of the recent pandemic. Within the plan, the investment dedicated to Energy Communities includes a clear reference to supporting projects focused on areas where the greatest socio-territorial impact is expected, specifying, in particular, municipalities under 5000 inhabitants as targets [35].

Implementing renewable and low-impact energy is the basic principle of a vision to counteract CO_2 emissions to the environment and achieve energy self-sufficiency in these communities. The proposed interventions also converge from the perspective of urban regeneration since historic urban settings, particularly those already in a state of disrepair, such as the cases studied herein, are particularly vulnerable to various climatic threats that jeopardize their preservation.

Due to their scale, energy supply interventions are potentially the most impactful on the landscape, especially in vulnerable-build contexts, among sustainable energy and climate adaptation interventions possibly included in the plan. The challenge is to reconcile the need for climate adaptation with technological elements to strengthen the quality of the built environment. This is why the paper focuses on technologies for energy supply from renewable sources and shows how they can be integrated into the historic fabric with a few targeted interventions, suggesting design choices that arise from the context study and analysis phase. During this study, it has been kept in mind that the cases studied are strongly characterized by evident physical characteristics, and the settlements are strongly influenced by their orography, producing their landscape appeal and infrastructural difficulties. It is understood that the actions presented have a high cost and that this may discourage administrations from implementing them, but because they are modular systems, implementation can be carried out in phases. The technologies that are most suitable in historical contexts and that are on the market still have lower efficiencies and higher costs than traditional ones, and being new, the necessary maintenance and useful life of these elements is still uncertain. Therefore, the calculation of payback time may be improper. In fact, however, these are elements could simultaneously respect the overall perception of the historic urban landscape and drive the energy transition towards the use of RES. Therefore, it is worth investigating. Wherever it is possible to install it, the geothermal plant is a good compromise; micro-wind power can be impactful on the landscape if not integrated in a park, as presented here.

If technologies for energy self-sufficiency from renewable sources were associated with a building renovation aimed at exploiting and enhancing the thermal energy conservation attitudes that traditional architecture generally preserves, fewer active technologies for energy production would be needed; therefore, the use of less-expensive solutions could also be realized. On the other hand, conservation is a strategy for sustainability, and understanding contemporary values to revitalize and rethink future practices in historic cities can help settlements respond to new needs and priorities, such as climate change [36]. I would conclude by reflecting that it is the built heritage itself that gives us the answer; design choices have been defined after careful analysis that highlight various morphological, typological, technical, material, and historical characteristics that suggest how to improve the energy behavior of the built environment.

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